ME 450

Spring Demonstration Device

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EXECUTIVE SUMMARY

At the University of Michigan, Mechanical Engineering students must complete an introductory design and manufacturing course, Mechanical Engineering 250. This course teaches fundamental principles such as gear trains, bearings, bolts, and springs. The instructor of this course, Michael Umbriac, approached our team in hopes of creating a spring demonstration device. This device should use compression springs of differing wire diameter, outside diameter, and free length to simultaneously launch 3 identical balls vertically into the air. We have done research to find existing similar devices that use compression springs to store energy and then release this energy to propel balls. Our sponsor has given us numerous requirements that the completed device must satisfy, and we have developed engineering specifications to meet those requirements. To generate concepts for our device, we performed a functional decomposition to divide the device into subsystems and focus our attention on developing concepts for the compression mechanism, trigger mechanism, and safety mechanism. After developing many concepts for these subsystems, we compared them against each other and selected the individual hand-held plunger for the compression mechanism, double door-style spring pin pulling for the trigger mechanism, and lever latch for the safety mechanism. From there, we developed a final concept for the complete device, which will have 3 chambers, each using a double door-style spring pin to hold a main spring in its compressed position. Upon pulling a lever that is connected to all the double door-style spring pins, the main springs will be released to launch 3 balls vertically into the air. Our primary design drivers come from our compression mechanism, trigger mechanism, and safety mechanism, and we conducted analyses for each of these. For the compression mechanism, we used equations of springs and kinematics to determine compression force and ball launch height. For the trigger mechanism, we performed empirical testing to determine the required force to pull a pin. For the safety mechanism, we built a mock-up of the lever to test the lever latch concept. Additionally, we created a Failure Mode and Effect Analysis (FMEA) to analyze the risks of this project. After our analysis, we developed CAD models and plans for manufacturing the device, and we have manufactured and assembled the final deliverable. Using the device, we tested to validate that it met the user requirements and engineering specifications. We found that the device was able to meet all engineering specifications except for the maximum launch height specification. Overall, we believe that the project turned out positively, and we hope that our sponsor will be happy with our work.

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PROJECT DESCRIPTION

Students at the University of Michigan must complete certain requirements to graduate from the Undergraduate Mechanical Engineering Program. The program requires that all students complete three design and manufacturing courses during their tenure. The first design course, MECHENG 250: Design and Manufacturing I, introduces students to theory and practicality of mechanisms such as gear trains, bearings, bolts, and springs (1). During the lecture on springs, the students are asked to use principle equations for springs (2) and projectile motion (3) to determine the strength of 3 separate springs and to choose the spring which will theoretically launch a projectile the furthest. Michael Umbriac, the instructor of this course, has approached our design team in hopes of coming up with a way to demonstrate the performance of the aforementioned springs during the lecture. The device we build must simultaneously launch 3 identical balls vertically into the air using springs of differing wire diameter, outside diameter, and free length. This will allow the students to check whether or not the spring they chose actually launches a projectile the furthest, while building interest for the topic on springs.

LITERATURE REVIEW

The overall goal of the project is to build a device to accurately demonstrate a spring problem that will be presented during class. Some initial observations showed us that we needed to do some research in several areas before we could begin forming requirements for our design. First we researched spring equations for maximum loading, and spring force per inch (4). These will be critical when deciding what types of compression springs we needed to buy and test. Next we did research on vertical projectile motion to come up with some equations to predict how high prescribed balls will travel when launched (5). We do not want the balls going through the ceiling, and we also do not want the balls to only fly a few inches. These pose safety concerns as well as concerns of a failed experiment. Another key part of this project is the way the springs and balls will be released. We did research on trigger mechanisms both through benchmarking and research, and found several pictures of trigger type, which are seen in Fig. 1-2 (6).

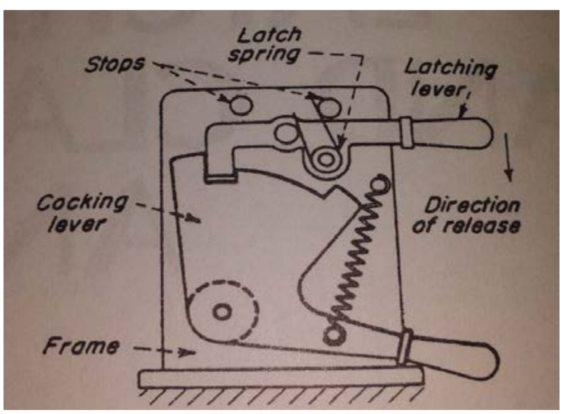

Fig. 1: This mechanism is used to cock the mechanism and the spring loaded release lever ensures a fast release.

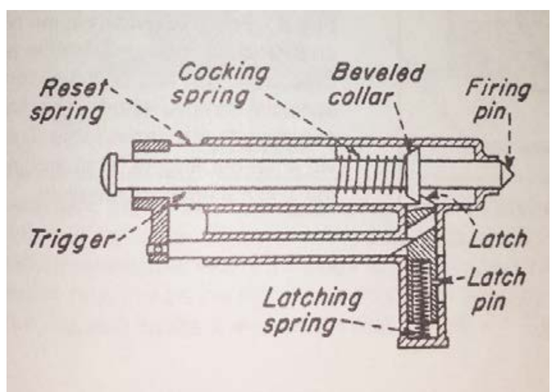

Fig 2: A firing pin mechanism is another simple way to release a compressed spring.

Many of these triggers included cams and springs, so we looked into the mechanics of cams and how they would interact with springs (7). We also believe that we will need to accurately predict ball launch height, so we looked into the law of conservation of energy, which will be used in any launch height prediction calculations. The Conservation of Energy states: energy can neither be created nor destroyed (8). Using an equilibrium of forces, energy conservation, and first principles on projectile motion and spring equations, we should be able to develop a model representing this system of three springs. Using the model, we can accurately predict how high the balls will be launched by simply plugging in different parameters of the springs. The desired final height of the balls can be determined and reverse engineering can be used to choose the springs that will achieve this desired height. Another issue we need to tackle is to keep all metal parts corrosion resistant, so we looked into corrosion prevention coatings for iron-based metals that could be used in our design. We see that there are a number of ways to avoid corrosion resistance in steel such as adding an aluminum coating (9), but we feel as if it will be most effective to just avoid using steel in all components except the springs themselves. Some options for both preventing corrosion in the spring and damping the noise generated when the springs are released are to either dip the springs in a thin film of rubber or to use shrink wrap made from polyethylene such as some springs in locomotives are (10). We will have to later look into the effects of these if the springs we buy are not pre-coated. Lastly we looked into the strength of aluminum and whether it would be safe enough. This was confirmed when we found an article showing that high strength aluminum components are often used as safety devices in automobiles (11).

BENCHMARKS

After researching existing literature on mechanisms similar to what will be necessary for our device and on the equations governing those mechanisms, we decided to research patents of similar devices to the one we have been tasked with creating. This will give us insight as to how others have accomplished similar problems and some of the challenges that we will face in creating a working device.

BALL TOSSING APPARATUS AND METHOD, Patent No.:US2014378249A1
Designed primarily for batting practice, the ball tossing apparatus consists of a support body with 12 launch devices arranged in a two-dimensional array. The launch devices include cylinders having compression springs fixed therein, and a ball carrier fixed to the spring. The balls are manually loaded into the ball carrier, and a spring retaining latch locks into one of a plurality of notches along the wall of the ball carrier. To launch the ball, a solenoid pulls the latch from the notch in the ball carrier, freeing the compressed spring to expand and launch the ball. An electronic control system launches the plurality of launch devices according to a sequence. This sequence can be randomly generated, programmed by the player, retrieved from memory, or the balls can be launched remotely (12).

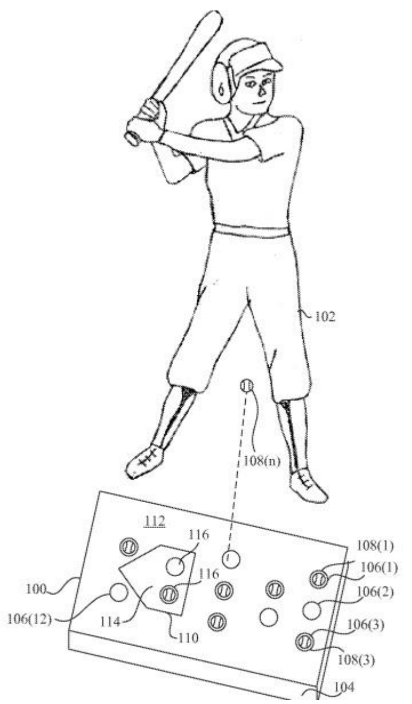

Fig. 3: Apparatus launches balls that are arranged in a two-dimensional array for batting practice.

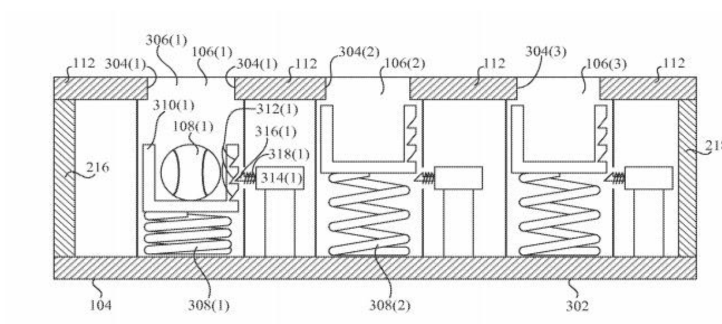

Fig. 4: Ball launching apparatus utilizes a solenoid and latch-locking mechanism to hold the compressed spring.

The device's containment of multiple balls and the possible launching of multiple balls at once closely resembles what our design must incorporate. However, the ball tossing apparatus is insufficient for our product for a number of reasons. The main drawback to this product is its complexity. Although the ball launching mechanism itself is not complex, the release of the ball carrier is dependent on an electronic solenoid that is actuated by an electronic control system. Although the cost is not stated in the patent, a programmable system is unnecessarily complex for our needs. In addition, the launcher itself only provides the balls with approx. 4 to 5 ft of height whereas our system will likely require a higher vertical launch height. Finally, our requirements specify 3 ball launchers and this product provides 12.

SPORTS BALL LAUNCHER, Patent No.: US7028682B1
Designed for inflated-ball sports practice, this sports ball launcher provides an impulse that projects the ball in a trajectory of pre-adjusted angle and velocity to obtain a desired height and landing distance from the launcher. A bowl-shaped ball holder is supported by 2 tubular members that are connected by a hinge joint used to adjust the launch angle. The launching energy is provided by a compressed coil spring that is reloaded by the user with foot-pump action. To set the launcher, the foot pump, attached to a grip plate, is depressed causing the grip plate to rotate slightly until its central hole grips the launcher rod, pulling the plunger core assembly. This process is repeated until launcher is loaded to desired launch strength. The core is launched when a push button depresses the extending arm of the grip plate, releasing the rod and plunger core assembly. The device includes an optional adjustable time delay to give the user time to get into position and receive each launch. (13)

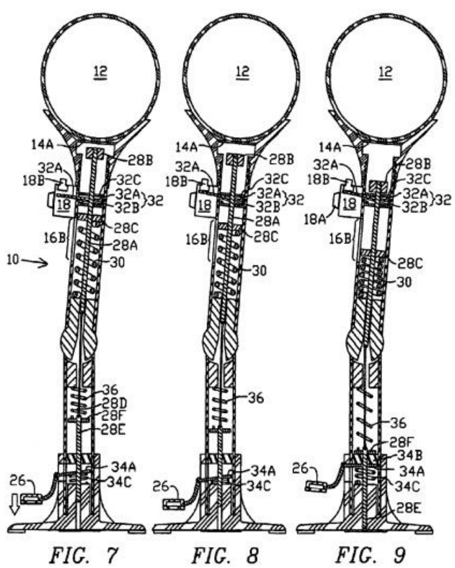

Fig. 5: Foot petal is utilized to cause grip plate to grip and pull plunger core, compressing the spring.

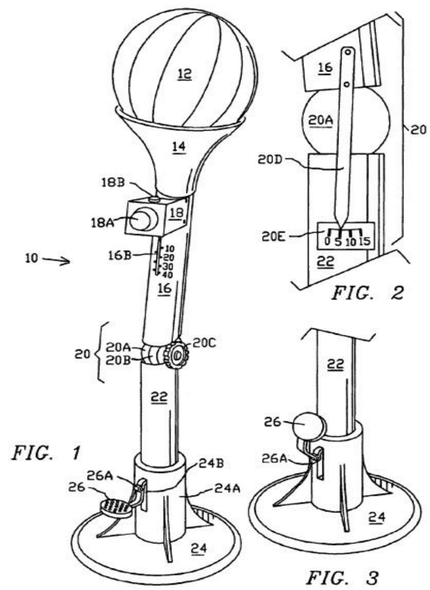

Fig. 6: Ball launcher can be set at a pre-adjusted angle to launch inflated sports balls.

The adjustability of the launch height and angle are both aspects of this device that will be incorporated into our device, however it is insufficient for our design. The primary insufficiency is derived from the fact that this product is designed for the launch of a single ball as opposed to the three ball launch that will be necessary for our device. In addition, there is no set positioning for the depression of the launch spring, it is variable to the number of pumps of the foot petal. Therefore, it would be difficult to repeat a launch to the same height over multiple trials as is required for our product.

BATTING TRAINER APPARATUS, Patent No.:US5221081A

Used for baseball batting training, this apparatus consist of a mounting plate with support cylinders mounted orthogonally and arranged to receive a baseball at its open, upper end. The tubular construction accommodates a baseball sphere, and within each is a compression spring including a plurality of spring rods fixedly mounted to adjacent coils of the spring. One of the spring rods is arranged for receiving a hook member that is attached to a suction cup. The suction cup is adhered to the mounting plate in the lower end of the cylinder, and each suction cup is arranged for randomly releasing the spring to project the spring upwardly and project the baseball from the cylinder. The mounting plate is also mounted to an underlying support that is adjustably mounted to enable different angular orientations. (14)

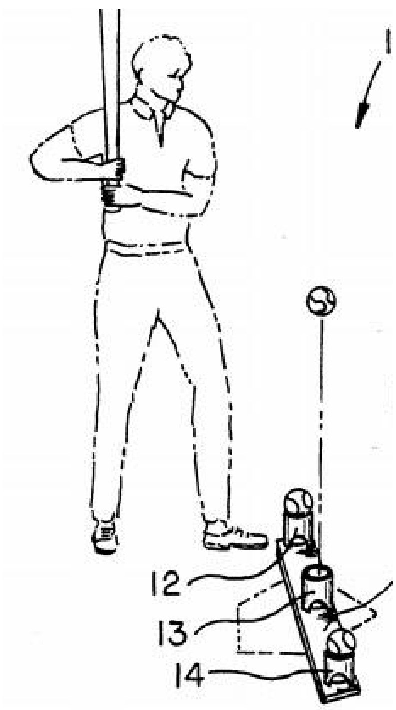

Fig. 7: Launching cylinders are arranged orthogonally on a mounting plate to launch balls for batting practice.

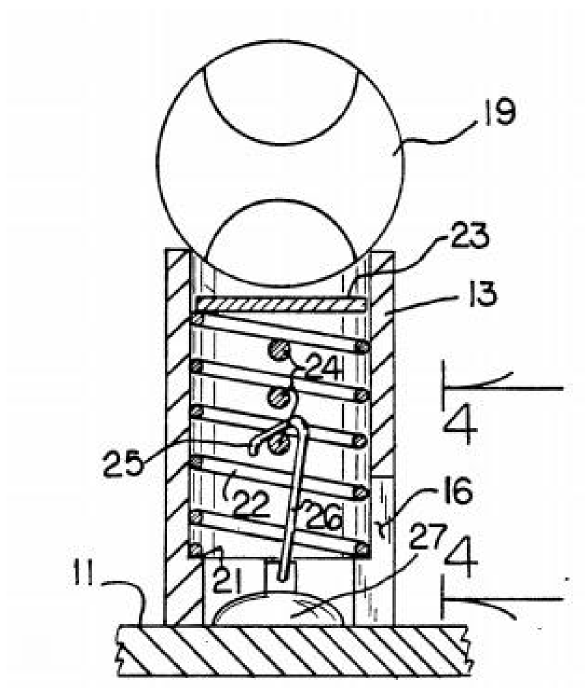

Fig. 8: Hook attached to a suction cup holds the compress spring.

This apparatus meets many of the specifications of the assigned product. It holds balls orthogonally to a surface plate, launches via the force of a compressed spring, and has an adjustable angle. However, the spring is held compressed by the force of a suction cup which presents a couple of conflicts to the assigned product specifications. Relying on the force of suction in the cups, the user cannot activate the launch himself. With this, the balls launch randomly. Given that one of the primary specification for our project is that the three balls must launch simultaneously, this batting training apparatus is insufficient to meet the assigned product demands.

BALL TOSS SPORT TRAINING APPARATUS, Patent No.: US5800288A

Used in sports training, this apparatus projects a ball into the air for training an athlete in the proper technique of hitting or catching the ball. The apparatus consists of a cylinder and a ball support piston connected to a compression spring that moves support between a cocked and an actuated state. The spring is held in place by a partial vacuum developed within an air chamber created when the piston enters the cylinder. To cock the apparatus, the piston is pushed down and air in the chamber exits unrestricted through a check valve at the bottom of the cylinder. A pneumatic control release is connected to the air chamber for allowing ambient air to enter the air chamber. When this happens, the vacuum is released, and the spring is actuated. The piston projects the ball into the air where it is hit or caught by the athlete. (15)

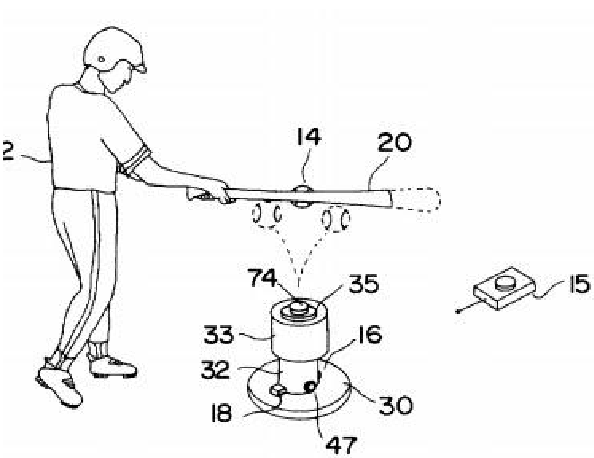

Fig. 9: Apparatus remotely launches ball for batting practice.

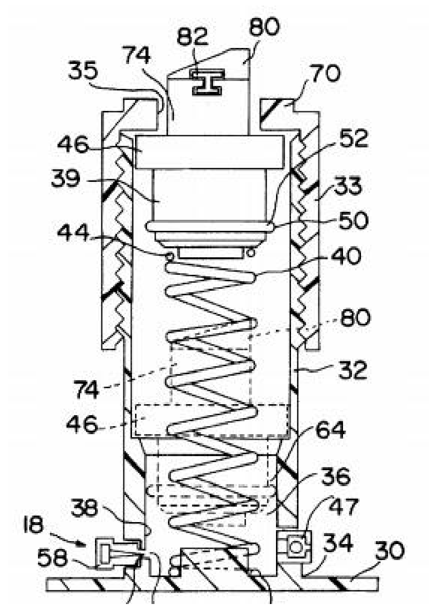

Fig. 10: Vacuum technology holds spring in compressed position and air-release valve fills the vacuum, launching the ball.

While the controlled launch of the ball vertically meets some of the needs for our device, there are multiple reasons that this training apparatus is insufficient to meet our project's needs. A primary downfall of this design is that there is only one ball launcher and the project requires three balls to be launched. In addition, there is no set stop for the compression of the spring. Therefore, the compression may be different over multiple launches, leading to different ball launch heights. Even if three of these apparatuses were utilized, there would be no means of simultaneously launching the three balls at the same time, which is critical to our projects success.

BASEBALL BATTING TRAINING APPARATUS, Patent No.: US5597160A

This product is an apparatus for baseball batting training. The apparatus includes a rigid-wall cylindrical tube with means to support a baseball at its top end. A striker piece is movable within the tube and is latched against a preselected force of a compression spring. When the striker is pushed down a spring-loaded pin is extended and retracted to engage a selected one of a plurality of latching détentes to hold the striker in a cocked position. Upon releasing the pin, the spring loaded striker is driven upward to impact the ball and propel the ball into the hitting zone of a batter. The inner diameter of the tube is larger than the small end of a bat to allow the bat to be pushed into the tube and reset the apparatus for a subsequent use. At the upper end of the striker, the point of contact with the ball can be altered to change the angle of the ball's motion. This allows for the baseball to project into different locations inside the hitting zone for enhanced practice. (16)

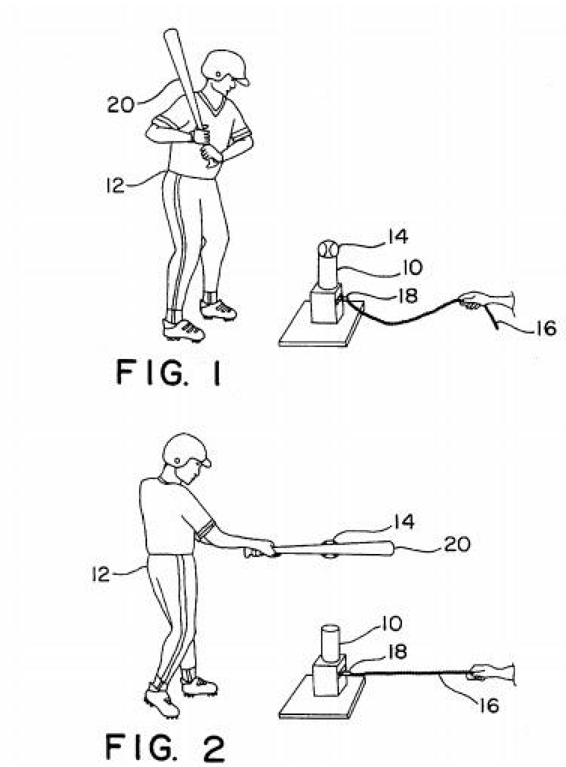

Fig. 11: Operator pulls pin to launch ball for batting practice purposes.

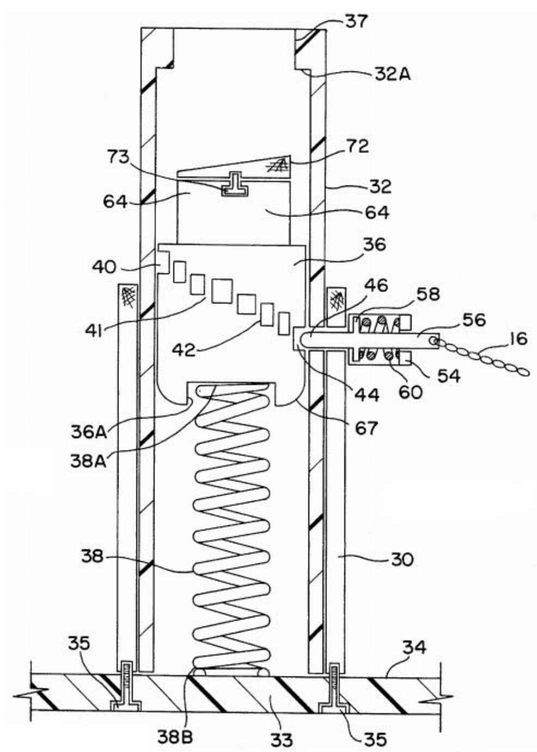

Fig. 12: Striker piece is pressed down and spring loaded pin holds piece by locking into latching dente.

