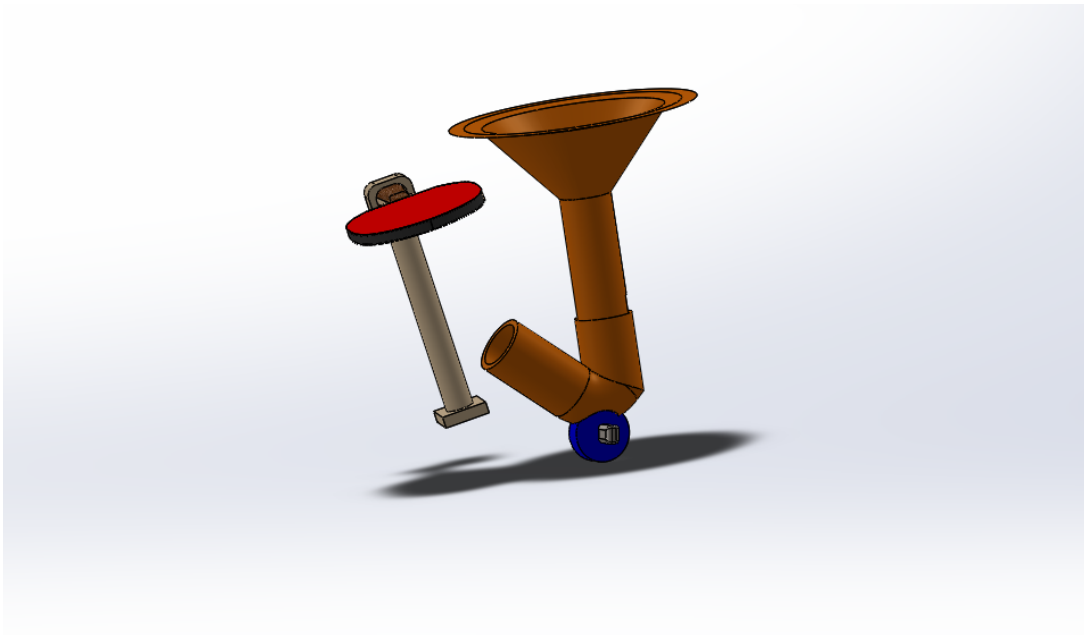
THE UNIVERSITY OF ILLINOIS AT CHICAGO
ME 250-Introduction to Engineering Design and Graphics
Fall 2022



Project #2: Device Design
Technical Memorandum

Submitted by:

Name 1

Name 2

Badhrie Sridhar

Name 4

Section #1

Team 7: Slime

December 2, 2022

I. Executive Summary

Team Slime, like all other teams this semester, was tasked with creating an autonomous ball launcher that can efficiently and effectively launch balls into a hole of a predetermined size with accuracy. The team first began to conceptualize the idea of a ball launcher in its most general form, and narrow it down from there. The way of executing the design uses a very simple and cost-effective solution needing only one motor and one servo motor. The design benefits from this simplicity in many ways including but not limited to low cost, efficient and simple operation, and consistency.

This project is meant to explore all of the different ways one should be able to solve the problem of launching projectiles and focuses on the process by which a team could execute it. The Process the team has followed has led us to a funnel ball launcher that exploits the movability of the paddle to become how the device aims itself. This design after much debate and a tough decision this design became the one to prevail.

Team Slime's goals and objectives during the entirety of the project remained clear, to provide a cheap, efficient, and practical launcher; however, that doesn't mean the design process was smooth. The function means tree and the key objectives changed a total of at least 3 times - making some design process stages such as the morph chart quite difficult because of the multiple revisions. After pushing through to the morphological chart the function means tree began to slowly solidify and in so doing brought the team closer to the final design in the aforementioned paragraph.

Overall the team has learned through this process the ways teams around the engineering world quantify ideas and execute the production of a product and how best to get it to where it needs to be. The team's final design remains a perfect result of all of the processes that have been used and remain simple and effective.

II. Introduction

A toy manufacturer has given Team Slime the opportunity of producing a highly precise and highly adjustable table tennis training machine. In this course project the team was tasked to design an autonomous (not remote operated) Launching Mechanism. The device will discharge up to ten ping pong balls in total, either one or multiple balls at a time into a target receptacle. The device may be adjusted, reset, and reloaded with balls before relaunching. To understand how the team approached with solving the project requirements, the report will be broken down into the following sections: Background Research, Problem Definition, Functional Analysis (Functions and Means), Generation and Selection of Concept Alternatives, Proof of Concept, Engineering Drawings and CAD, Conclusions, and References. The Background Research will mention/summarize the different types of videos watched and different types of patents read to get a background idea and initial thoughts of a launching mechanism. The Problem Definition section will mention the design problem and includes a set of objectives, and a list of constraints. There is also an explained objective tree. The Functional Analysis section will mention the primary/secondary functions and how they will work together to help with the brainstorming and design process. The Generation and Selection of Concept Alternatives section will mention different concept ideas and the total number of design possibilities. From that the team had to pick top concepts from different criteria in which one concept had to be picked. The Proof of Concept section will display the initial designs the team sketched out along with the final design the team ultimately ended up choosing. The CAD section will show part drawings of each assembly piece of the device (a part drawing is a picture that is used to convey dimensional information about a device/part). The Conclusion section will mention a quick summary of the lessons the team learned throughout Project 2.

III. Background Research

The team researched different types of Arduino launching mechanisms that already existed through YouTube videos and through patent searches that enable the different types of functions in the launching mechanism.

Video 1

In the first video, the user built a launching mechanism with the help of the arduino that ejects the paper ball. But the catapult has only one set height that it goes to along with the user needing to manually put a ball each time after launch. This video gave our team the idea of a basic structure for the launching mechanism [2] .

Video 2

In the second video, the user built a catapult system with the same concept of the first video, but in this video, the catapult system was able to move in different directions along with a better motor for the catapult. This video gave our team a better understanding on how to improve the catapult system to the project's requirements[3] .

Video 3

In the third video, the catapult built was similar to the catapult from the first video, but the main unique features were a button to increase/decrease the launching distance of the ball along with using a spring system to make sure that the catapult launcher does not break hitting the ground after the launch. This video helped our team understand that having a launching mechanism that can launch the balls in different angles along with incorporating some type of spring system with the catapult to avoid damage when the catapult launcher hits the ground after the launch to avoid any malfunctions with our launching mechanism[4] .

Video 4

In the fourth video, the user built a catapult system similar to the videos bove, but one big drawback that I saw with this system is that once the catapult is launched, then it doesn't go back down on its own. Though, it does have good features such as using different angles for the catapult system. From this video, the team acknowledged that while the implementation of the launching mechanism was good, we needed to make sure that our catapult system goes back down on its own to satisfy the project requirements[5] .

Patent Search

<u>The first patent</u> is a rapid fire dart launcher with a mechanism that continuously reloads the launcher in quick succession[6] .
<u>The second patent</u> is a basketball training device with a ball launch system that works by pulling a launch arm back against a spring which is then released to launch a basketball[7] .
<u>The third patent</u> is a paintball gun that fires paintballs by using a mechanism that includes a movable piston, compressed gas, a cylinder, and a spring.
The fourth patent is a ball launcher that consists of a switch that senses the presence of a ball that then sends a signal to a drive shaft which then puts tension on a spring[8] .

Additional Information

It would be extremely helpful/useful to look into projectile motion and how with our calculations, we are able to angle the launcher a certain way to get the ball into the hole. When designing our device, it will be important to figure out the next steps after the background research. There are multiple different paths that can be taken during the engineering design process. It is important to know/have an idea of what the ping pong ball launcher will look like and how we want to implement the rapid launch of the balls that are placed into it[9] .