Although this design satisfies many requirements of the project such as vertical launch and adjustability of compressed length, it has a couple of insufficiencies. The most substantial problem is that this apparatus only launches a single ball at a time and the project calls for the launch of three balls simultaneously. Even if three of these apparatuses were used, it would be very difficult to pull all three pins simultaneously to launch all three balls at the same time. In addition, this apparatus launches balls to a height of 4 to 5 ft. The project calls for a height of 5 to 25 feet of ball launch capability. For these reasons, this design is insufficient to meet the specifications of the assigned project.

BASEBALL BAT WITH A BALL-SERVING DEVICE, Patent No.: US2002072436A1
This device is designed to assist in baseball batting training. The baseball bat includes a tubular body with a resilient member, a ball-pushing unit which is set inside the bat body, a gripping rod that retains the ball-pushing unit within the bat body, and an adjustment member that is coupled with the gripping rod. The member is formed with a retaining projection that engages a hole in the ball-pushing unit. The member can be actuated to separate the projection from the hole so that the ball-pushing unit is biased by a spring to move quickly in the bat body, shooting a ball from an opening in an end of the bat body. When performing a subsequent ball serving action, an adjustment member is pulled out from the bat body to engage the retaining projection with the hole, after which the adjustment member is returned to its normal position on the bat body. (17)

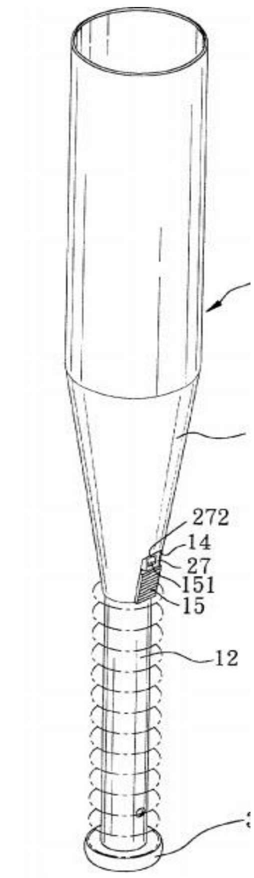

Fig. 13: Ball serving device exterior consists of a tubular body with adjustment piece for triggering ball launch.

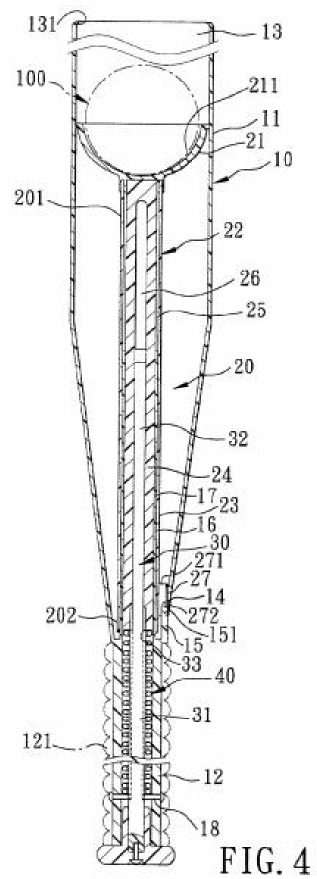

Fig. 14: Ball pushing unit is stationed against compressed spring by a gripping rod.

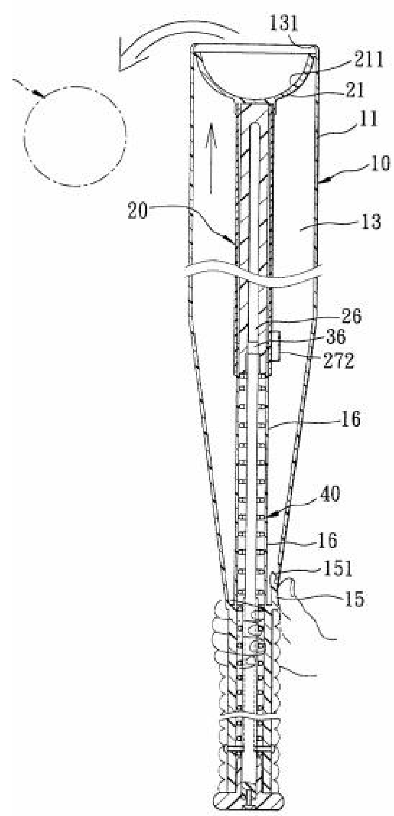

Fig. 15: Adjustment piece releases gripping rod which in turn releases ball pushing unit.

The launching of a ball and the ability to adjust the angle of launch are both things that will be required of our final design, however the baseball bat with a ball-serving device insufficient for the project. Its main shortcoming is the fact that the device can only shoot one ball at a time, while our device must have the ability to shoot three balls simultaneously. In addition, this device must be held by the user when launching the ball. Therefore, it would be difficult and inconvenient to launch the ball vertically and at consistent angles.

EXISTING PRODUCTS

After researching patents for similar devices, we decided to research products that not only have been designed, but are also available for purchase commercially. These products have designs that have been successful, at least to some extent, on a commercial level, so they offer potentially extremely valuable insight.

SPRING LOADED TOY GUN (18)
The first of the existing products that we found that accomplished similar things to what our device will need to accomplish is a spring loaded toy gun intended for kids.

Fig. 16: The ball launcher is a simple toy popular for children.

The spring is compressed via a cocking mechanism and is then released by a trigger. A foam ball is then projected out toward the target. Although this spring is quite lightweight and is used by kids, the trigger mechanism can be examined to refine our own trigger mechanism.

SPRING PISTON AIR RIFLE (19)
These high-powered rifles use an air piston driven by a compression spring and will shoot a 0.177 caliber lead pellet at speeds up to 1400 feet per second.

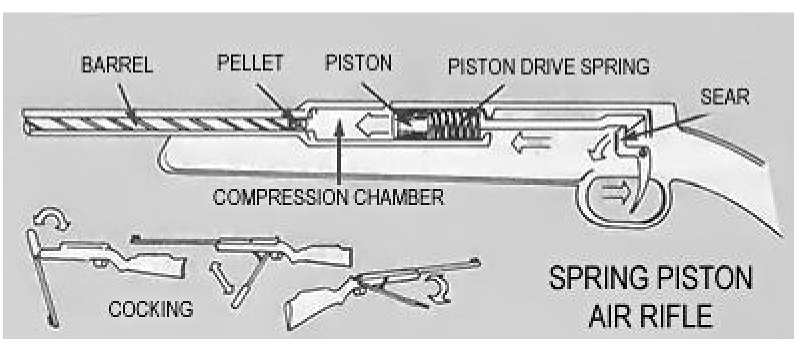

Fig. 17: The air rifle is used in hunting, pest control, recreational shooting, and competitive sports.

These springs last thousands of shots and are primarily designed to produce high velocity to the air piston and to hold up to the extreme forces of being compressed and released repeatedly. This product can be examined to optimize the robustness and speed of our springs if needed.

PINBALL LAUNCHER MECHANISM (20)
The handle is pulled toward the user which compresses the spring. When the spring is released, the ball is launched into play.

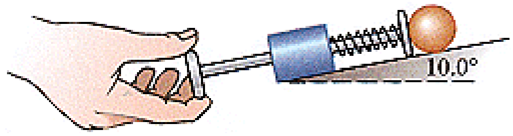

Fig. 18: Simple view of ball launcher for a pinball machine.

Although these springs are much smaller than the ones we will eventually settle on, it is a great representation of the problem. The difference in spring compression distance has a great impact on the launch speed, which is what we are most interested in in this scenario. We also can use this as a benchmarking technique to design a hard stop to slow the advancement of the spring to make the overall setup of our design safer and more robust.

USER REQUIREMENTS & ENGINEERING SPECIFICATIONS

In order to help guide our design work and guarantee a successful design, we have created a list of requirements for our device and engineering specifications for each of those requirements. We have also assigned each of these requirements an importance rating (5 being the most important, 1 being the least important), specified the source of the requirement, and briefly discussed the rationale behind the requirement.

User Requirements	**Importance (5 Most Important)**	**Source**	**Specification**	**Rationale**
Ball characteristics	5	Sponsor	diameter > 3” weight +/- 5 g color contrasts with Stamps stage	As specified by the sponsor, the balls must be visible from the back of Stamps Auditorium.
Quantity of spring-powered launchers	5	Sponsor	3 launchers (3 springs)	The sponsor specified that 3 balls were to be launched simultaneously.
Simultaneous launch	5	Sponsor	< 0.1 seconds	Simultaneous launch will allow the students to see the difference in launch height.

Durable	5	Sponsor	> 10 years without breaking any parts latch must survive > 100 launches > 20 straight performances without mechanical failure	The sponsor expects to use the product for many future semesters and needs the product to last for an extended period of time.
Spring dimension variation	4	Sponsor	K = +/- 10 N/m Minimum 15% in wire diameter Minimum 15% in free length Minimum 15% in outside diameter	The size and compression length must not immediately indicate which ball will launch the highest.
Vertical launch	4	Sponsor	+/- 5 degrees	The balls must launch vertically for students to be able to view the maximum launch height from the back of the lecture room.
Total volume	4	Sponsor	< 8 ft^3	The sponsor needs to be able to easily carry the product to and from the lecture.
Lightweight	4	Sponsor	< 25 lbs	The sponsor needs to be able to easily carry the product to and from the lecture.
Easy to reload	4	Sponsor	t < 60 seconds 0 tools required	The sponsor needs to be able to reset the product in lecture without using too much time.
Easy to activate	4	Sponsor	< 5 lb	The sponsor needs to be able to trigger the launch by exerting a minimal amount of force.
Surface corrosion	3	Sponsor	<5% of surface area corroded at the time of Design Expo	The sponsor plans on using the product for many demonstrations.

Low cost	3	Sponsor	< $400	The product needs to be reasonably affordable as it is only planned on being used one day a semester.
Launch height variation	2	Team	3 different launch heights 20’ ± 3’ maximum launch height < 16’ launch for lower two launches > 5’ launch for lower two launches	The launch and difference in launch height needs to be visible from the back of Stamps Auditorium.
Adjustable spring compression	2	Sponsor	> 1” adjustability in compressed length	The sponsor would like to be able to adjust the spring compression to allow for changes in launch height for individual balls/springs.
Angle of launch variability	1	Team	> 30° adjustability in launch angle	The sponsor would like to be able to adjust the launch angle for demonstrations for future versions of the class where the angle of launch may be an important factor.
Duplicate springs	1	Team	Provide two sets of identical springs as within mechanism	In order for students to examine the springs in the device, separate additional identical springs will be provided.
Base size	1	Team	< 6 feet^2	The sponsor needs to be able to set the product on a typical table in the front of the lecture hall.
Compression mechanism	1	Team	< 50 lbs of force	The device must be able to be compressed easily without using any tools during class.

CONCEPT GENERATION

To begin generating concepts for our device, we performed a functional decomposition of the device, generated numerous ideas for each function, scored the ideas within performance categories, and finally used this scoring to develop a final design concept.

Functional Decomposition

To start the concept generation process, we categorized the main functions that our device would need to perform in order for it to successfully launch three balls simultaneously. The device was broken down into seven major components: the base, the ball/spring interface, the ball containment mechanism, the spring adjustability mechanism, the compression mechanism, the trigger mechanism, and the safety mechanism.

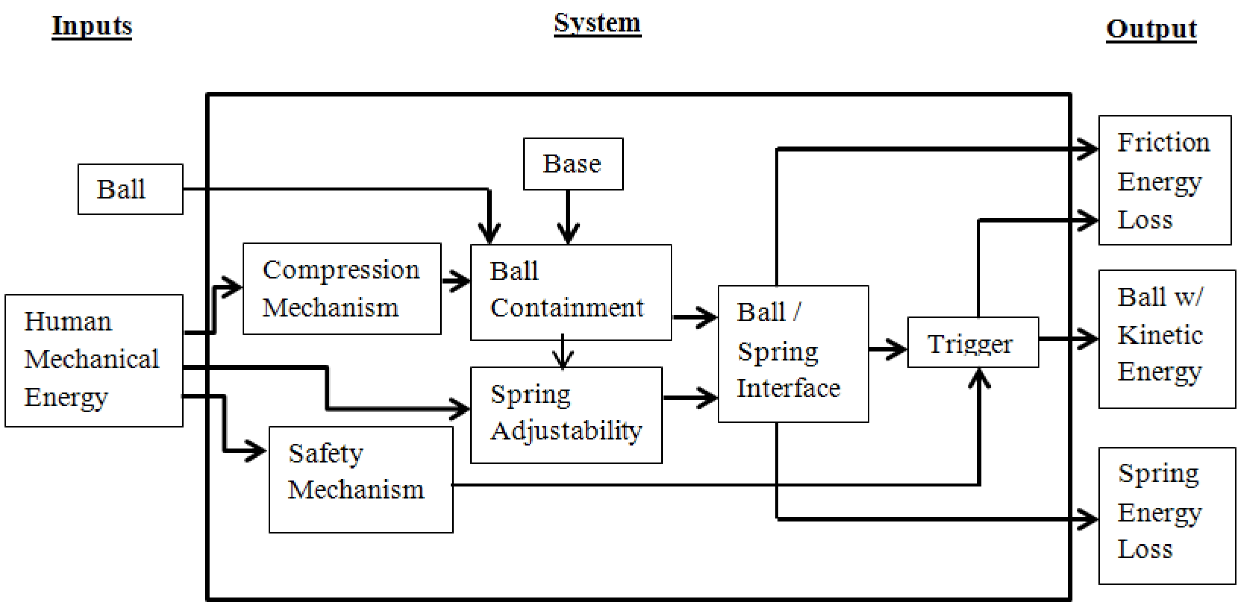

Fig. 19: Functional decomposition diagram with inputs, functions, and outputs.

Base

The base consists of the groundwork structure of the device. The base will be used as a platform to which other components are bolted such as support legs and the internal workings of the spring mechanism itself.

Ball/Spring Interface

The ball/spring interface consists of the spring itself, the ball itself, the "cup" that holds the ball on the spring and the hardware that holds this assembly to the base. Parts of this interface could possibly be considered a part of the trigger as well as they are closely intertwined.

Ball Containment
We defined the ball containment to be the physical barrier that keeps the ball from launching at an angle less than vertical as well as its attachment to the base.

Spring Adjustability
The spring adjustability system refers to the part of the device that allows for the spring's compressed length to be adjustable over a period of time.

Compression Mechanism
The compression mechanism is defined as the part of the device that applies force to the springs in order for the trigger to be set. This includes all of the workings of such mechanism including any lever arms, pushers, or their hardware.

Trigger Mechanism
The trigger mechanism will consist of all of the workings that will release the spring and ball during the launch period. This includes any routing of linkages or latch mechanisms that may be included.

Safety Mechanism
The safety mechanism was added as a major component to keep the users of the device as safe as possible. This includes any mechanism or hard-stop that prevents activating the trigger and launching the balls when launch is not desired, such as while loading the machine.

We decided that we would focus our attention on the most complex subsystems in the device: the compression mechanism, the trigger mechanism, and the safety mechanism. We believed that the design of these three major subsystems will greatly impact the rest of the mechanism, and that the designs of the other subsystems will naturally follow from our choices of compression mechanism, trigger mechanism, and safety mechanism.

Compression Mechanism
One of the single most important aspects of this entire spring demonstration device is actually finding a way to compress the springs. Without compressing the springs and storing energy, the demonstration would be utterly uneventful and would be deemed a failure. We started brainstorming individually and came together with 10 generated concepts for the compression mechanism. A few of the mechanisms discussed are the individual hand-held plunger, the vertical cable pull, and the attached lever arm.

Individual Hand-Held Plunger
The individual hand held plunger is basically a bar with a handle that is used to push the spring down. The user will grip the handle and press down to load the spring in the compressed

position. The plunger is then placed in a specified slot on the base so that it is out of the way when launching. Some advantages of this design are that is very simple and robust. This concept could lead to loss of the compression mechanism because it is not attached to the base.

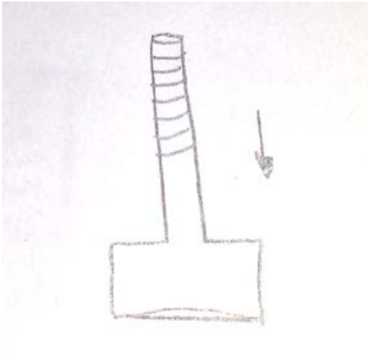

Fig. 20: Individual Hand-Held Plunger

Vertical Cable Pull

The vertical cable pull is a cable threaded through the center of the spring and attached to a handle. The other end is tied to a washer so that when the handle is pulled, the cable will not pull out of the spring. The spring is compressed as the cable is pulled downward. Although this design is very simple, we feel as if it is going to be hard to pull the cable down unless the base has a lot of clearance under it.

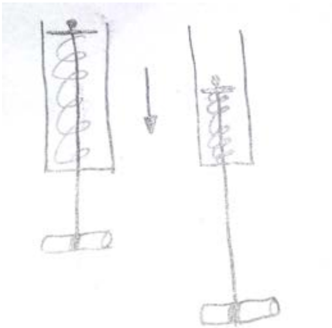

Fig. 21: Vertical Cable Pull

Attached Lever Arm

The attached lever arm is essentially a lever arm that has a pivot point off to the side of the spring. The lever has a plunger on it so that when the user pushes down on the handle, then the plunger will push the spring down compressing it. The lever then folds out of the way when not in use. This lever will provide a lot of force to the springs, but the alignment of the plunger with the tube could pose problems.

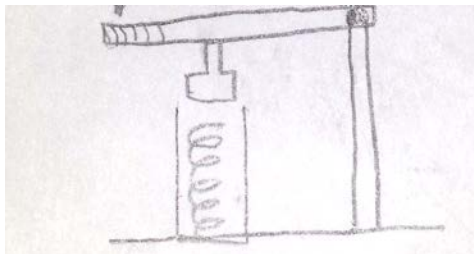

Fig. 22: Attached Lever Arm.

The remaining seven design concepts can be found in Appendix A.1.

Trigger Mechanism

Another crucial part of the spring demonstration mechanism is the trigger itself. The trigger mechanism is going to be the most complex system in the device’s performance; all three triggers must release their ball at the same exact time for the demonstration to be successful. Therefore, we developed 10 concepts for the trigger mechanism itself. A few of the more prominent concepts include the door-style spring pin, a double door latch, and a simple pin-pulling action.

Door-Style Spring Pin

The door style pin uses a single spring loaded pin that resembles the shape of a door latch. It attaches to a flat spot on the spring/ball interface that latches the mechanism when the springs are compressed. The pin is then pulled out to release the mechanism. This is great because the trigger is automatically set when the spring is compressed. This could be a great design, but the forces will cause the spring to twist sideways when the mechanism is locked in position.

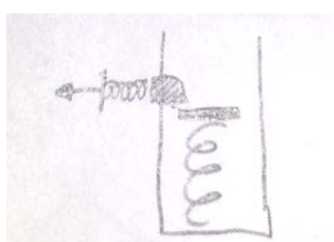

Fig. 23: Door-Style Spring Pin

Double Door Latch: Like the door-style spring pin, the double door latch uses door style latches that hook onto a flat spot on the spring/ball interface. One difference though is the fact that there will be two latches used, with one on each side of the spring to avoid moments exerted by the compressed spring. Although this provides good stability in the compressed spring, it also poses a challenge as to how we would pull the latches outward to release the spring.

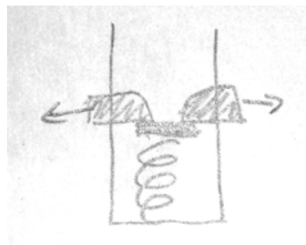

Fig. 24: Double Door Latch

Pin Pulling: The simplest design we had was the simple pin pulling mechanism. The spring containment vessels simply have a hole through them with a pin through the hole. This allows for a secure launch. The pins are attached to cables at a single point and the cables are pulled to release the spring. Although this design is very simple, the pins will have to be pulled very fast to avoid the spring launching sideways in the tube.

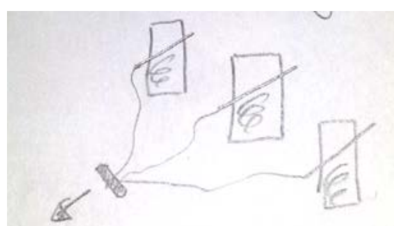

Fig. 25: Pin Pulling

The remaining seven design concepts can be found in Appendix A.2.

Safety Mechanism

To ensure safety to the operator of the mechanism and the audience, we decided it would be very important to incorporate a safety mechanism that would act as a safeguard when loading or when the device was not being launched. This safety mechanism would be incorporated as either an anti-triggering-mechanism or as a hard stop to prevent the ball from launching out of the containment tube if accidental discharge occurs. We also developed 10 concepts for this system of the device. Three important concepts include the individual pins, the interior plate, and the lever latch.

Individual Pins

When the springs are compressed and the triggers are set, the pins are inserted through the spring containment vessel to ensure the spring cannot release. Even if the trigger is set off, the spring will simply hit the pin instead of launching the ball and potentially hurting someone. This design is very robust, but the time it takes to reset the pins may make it undesirable to the user to actually use the safety.

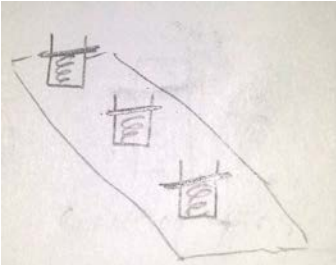

Fig. 26: Individual Pins

Interior Plate

Essentially, this safety mechanism involves milling a notch halfway through the spring containment vessels. Once the triggers are set, the operator will simply slide a plate into this slot until the device is ready to launch. This design is also very simple, and doesn’t take much time to set the safety. One drawback is the weight of this plate will substantially cut into the weight specification of 25 pounds.

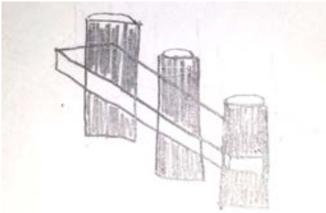

Fig. 27: Interior Plate

Lever Latch

If the device requires a lever to activate the trigger mechanism, we can incorporate a safety right into the lever. The lever would be mounted on an axle to allow it to pivot. A hole within the support would allow for a pin to be inserted, restraining movement of the lever, thus disabling the trigger. This design is very simple and greatly reduces the safety set time by using only one pin. Although the lever cannot be moved, the cables could still be independently pulled by accident.

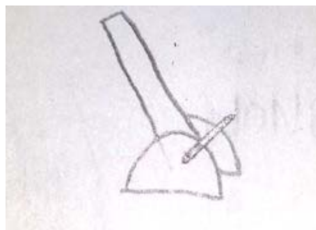

Fig. 28: Lever Latch

The remaining seven design concepts can be found in Appendix A.3.

CONCEPT SELECTION

To help narrow down the concepts we generated for the compression mechanism, the trigger mechanism, and the safety mechanism, we first came up with several metrics. These metrics represented the most important attributes that the mechanism would need to have to successfully fulfill the requirements for the project. These metrics were ranked by importance on a scale from 1 to 5 with 5 being the most important. These were all inserted into a Pugh chart and each concept was scored on a scale from 1 to 5 (with 5 being the best) as to how well the concept fulfills the specified metric. A final score was calculated, and the final concept was selected.

Compression Mechanism

	Lightweight (2)	Loading Force (3)	Robustness (5)	Manufacturability (3)	Safety (4)	Simplicity (4)	Loading Time (3)	TOTAL
individual hand-held plunger	4	3	5	5	2	5	3	94
3-in-1 handheld plunger	3	1	5	4	2	4	5	85
cable pulls spring down	5	3	3	2	5	1	3	73
attached lever arm	2	5	3	2	4	3	5	83
jack-in-the-box lid	4	3	2	3	3	3	3	69
slotted housing with a lever	2	5	3	2	4	3	5	83
electric motor	2	5	3	1	4	2	3	70
screw mechanism	2	4	3	2	3	2	1	60
foot operated plunger	2	4	3	3	2	4	2	70
hydraulic arm	1	5	3	2	4	2	1	65

We decided to incorporate the concept of the individual hand-held plunger into our final design. This plunger will be very robust and will not be sensitive to alignment or mechanical failure while loading. This is most important because we do not want the compression mechanism to slip off the spring, and we do not want this mechanism to fracture and potentially put the user in danger. This is also the simplest design that we developed, playing into the robustness of the mechanism.

Trigger Mechanism

	Lightweight (2)	Robustness (5)	Manufacturability (3)	Simplicity (3)	Force Applied (5)	Trigger Set Time (4)	Safety (3)	TOTAL
mousetrap hinge	4	3	4	4	4	4	2	89
lever arm lock	2	4	3	4	4	5	3	94
door-style spring pin	4	4	2	3	3	3	4	82
rotating plate	3	4	3	4	2	4	4	85
rotating linkage	3	3	2	2	2	4	3	68
double door-style latch	3	3	2	2	3	4	3	73
pin pulling	5	5	5	5	3	3	5	107
jack-in-the-box lid	4	2	3	3	4	4	2	78
central button/lever	3	4	2	4	3	3	1	74
hook linkage	3	2	2	2	4	2	3	65

We decided to combine both the concept of the double door-style spring pin and the pin pulling concept into one. Despite the double door-style latch having a low score in our Pugh chart, we believe that the combined concept would be the best solution. When coming up with our original concepts, we did not anticipate that we could use the non-rigid cables from the pin pulling into the concept of the door mechanisms. There will be two spring style pins for each tube with cables attached to each one. This trigger reduces the moment force exerted by the spring and also will allow for automatic trigger engagement when the spring is compressed. Since normal door latches last for thousands of cycles when opening doors, we feel this is a very robust, repeatable, and simple design. This also reduces the trigger set time, which is critical in reducing the reset time of the device to less than 1 minute. Most importantly, the design of these triggers allows for a very small trigger set force and drastically reduces the amount of force to release the spring. This is important because we have a maximum trigger force of 5 pounds as an engineering specification.

Safety Mechanism

	Lightweight (3)	Alignment (4)	Safety (5)	Robustness (5)	Manufacturability (2)	Simplicity (4)	Set Time (3)	TOTAL
individual pin	5	4	4	3	5	5	2	102
connected pins	4	2	4	3	2	3	3	80
single pin	4	1	5	5	5	4	3	101
individual plate	2	4	3	5	4	4	3	95
shelf lid / plate	2	5	2	4	2	3	4	84
interior plate	2	5	3	4	4	5	5	104
lever latch	5	4	3	5	5	5	4	113
latch strap	3	4	2	2	3	5	3	80
heavy weight	1	4	2	4	3	5	4	87
rotating lever	4	3	3	3	5	4	5	95

We decided to use the safety mechanism that is incorporated into the lever arm. Since we decided to use the cables, spring door hinges, and lever arm for launch, we figured this mechanism would be best. This device is very simple and easy to use, which will not discourage the user from actually using the safety device. Pins are very strong, so there is little risk that the pin will fail and launch the mechanism involuntarily. This is a very simple, robust, and easy to align safety mechanism which will add another layer of protection to the user.

Final Design Concept

Our final design concept consists of an individual hand-held plunger for compressing the spring, a combination of spring door latches with cables for the trigger, and a pin safety incorporated into the lever of the machine. To start, we will have a base with legs attached to its underside. Different sets of legs with varying length will allow us to change the launch angle. The spring will then be attached to a threaded plate on the bottom and a cup for the top that will hold the balls in place before launch. Around this spring, there will be a cylinder which will be attached to the base. On each side of the spring, there will be an assembly consisting of a spring door-style pin, a pulley, and a housing. A series of cables will then be routed through the pulleys and attached to the pins in the trigger. These cables will be fixed at one point to a lever arm at the other end of the base and will be adjusted so that when the lever is pulled, all of the triggers will release simultaneously. The housing around the lever will have pin holes through it for the safety mechanism. A bolt will be threaded through the base and into the bottom plate of the spring to provide adjustability to the spring's compressed length.

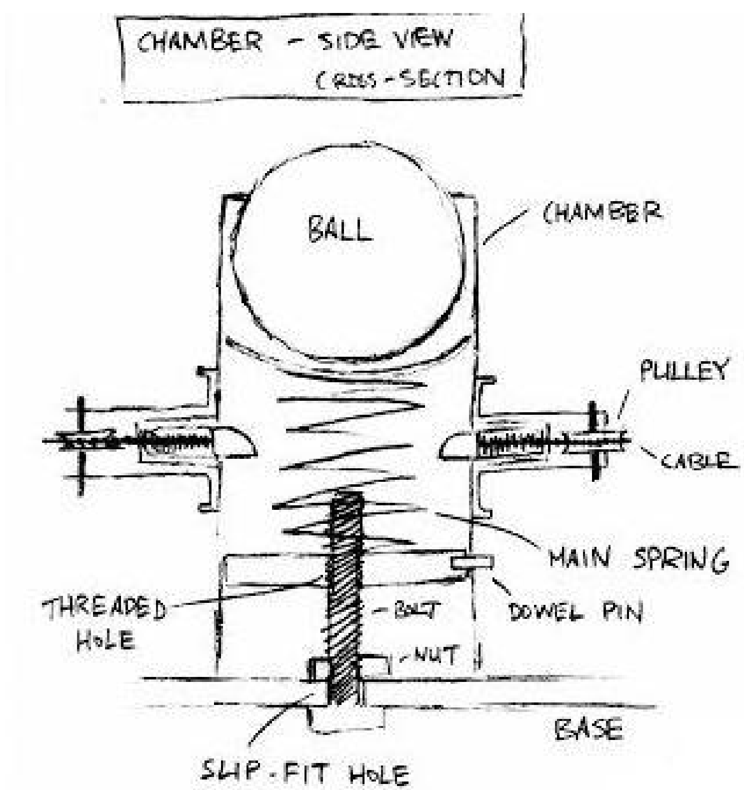

Fig. 29: The cross sectional view of the spring chamber is shown. As you can see, the spring is housed inside a cylinder and has a bottom threaded plate and a cup-shaped plate attached to the top to hold the ball. When the spring is compressed, the spring triggers automatically compress and lock the spring in place. Each spring trigger is attached to a cable which is ran around a pulley and back to the lever arm (not shown). Adjustability of the spring's compressed length is controlled by turning the bolt at the bottom of the base.

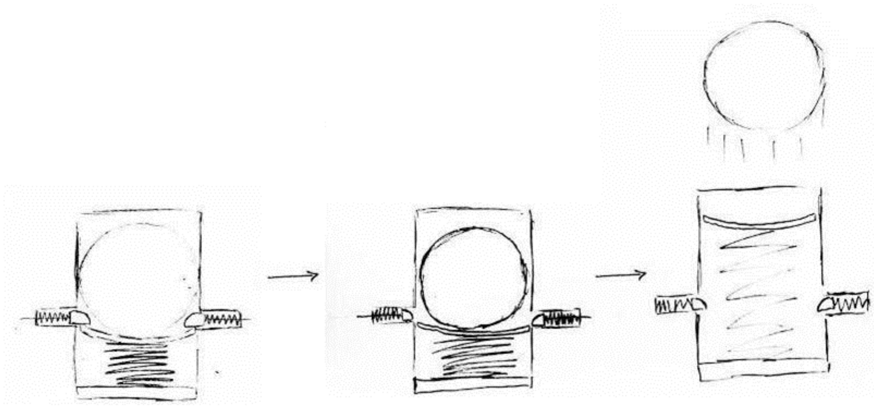

Fig. 30: This shows the in-process drawing of the ball being launched. The picture shows the spring is compressed and the device is loaded. Next, the pins are pulled outward and the spring launches the ball.

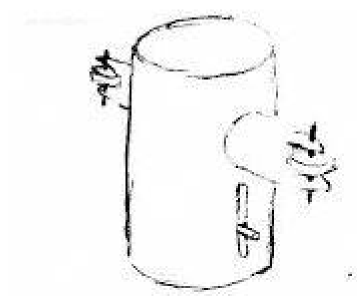

Fig. 31: This is a visual representation of an isometric view of the spring/trigger chamber. The slotted hole on the side is intended to be used to insert a pin to keep the bottom plate from rotating when the compressed length is being adjusted.

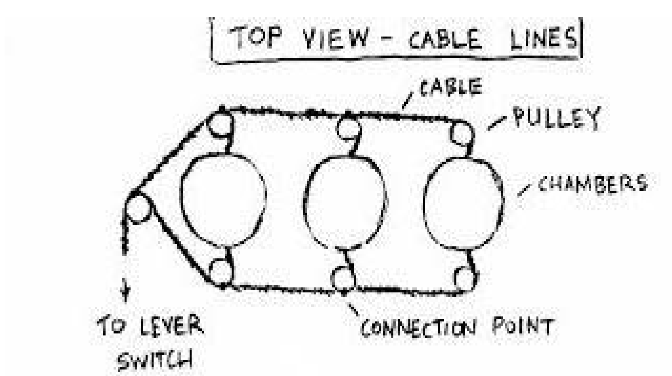

Fig. 32: This shows how the setup of the apparatus will look from the top. Each chamber will have two pulleys in which cables are routed back to a central point. This point will be connected to the lever switch.

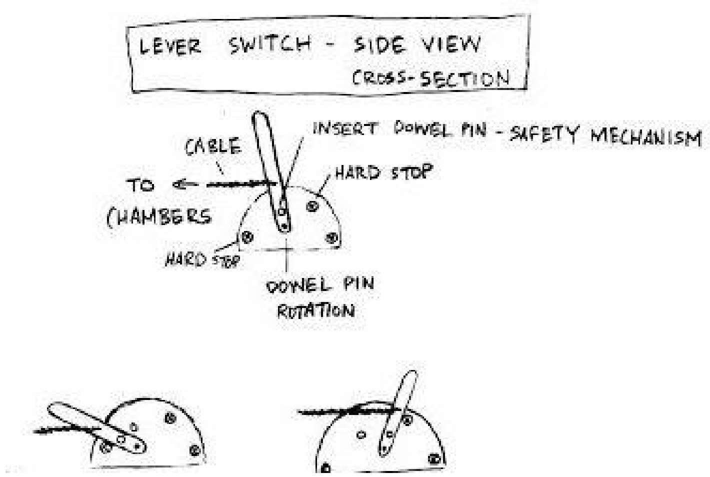

Fig. 33: The lever switch will consist of a bar and two hemispherical plates. The bar will have a pivot between the two plates and will be connected to the cables running to the triggers. With one short motion, the lever will pull every cable and release all triggers simultaneously. To prevent unintentional firing of the apparatus, there will be slots for pins. When the pins are inserted, the lever cannot be pulled, which won't allow the triggers to release.

Advantages

The main advantage of our final design is that it is an entirely mechanical solution. The end user will not need to plug in the unit, service motors, or worry about a battery going dead. This also reduces weight of the final design and increases its robustness. The functionality of this device is more important than pure bells and whistles, so simplicity is key. By using a double latch system, moment forces exerted by the compressed spring should not be an issue. Another great thing about the triggers is that when the chamber is pressed down, the triggers automatically engage. This makes it safer when loading because the user can use both hands to load instead of using one hand to load and another to set the trigger. The compression mechanism is also very robust and will not be able to fail, which increases the safety of the overall design as well. Other advantages include low friction and the lever arm can be adjusted to meet the specification of a 5 pound trigger pull. In addition, the safety mechanism we are using is so simple that there will be no reason for the user to avoid using it.

Disadvantages

One major disadvantage that we foresee is the complexity of the trigger design and housing. Although the overall idea of this is relatively simple, it is going to be hard to manufacture these components. Another disadvantage is the routing of the cables. It may end up being difficult to adjust the cables in such a way that all triggers will be released simultaneously. Lastly, the individual hand-held plunger may pose some problems because it is separate from the machine. To solve this, we plan on making a specified area on the base specifically for this plunger with straps to secure it to the base. This will reduce the chances of it falling off or getting lost.

KEY DESIGN DRIVERS AND CHALLENGES

After identifying our design specifications, the team began to analyze the challenges of our projects and our potential means of addressing and overcoming the problems that we may encounter.

Above all other challenges, the trigger mechanism challenges our team the most from a design standpoint. Specifically, the requirement that the device must be capable of launching 3 balls simultaneously with less than 0.1 sec delay between the launches has proven to be the central challenge thus far in the design process. To practically satisfy this requirement, the launch must be semi-autonomous with the operator performing one quick motion to activate a mechanism that launches all three balls. The challenge of designing, manufacturing, and implementing a mechanism that can perform this task will test our knowledge of classical mechanics, dynamics and materials.

Since the project is a senior design term project, we are set in a number of constraints. The largest constraint that we have is time. With less than 4 months to research, design, prototype, fabricate, test, and deliver this prototype, the team must be organized and operate efficiently. In addition, we are limited by our own novice manufacturing abilities as opposed to outsourcing the machining to professionals. The device is also supposed to be primarily mechanical, deterring us from using mechatronic components and programmable mechanisms to accomplish the goals.

Our design drivers are directly derived from our sponsor's user requirements and the specific engineering requirements. Above all else, our sponsor has emphasized the desire for functionality of the machine. The device must be durable and reliable enough to successfully launch every time it is activated and to do so over at least a decade. To accomplish this, the team has placed the trigger mechanism, compression mechanism, and safety mechanism as the primary design drivers. Since a major source of risk is found in the triggers ability to launch 3 balls simultaneously over many repetitions, we aim to design a latch that is simple in structure and operation in addition to implementing a trigger that is of few moving parts to reduce complexity in operation. We must also design a compression mechanism that is durable, user friendly, and can quickly and safely compress each cylinder plate. Since our device is a failure if it puts others at risk, the team aims to design our system with an integrated safety mechanism to prevent accidental launches. For all three of these mechanisms, the team must manufacture with precision so that the components will assemble as close to nominal as possible. Particularly when manufacturing the trigger, the team will seek out the assistance of experienced machinists and will utilize precision machining equipment such as the mill and lathe.

FINAL CONCEPT DESCRIPTION

Our final concept consists of an individual hand-held plunger for compressing the spring, a combination of spring door latches with cables for the trigger, and a pin safety incorporated into the lever of the machine. To start, we will have a wooden base with legs attached beneath. Different sets of legs with varying length can be interchanged to allow us to change the launch angle. Inside each of the three identical cylinder housings, the ball will rest on top of a plate connected to the top of the spring. An in individual hand-held plunger will be utilized to compress the spring-interface plate. Two pin latch mechanisms will be threaded opposite one another inside the cylindrical structure, and they will lock the plate in place after the plate is compressed. The bottom of the spring will interface with another plate that is separated from the base by a spacer. To allow the user to modify the spring compression length, the spacer will be interchangeable with other spacers with different specified lengths.

Fig. 34: Isometric view of the final design.

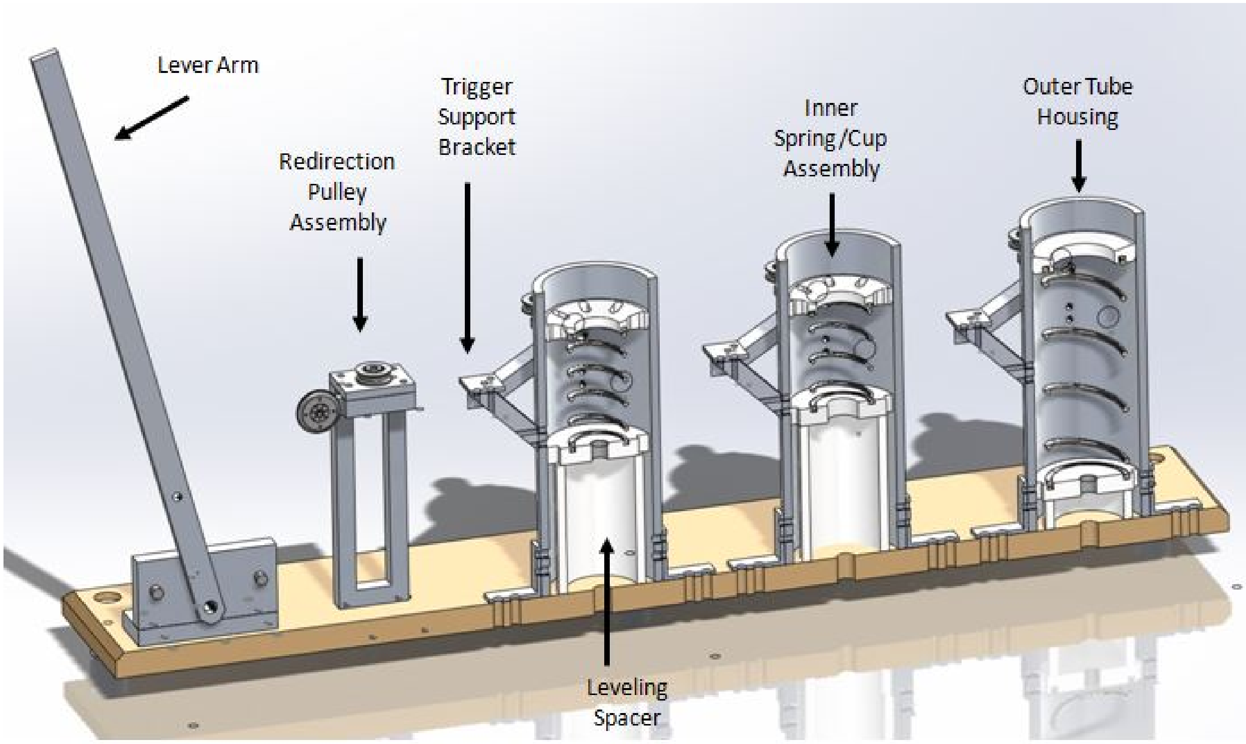

Fig. 35: Cut-away view with key components called out for emphasis.

On the outside of the cylinders, cables will connect to each of the latch mechanisms. Through a series of pulleys, these cables will route to one central pulley that will direct a single cable to a lever. The cable will attach to the bottom of the lever so that when the lever is pulled by an operator, each cable will simultaneously pull each latch mechanism, launching all three balls from their respective cylinders simultaneously. To support the pulleys and pin structures, mounting plates are attached to the side of the cylinders and further supported by angled gussets that come together outside the center of each cylinder. The angle gussets strengthen the support plates against the torsional forces of the pulleys. A stand supports the central pulley that routes the cables to the lever. This pulley is necessary to account for the transitioning of the cable - lever interface point that occurs when the lever rotates. The lever housing will incorporate a removable safety pin that crosses the levers rotation path to prevent accidental launching of the balls. Additional and more detailed views of the final design are located in Appendix C. Since the development of the design and model, some changes have been made which are located in Appendix E.

ENGINEERING ANALYSIS

We previously decided on three major design drivers associated with our design. They are the compression mechanism, trigger mechanism, and the safety mechanism.

Chosen Ball

The ball we chose to use for this experiment is a low-density street-hockey ball. It weighs 47 grams and has a diameter of 2.625 inches. This ball is light enough to launch with minimal force, and it will not bounce very high after it returns to Earth and hits the stage. This will enable the instructor to quickly gather the balls without having to chase them all over the auditorium. This ball is somewhat elastic so this would cause no harm to any student even if it did land on them.

Fig. 36: The ball we chose to use for our final design.

Chosen Springs

We did a lot of background research into the spring properties before we were able to decide on a set of three. The main goal of this was to select springs where the performance would not be obvious by simple inspection. Before we could start developing our final design dimensions and spacing, we first had to know how large the springs were because this would constrain the rest of the design parameters. The spring properties for our selected springs are shown in the table below.

Spring	72876S	S-3094	S-1528
Wire Diameter (in)	0.135	0.156	0.12
Outside Diameter (in)	1.687	1.781	2.375
Free Length (in)	3.5	6.63	3
Active Coils	6	5	4

Table 1: The spring dimension table shows that there is a significant difference in each wire diameter, outside diameter, and free length. All springs are made of stainless steel.

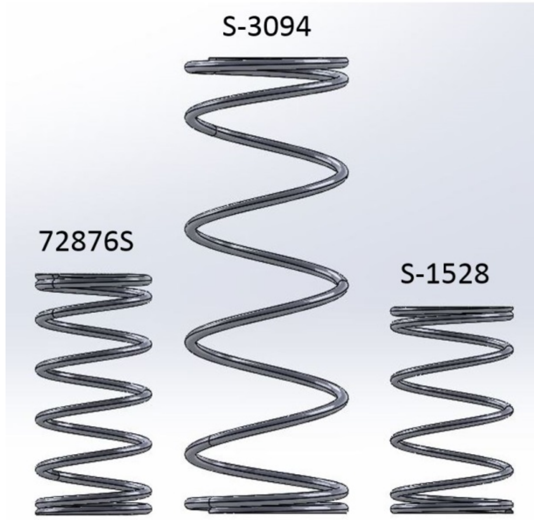

Fig. 37: The solid models for the selected springs show the overall size difference between the three. It is not obvious from inspection which spring will launch the ball the highest.

Deriving the Spring Constant

To perform a spring compression force analysis on our design, we decided to create a model. For this model, we first looked at the appropriate physics principles. To calculate the spring constant for each spring, we first would need the physical properties of the spring such as the wire diameter, number of active coils, the outer diameter, and the spring compressed length. We also would need to obtain material properties for stainless steel such as Young's modulus and Poisson’s ratio in order to calculate the modulus of rigidity of the material. The modulus of rigidity, *G*, would be found in Eq. 1:

$$G = \frac{E}{2\,(1+v)} \qquad \text{Eq. 1}$$

where *E* is the Young’s modulus and *v* is the Poisson’s ratio for stainless steel. To calculate the spring constant, *k*, for the spring we would use Eq. 2:

$$k = \frac{G\,d^4}{8\,n\,D^3} \qquad \text{Eq. 2}$$

where *d* is the wire diameter, n is the number of active coils, and *D* is the mean coil diameter. Since we are ordering springs from a website that tells us the spring constant of each spring, all of these variables do not come into account for our calculations. It is important, however, to note where the spring constant comes from and what variables affect the spring constant.