IV. Problem Definition

Whenever designing a product for a client, engineers utilize the design process to create well-rounded devices/mechanisms. Engineers use this procedure because it allows them to clearly compare and contrast multiple ideas for a potential product; however, before mapping out ideas, engineers must come up with something called a “problem definition.” The problem definition is essentially an objective statement that has to satisfy a list of criteria that can be objectively evaluated using metrics. The problem the team was tasked with was to build a launching mechanism that was autonomous 10 balls consecutively.

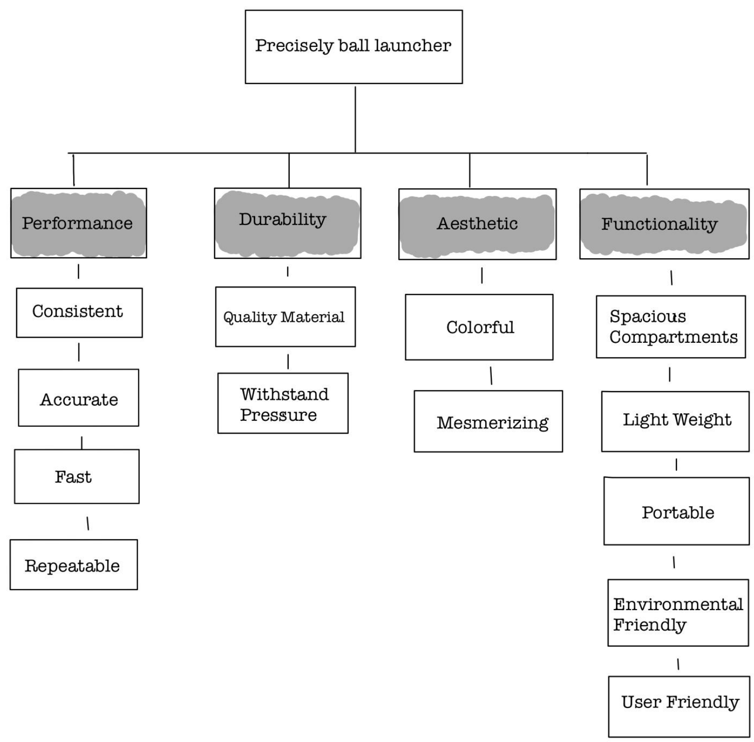


Figure 1.1: Objectives

Constraints:

1. No moving parts (excluding ping pong balls)
2. Mechanism is autonomous
3. 10 ping pong balls need to be launched into the air
4. No more than 4 motors can be used
5. Mechanism must not take longer than 3 minutes
6. Mechanism must stay in specified area
7. No commercial products
8. Design must be original
9. Device must be submitted by week 15

The objectives stated in figure 1.1 above makes known the most general ideas that the ball launcher needs to do for the team's purposes and what characteristics that the device needs to have in order to get them done in the way that the team needs them to. Below summarizes these things even more into four sub categories including performance, durability, aesthetic, and functionality. These are the main subgroups that the team has decided make the most sense for the ball launcher.

For the design subgroup, the team concluded that the device should be colorful and or aesthetically pleasing in order to fulfill the team's interpretation of the project goal. Along with these two design choices, customizability and ease of use also play a role in the design - because if the design is not easy to use or set up it adds more variables that would make it harder to fulfill the goal as a team.

Characteristics of the launcher are things the launcher needs to do on the whole independent of its looks or purpose. The cost and environmental impact are some of the two biggest concerns for the characteristics, second only to the safety of the device. Without these three durability and portability are useless. The foundation for the project is laid down in the characteristics and are built off of them.

Once the foundation is built the performance and functionality of the device begin to fall into place quite well. The performance of the launcher represents one full cycle from loading to firing, and the functionality represents everything in between that process and everything that makes that process happen smoothly. Performance the team harps on speed efficiency and accuracy the most while in the inbetween stages repeatability, redundancy and storage needs are taken into account. The objective tree shown below is the teams final iteration. This final iteration shows the changes made by the team in regards to the 4 subgroups of the primary objective. However, everything below those subgroups remains relatively the same.

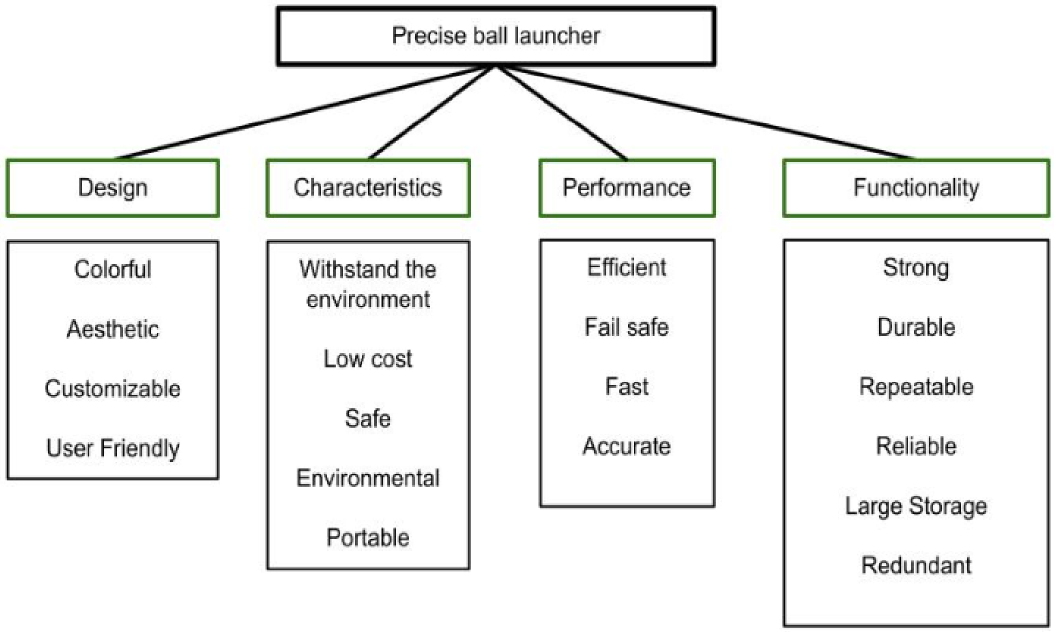


Figure 1.2: Objective Tree

In order to determine the main functions, and constraints in this project, the team determined that a function-means tree would adequately represent what was needed. This tree lists the primary functions at the top in orange, followed by the means in yellow. The functions are defined as what the actions that the mechanism should do, while the means are items/materials that can be used to get there. The primary function was determined to be that the mechanism should launch/shoot the balls. Below that are the subfunctions, such as autonomously reloading balls, having the balls become airborne, and being able to start the device. In order to start the device, there were two options – electrical power or gravitational power. Electrical would include any bluetooth, usb connection, or arduino based connection. On the other hand, gravitational power includes any mechanical/non-arduino based starting of the device. In order for this to be fulfilled, the team came up with several mechanisms, such as a plunger in tube, catapult, slingshot, etc. Additionally, the team brainstormed several other ideas if they had decided to implement the use of a paddle. If this idea was to be used, materials such as CAD/SolidWorks, plywood, PVC, etc. can be used to fulfill the function of hitting the paddle before landing in the hole.

V. Functional Analysis (Functions and Means)

During the design process, it is important for engineers to define the main functions that the mechanism must fulfill. From there, the means to get there must, also, be defined. Engineers use this procedure because it allows them to brainstorm all the design paths that could be taken when building the mechanism. This can be achieved using a ‘function-means tree’. The ‘function-means tree’ is a graphical representation of the primary/secondary functions and how they will be met.