Calculating Ball Launch Height

To calculate the ball’s launch height for each spring, we needed to first determine how fast the ball would be going when it exits the spring. To determine this, we calculated the acceleration *A* of the ball as a function of time in Eq. 3, then integrated to determine its velocity *V* in Eq. 4, and then integrated again to determine its height *H* in Eq 5:

$$A(t) = g + \frac{C_d \, \rho \, V^2 \, Area_{\text{cross section}}}{2\,m} \qquad \text{Eq. 3}$$

$$V(t) = V_0 + \int_0^t A(t)\, dt \qquad \text{Eq. 4}$$

$$H(t) = \int_0^t V(t)\, dt \qquad \text{Eq. 5}$$

where m is the mass of the ball, g is the acceleration due to gravity, C_d is the drag coefficient for a smooth sphere, ρ is the air density/, and V_0 is the velocity at the previous time step. V_0 is used because velocity changes at every time step. Below is a general schematic of the forces acting on the ball when the spring is released.

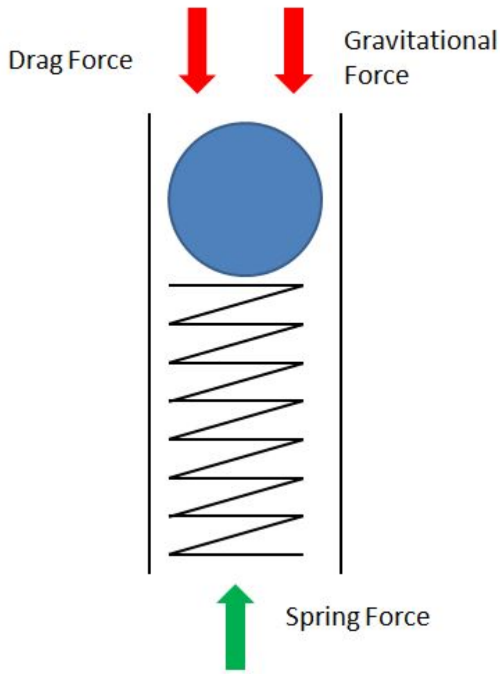

Fig. 38: When the ball is launched, the spring force must overcome the sum of the drag force and the gravitational force acting on the ball. From this we are able to predict how high the ball will go at launch time. For the figure below, we can see the estimated launch heights for the balls using the three springs we selected.

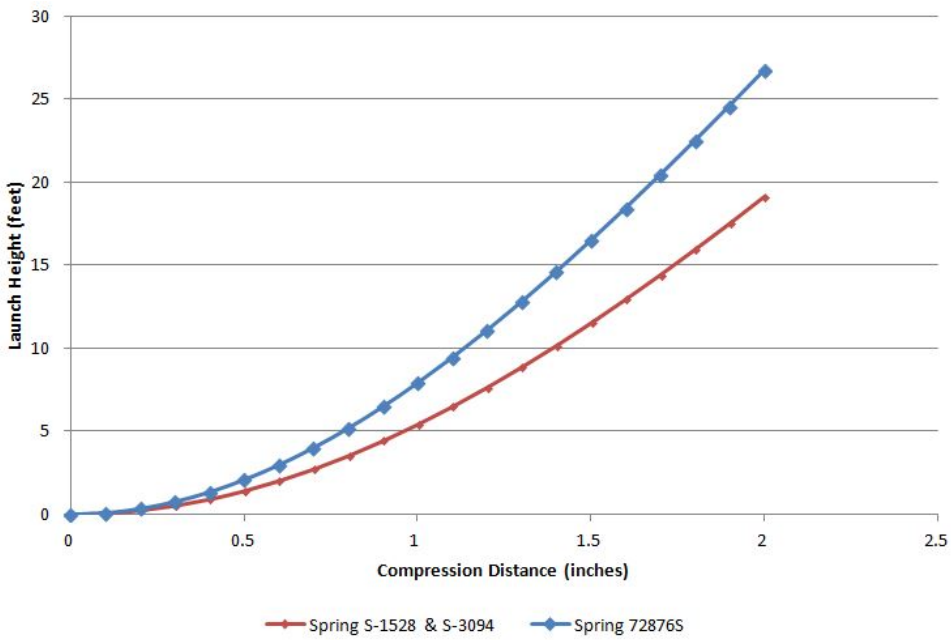

Fig. 39: As you can see from the graph, there are only 2 curves. Since Spring S-1528 and Spring S-3094 have the same spring constant, their launch heights will lie along the same line. We can also see that the correlation is quadratic, which is what we can expect.

Spring Compression Force

Our first design driver was the compression mechanism of the design. For this design, we wanted to make sure that we minimized the force required to compress the springs, but also wanted to have a sufficient launch height for the balls. The figure below shows how the compression force is equal to the spring force. As you compress the spring, it takes more and more force to do so.

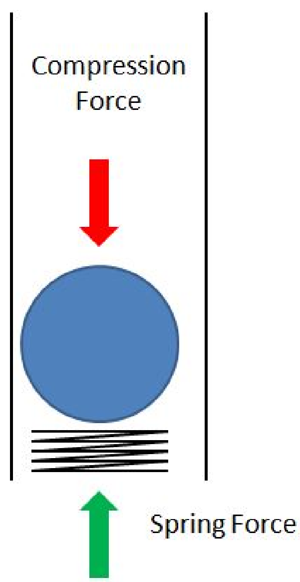

Fig. 40: As the spring is compressed, the spring force increases linearly.

To calculate the compression force needed to compress the spring a prescribed distance, x, we simply used the fact that the force of a spring is proportional to the distance it is compressed. More formally, the force F:

$$F = k\,\Delta x \qquad \text{Eq. 6}$$

where k is the spring constant and Δx is the compression distance. For each spring, we calculated the force required for a compression distance from 0 to 2 inches in increments of 0.1 inches. The following graph shows the correlation.

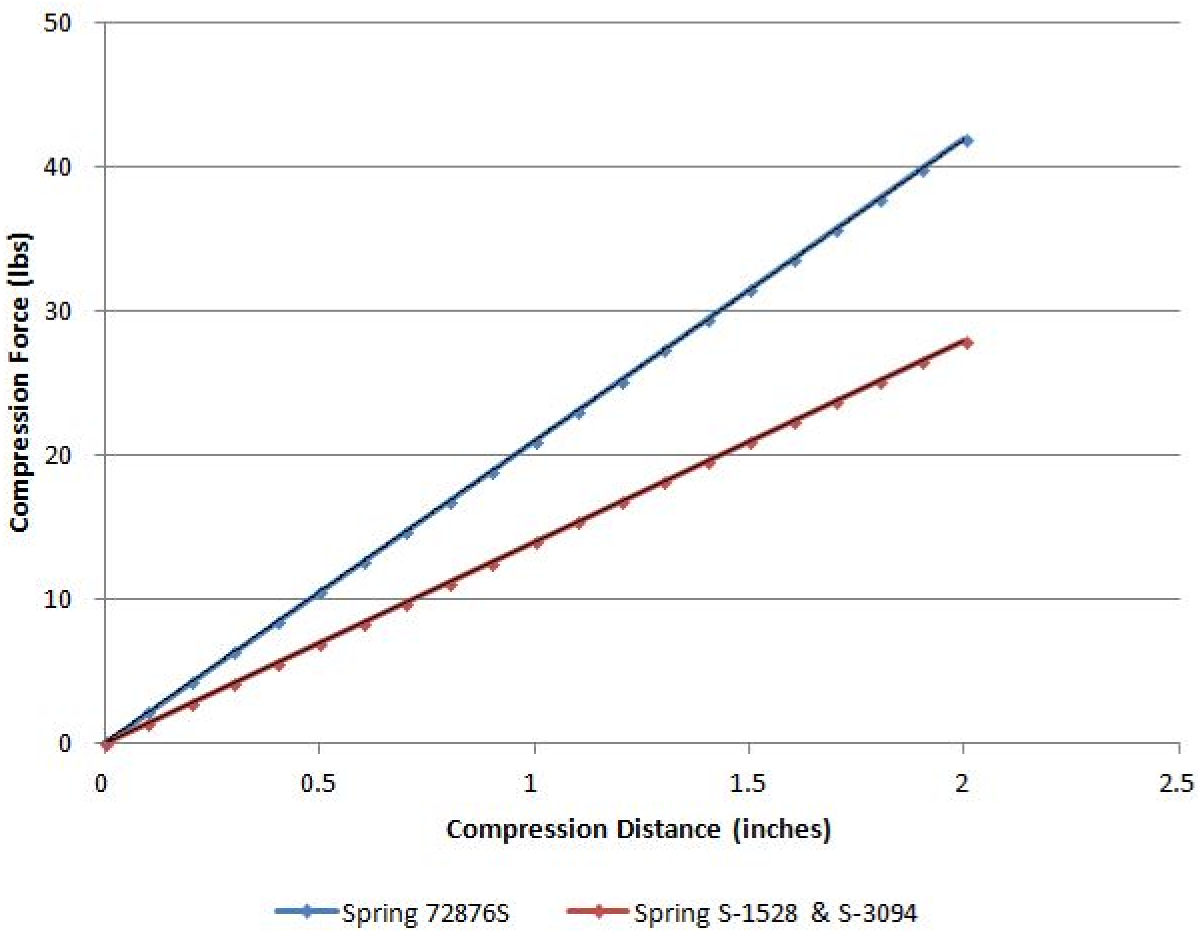

Fig. 41: As you can see from the graph, there are only 2 curves. Since Spring S-1528 and Spring S-3094 have the same spring constant, their forces will lie along the same line. We can also see that the correlation is linear, which is what you would expect.

Trigger Force Empirical Analysis

To test the force required to pull the pins on the triggers, we built a test chamber. We took a piece of PVC tube and a scrap spring with considerable length and cut both to size. The spring specifications are in Table 2 on the next page.

Wire Diameter (in)	0.042
Outside Diameter (in)	0.5
Free Length (in)	11
Active Coils	68

Table 2: Specifications for the test spring are recorded for further calculations.

The PVC was cut to 12 inches and the spring was cut to 11 inches. Along the PVC tube, we drilled a series of 10 holes at ½ inch intervals. We then mounted a piece of ¼ inch thick aluminum plate to the pipe and aligned the hole in the aluminum with the hole in the PVC tube. This is to simulate the selected pin being pulled along the same thickness and material as we have chosen for the walls of our launch chambers. The spring was compressed and a pin (¼ inch hex key) was inserted to the desired compressed length hole. We used the flat hex key because it more closely represented the flat style of trigger interface that we would be using, rather than a cylindrical one.

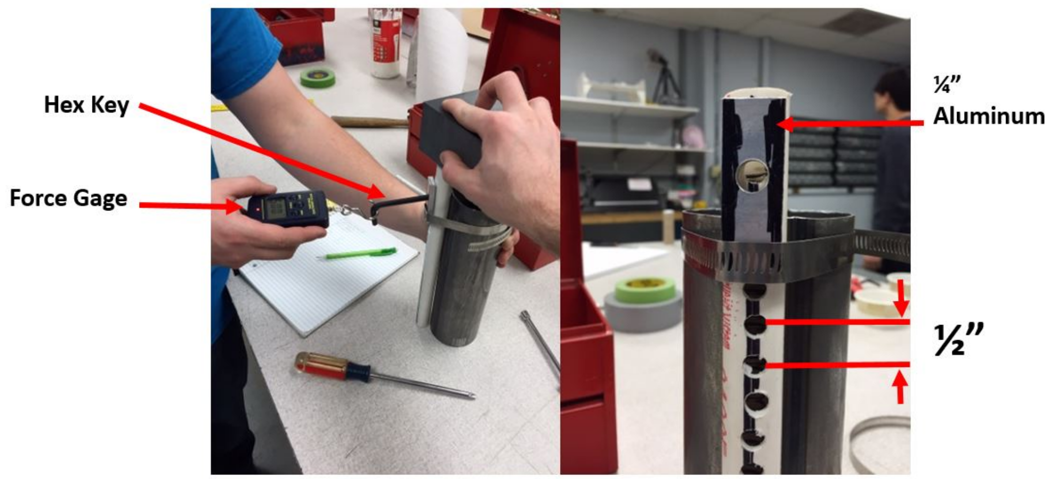

Fig. 42: The test procedure for the trigger force experiment can be shown in this series of photographs.

Once the spring was compressed, the key was pulled out with a force gauge, and the force required was recorded for 3 tests per compression length. The results are as follows:

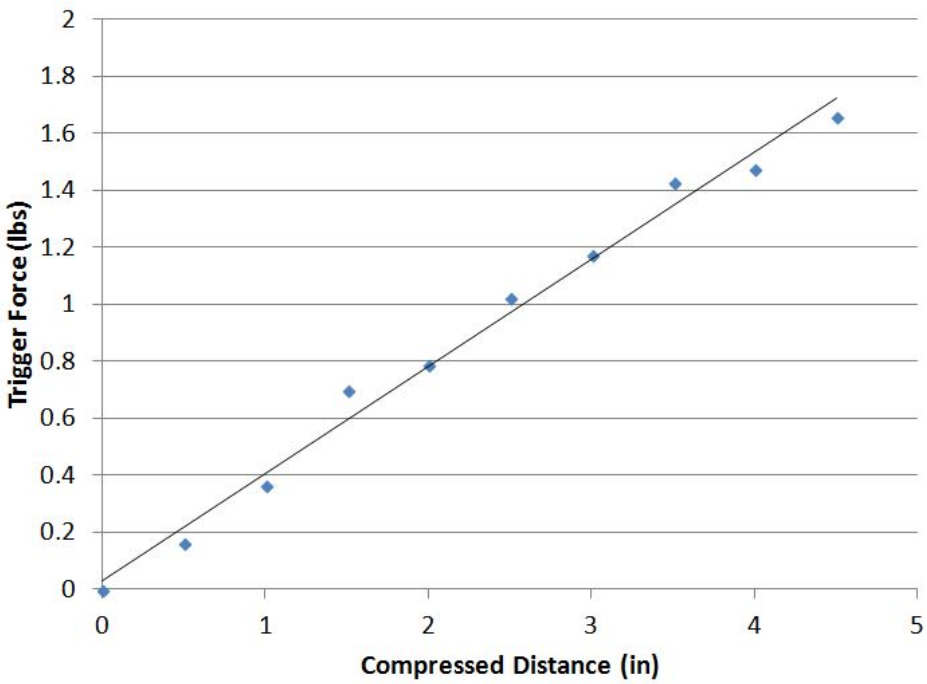

Fig. 43: As the compression distance increases, the trigger force also increases linearly.

Additionally, to test for possible differences in latch release behavior as a result of different applied forces from the three springs, we designed a rig to mimic the latch and trigger system, as shown in Figure 43 below. Using the force gauge, we found that it required 1 pound to trigger one latch and 2 pounds to trigger two latches together. Then we added the spring to apply a force of 3 pounds on the latch, and we found it required 3 pounds to trigger that latch and 4 pounds to trigger the two latches together.

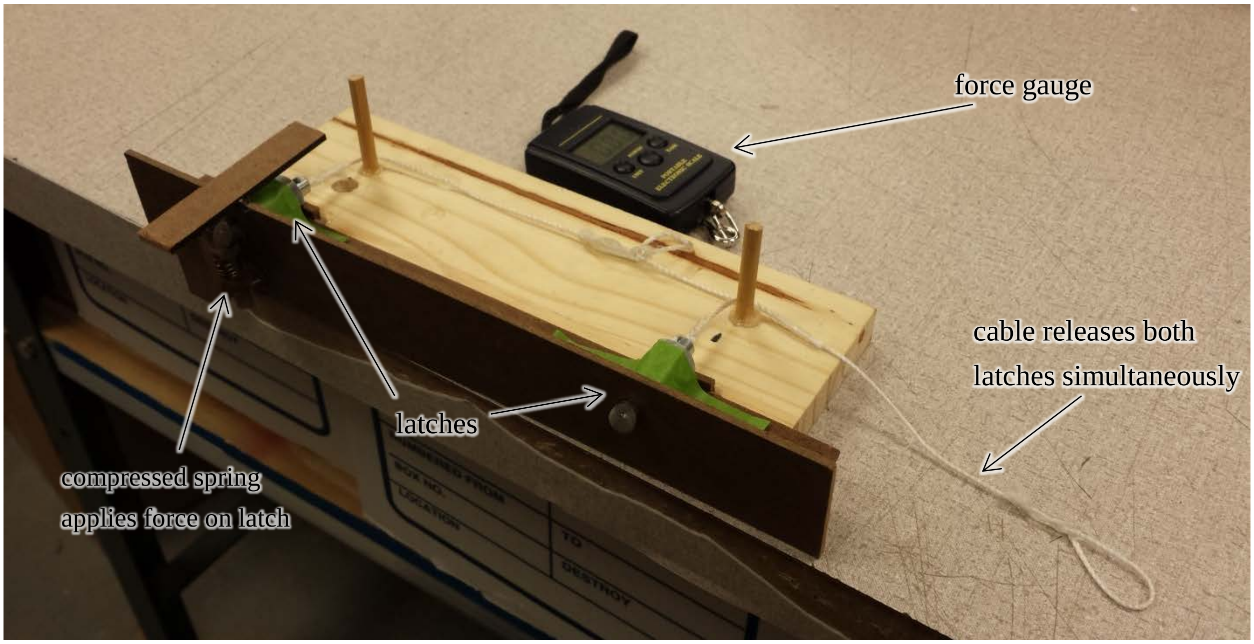

Fig. 44: Testing rig for difference in latch release behavior

Despite the difference in forces required, we found that the release behavior was ultimately determined by cable pull length. Because the cable pulls the latches the same distance, and because the cable does not stretch, the latches release simultaneously regardless of applied force. Using this data, we can later scale up this data to match the dimensions of our springs. This way we should be able to determine the force that the triggers will require for the final design.

Lever Safety Mockup Analysis

The lever safety mechanism is a very simple mechanism. To represent this, we simply created a mockup showing this design aspect. We simply used foam core to construct both the base and the lever arm itself. We attached the lever to the base by using a bolt. Then, at the specified position, we put a pin through the base as well. At this position, the lever cannot be pulled, and therefore the springs will not release. We even went as far as making the pin position such that when the lever is in a resting state, the cables going to each trigger will be in a relaxed state. This will avoid any undesired launches due to gravity acting on the lever arm itself.

Fig. 45: The lever mechanism consists of a base and a lever arm. To prevent accidental launch, a pin is inserted to act as a hard stop. It is inserted through the base to prevent the lever from being pulled. This is simple and will ensure that the pin safety will be used every time.

We learned that this is going to be a relatively easy piece of the design to manufacture. We also know that setting the pin is a very easy and fast process. This will reduce setup time and will encourage the user to use the safety mechanism every time. In the future, the lever and base will be made of aluminum but the overall assembly process will be similar.

RISK ANALYSIS

Upon developing a final design, the team broke the design into components and performed an Failure Mode and Effect Analysis (FMEA) on the product. The following table and section details our results.

Function	Potential Failure Mode	Potential Effects of Failure	SEV	Potential Cause / Mechanism of Failure	OCCUR	Current Design Control	DETECT	RPN
Trigger								
Pin Mechanism	Pin slips off plate, back into mechanism	Plate released pre-maturely, balls launch, injury to unaware bystanders	10	Vibrations, loss of trigger spring compression, deformation/deflection of pin	2	Pin mounting method, testing	1	20
	Pin breaks	Plate released pre-maturely, balls launch, injury to unaware bystanders	10	Fatigue failure, wear	2	Material, force analysis, testing	1	20
	Pin jams	Plate does not release as timed, does not release at all, not simultaneous launch	8	Trigger spring locks, misalignment in pin mechanism deformation of pin	2	Testing, tolerances	1	16
	Pin does not retract fully into mechanism	Plate does not release as timed, does not release at all, not simultaneous launch, launch but pin drags on plate - lowered height	8	Trigger spring compression failure, pin not pulled with enough force each time, deformation of pin	3	Testing, pin positioning	1	24
Pulley System	Cable connection slips	Launch on one or all of cylinders is delayed or doesn't occur at all; incomplete pin removal - lowered height at launch	8	Stripping of cable, loose fittings, cable material yield	3	Correctly sized connectors, testing	1	24
	Cable connection breaks	Launch on one or all of cylinders doesn't occur at all	8	Material yield, fatigue failure, wear	2		1	16
	Cable slips off pulley	Launch on one or all of cylinders is delayed or doesn't occur at all; incomplete pin removal - lowered height at launch	8	Misalignment, impact, vibrations, slack in cable	3	Deep grooved pulley, testing	1	24
	Pulley jams	Launch on one or all of cylinders is delayed or doesn't occur at all; incomplete pin removal - lowered height at launch	8	Misalignment, impact, vibrations, bearing seizure	2	Quality bearing, testing	1	16
Lever Device	Lever jams	No pulling of cables to release pins - no launch	8	Misalignment, impact, deformation of lever	2	Tolerances, materials, oversized holes	1	16
	Lever breaks	No pulling of cables to release pins - no launch; Incomplete removal of pins (depending on when lever breaks)	8	Deformation of lever, impact, fatigue failure, wear	2	Material selection	1	16
Safety								
Pin in lever attatchment	Pin removed pre-maturely moved from position in lever attatchment	Lever unguarded against accidental launch - potential injury to unaware bystanders if launch occurs	9	Impact, vibrations, plate hole deformation, loose fitting	2	Tolerances, materials, testing	1	18
	Pin breaks from position in lever attatchment	Lever unguarded against accidental launch - potential injury to unaware bystanders if launch occurs	9	Pin material fatigue failure, impact, wear	2	Materials, testing	1	18
	Pin jams / becomes stuck in lever attatchment	No pulling of cables to release pins - no launch	8	Deformation of pin, misalignment	2	Materials, testing, tolerances	1	16
Compression								
Compression Tool	Tool breaks while in use	Incomplete / no compression of springs, potential injury to user if piece contacts him with force	9	Material yield, fatigue failure, wear	2	Materials, force analysis	1	18
	Tool slips from users control	Incomplete / no compression of springs, potential injury to user if piece contacts him with force, annoyance to user	9	Slick user hands, loose grip, deformation of material	3	Design for ergonomics, testing	1	27
Compression Adjustment	Adjustment spacers shift	Loss of compression, launch height potentially altered	7	Vibrations, impact, deformation of spacers	2	Materials, testing, sizing/positioning in cylinder	1	14
Spring	Spring buckles	Loss of compression - launch height potentially altered; plate misaligned - launched at an angle	7	Binding in spring material, too much compression	3	Spring diameter and other physical characteristics, cylinder diameter, testing	1	21
	Spring breaks	Loss of compressability, no launch or launch height altered	8	Material yield, fatigue failure, wear	2	Materials, testing	1	16
Ball Interface Plate	Plate breaks	Jaming in cylinder - no launch or altered launch height, injury to bystanders if piece contacts	9	Material yield, fatigue failure, wear, impact	2	Materials, force analysis to compress, testing	1	18
	Plate jams in cylinder	No launch or altered launch height of one or multiple cylinders	8	Deformation, misalignment, vibrations	3	Plate sizing, tolerances, testing	1	24

In performing the FMEA, each primary function of the product was broken down into potential failures. The potential effects and causes of each failure were determined and the severity and likelihood of occurrence were quantified (Tables 4 and 5). Finally, current design controls that the team has implemented or plans to implement were determined, the likelihood of detection was quantified (Table 6), and finally the factors of severity, occurrence, and detection were multiplied to yield the Risk Priority Number (RPN). A RPN above 100 is high risk, between 100 and 31 is moderate risk, between 30 and 2 is low risk, and 1 is negligible risk.