In order to determine the main functions, and constraints in this project, the team determined that a function-means tree would adequately represent what was needed. This tree lists the primary functions at the top in orange, followed by the means in yellow. The functions are defined as what the actions that the mechanism should do, while the means are items/materials that can be used to get there. The primary function was determined to be that the mechanism should launch/shoot the balls. Below that are the subfunctions, such as autonomously reloading balls, having the balls become airborne, and being able to start the device. In order to start the device, there were two options – electrical power or gravitational power. Electrical would include any bluetooth, usb connection, or arduino based connection. On the other hand, gravitational power includes any mechanical/non-arduino based starting of the device. In order for this to be fulfilled, the team came up with several mechanisms, such as a catapult, tracks, ramp, slingshot, etc. Additionally, the team brainstormed several other ideas if they had decided to implement the use of a paddle. If this idea was to be used, materials such as CAD/SolidWorks, plywood, PVC, etc. can be used to fulfill the function of hitting the paddle before landing in the hole.

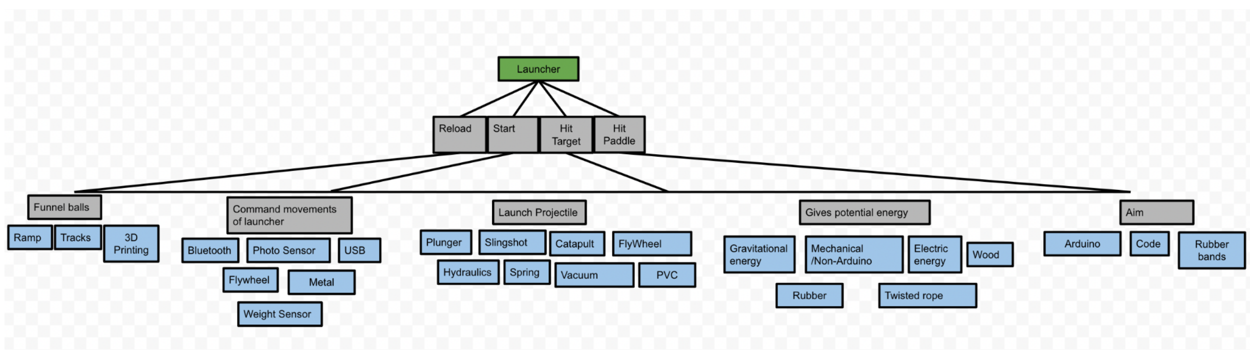


Figure 1.3: Final Function Means Tree

The result of this shown in the image above is a culmination of every possible way to meet the needs of the project at hand. The team laid out all of the functions believed to be necessary in the construction of the device – represented by the gray boxes – and underneath – the blue boxes – represent the different ways of executing each function. Though the options are not mutually exclusive to each of the functions it gives us a pretty simple and intuitive understanding of the ways that the team can execute each function in a unique way.

For example with the function of potential energy, the focus was using a purely mechanical design, and for the one that requires signal input it was chosen that an Arduino based design would be a possible design component. Below everything is the materials that are not mutually exclusive to either design as they are placed below everything. This shows the two ways that we have chosen that we could go about building the device while also fulfilling the original functions that we chose were most important to make the device function satisfactorily.

Overall in this part of the project, the team needed to define the necessary functions of the project and come up with potential means to achieve the specified functions. Using a function-means tree made it easier for the team to understand and list out potential ideas in an organized manner. A function-means tree is a visual representation of the breakdown of the different levels of functions and means that could be potentially used in the project. Doing a function-means tree is crucial in any project because it gives the team the opportunity to think about a wide variety of options that can be used to implement the final product.

VI. Generation and Selection of Concept Alternatives

A morphological chart is a matrix resulting from the combination of different means and functions [1]. This matrix allows the designer to look at all possible design concepts and combinations, both feasible and infeasible. In this report, a detailed morphological chart will be shown for the team's device and all possible design possibilities to approach. The team, then, simplified the original morphological chart to a reduced morph chart, where all infeasible combinations were eliminated. As a result, the team was left with the top 20 design concepts to consider, and from those emerged the top 5 concepts. Ultimately, the team picked the concept that ranked best in the comparison chart.

The team's original morphological chart had 840157920 concepts. From this, the team had to decide which means would be infeasible in terms of availability of materials, and safety of the design. The first reduced morphological chart resulted in a possible 4644864 designs. The second reduced morphological chart resulted in a possible 622080 designs. These stated possible design numbers were calculated by multiplying the total number of means for each function by one another.

Table 1.1: Original Morphological Chart

		Means 1	Means 2	Means 3	Means 4	Means 5	Means 6	Means 7	Means 8	Means 9	Means 10	Total # of Means
Function 1	*Launch*	Plunger	Spring	FlyWheel	Hydraulics	Gravity	Servo	Catapult	Rubber Bands			8
Function 2	*Reload*	Electrical Energy	Gravitational Energy	Spring	Vacuum	Plunger	Servo	Switch				7
Function 3	*Start Device*	Gravity	Switch	Light	Code	PhotoSensor	Button					6
Function 4	*Hit Target*	Arduino	PVC	Plastic	Aluminum	Nickel Silver	Glass	Stainless Steel	Catapult	Spring		9
Function 5	*Become Airborne*	Photo Sensor	Weight Sensor	Fly Wheel	Wood	PVC	3D printing	Funnel				7
Function 6	*Funnel balls*	Mechanical/Arduino	Ultrasonic Sensor	Tracks	Funnel	Sheet Metal	Servo	Gravity				7
Function 7	*Hit Paddle*	Rubber Band	Catapult	FlyWheel	Plunger	Spring	Hyrdaulics	Gravity				7
Function 8	*Send Signals*	USB	Bluetooth	Wires	Metal	Photo Sensor	Ultra Sensor	Scale	Servo Motor	Steppa Motor		9
Function 9	*Aim*	Nickel Silver	Rubber	Sheet Metal	Tinplate	PVC	Arduino	Code	Servo	Gravity		9
Function 10	*Gives Structure*	Glass	Metal	Plastic	Glass	PVC	MDF	Nickel Silver	PLA plastic	Sheet Metal	Acrylic	10
												840157920

Table 1.2: First Reduced Morphological Chart

		Means 1	Means 2	Means 3	Means 4	Means 5	Means 6	Means 7	Total # of Means
Function 1	*Launch*	Spring	FlyWheel	Hydraulics	Firing Pin				4
Function 2	*Reload*	Electrical Energy	Gravitational Energy	Spring	Servo	Plunger	Bolt		6
Function 3	*Start Device*	Electrical Energy	Switch	Code	Light				4
Function 4	*Hit Target*	Arduino	Plastic	Catapult	Spring				4
Function 5	*Become Airborne*	Weight Sensor	Spring	Flywheel	Photo sensor	3D printing	Funnel		6
Function 6	*Aim*	Plunger	FlyWheel	Servo	Funnel				4
Function 7	*Hit Paddle*	Catapult	Spring	Flywheel	Funnel	3D printing	Hydraulics		6
Function 8	*Send Signals*	USB	Wires	Bluetooth	Photo Sensor	Code	Arduino		6
Function 9	*Funnel balls*	Aluminum	PVC	Tracks	Funnel	Servo	Wood	3D Printing	7
Function 10	*Gives Structure*	Plastic	PVC						2
									4644864

Table 1.3: Second Reduced Morphological Chart

		Means 1	Means 2	Means 3	Means 4	Means 5	Means 6	Total # of Means
Function 1	*Launch*	Spring	FlyWheel	Firing Pin				3
Function 2	*Reload*	Electrical Energy	Gravitational Energy	Spring	Servo	Turntable	Bolt	6
Function 3	*Start Device*	Electrical Energy	Switch	Code				3
Function 4	*Hit Target*	Arduino	Plastic	Catapult	Spring			4
Function 5	*Become Airborne*	Spring	Flywheel	3D printing	Funnel			4
Function 6	*Aim*	FlyWheel	Servo	Funnel				3
Function 7	*Hit Paddle*	Catapult	Spring	Flywheel	Funnel	3D printing		5
Function 8	*Send Signals*	USB	Wires	Code	Arduino			4
Function 9	*Funnel balls*	PVC	Funnel	Servo	Wood	3D Printing	Ramp	6
Function 10	*Gives Structure*	Plastic	PVC					2
								622080

Table 1.4: Top 20 Concepts

Concept 1	Spring	Electrical Energy	Switch	Arduino	3D Printing	Catapult	USB	Funnel
Concept 2	Spring	Gravitational Energy	Code	Catapult	Funnel	Servo	Wires	3D Printing
Concept 3	FlyWheel	Electrical Energy	Electrical Energy	Plastic	FlyWheel	Funnel	USB	Servo
Concept 4	FlyWheel	Gravitational Energy	Switch	Code	Spring	Spring	Wires	Wood
Concept 5	Spring	Spring	Electrical Energy	Plastic	3D Printing	3D Printing	Wires	Funnel
Concept 6	Spring	Servo	Code	Catapult	FlyWheel	Spring	Wires	Funnel
Concept 7	FlyWheel	Spring	Arduino	FlyWheel	Funnel	FlyWheel	USB	Servo
Concept 8	FlyWheel	Gravitational Energy	Switch	Arduino	Funnel	3D Printing	USB	Wood
Concept 9	Spring	Gravitational Energy	Arduino	Arduino	3D Printing	3D Printing	Wires	PVC
Concept 10	Spring	Spring	Switch	Plastic	Funnel	Catapult	Code	PVC
Concept 11	FlyWheel	Turntable	Code	Spring	FlyWheel	Spring	Arduino	Ramp
Concept 12	FlyWheel	Servo	Switch	Catapult	Spring	Funnel	Arduino	3D Printing
Concept 13	Spring	Turntable	Arduino	FlyWheel	Servo	Spring	Code	Ramp
Concept 14	Spring	Gravitational Energy	Electrical Energy	Spring	Funnel	Funnel	Wires	PVC
Concept 15	FlyWheel	Servo	Code	Plastic	Servo	Catapult	USB	Wood
Concept 16	Firing Pin	Bolt	Code	Spring	FlyWheel	Funnel	USB	PVC
Concept 17	Firing Pin	Electrical Energy	Electrical Energy	Arduino	3D Printing	Spring	Wires	Funnel
Concept 18	Firing Pin	Gravitational Energy	Arduino	Plastic	Funnel	Catapult	Code	Ramp
Concept 19	FlyWheel	Bolt	Switch	Catapult	Servo	Funnel	Arduino	3D Printing
Concept 20	Firing Pin	Turntable	Switch	FlyWheel	3D Printing	Spring	Wires	Ramp

To choose the top 20 concepts, the team decided that it would be best to include a series of combinations using a spring, flywheel, or firing pin as a means to the primary function – launch. Following that, there were many different means to help fulfill the secondary functions – reloading the device, starting the device, hitting the target, etc. Some of the most common means for many of the different functions included springs, flywheels, funnels, and arduino. The top 20 concepts were formed to be different combinations of these means with one another to help the team consider all possible options for this product. Many of the top 20 concepts used a spring or flywheel to launch the device, and electrical or gravitational energy to reload the balls autonomously after each one has been fired. The fulfillment of the rest of the functions were just a matter of material choosings, such as wood, PVC, wires, plastic, and more.

The top 5 concepts were chosen based on the following requirements: aesthetic, environmental friendliness, safety, precision, and risk of error. The most important requirements for the team were chosen to be precision and risk of error. The team wished to have some designs that used a combination of the flywheel and spring with the different energies mentioned above. The remainder of the top 5 concepts included designs that used a firing pin, but, also, very similar materials and means to those before them. A clearer table of the top 5 design concepts can be seen below.

Table 1.5: Top 5 Concepts

Concept 1	Spring	Electrical Energy	Switch	Arduino	3D Printing	Catapult	USB	Funnel
Concept 2	Spring	Gravitational Energy	Code	Catapult	Funnel	Servo	Wires	3D Printing
Concept 5	Spring	Spring	Electrical Ener	Plastic	3D Printing	3D Printing	Wires	Funnel
Concept 11	FlyWheel	Turntable	Code	Spring	FlyWheel	Spring	Arduino	Ramp
Concept 16	Firing Pin	Bolt	Code	Spring	FlyWheel	Funnel	USB	PVC

After much consideration, the team decided to go with a design that implemented a funnel to flywheel methodology to launch the balls to hit against the paddle. After comparing the top 5 concepts, the team felt that concept 11 was the best concept choice to implement the design vision. This concept ranked highest amongst all the others, and will produce the best results. The comparison chart for these concepts can be found below in Table 1.4, where a ranking of 5 was "the best" and 1 was "not good." This comparison chart method was drawn from examples as seen in the "*Engineering Design"* textbook [1].

Table 1.6: Comparison of Concepts

	Aesthetic (15%)	Environmental Friendliness (5%)	Safety (10%)	Precision (40%)	Reduced Risk of Error (30%)	Score/Ranking
Concept 1	4	2	3	3	2	2.8
Concept 2	3.5	2.5	3	2.5	2	2.7
Concept 5	3.5	3	3	3	3	3.1
Concept 11	3	4	4	4.5	4.5	4
Concept 16	2	2	3	3.5	3	2.7

Overall, the team used the original and reduced morphological chart to help organize potential designs for the mechanism. By listing out the various means that could be used, the team was able to critically analyze the different concepts and narrow it down into two separate reduced morphological charts. These charts helped with choosing the top 20 concepts, the top 5 concepts, and the top concept. The team concluded that the chosen top concept – concept 11 – was the one that best matched the main objectives.

VII. Proof of Concept

With the help of the reduced morphological charts, the team was able to narrow down all design possibilities to 3 top contenders. These designs included a variety of means to launch the balls, such as a catapult, spring, or servo motor attached to the ramp. These top three concepts can be seen below in their respective sketches – Figure 1.4, 1.5, and 1.6. Additional descriptions of these designs can be found below as well.