Category (Product)	Criteria: Severity of Effect (Effect on Product)	Rank
Failure to Meet Safety or Regulatory Requirements	Potential failure mode affects safe operation or regulatory requirements, without warning	10
	Potential failure mode affects safe operation or regulatory requirements, with warning	9
Loss or Degradation of Primary Function	Loss of primary function	8
	Degradation of primary function	7
Loss or Degradation of Secondary Function	Loss of secondary function	6
	Degradation of secondary function	5
Annoyance	Item operable, but with annoyance noticed by > 75% of customers	4
	Item operable, but with annoyance noticed by 50% of customers	3
	Item operable, but with annoyance noticed by < 25% of customers	2
No Effect	No noticable effect	1

Table 3: Severity of potential effect on product

Table 4 describes the rankings of effect severity on a range of 1 to 10, with 10 being high safety risk and 1 being no noticeable effect.

Probability of Occurance	Rank
Very high: Failure all but guaranteed	10
	9
High: Repeated but unpredicatable failures	8
	7
Moderate: Occasional failures	6
	5
	4
Low: Relatively few failures	3
	2
Highly Improbable	1

Table 4: Probability of occurrence

Table 5 describes the ranking of a failure's occurrence probability on a range of 1 to 10, with 10 being failure all but certain and 1 being highly improbable.

Failure Detection	Rank
Almost no chance of detection prior to release to customers	10
	9
Low: highly likely customers will be the first to detect it	8
	7
Moderate: first noticed by many customers	6
	5
	4
Moderate: first noticed by a few customers	3
High	2
Almost certain	1

Table 5: Probability of failure detection

Table 6 describes the ranking of a failure's detection probability on a range of 1 to 10, with 10 being all but no chance of detection before product delivery and 1 being highly almost certainly will be detected.

Although all of the failures were found to be within the low risk range, failure of the compression tools function was determined to have the highest Risk Priority Number of 27. Specifically, the failure of the operator to control or hold grip on the device was calculated to be of relatively significant risk. The failure was given a severity ranking of 9 because if the user loses control of the compression device, not only will the spring fail to compress but there is the risk that the spring could propel the tool back at the user and potentially cause injury. An occurrence probability of 3 is low, but it is higher than other failure modes because of variables going into the human interaction with the tool such as hand slickness and strength of grip on tool. To mitigate this risk of failure, the tool will be designed specifically with human ergonomics in mind. In addition, the team plans to extensively test the compression mechanism before delivery to the customer so it is almost certain that this failure will be detected.

While the likelihood of failure exists, steps are being taken by the team to mitigate its effects. To specifically address this risk, features such as a hand grip and hard-stop against hand sliding will be implemented. The risk of the user losing control of the compression tool exist, it is overall low, and with the implementation of ergonomic features described above, this risk is within the acceptable level given the necessity of the tool to the mechanisms operation.

FINAL CONCEPT MANUFACTURING AND ASSEMBLY

After designing the device and creating manufacturing plans, we manufactured and assembled the spring demonstration device.

Fig. 46: Spring assemblies

Fig. 47: Compression mechanism

Fig. 48: Final concept design fully manufactured and assembled

VALIDATION EXPECTATIONS AND RESULTS

Weight

To test the weight of the entire device, we will just need to locate a scale and weigh the device. Although very simple, this is a specification that was important for transportability. The weight of the device was measured to be 21.55 lbs, which meets the specification of less than 25 lbs.

Cable Assembly

Before any validation testing can take place, we must ensure that the device works as it is supposed to. The main concern we have with this device is the ability to make all of the cables be pulled the same amount, thus releasing all three spring chambers simultaneously. To do this, we will first connect the first set of cables to the pins on one end with crimp fasteners and route the cables through the pulleys. The remaining free end is then connected through the lever arm using adjustable clamps. We then will adjust the cable lengths to ensure that the first chamber has both triggers firing simultaneously. Then we will do the same for both chambers 2 and 3 except that the free end will be attached to the cables running from the chamber in front of it. Using this method should result in a launch that is close, but not necessarily to our specified requirement of launching in less than 0.1 seconds. Adjusting the cables requires cable cutters and a wrench to tighten the adjustable clamps. During our testing, we have found a cable setting that works consistently, thus validating the requirement.

Compression Force

We need to make sure the loading force is less than 50 pounds per spring. To perform this testing, we will need a cable and a force gauge. To test this, the cable will be strung through the center of the chamber and through the bottom of the device. The spring chamber will be compressed and loaded. Then the force gauge is connected to the other end of the cable and pulled downward until the top plate disengages from the triggers. At this point, the force will be noted for each spring.

Cylinder	Measured Force (lbf)	Specification Compression Force (lbf)	Validation Status
1	48	≤ 50	Verified
2	32	≤ 50	Verified
3	34	≤ 50	Verified

Table 7: Compression force specifications were met.

Load Time

We need to perform testing to validate the load time of less than 60 seconds. To perform this testing, we will need just a timer. Each one of us will then load the device for launch by compressing all three springs and inserting the balls into the chambers. We will then use the average of these times to determine if the device can be loaded in less than 60 seconds.

Trial	Load Time (sec)	Specification Time (sec)	Validation Status
1	7.56	≤ 60	Verified
2	6.98	≤ 60	Verified
3	6.20	≤ 60	Verified
4	5.48	≤ 60	Verified
Avg	6.56	≤ 60	Verified

Table 8: Load time specifications were met.

Trigger Force

We need to validate the force required to trigger the mechanism. To perform this we will just need a force gauge with at least a 5 lb reading. To test, we will simply load all three chambers and trigger the device by pulling on the force gauge which is attached to the lever arm. After several tests, the results will be averaged to ensure if the force required to trigger the mechanism is less than 5 pounds.

Trial	Measured Force (lbf)	Specification Trigger Force (lbf)	Validation Status
1	4.36	≤ 5	Verified
2	4.62	≤ 5	Verified
3	4.30	≤ 5	Verified
Avg	4.43	≤ 5	Verified

Table 9: Trigger force specifications were met.

Simultaneous Launch

We need to test to validate the requirement of a simultaneous launch of the triggers. To do this, all we will need is a video camera and a computer. We will simply record the launch of the device, upload the video and run it in a frame-by-frame software. Using the frame rate of the video and the number of frames between the first and last ball launching, we will be able to accurately determine any time delay between the chambers. Several videos will be taken to rule out any inconsistencies and to get a nice average for the actual time to launch.

Trial	Delay Time (sec)	Specification Delay Time (sec)	Validation Status
1	0.008	≤ 0.1	Verified
2	0.008	≤ 0.1	Verified
3	0.010	≤ 0.1	Verified
Avg	0.009	≤ 0.1	Verified

Table 10: Simultaneous launch specification was met.

Vertical Launch

We need to validate the vertical launch specification. To do this, we can simply use any video we previously had taken using the camera and the computer. We can then take a screenshot at the peak of the balls' heights and use a 5 degree line overlaid onto the screenshot to determine if the angle is less than 5 degrees from vertical.

Fig. 49: (left) Side view displaying angle of launch (right) Front view displaying angle of launch

View	Cylinder	Angle from Vertical (degrees)	Specification (degrees)	Validation Status
Side	1	2	± 5	Verified
	2	1	± 5	Verified
	3	2	± 5	Verified
Front	1	5	± 5	Verified
	2	2	± 5	Verified
	3	2	± 5	Verified

Table 11: Vertical launch specifications were met.

Launch Height

The most important specification that we need to validate is the height that each chamber launches the ball. To check this height, we plan to use a video camera, a tape measure and a camera. Before the test, we will set up the launcher in front of a wall so that we have a frame of reference. Also, one of us will be standing next to the mechanism when is is launched to give the video a frame of reference of roughly 6 feet. Then we will have to load the three chambers and load the balls into the chambers. When ready to launch, another member of our team will record the launch from a distance using the camera. This footage can then be uploaded to a computer and slowed down to determine the highest point that each ball reaches. The “human” frame of reference will then be extrapolated for each ball to determine the height that the ball launches within a foot of precision. We will perform this same test several times to confirm consistency in the system and the launch heights.

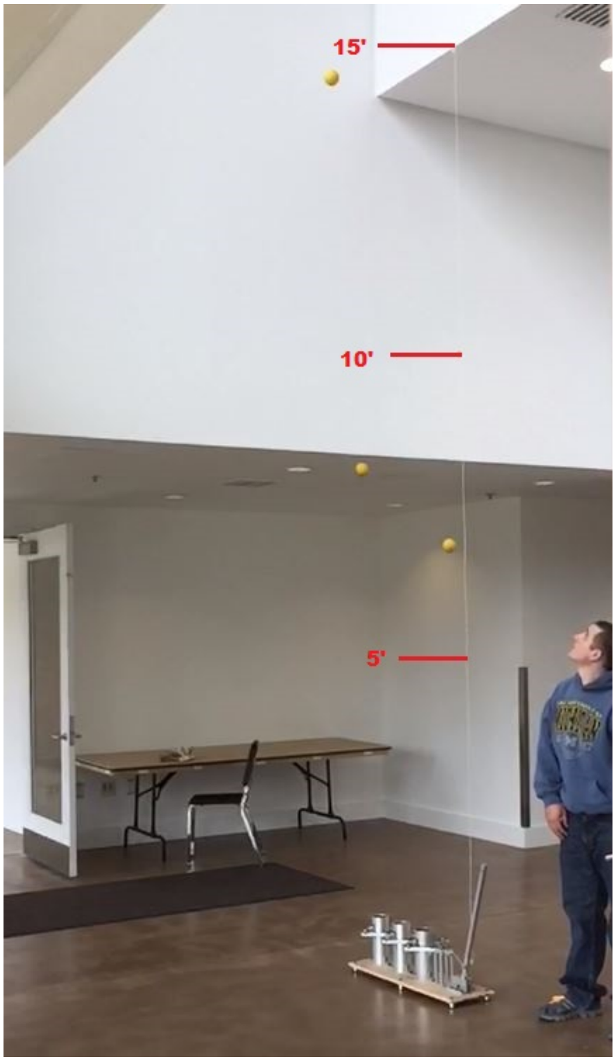

Fig. 50: Height of launch

Trial	Cylinder	Max Height (ft)	Specification Height (ft)	Validation Status
1	1	12	20 ± 3	Not Met
	2	7	$5 \leq x \leq 16$	Verified
	3	7	$5 \leq x \leq 16$	Verified
2	1	15	20 ± 3	Not Met
	2	7	$5 \leq x \leq 16$	Verified
	3	8	$5 \leq x \leq 16$	Verified
3	1	14	20 ± 3	Not Met
	2	7	$5 \leq x \leq 16$	Verified
	3	8	$5 \leq x \leq 16$	Verified
4	1	14.5	20 ± 3	Not Met
	2	8	$5 \leq x \leq 16$	Verified
	3	8	$5 \leq x \leq 16$	Verified
5	1	14	20 ± 3	Not Met
	2	8	$5 \leq x \leq 16$	Verified
	3	8	$5 \leq x \leq 16$	Verified
6	1	14	20 ± 3	Not Met
	2	9	$5 \leq x \leq 16$	Verified
	3	9	$5 \leq x \leq 16$	Verified
Avg	1	14	20 ± 3	Not Met
	2	8	$5 \leq x \leq 16$	Verified
	3	8	$5 \leq x \leq 16$	Verified

Table 12: Launch height specifications except for highest launch specification were met.

Durability

Once all of these previous tests are completed, we will have a good idea on the durability of the device. At this point, we will have performed dozens of launches and any faulty parts will already be determined. Before the design expo, all pieces will be closely observed and any cracks, chips, and other faults will be documented. If we do have any failures, these failures will be addressed and design changes will ensue. After all of our testing and demonstration, we have well exceeded the specification of 100 launches without mechanical failure.

DESIGN CRITIQUE AND FUTURE WORK

Overall, the team was very pleased with the outcome of the project. We designed a unique device that met all of the user specifications, manufactured and assembled the components with quality craftsmanship and precision, and carried out detailed validation plans that proved the device met their engineering specifications except for maximum height. The maximum height that the ball reaches is acceptable (14’ instead of 20’) in clearly demonstrating which ball goes the highest, but some factors could be reconsidered to meet the original specification. In the team’s original height calculations, they would better account for the launch plate mas in addition to friction of the Delrin plate along the aluminum cylinder. Spring energy losses would also be better accounted for in the calculations. Although the trigger force is much less than expected due to lack of friction in pins and pulley system, the pins themselves are more difficult to perfectly synchronize than expected.

While the team is very satisfied with the outcome of the project, a few things would be changed given more time and resources. The base and launch plates would be 3D printed to improve their interface with the inside of the cylinder and their mounting on the springs themselves. The team would also investigate materials that had a lower mass density yet maintained the devices structural needs in order to reduce overall weight of the device. A method for adjusting the launch angle of the cylinder would also be implemented if given more time and resources. In terms of broader implications, this project will serve as a learning and demonstration device for future ME 250 classes, and it will hopefully spark the student’s interest and comfort in implementing springs into their projects. The success of the spring demonstration project also lays the groundwork for future ME 450 projects to create demonstrate tools for other mechanical devices that are introduced in ME 250.

AUTHORS

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Vincent Qiu : Vincent is a senior undergraduate Mechanical Engineering and Asian Languages & Cultures student at the University of Michigan. From New Jersey, he developed an interest in structures and kinematics during high school. He has worked with Procter & Gamble on advanced paper web handling within manufacturing systems. Additionally, he is pursuing a concentration in Japanese language and culture, and has spent a summer studying future automotive technologies at Nagoya University in Japan. Outside of academics, he enjoys running, listening to music, and cooking.

Evan VanBeelen : Evan is a senior undergraduate Mechanical Engineering student at the University of Michigan. Originally from St. Johns, MI, he was destined to become a mechanical engineer all the way back to his days of being fascinated with Legos as a young boy. His strengths are in structural mechanics and automotive engineering. The last two summers he has spent in internships at Yazaki North America in Canton, MI and at OG Technologies in Ann Arbor, MI. He is also on the Leadership Team for the on-campus organization MUSIC Matters, where he serves as the Logistics and Operations Manager for SpringFest. Personal interests include off-road vehicles, drag racing, hunting, and Michigan football.

Aaron T. Wilson : Aaron is a senior undergraduate Mechanical Engineering student at the University of Michigan. From Commerce, MI, his strengths and interests are in mechanical systems design and manufacturing. Outside of class, he has been a member of S3FL projects for the past 4 years including CanSat (1yr), and the Robotics for the Exploration of Space Team (3yrs). During his internships, Aaron spent 1 summer at Design Research Engineering investigating ATV rollover accidents, and the past 2 years at Technical Directions, Inc. designing assembly fixtures for small turbojet engines. Personal interests include long distance running, water sports, Michigan football, and spending time with friends and family.

APPENDIX

Appendix A.1: Additional Design Concepts for Compression Mechanisms

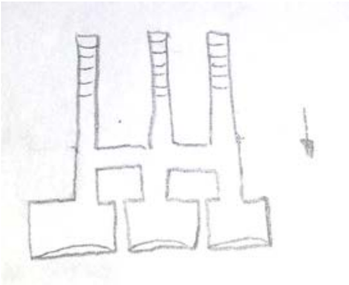


Figure A.1.1: Triple Hand-Held Plunger

Figure A.1.1 shows a hand-held device that the user applies downward force on to compress the springs in all three cylinders at once.

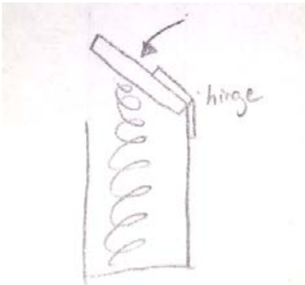


Figure A.1.2: Jack-in-the-Box Lid

Figure A.1.2 depicts a hinged lid that the user applies downward force on to compress the spring in the cylinder.

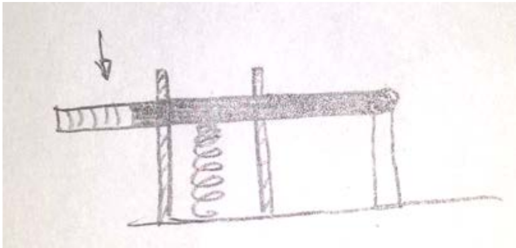


Figure A.1.3: Slotted Housing with Lever

Figure A.1.3 shows a lever that fits over slots in the housing. The user applies downward force on the end of the lever to compress the spring in the cylinder.

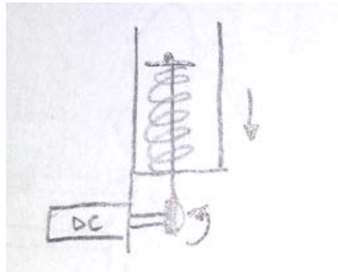


Figure A.1.4: Electric Motor

Figure A.1.4 involves a cable attached at the top to a plate on the spring and at the bottom to the shaft of a motor. The motor turns and winds the cable around the shaft, compressing the spring.

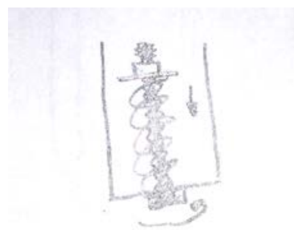


Figure A.1.5: Screw Mechanism

Figure A.1.5 involves a screw attached at the top to a plate on the spring and runs through the bottom of the base. The screw rotates, threading into the top plate and bringing the plate to the bottom, compressing the spring.

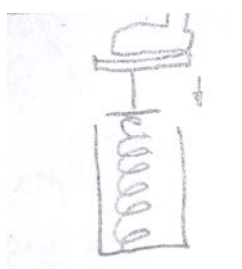


Figure A.1.6: Foot-Operated Plunger

Figure A.1.6 illustrates a foot plunger device that when pressed upon by a foot, compresses the spring.

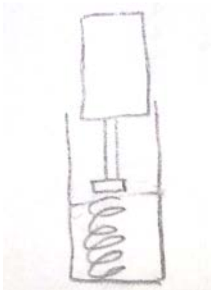


Figure A.1.7: Hydraulic Arm

Figure A.1.7 illustrates a device that involves a hydraulic arm being deployed to compress the spring.

Appendix A.2: Additional Design Concepts for Trigger Mechanisms

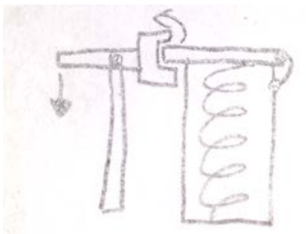


Figure A.2.1: Mouse Trap

Figure A.2.1 illustrates a device that when one arm is compressed, a latch rotates and frees a pin and thereafter releases the spring plate.

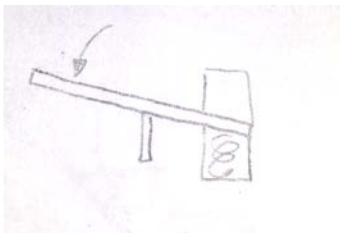


Figure A.2.2: Lever Arm Lock

Figure A.2.2 illustrates a device that when one end of the lever is compressed, the other end is freed from a lock and releases the spring plate.

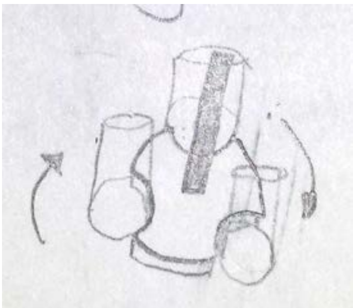


Figure A.2.3: Rotating Plate

Figure A.2.3 illustrates a device that when the arm is rotated, a plate with holes rotates, releasing the ball and spring plates.

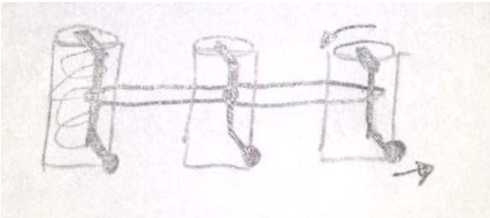


Figure A.2.4: Rotating Linkage

Figure A.2.4 illustrates a device that when one latch is rotated, a linkage rotates the other two connected latches, releasing all three balls.

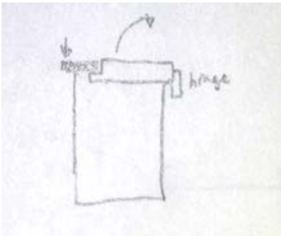


Figure A.2.5: Jack-in-the-Box

Figure A.2.5 illustrates a device that has a plate on top of the cylinder holding the spring compressed. A latch releases the plate which then rotates about a hinge, freeing the spring.

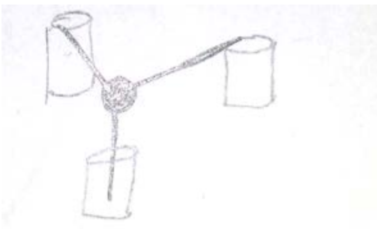


Figure A.2.6: Central Button

Figure A.2.6 illustrates a device that when one central button is turned, three attached rods turn, releasing all three compressed springs.

Figure A.2.7: Hook Linkage

Figure A.2.6 illustrates a device that when a hook connected to a rod is turned, the piece is freed and allows for the compressed spring to release.

Appendix A.3: Additional Design Concepts for Safety Mechanisms

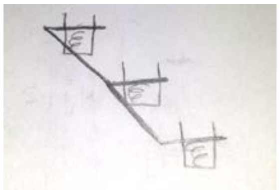


Figure A.3.1: Connected Pins

Figure A.3.1 illustrates a device where thee pins are connected and protrude through a hole in the side of a cylinder. When the device is pulled, all three springs are clear to be launched.

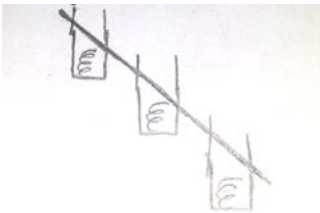


Figure A.3.2: Single Pin

In Figure A.3.2, a single pin run through all thee cylinders and prevents the springs from launching on accident.

Figure A.3.3: Individual Plate

In Figure A.3.3, a single plate covers the inside of the cylinder and prevents the springs from launching on accident.

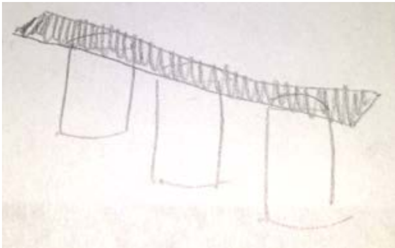


Figure A.3.4: Shelf Lid Plate

In Figure A.3.4, a single plate covers the inside of all three cylinders and prevents the springs from launching on accident.

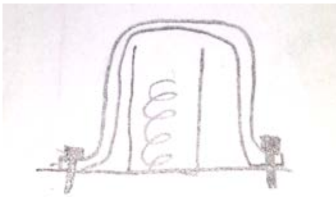


Figure A.3.5: Latch Strap

In Figure A.3.5, a latch covers the top of a cylinder and prevents the springs from launching on accident.