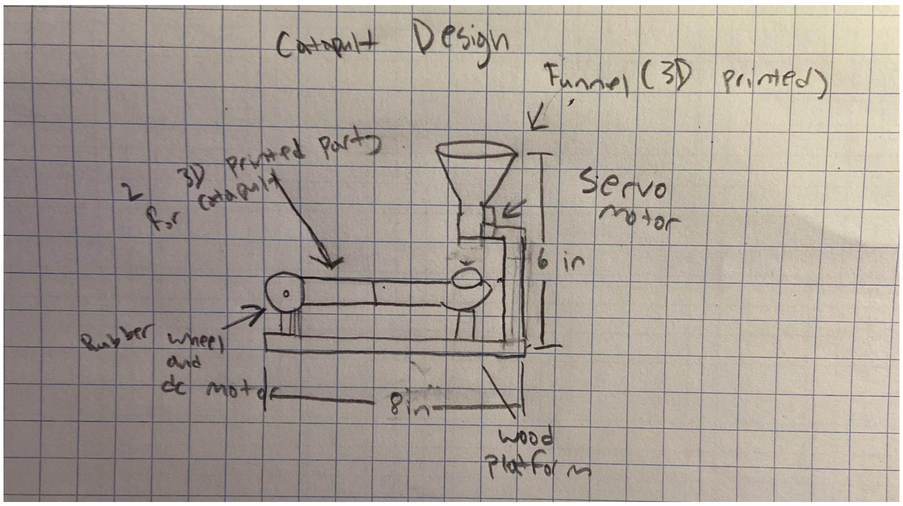


Figure 1.4: Funnel to Catapult

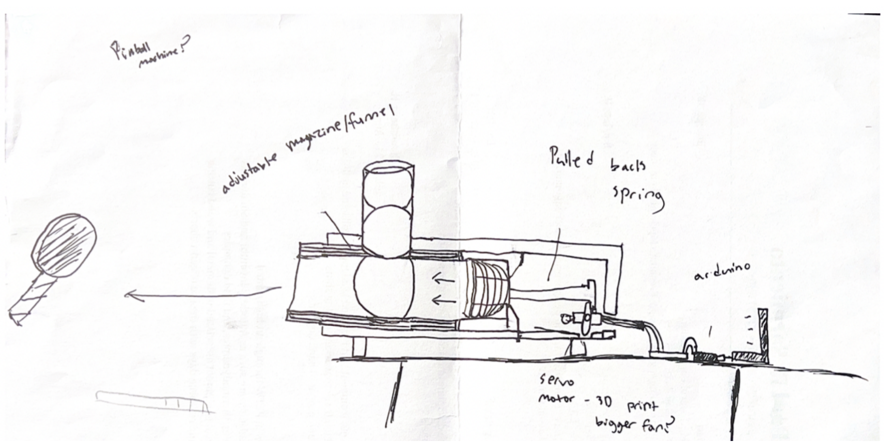


Figure 1.5: Servo to Spring

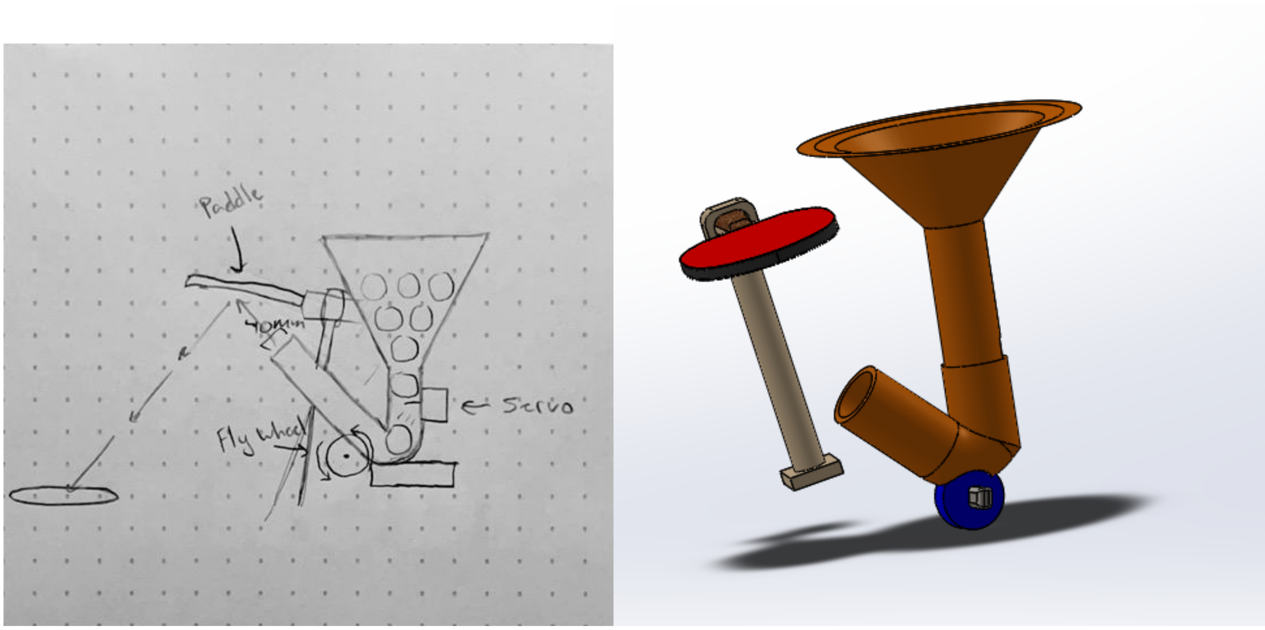


Figure 1.6: Funnel and Flywheel

Figure 1.4 was a mechanism that included a funnel that dropped the balls onto some sort of holder that would then be fired with the use of a pin. A servo motor would hold back all balls from falling at once. This device was not picked because the device had too many moving parts.

Figure 1.5 was a mechanism that included a spring that was used to launch the balls through a chamber. The spring was pulled back using a 3D printed hook piece and a servo motor. The balls were loaded into the device using a tube that was adjustable. This concept was ultimately scrapped due to the complexity of the design, the difficulty of springs, and the low power output of servo motors.

Figure 1.6 depicts the team's top concept. This design was a simple funnel to a ramp that would shoot out the balls using a flywheel powered by an arduino. The servo motor placed on the ramp would keep all balls from falling in at once and creating a jam in the mechanism. All materials needed to build this mechanism/design are listed below in Table 1.5. This table includes all parts in the mechanism, the materials needed, the quantity of the materials, and price per unit of the materials used.

Table 1.7: Bill of Materials

Part Name	*Material*	*Quantity*	*Price Per Unit*
Funnel/Hopper	3D Printing	~1 roll	$20 per kg
FlyWheel	3D Printing	~1 roll	$20 per kg
Tube/Ramp	PVC	~3 tubes	$3 per ft
Servo Motor	Arduino	~1	-
Paddle	3D Printed	~1/2-1 roll	$20 per kg
Mechanism Stand	Wood	~3	$3.98 per ft
Rods	Wood	~1	$3.98 per ft
Regular Motor	Arduino	~1	-
Ping Pongs	-	~10	-
		Approximate Cost:	84.92

VIII. Engineering Drawings and CAD

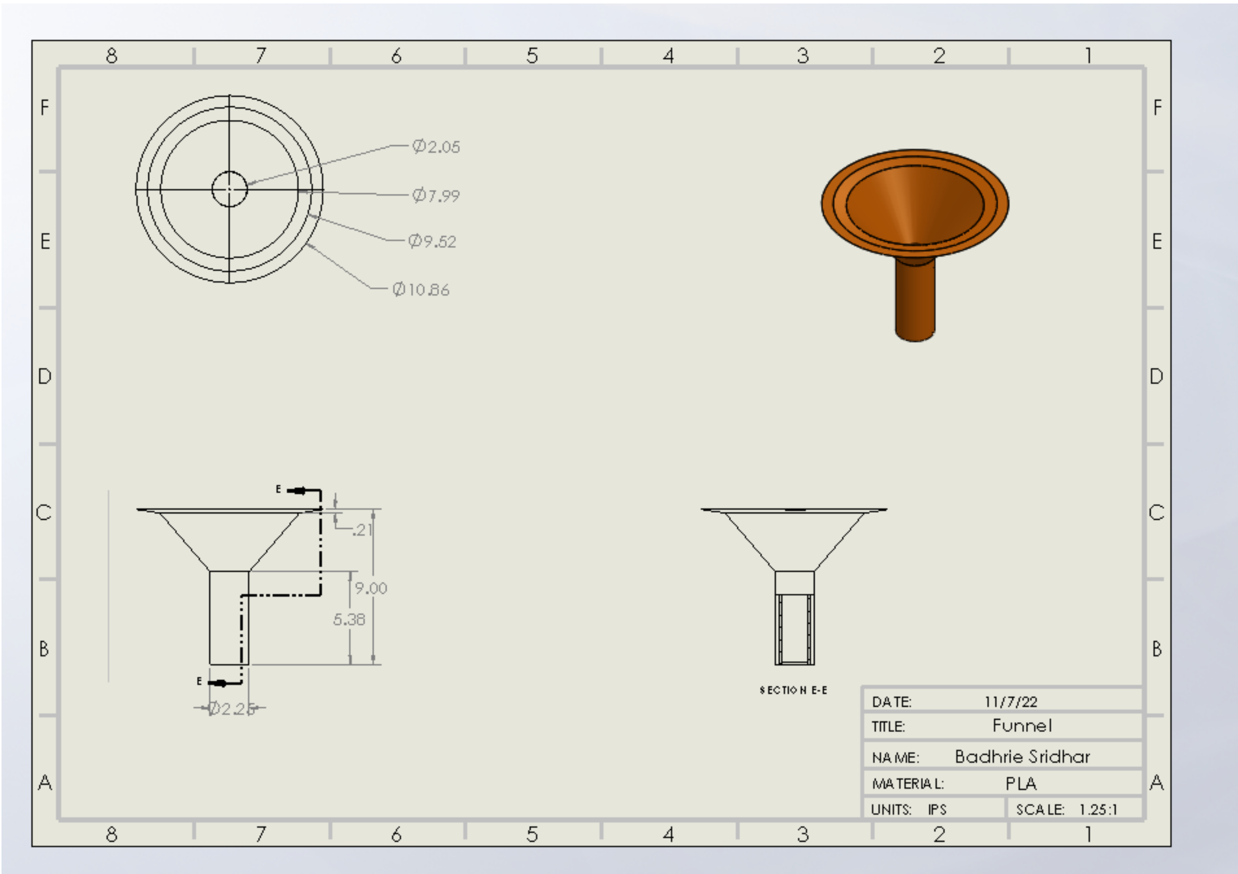


Figure 1.7: Funnel

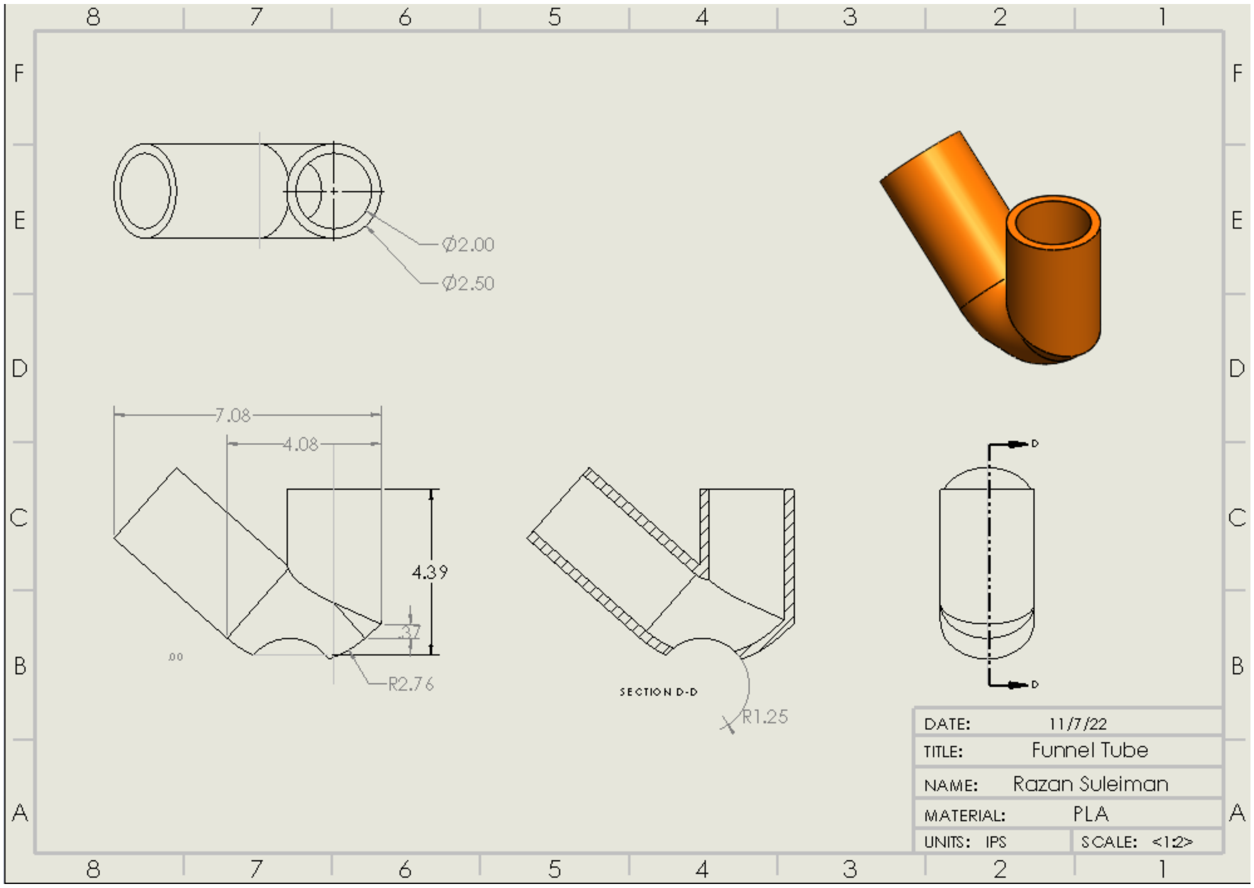


Figure 1.8: Funnel Tube