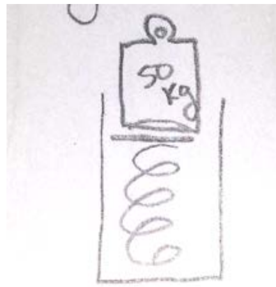


Figure A.3.6: Heavy Weight

In Figure A.3.6, a weight covers the top of a cylinder and prevents the springs from launching on accident.

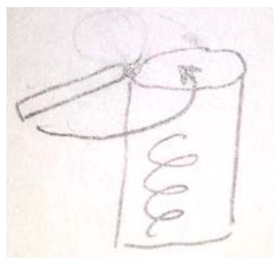


Figure A.3.7: Rotating Lever

In Figure A.3.7, a lever on a pivot covers the top of a cylinder and prevents the springs from launching on accident.

Appendix B: Current Challenges at Design Review 3

The team continues to look ahead to current and future challenges of our projects and our potential means of addressing and overcoming the problems that we may encounter.
With a rough draft version of our design, we begin to look at the challenge of manufacturing and implementing our design. From the design process, we found that the implementation of a latch mechanism and entire trigger system is going to present a significant challenge. In minimizing torque on our pulley system, we elected to use a pre-manufactured pull pin spring and mill flat and beveled faces on opposite sides which adds complexity to manufacturing. Since these latches must release the plate at the same time, it is crucial that their alignment is accurate, posing another manufacturing and tolerance challenge. We plan to combat this challenge by first referring to the CES database. We will look into processes for shaping low-carbon steel, specifically the technique implemented in face milling the bevel. From here, we plan to consult with the experienced machining staff in the ME machine shop, and ask them to guide us further on specific milling techniques that will hold to our prescribed detailed design and associated tolerances.

In addition, we anticipate challenges with implementing the pulley system that activates the pull pins. It will be challenging manufacturing cables that are of precise length as to pull the pins simultaneously without stretching or slipping apart. With a substantial torque on the pulleys that

guide the cables, it will be a challenge to ensure that the pulleys do not deflect and that the cable does not slip off of the pulleys. We have combated the torque challenge by minimizing the length of the pin and therefore the overall length of the side of the cylinder that the pulley is fastened, minimizing torque. We have also added a form of gussets coming off of each side to meet in the center of the device. These will stabilize the mounting plates against the torsional forces of the cable system. Overall, the challenge of designing, manufacturing, and implementing this system will test our knowledge of classical mechanics, dynamics and materials.
Since the project is a senior design term project, we are set in a number of constraints. The largest constraint that we have is time. With less than 4 months to research, design, prototype, fabricate, test, and deliver this prototype, the team must be organized and operate efficiently. In addition, we are limited by our own novice manufacturing abilities as opposed to outsourcing the machining to professionals.

Appendix C: Additional Views of Final Design

Figure C.1: Exploded view of base assembly

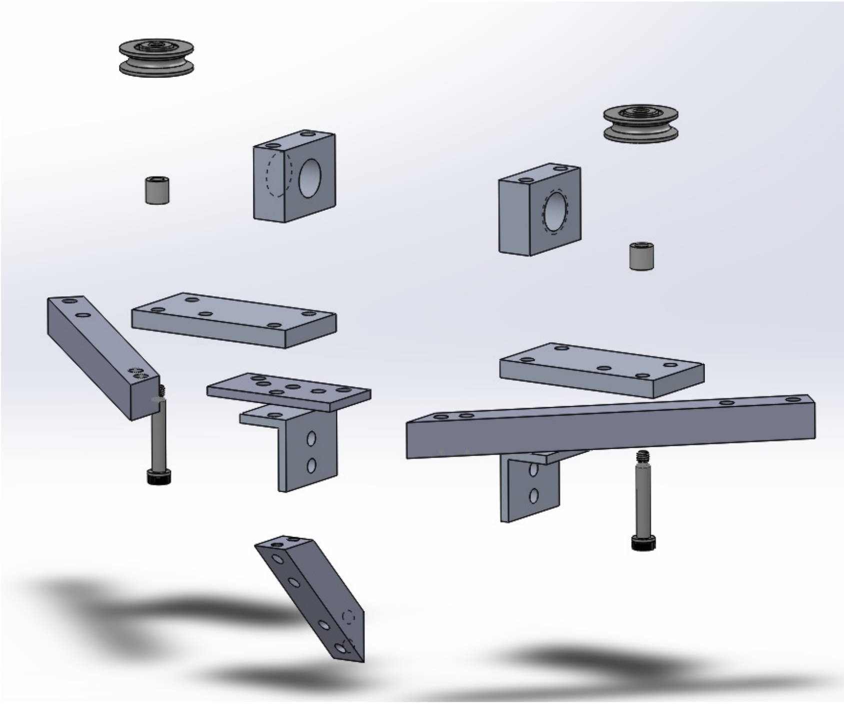


Figure C.2a: Exploded view of latch assembly

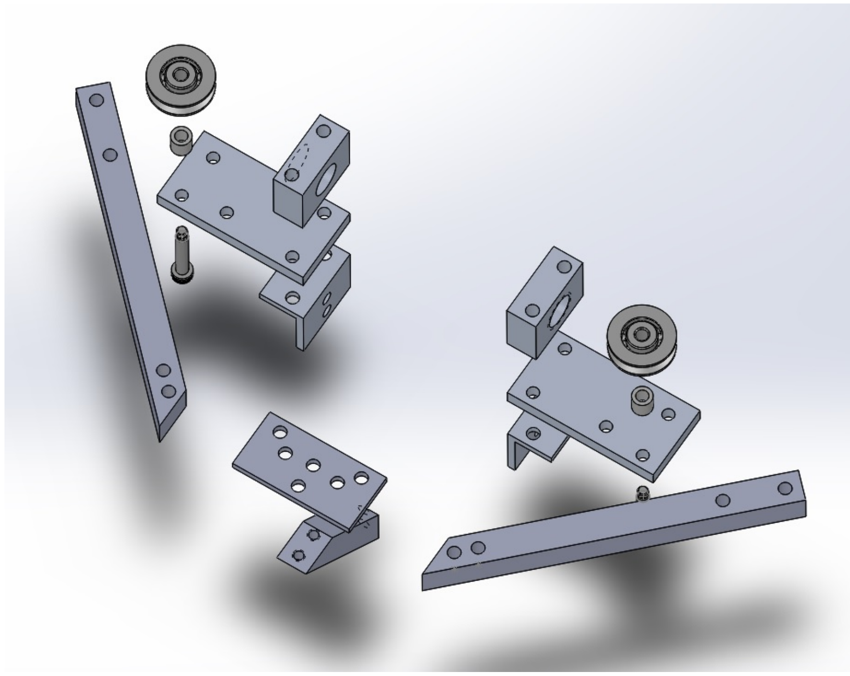


Figure C.2b: Alternate exploded view of latch assembly

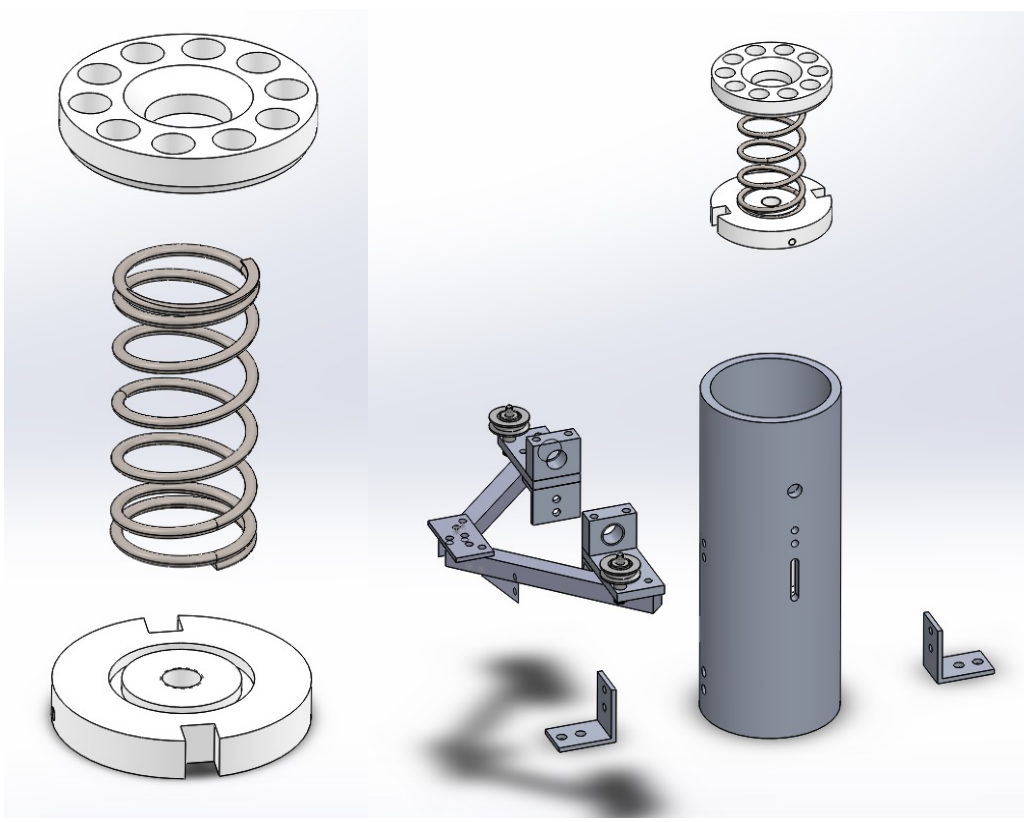


Figure C.3: Chamber assembly for first spring

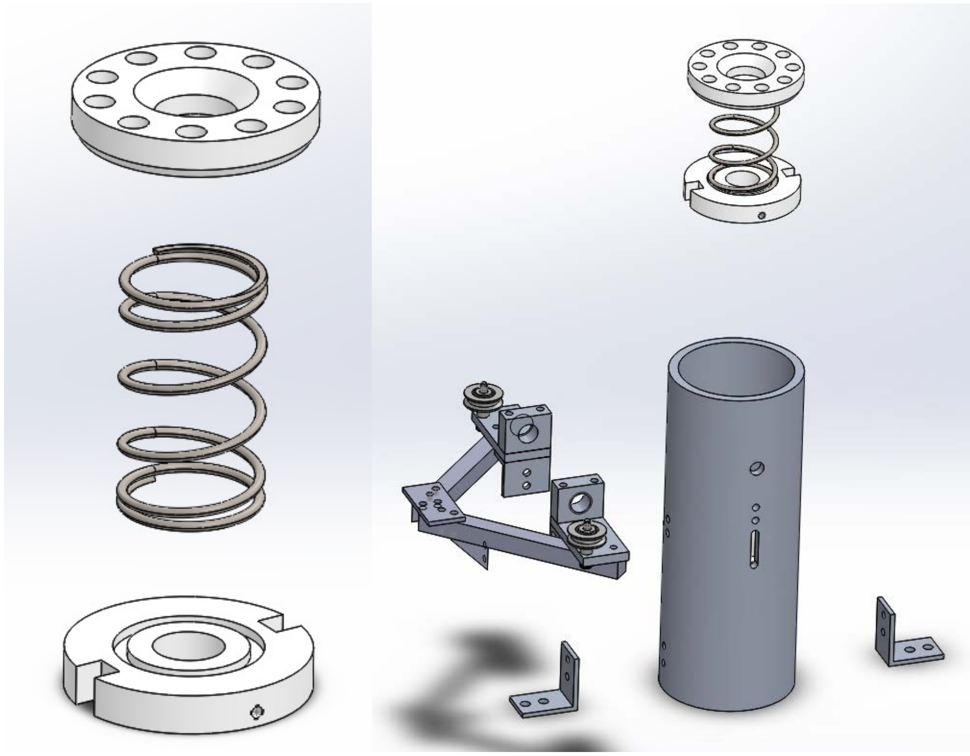


Figure C.4: Chamber assembly for second spring

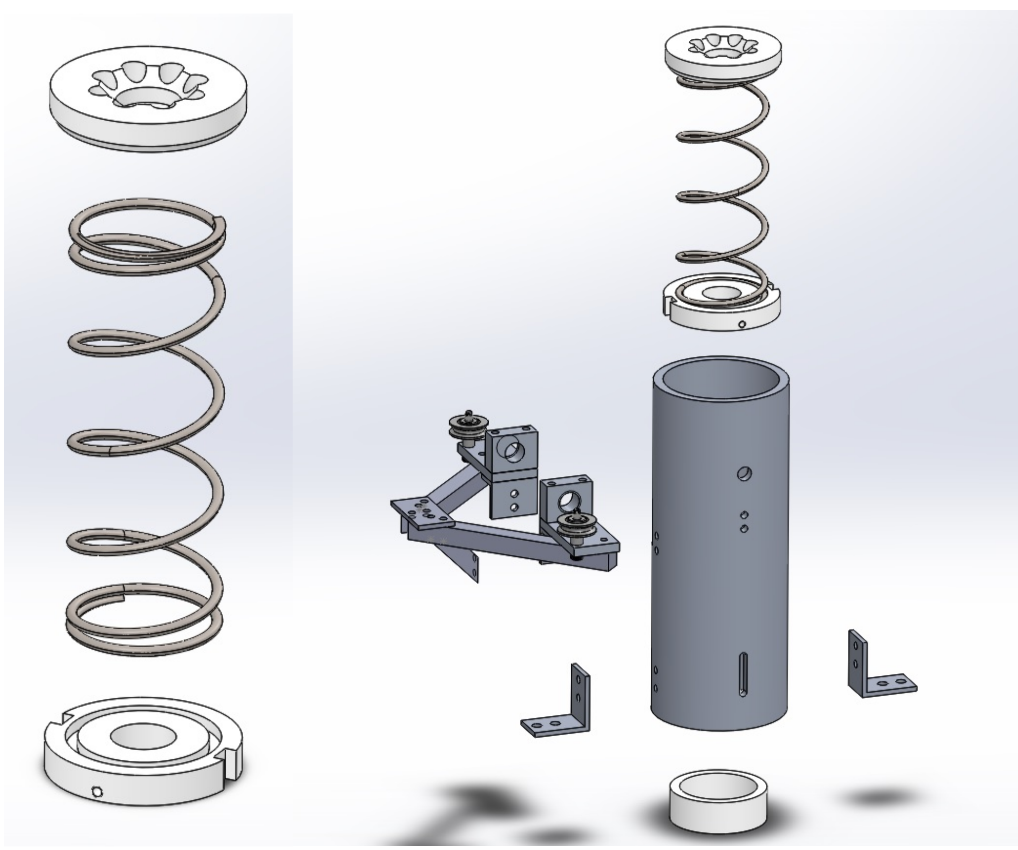


Figure C.5: Chamber assembly for third spring.

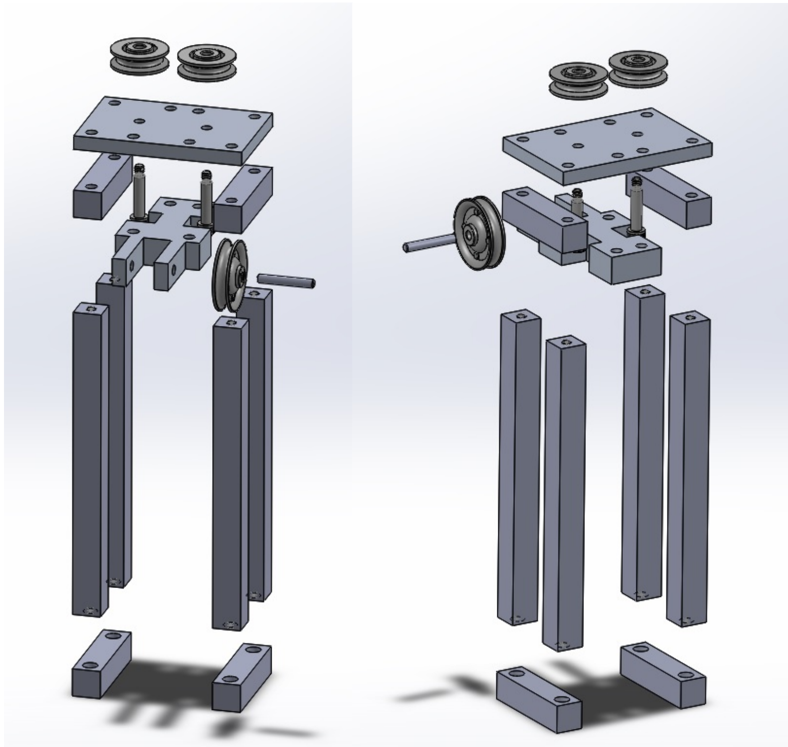


Figure C.6: Exploded views of redirection pulley riser assembly

Figure C.7: Exploded view of lever assembly

Appendix D: Initial Manufacturing Plan

To develop manufacturing plans, we first modeled the parts in SolidWorks so that we could determine dimensions and connections. After this, we were able to determine the order of processes required to manufacture our device.

Appendix D.1: Explanation of Chosen Manufacturing Method

The components of our device are detailed in the Manufactured Parts Bill of Materials and Purchased Parts Bill of Materials tables below. Most of the components that we will be creating for our prototype will be created using traditional methods (mill and lathe). This is due to the need for fairly tight tolerances on how the components are assembled together to ensure a fully operational prototype. This type of manufacturing unfortunately means that the components will take longer to create and if the machine were to be produced for sale, it would drive the cost up due to machining time. If the device were to be produced for large-scale sale, then a more customized manufacturing method would likely be utilized, but that is unrealistic for the scope of producing a prototype.

Some parts, such as the ball cup and the spring base, will have their basic shape created using a waterjet machine due to the parts having larger tolerances that can be achieved using a waterjet and also that the shape would be difficult to make using traditional methods while still being efficient with material. These parts will then be further machined using traditional methods to achieve features that are not possible by waterjetting alone.

Appendix D.2: Manufactured Parts Bill of Materials

Part Number	Part Name	Number Required	Raw Material
001	Lever Plate Bottom	2	1/2” Aluminum Plate
002	Lever Plate Top	2	1/2” Aluminum Plate
003	Latch Support Arm Joining Plate	3	1/8” Aluminum Plate
004	Base Leg	4	1” Diameter Aluminum Rod
005	Cylinder Attachment Bracket	6	1 ½” x 1 1/2” Angle Aluminum
006	Latch Mounting Plate	6	¼” Aluminum Plate
007	Latch Angle Bracket	6	1” x 1” Angle Aluminum
008	Latch Support Block	6	½” Aluminum Plate
009	Latch Support Arm	6	½” x ½” Aluminum Bar
010	Latch Support Arm Support	3	½” x ½” Aluminum Bar
011	Cup For Spring 72876S	1	½” Aluminum Plate
012	Base For Spring 72876S	1	½” Aluminum Plate
013	Tube For Spring 72876S	1	3.5” OD, 3” ID Aluminum Tube
014	Cup For Spring S-1528	1	½” Aluminum Plate
015	Base For Spring S-1528	1	½” Aluminum Plate
016	Tube For Spring S-1528	1	3.5” OD, 3” ID Aluminum Tube

017	Cup For Spring S-3094	1	½” Aluminum Plate
018	Base For Spring S-3094	1	½” Aluminum Plate
019	Tube For Spring S-3094	1	3.5” OD, 3” ID Aluminum Tube
020	Base	1	1” Thick Oak Wood Plank
021	Redirection Pulley Base	1	¼” Aluminum Plate
022	Second Redirection Pulley Base	1	½” Aluminum Plate
023	Redirection Pulley Riser	2	½” Aluminum Plate

Appendix D.3: Purchased Parts BOM

Part Number	Qty	Description	Cost Per Unit	Total Cost	Manufacturer
3164T11	1	Steel Pulley for Wire Rope	$11.42	$11.42	McMaster Carr
3434T74	8	Pulley for Wire Rope	$4.22	$33.76	McMaster Carr
90107A007	1	Washer for No. 6 Screw	$0.03	$0.03	McMaster Carr
90107A010	14	Washer for No. 8 Screw	$0.03	$0.48	McMaster Carr
90107A011	102	Washer for No. 10 Screw	$0.05	$4.90	McMaster Carr
90107A029	52	Washer for 1/4" Screw	$0.08	$4.29	McMaster Carr
90107A127	4	Washer for 3/8" Screw	$0.32	$1.28	McMaster Carr
90480A007	1	6-32 Machine Screw Hex Nut	$0.01	$0.01	McMaster Carr
90480a009	8	8-32 Machine Screw Hex Nut	$0.01	$0.12	McMaster Carr
90480a011	40	10-24 Machine Screw Hex Nut	$0.02	$0.69	McMaster Carr
91259A168	6	3/16" Shoulder Screw, 1" Length	$1.85	$11.10	McMaster Carr
91259A626	1	3/8" Shoulder Screw, 1 1/4" Length	$1.64	$1.64	McMaster Carr
92185A245	10	10-24 Stainless Socket Cap Screw, 3/4" Length	$0.22	$2.19	McMaster Carr
92185A246	12	10-24 Stainless Socket Cap Screw, 7/8" Length	$0.50	$5.96	McMaster Carr
92185A247	33	10-24 Stainless Socket Cap Screw, 1" Length	$0.23	$7.50	McMaster Carr
92185A249	4	10-24 Stainless Socket Cap Screw, 1 1/4" Length	$0.57	$2.28	McMaster Carr
92185A253	12	10-24 Stainless Socket Cap Screw, 2" Length	$0.85	$10.18	McMaster Carr
92185A540	12	1/4-20 Stainless Socket Cap Screw, 3/4" Length	$0.34	$4.09	McMaster Carr
92185A548	12	1/4-20 Stainless Socket Cap Screw, 1 3/4" Length	$0.56	$6.68	McMaster Carr
92185A550	10	1/4-20 Stainless Socket Cap Screw, 2" Length	$0.71	$7.12	McMaster Carr
92185A626	4	3/8-16 Stainless Socket Cap Screw, 1 1/4" Length	$1.07	$4.30	McMaster Carr
90665A128	4	10-24 Low-Profile Socket Cap Screw, 3/4" Length	$0.15	$0.60	McMaster Carr

92320A463	6	Unthreaded Spacer, 0.192 ID, 5/16" Length	$2.01	$12.06	McMaster Carr
92463A418	2	Stainless Steel Binding Post, 1 1/2" Length, 5/16" Dia.	$4.59	$9.18	McMaster Carr
93827A211	22	1/4-20 Hex Nut	$0.07	$1.48	McMaster Carr
95255A371	1	Quick Release Pin, 5/16" Dia., 2" Length	$4.63	$4.63	McMaster Carr
97345A117	1	5/32" Shoulder Screw, 1" Length	$10.64	$10.64	McMaster Carr
97345A492	2	3/16" Shoulder Screw, 5/8" Length	$5.01	$10.02	McMaster Carr
RET-625	6	Pull Pin	$10.65	$63.90	Pivot Point

Appendix D.4: Initial Manufacturing Plans

Revision Date: 2/24/2015

Part Number: 001
Part Name: Lever Plate Bottom

Raw Material Stock: 1/2" Aluminum Plate

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut block to +1/2" of its final dimensions in each direction	Bandsaw		Feeder block	275-325
2	Insert the piece into the vise, making sure to set the uncut edge against the bottom of the vice	Mill	Vise		
3	Machine the top of the piece until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise, and break all edges by hand			File	
5	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
6	Remove part from vise, break all edges by hand, and place part back in vice for milling of unfinished edge	Mill	Vise	File	
7	Machine unfinished edge until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840

8	Remove part from vise, and break all edges by hand			File	
9	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
10	Remove part from vise, and break all edges by hand			File	
11	Replace part in vise for drilling of bolt through holes	Mill	Vise		
12	Find datum lines for X and Y	Mill	Vise	Edge finder, drill chuck	900
13	Centerdrill and drill larger bolt clearance holes	Mill	Vise	Drill chuck, centerdrill, size H drill bit	3600 or less
14	Centerdrill and drill smaller bolt clearance holes	Mill	Vise	Drill chuck, centerdrill, #7 drill bit	3600 or less
15	Remove part from vice and deburr all holes			Deburring tool	

Part Number: 002 Revision Date: 2/25/15
Part Name: Lever Plate Top

Raw Material Stock: 1/2" Aluminum Plate

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut block to +1/2" of its final dimensions in each direction	Bandsaw		Feeder block	275-325
2	Insert the piece into the vise, making sure to set the uncut edge against the bottom of the vice	Mill	Vise		
3	Machine the top of the piece until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise, and break all edges by hand			File	
5	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840

6	Remove part from vise, break all edges by hand, and place part back in vice for milling of unfinished edge	Mill	Vise	File	
7	Machine unfinished edge until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
8	Remove part from vise, and break all edges by hand			File	
9	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
10	Remove part from vise, and break all edges by hand			File	
11	Replace part in vise for drilling of bolt through holes	Mill	Vise		
12	Find datum lines for X and Y	Mill	Vise	Edge finder, drill chuck	900
13	Centerdrill and predrill for reaming the larger through hole	Mill	Vise	Drill chuck, centerdrill, 23/64 drill bit	3600 or less
14	Ream larger through hole	Mill	Vise	Drill chuck, 3/8 reamer	2000
15	Centerdrill and drill smaller through holes	Mill	Vise	Drill chuck, 11/32" drill bit	3600 or less
16	Remove part from vise and deburr all holes			Deburring tool	
17	Replace part in vise for drilling of tapped holes	Mill	Vise		
18	Centerdrill and predrill holes for tapping	Mill	Vise	Drill chuck, centerdrill, #25 drill bit	3600 or less
19	Remove part from vise and deburr all holes			Deburring tool	
20	Tap holes		Vise	Tap handle, 10-24 tap	

Part Number: 003 Revision Date: 2/25/15
Part Name: Latch Support Arm Joining Plate

Raw Material Stock: 1/8" Aluminum Plate

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut block to +1/2" of its final dimensions in each direction	Bandsaw		Feeder block	275-325
2	Insert the piece into the vise, making sure to set the uncut edge against the bottom of the vice	Mill	Vise		
3	Machine the top of the piece until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise, and break all edges by hand			File	
5	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
6	Remove part from vise, break all edges by hand, and place part back in vice for milling of unfinished edge	Mill	Vise	File	
7	Machine unfinished edge until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
8	Remove part from vise, and break all edges by hand			File	
9	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
10	Remove part from vise, and break all edges by hand			File	
11	Replace part in vise for drilling of bolt through holes	Mill	Vise		
12	Find datum lines for X and Y	Mill	Vise	Edge finder, drill chuck	900
13	Drill through holes	Mill	Vise	Drill chuck, centerdrill, #7 drill bit	3600 or less

14	Remove part from vise and deburr all holes			Deburring tool	

Part Number: 004 Revision Date: 2/25/15
Part Name: Base Leg

Raw Material Stock: 1" Diameter Solid Aluminum Rod

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to +1/2" of its final length	Bandsaw		Feeder block	275-325
2	Insert piece into chuck	Lathe	Chuck		
3	Turn face until the entire surfaced has been machined	Lathe	Chuck	Cutting tool	1910
4	Remove part from chuck and break machined edge			File	
5	Replace part in chuck, making sure to leave the unmachined end towards the outside of the chukc	Lathe	Chuck		
6	Turn face, making several passes at 0.05" per pass, until the final length is achieved	Lathe	Chuck	Cutting tool	1910
7	Centerdrill and predrill hole to be tapped	Lathe	Chuck	Drill chuck, centerdrill, 5/16" drill bit	3600 or less
8	Remove part from chuck and break machined edge			File	
9	Tap hole			Tap handle, 3/8-16 tap	

Part Number: 005 Revision Date: 2/25/15
Part Name: Cylinder Attachment Bracket

Raw Material Stock: 1.5 X 1.5 Angle Aluminum, 1/4" Thick

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut block to +1/2" of its final dimensions in each direction	Bandsaw		Feeder block	275-325

2	Insert piece into vise, leaving one edge hanging past the edge	Mill	Vise		
3	Machine the edge of the piece until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise, and break all edges by hand			File	
5	Replace part in vise, making sure to leave the unmachined edge hanging past the edge of the vise	Mill	Vise		
6	Machine the edge of the piece, making several passes at 0.05" per pass, until final length is achieved	Mill	Vise	3/4" 2-flute endmill, collet	840
7	Remove part from vise, and break all edges by hand			File	
8	Place part in vise for drilling of first set of clearance holes	Mill	Vise		
9	Centerdrill and drill first set of clearance holes	Mill	Vise	Drill chuck, centerdrill, size H drill bit	3600 or less
10	Remove part from vise and deburr all holes			Deburring tool	
11	Replace part in vise for drilling of second set of clearance holes	Mill	Vise		
12	Centerdrill and drill second set of clearance holes	Mill	Vise	Drill chuck, centerdrill, size H drill bit	3600 or less
13	Remove part from vise and deburr all holes			Deburring tool	

Part Number: 006 Revision Date: 2/25/15
Part Name: Latch Mounting Plate

Raw Material Stock: 1/4" Aluminum Plate

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut block to +1/2" of its final dimensions in each direction	Bandsaw		Feeder block	275-325
2	Insert the piece into the vise, making sure to set the uncut edge against the bottom of the vice	Mill	Vise		

3	Machine the top of the piece until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise, and break all edges by hand			File	
5	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
6	Remove part from vise, break all edges by hand, and place part back in vice for milling of unfinished edge	Mill	Vise	File	
7	Machine unfinished edge until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
8	Remove part from vise, and break all edges by hand			File	
9	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
10	Remove part from vise, and break all edges by hand			File	
11	Replace part in vise for drilling of reamed hole	Mill	Vise		
12	Find datum lines for X and Y	Mill	Vise	Edge finder, drill chuck	900
13	Centerdrill and predrill for reaming the smaller through hole	Mill	Vise	Drill chuck, centerdrill, size 14 drill bit	3600 or less
14	Ream smaller through hole	Mill	Vise	Drill chuck, 3/16" reamer	4000
15	Centerdrill and drill larger through holes	Mill	Vise	Drill chuck, size 7 drill bit	3600 or less
16	Remove part from vise and deburr all holes			Deburring tool	

Part Number: 007 Revision Date: 2/26/15
Part Name: Latch Angle Bracket

Raw Material Stock: 1" X 1" Angle Aluminum,
1/8" Thick

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut piece to +1/2" of its final length	Bandsaw		Feeder block	275-325
2	Insert piece into vise, making sure to leave one edge hanging over the edge of the vise	Mill	Vise		
3	Machine the side of the piece until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise and break all edges by hand			File	
5	Replace part in vise, making sure to leave unmachined edge hanging over the edge of the vise	Mill	Vise		
6	Machine the side of the piece, making several passes at 0.05" per pass, until the final length is achieved	Mill	Vise	3/4" 2-flute endmill, collet	840
7	Remove part from vise and break all edges by hand			File	
8	Replace part in vise for machining one edge down	Mill	Vise		
9	Machine edge down, making several passes at 0.05" per pass until final height is achieved	Mill	Vise	3/4" 2-flute endmill, collet	840
10	Remove part from vise and break all edges by hand			File	
11	Replace part in vise for drilling first set of clearance holes	Mill	Vise		
12	Centerdrill and drill first set of clearance holes	Mill	Vise	Drill chuck, centerdrill, size 7 drill bit	3600 or less
13	Remove part from vise and deburr holes			Deburring tool	
14	Replace part in vise for drilling second set of clearance holes	Mill	Vise		

15	Centerdrill and drill second set of clearance holes	Mill	Vise	Drill chuck, centerdrill, size 7 drill bit	3600 or less
16	Remove part from vise and deburr holes			Deburring tool	

Part Number: 008 Revision Date: 2/26/15
Part Name: Latch Support Block

Raw Material Stock: 1/2" Aluminum Plate

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut block to +1/2" of its final dimensions in each direction	Bandsaw		Feeder block	275-325
2	Insert the piece into the vise, making sure to set the uncut edge against the bottom of the vice	Mill	Vise		
3	Machine the top of the piece until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise, and break all edges by hand			File	
5	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
6	Remove part from vise, break all edges by hand, and place part back in vice for milling of unfinished edge	Mill	Vise	File	
7	Machine unfinished edge until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
8	Remove part from vise, and break all edges by hand			File	
9	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
10	Remove part from vise, and break all edges by hand			File	

11	Replace part in vise for drilling of bolt through holes	Mill	Vise		
12	Find datum lines for X and Y	Mill	Vise	Edge finder, drill chuck	900
13	Centerdrill and drill through holes	Mill	Vise	Drill chuck, centerdrill, size 7 drill bit	3600 or less
14	Remove part from vise and deburr all holes			Deburring tool	
15	Replace part in vise for drilling of threaded hole	Mill	Vise		
16	Centerdrill and predrill hole to be threaded	Mill	Vise	Drill chuck, centerdrill, 37/64" drill bit	2292
17	Tap hole		Vise	Tap handle, 5/8-11 tap	

Part Number: 009 Revision Date: 2/26/15
Part Name: Latch Support Arm

Raw Material Stock: 1/2" X 1/2" Aluminum Bar

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to +1/2" of its final length	Bandsaw		Feeder block	275-325
2	Insert the piece into the vice, making sure to have one edge hanging outside the vise	Mill	Vise		
3	Machine the edge of the part until one entire edge has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise and break all edges by hand			File	
5	Replace part in vise, making sure to leave unmachined edge hanging past the edge of the vise	Mill	Vise		
6	Machine the edge of the part, making several passes at 0.05" per pass, until the final length is achieved	Mill	Vise	3/4" 2-flute endmill, collet	840
7	Remove part from vise and break all edges by hand			File	
8	Place part in vise in preperation for machining the 45 degree face	Mill	Vise		

9	Mill the corner of the part until the 45 degree edge goes completely between two parallel faces, but no further	Mill	Vise	3/4" 2-flute endmill, collet	840
10	Remove part from vise and break all edges by hand			File	
11	Replace part in vise for drilling of clearance holes	Mill	Vise		
12	Find datum lines for X and Y	Mill	Vise	Drill chuck, edge finder	900
13	Centerdrill and drill clearance through holes	Mill	Vise	Drill chuck, centerdrill, size 7 drill bit	3600 or less
14	Remove part from vise and deburr all holes			Deburring tool	

Part Number: 010 Revision Date: 2/26/15
Part Name: Latch Support Arm Support

Raw Material Stock: 1/2" X 1/2" Aluminum Bar

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to +1/2" of its final length	Bandsaw		Feeder block	275-325
2	Insert the piece into the vice, making sure to have one edge hanging outside the vise	Mill	Vise		
3	Machine the edge of the part until one entire edge has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise and break all edges by hand			File	
5	Replace part in vise, making sure to leave unmachined edge hanging past the edge of the vise	Mill	Vise		
6	Machine the edge of the part, making several passes at 0.05" per pass, until the final length is achieved	Mill	Vise	3/4" 2-flute endmill, collet	840
7	Remove part from vise and break all edges by hand			File	

8	Place part in vise for machining the first 45 degree face	Mill	Vise		
9	Mill the corner of the part until the first 45 degree edge goes completely between two parallel faces, but no further	Mill	Vise	3/4" 2-flute endmill, collet	840
10	Remove part from vise and break all edges by hand			File	
11	Replace part in vice for machining the second 45 degree face	Mill	Vise		
12	Mill the corner of the part until the second 45 degree edge goes completely between two parallel faces, but no further	Mill	Vise	3/4" 2-flute endmill, collet	840
13	Remove part from vise and break all edges by hand			File	
14	Replace part in vise for drilling of clearance holes	Mill	Vise		
15	Find datum lines for X and Y	Mill	Vise	Drill chuck, edge finder	900
16	Centerdrill and drill clearance through holes	Mill	Vise	Drill chuck, centerdrill, size 7 drill bit	3600 or less
17	Remove part from vise and deburr all holes			Deburring tool	
18	Replace part in vise for predrilling of holes to be tapped				
19	Find datum lines for X and Y	Mill	Vise	Drill chuck, edge finder	900
20	Centerdrill and predrill holes to be tapped	Mill	Vise	Drill chuck, centerdrill, size 25 drill bit	3600 or less
21	Tap holes		Vise	Tap handle, 10-24 tap	

Part Number: 011, 014, 017 Revision Date: 2/26/15
Part Name: Cup For Spring XXXXXX

Raw Material Stock: 1/2" Aluminum Plate

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Waterjet flat version of final part	Waterjet			
2	Place part in lathe for machining of chamfers	Lathe	Chuck		

3	Turn the chamfer into the part	Lathe	Chuck	Cutting tool	450
4	Turn the spring groove	Lathe	Chuck	Grooving tool	450
5	Remove part and break all edges by hand			File	
6	Replace part in chuck, turned 180 degrees around	Lathe	Chuck		
7	Machine larger chamfer into the part	Lathe	Chuck	Cutting tool	450

<u>Part Number:</u> 012, 015, 018 Revision Date: 2/26/15
<u>Part Name:</u> Base For Spring XXXXXX

<u>Raw Material Stock:</u> 1/2" Aluminum Plate

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Waterjet flat version of final part	Waterjet			
2	Turn the spring groove	Lathe	Chuck	Grooving tool	450
3	Remove part and break all edges by hand			File	
4	Turn the spring groove	Lathe	Chuck	Grooving tool	450
5	Remove part and break all edges by hand			File	
6	Insert part into vise for drilling of tapped hole	Mill	Vise		
7	Find datums for X and Y	Mill	Vise	Drill chuck, edge finder	900
8	Centerdrill and predrill hole to be tapped	Mill	Vise	Drill chuck, centerdrill, size 25 drill bit	3600 or less
9	Tap hole		Vise	Tap handle, 10-24 tap	
10	Insert part into fixture for milling of grooves	Mill	Vise	Base alignment fixture	
11	Mill groove	Mill	Vise	Base alignment fixtue, collet, ***ENDMILL SIZE***	***TBD***
12	Remove part from vise and break all edges by hand			File	
13	Replace part into fixture for milling of opposite groove	Mill	Vise	Base alignment fixture	
14	Mill groove	Mill	Vise	Base alignment fixtue, collet, ***ENDMILL SIZE***	***TBD***

15	Remove part from vise and break all edges by hand			File	

Part Number: 020 Revision Date: 2/27/15

Part Name: Base

Raw Material Stock: 1" Thick Oak

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut block to +1/2" of its final dimensions in each direction	Badsaw		Feeder block	TBD
2	Insert the piece into the vise, making sure to set the uncut edge against the bottom of the vice	Mill	Vise		
3	Machine the top of the piece until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	TBD
4	Remove part from vise, and break all edges by hand			File	
5	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	TBD
6	Remove part from vise, break all edges by hand, and place part back in vice for milling of unfinished edge	Mill	Vise	File	
7	Machine unfinished edge until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	TBD
8	Remove part from vise, and break all edges by hand			File	
9	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	TBD
10	Remove part from vise, and break all edges by hand			File	

11	Replace part in vise for drilling of bolt through holes	Mill	Vise		
12	Find datum lines for X and Y	Mill	Vise	Edge finder, drill chuck	900
13	Centerdrill and drill smaller size bolt clearance holes	Mill	Vise	Drill chuck, centerdrill, size H drill bit	TBD
14	Centerdrill and drill large size bolt clearance holes	Mill	Vise	Drill chuck, centerdrill, 1/2" drill bit	TBD
15	Centerdrill and drill medium size bolt clearance holes	Mill	Vise	Drill chuck, centerdrill, size X drill bit	TBD
16	Counterbore medium size bolt holes	Mill	Vise	Drill chuck, centerdrill, 13/16" counterbore	TBD

Part Number: 021 Revision Date: 2/27/15
Part Name: Redirection Pulley Base

Raw Material Stock: 1/4" Thick Aluminum Plate

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut block to +1/2" of its final dimensions in each direction	Bandsaw		Feeder block	275-325
2	Insert the piece into the vise, making sure to set the uncut edge against the bottom of the vice	Mill	Vise		
3	Machine the top of the piece until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise, and break all edges by hand			File	
5	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
6	Remove part from vise, break all edges by hand, and place part back in vice for milling of unfinished edge	Mill	Vise	File	

7	Machine unfinished edge until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
8	Remove part from vise, and break all edges by hand			File	
9	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
10	Remove part from vise, and break all edges by hand			File	
11	Replace part in vise for drilling of bolt through holes	Mill	Vise		
12	Find datum lines for X and Y	Mill	Vise	Edge finder, drill chuck	900
13	Centerdrill and drill bolt clearance holes	Mill	Vise	Drill chuck, centerdrill, No. 7 drill bit	3600 or less

Part Number: 022

Revision Date: 2/27/15

Part Name: Second Redirection Pulley Base

Raw Material Stock: 1/2" Thick Aluminum Plate

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut block to +1/2" of its final dimensions in each direction	Bandsaw		Feeder block	275-325
2	Insert the piece into the vise, making sure to set the uncut edge against the bottom of the vice	Mill	Vise		
3	Machine the top of the piece until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
4	Remove part from vise, and break all edges by hand			File	
5	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840

6	Remove part from vise, break all edges by hand, and place part back in vice for milling of unfinished edge	Mill	Vise	File	
7	Machine unfinished edge until the entire surface has been machined	Mill	Vise	3/4" 2-flute endmill, collet	840
8	Remove part from vise, and break all edges by hand			File	
9	Place part in vise to machine the top surface down to the desired size, making several passes at 0.05" per pass	Mill	Vise	3/4" 2-flute endmill, collet	840
10	Remove part from vise, and break all edges by hand			File	
11	Replace part in vise for milling of internal shape	Mill	Vise		
12	Mill out shape, making several passes at 0.05" per pass	Mill	Vise	1/2" 2-flute endmill, collet	1261
13	Remove part from vise, and break all edges by hand			File	
14	Replace part in vise for drilling of bolt through holes	Mill	Vise		
15	Find datum lines for X and Y	Mill	Vise	Edge finder, drill chuck	900
16	Centerdrill and drill bolt clearance holes	Mill	Vise	Drill chuck, centerdrill, No. 7 drill bit	3600 or less
17	Remove part from vise, and deburr all holes			Deburring tool	
18	Replace part in vise for drilling and reaming of hole	Mill	Vise		
19	Centerdrill and predrill through hole	Mill	Vise	Drill chuck, centerdrill, No. 14 drill bit	3600 or less
20	Ream hole	Mill	Vise	Drill chuck, centerdrill, 3/16" reamer	TBD
21	Remove part from vise and deburr all holes			Deburring tool	

Part Number: 023 Revision Date: 2/27/15
Part Name: Redirection Pulley Riser

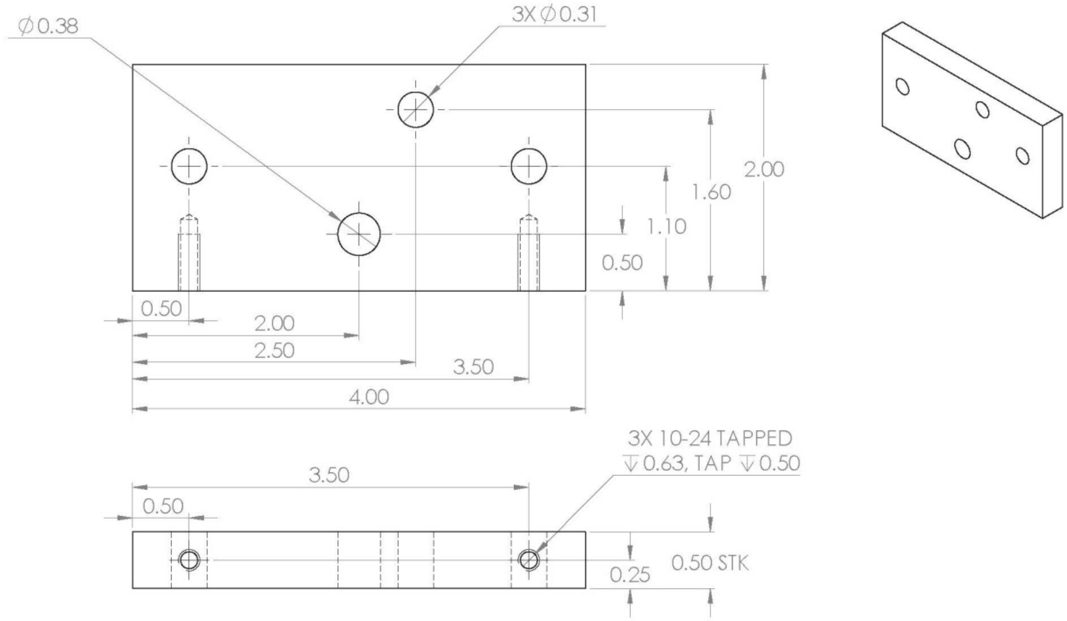
Raw Material Stock: 1/2" Thick Aluminum Plate

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Waterjet basic part shape from plate	Waterjet			
2	Place part in vise for drilling tapped holes	Mill	Vise		
3	Find datums for X and Y	Mill	Vise	Drill chuck, edge finder	900
4	Centerdrill and predrill holes to be tapped	Mill	Vise	Drill chuck, centerdrill, No. 25 drill bit	3600 or less
5	Remove part from vise and deburr all holes			Deburring tool	
6	Tap hole		Vise	Tap handle, 10-24 tap	
7	Replace part in vise for drilling of through holes	Mill	Vise		
8	Find datums for X and Y	Mill	Vise	Drill chuck, edge finder	900
9	Centerdrill and drill bolt clearance holes	Mill	Vise	Drill chuck, centerdrill, size H drill bit	3600 or less
10	Remove part from vise and deburr all holes			Deburring tool	