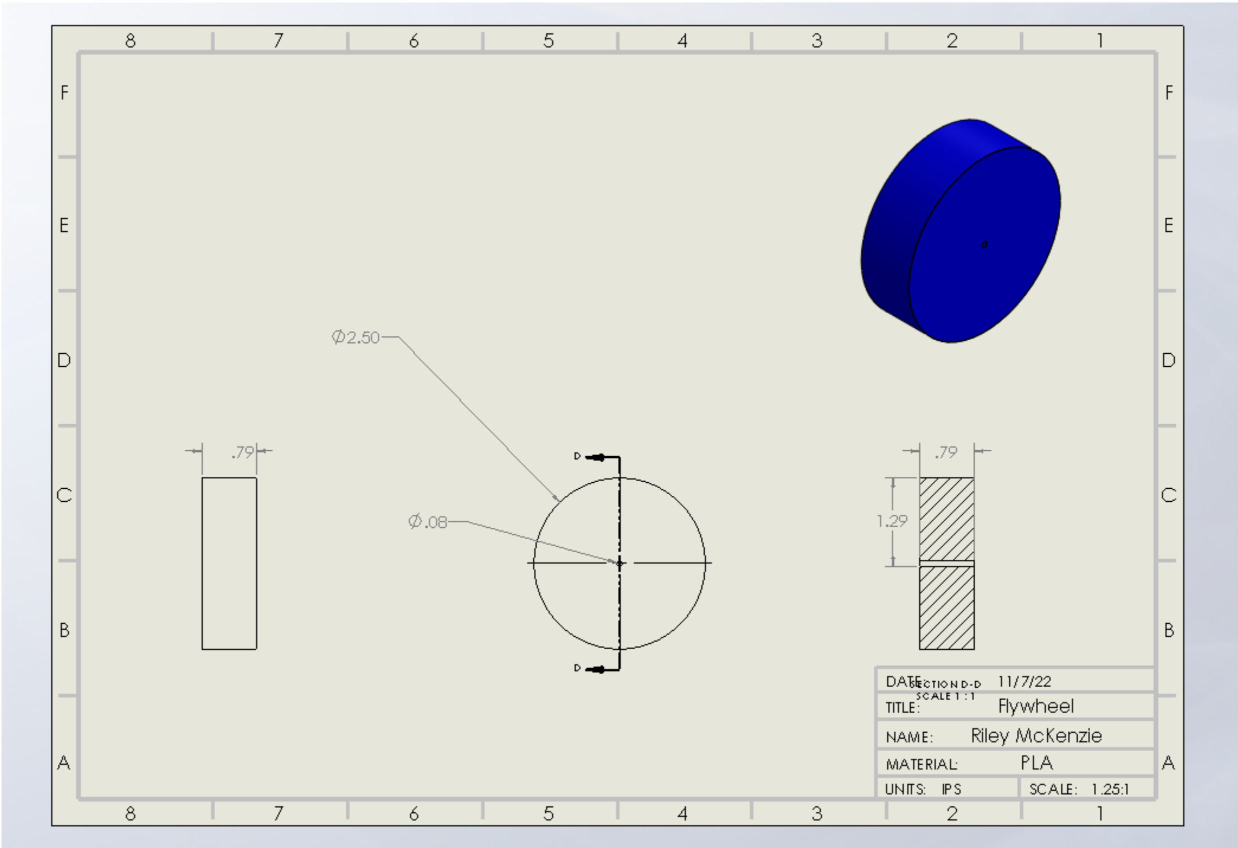


Figure 1.9: Flywheel

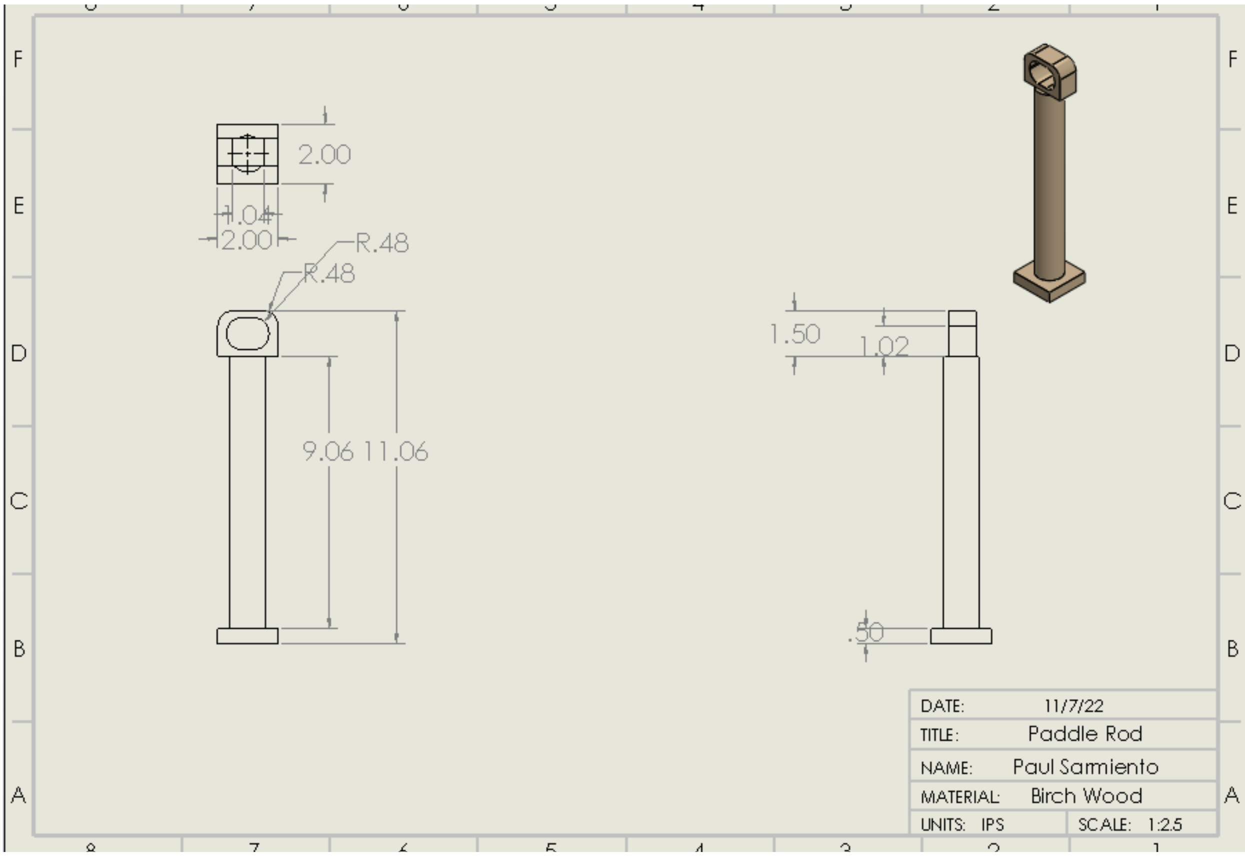


Figure 1.10: Paddle Rod

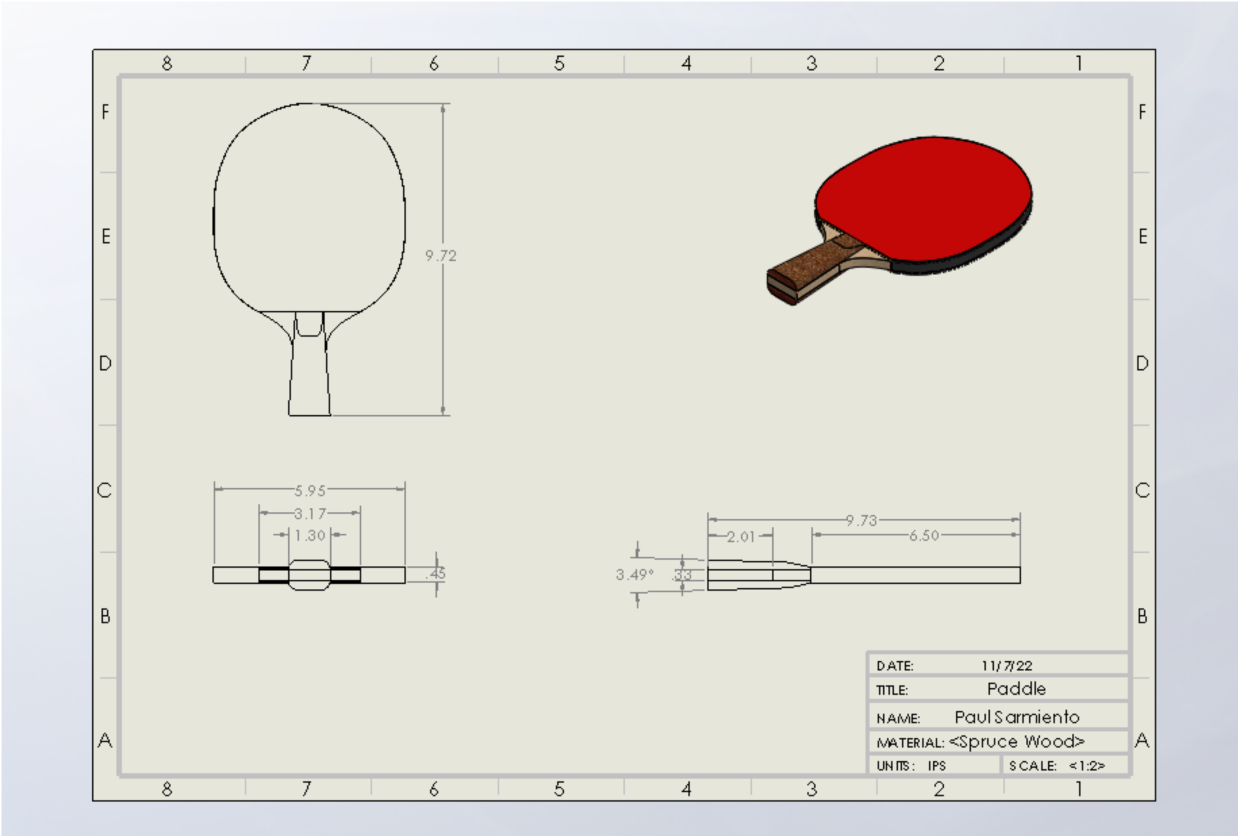