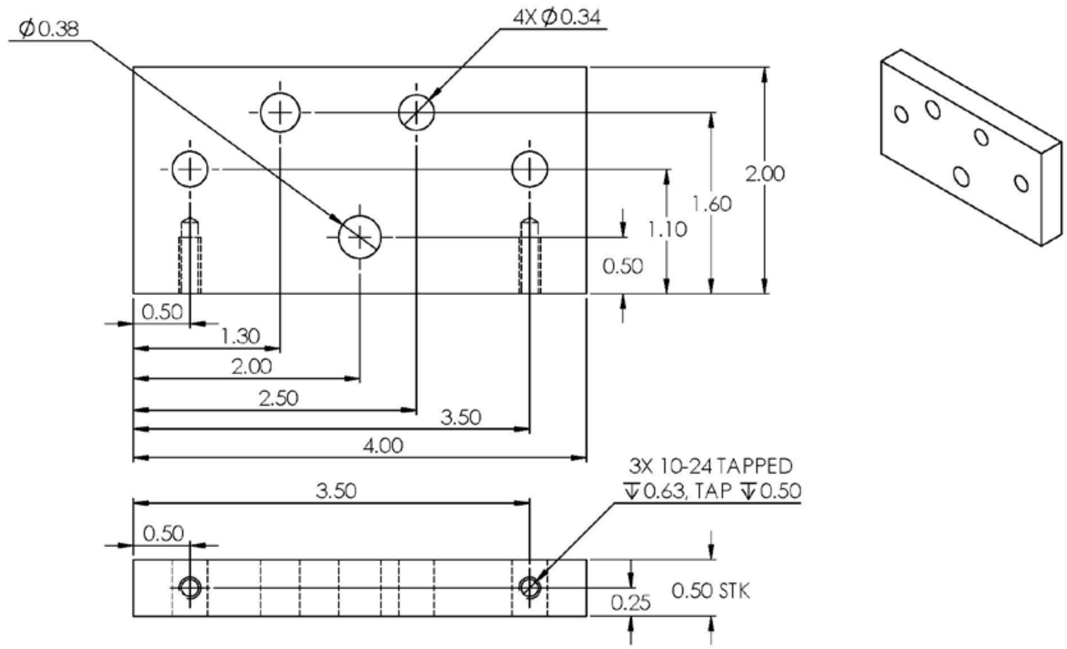
Appendix E: Engineering Design Changes After Design Review 4

Appendix E.1: 002 Lever Plate Top

Was:



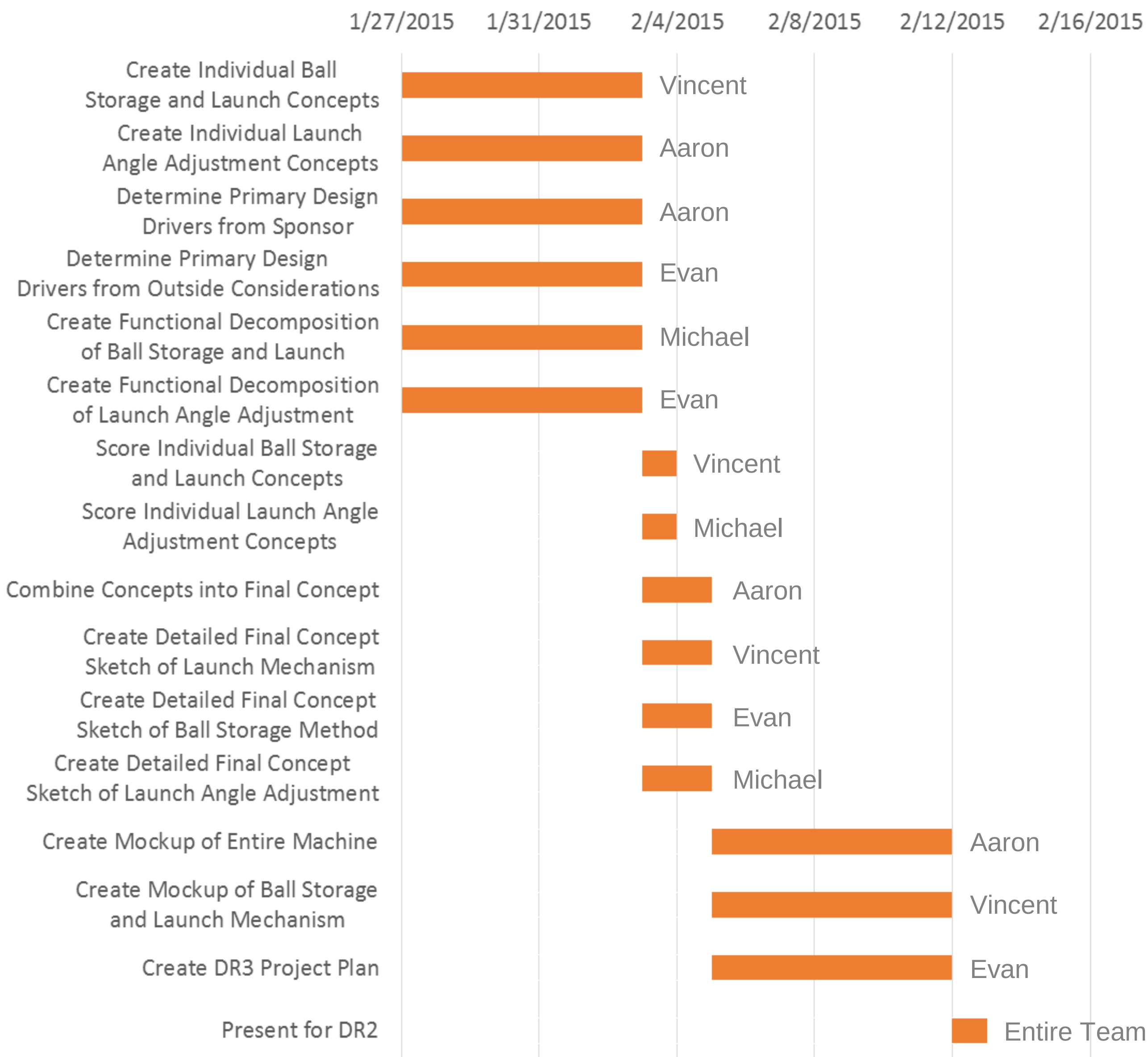
Is:



A hole was added to Part 002 Lever Plate Top because, during testing, the team noticed that the lever's range of motion was too large. By inserting a hardstop into this additional hole, the range of motion of the lever is more constrained, improving reliability in the cable assembly and trigger mechanism. The change was authored by Evan VanBeelen on April 2, 2015.

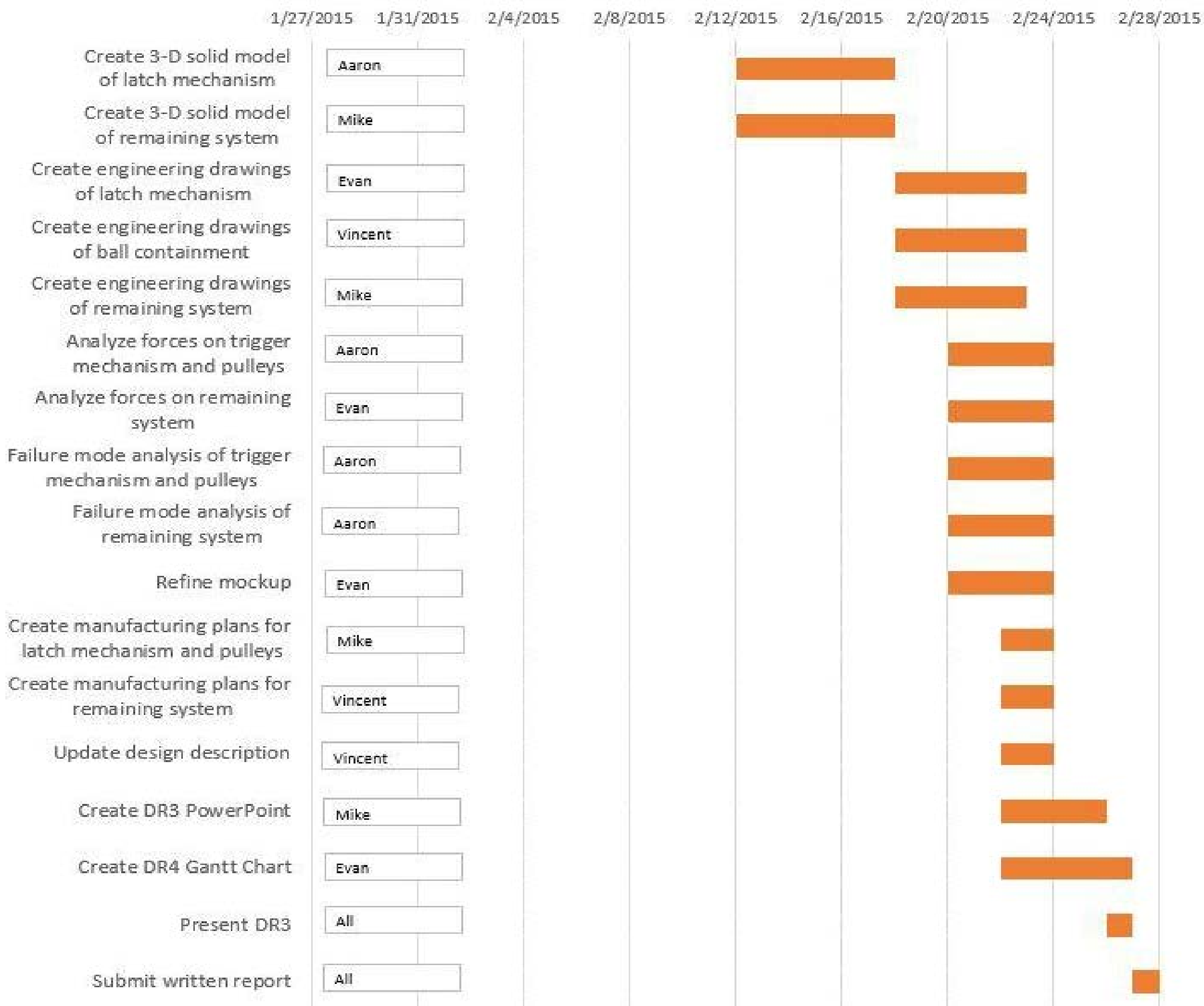
Appendix F: Design Review Project Plans

Appendix F.1: Design Review 2 Project Plan
In order to guarantee successful completion of materials required for the 2nd design review, we have created a Gantt chart that will guide our progress until that review. We have also indicated who will be responsible for each of the tasks to be completed for design review 2.



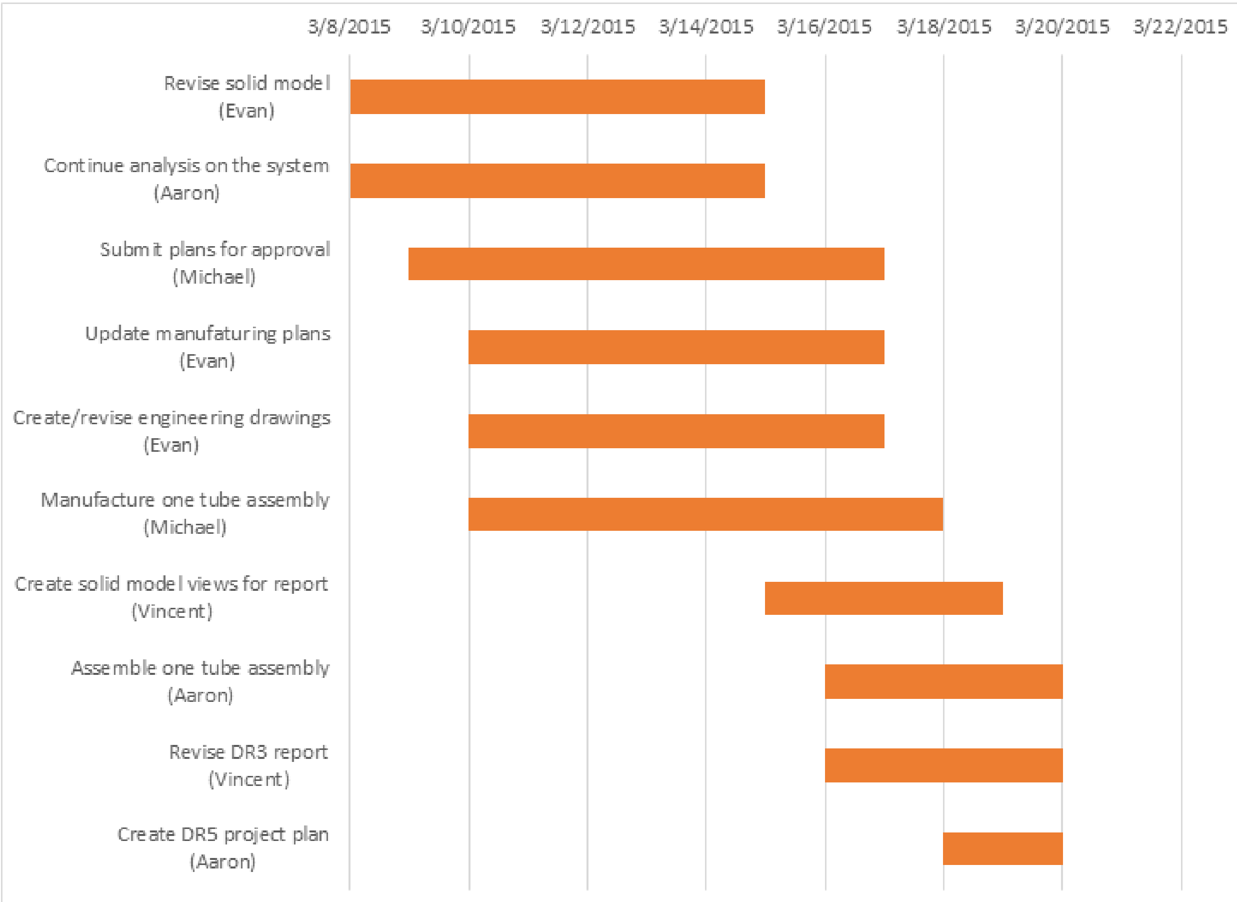
Appendix F.2: Design Review 3 Project Plan

In order to guarantee successful completion of materials required for the 3rd design review, we have created a Gantt chart that will guide our progress until that review. We have also indicated who will be responsible for each of the tasks to be completed for Design Review 3.



Appendix F.3: Design Review 4 Project Plan

In order to guarantee successful completion of materials required for the 4th design review, we have created a Gantt chart that will guide our progress until that review. We have also indicated who will be responsible for each of the tasks to be completed for Design Review 4.



Appendix F.4: Design Review 5 Project Plan

In order to guarantee successful completion of materials required for the 5th design review, we have created a Gantt chart that will guide our progress until that review. We have also indicated who will be responsible for each of the tasks to be completed for Design Review 5.

Appendix G: Individual Ethical Design and Environmental Impact Statements

Appendix G.1: Ethical Design Statements

Michael: During our design process, ethics often times was an important issue to discuss. The main reason for this is the fact that our project revolved around a high stiffness spring launching a projectile several feet into the air. As one can notice, this project can be dangerous to both the engineers and to the end user. Several things could happen that would turn dangerous very quickly and could cause serious injury. Things could break off and fly through the air, and things could impact objects and humans. A lot of the ways we addressed ethics in our design were by selecting robust materials. For instance, we decided to use aluminum tubes for the chambers instead of transparent plastic or PVC. This would ensure that even if a catastrophic failure occurred inside of the chamber, the chamber itself would not fail and nothing could project out toward the viewers in the audience. We also used high-strength ABS plastic for the cups that would hold the balls. This plastic combined with an epoxy rated at 3500 psi made the chamber even more safe. In the event that this high-strength epoxy does fail, the weight of the top plastic cup coming down would not warrant a significant to any user or bystander. We also looked at this aspect of potential energy when selecting the balls for this launch. The balls we selected were flexible, lightweight, and did not bounce very much even when dropped from 20 feet or higher. Most importantly, we followed the Code of Ethics for Mechanical Engineers by using common sense and by being honest with every aspect of this project. Problems were not ignored, but instead were addressed. We also used reputable suppliers for all of our parts. We used Century Spring Corp. for all springs and also used McMaster Carr and Do-It-Best Hardware for all hardware and bought items for the project. We also included a safety mechanism as one of our three design drivers, so that the device could not be accidentally triggered. This contributes to the well being and safety of any user or spectator of this device.

Vincent: In the design of a device that uses spring energy to launch objects into the air, there are ethical issues that must be addressed. The primary focus of the team during the design and development process was on safety throughout manufacturing, assembly, testing, and use. Because the device is unique and has a production quantity of only one, the manufacturing, assembly, and testing processes primarily involve the team. In designing the device, we purposely included safety measures to reduce possibility of accidents. The selected component materials are rated to be able to sustain the stresses of using the device. The selected balls, in particular, are soft and bounce little to reduce possibility of injury to users and bystanders. In manufacturing, we used stock material provided by the University. Here I cannot speak with certainty, but I hope this stock material was produced and acquired ethically. Additionally, we bought aluminum tube stock, springs, spring-loaded pins, and balls from reputable suppliers. In machining, we used the University machine shop and followed all of its safety procedures. In assembly and testing, we worked on the device in areas away from bystanders to reduce risk of injury to them. In use, the user will follow proper safe use and handling procedures.

Evan: Throughout our design process, ethics have been something that has been applied at each step. In following with the Code of Ethics of Engineers, published by the American Society of Mechanical Engineers (ASME), we have made sure that we followed each of their fundamental canons. In our design, we made sure to protect those using our device and those around it when it is in use in a number of ways. The first was including a removable hard stop safety that prevents pulling the lever and firing the device as it is being loaded or at any other time that it is not to be fired. We also made sure that the balls that the device fires are lightweight and soft so as to insure that if they come in contact with anyone, they do not injure them. These balls also bounce very little, decreasing the overall likelihood of someone being hit by the balls. We also made sure to stay within the bounds of our own competence when designing the machine. While electronics could have been used in the design of the device, none of our team felt comfortable with being responsible for the designing of this part of the system, so we decided that it would be best for us to forgo the use of electronics. Throughout the process we also made sure that any literature or information that we used which came from an outside source was properly cited. This guarantees that those who deserve credit for creating the information we needed in our project were properly credited for their work. When we were faced with a problem for which we didn't have the exact solution, we made sure to do adequate research to understand the behavior of the problem before tackling it. We knew that there would be some aspects of this project that would be outside the scope of our coursework and previous knowledge and that would require additional investigation, so we made sure to find reputable resources to help guide us in our work. This included consulting professionals in the fields of machining and manufacturing and literature research. Our design process also included considerations with regard to the environment, which you can read more about in our Environmental Impact Statement section of this report.

Aaron: Ethical considerations were taken into account throughout our design and manufacturing process. Above all else, the safety of the operators and anyone in contact with our device was held in the highest regard. To prevent accidental launching of the balls, we safety pin in the trigger. In addition, we designed a compression mechanism to safely and effectively load the system, further reducing user risks. In selecting balls, we went with soft, light, plastic balls to ensure that they would not cause harm to bystanders when returning to the ground. The team also took careful considerations when design the structures of the mechanism. We were careful to design and analyze the parts to ensure that they could withstand stresses greater than what may be expected as to not break and harm anyone. The team also took du diligence in thoroughly testing the device before delivering it to our sponsor. By buying our supplies from McMaster, Do-It-Best hardware, and other local sources, we ensured that we were supporting reputable organizations. We only designed components that were within our areas of expertise, and we referred only to reputable instructors with questions. Our sponsor is also a man of reputable status and we trust that he will operate the device with high ethical considerations.

Appendix G.2: Environmental Impact Statements

Michael: During our design process, we did discuss the environmental impact of our design. Since all of our materials are easily obtained, we did not have an issue in finding any pieces that may hurt the environment such as rare earth heavy metals or radioactive pieces. This device is also not going to be mass produced, so its environmental footprint is not going to be large at all. Sure it takes a lot of energy to make aluminum from ore, but out device has a very small amount of aluminum included. We also used wood and stainless steel. Wood is renewable and the aluminum and stainless steel is indeed recyclable. The plastic we used is also recyclable. Really, there isn’t anything used in our device that isn't really recyclable or reusable. The impact of this device will also be minimal because we expect that the life span should meet or exceed 10 years of use. Since this device will actually be used and not just built for purposes of this course and thrown away, its positive influence will greatly outweigh its negative impact on the environment.

Vincent: In the design of a device that uses spring energy to launch objects into the air, the team considered environmental impacts. The primary effect of this device on the environment is in its material composition. The two main materials used in this device are aluminum and plywood. Aluminum stock production does require a significant amount of energy, and plywood production does heighten deforestation. Additionally, energy was expended by computers in the modeling of the device and by machine tools in the manufacturing of the device. However, because this device has a production quantity of only one, environmental impact of the materials is a one-time occurrence, and the device is designed to function for at least ten years. Furthermore, there are no further environmental impacts of the device after it is manufactured and assembled because it only relies on a single human’s energy input to function. Therefore, the overall environmental impact of the device is low.

Evan: In our design process, we made sure to keep the environmental impact of our device as low as possible while still achieving the necessary requirements. Our device has essentially no impact on the environment during its use because it doesn’t require any electricity or any type of maintenance parts. The device is designed to last for a long period of time and is a purely human-powered mechanical device. In selecting the materials of our device we made sure that all of the materials are either biodegradable (the wooden base) or recyclable (aluminum, steel, and ABS/PVC plastic). This means that when the device is no longer needed for use, it can be disposed of in a way that is environmentally friendly. In production of our device we did our best to ensure that we minimized the amount of machining that would be necessary so as to reduce the amount of electricity used in production. This was mainly accomplished through using standard sized materials in our design and leaving many of the stock dimensions for the finished part. We also made all efforts to use scrap metal from the machine shop and to use lengths of stock that would minimize leftover material. We also selected a piece of wood for the base that one of the team members already had rather than going and purchasing a new piece of wood. One way that we could have better optimized our production for minimizing environmental impact would have been to use one piece of aluminum tube that would be just enough to allow for proper machining as opposed to using three individual tubes which were each three inches too long. We could have eliminated approximately eight inches of material (25%) by doing it this way. Unfortunately when we purchased the material we hadn't finalized a length for the tubes, so we bought the max that we thought we would need. We also could have reduced the overall length of the tubes so that the longest spring/base/cup assembly didn't require a base spacer. This would reduce the overall length of aluminum tube needed and would also reduce some of the PVC tube needed for the base spacers. This was avoided to allow for additional adjustability in the compressed distance, however this does not seem necessary now that we are at the completion of the design process.

Aaron: Environmental and sustainability considerations were taken into account throughout our design and manufacturing process. In terms of materials, the device is made primarily out of wood and aluminum. Wood is a natural, renewable resource however it undergoes much chemical processing and energy intensive treatments before we, as consumers retrieved it. It is used as our base, which is a fraction of the material used for the rest of the device. The brackets, plates, supports, and tubes are made out of aluminum. The process of forming raw aluminium is very energy intensive and pollution also occurs during transport from the processing plant to the retailer. In addition, the team machined all of the components in the machine shop where energy was consumed operating the mill, lathe, and drill press. Recycled or more environmentally friendly materials may have been considered, however our low budget and durability requirements necessitated our chosen materials. The mechanism is also very small and will not be mass produced, lowering the overall impact of material selection. Our device is completely mechanically powered and therefore does not consume any electrical energy during the use phase. The product is also expected to have a long lifetime of at least 10 years. As parts break down, the user will perform maintenance on it as opposed to discarding it. At the time when the product is finally retired, it is likely that it will be taken apart and the parts reused for future ME 450 classes.

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