Figure 1.11: Paddle

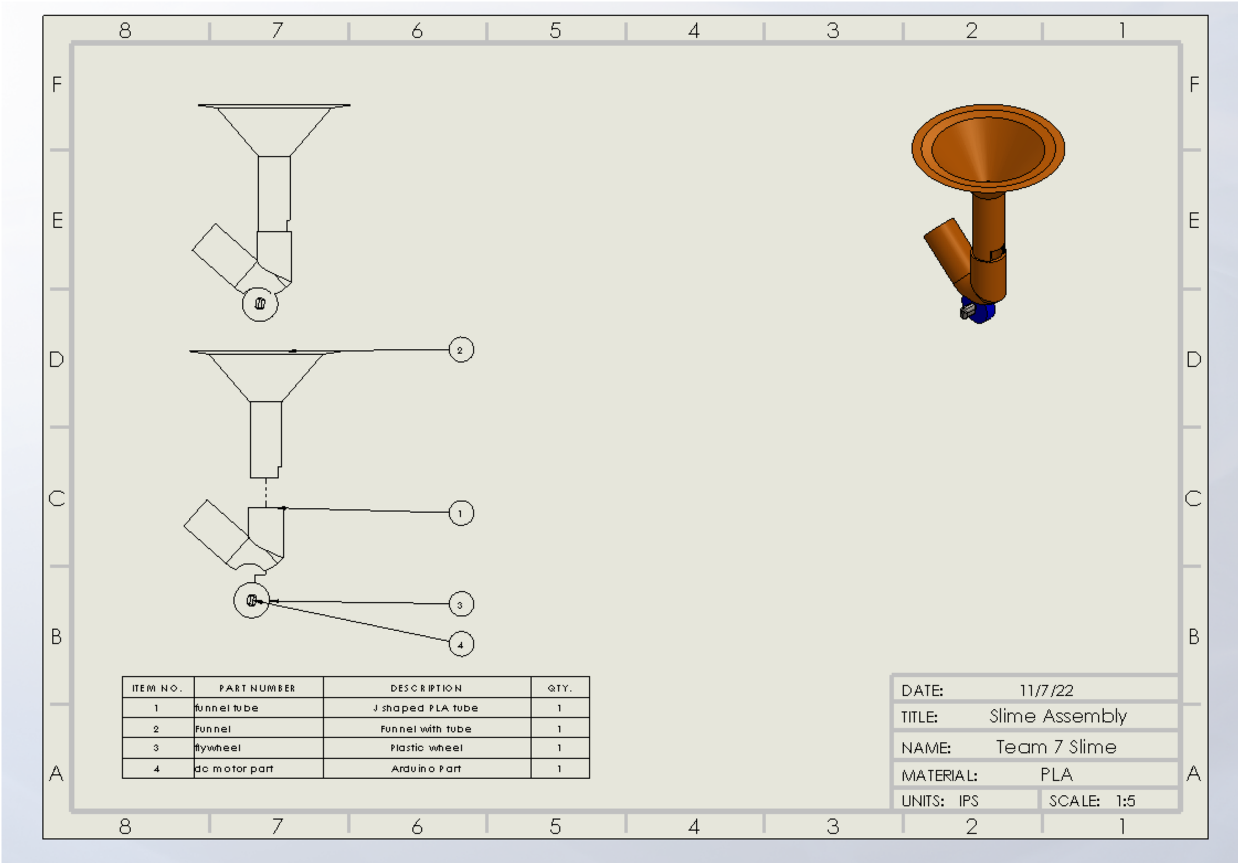


Figure 1.12: Main Assembly and Exploded View

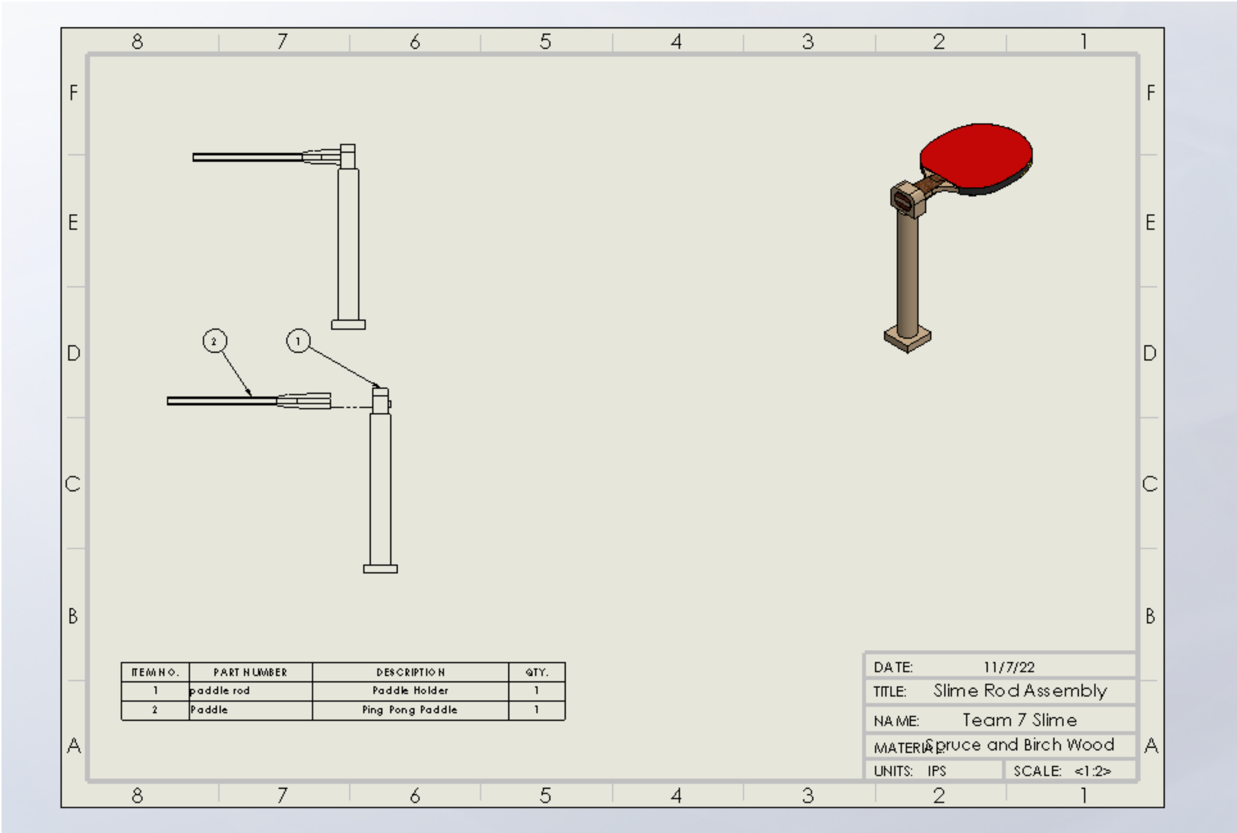


Figure 1.13: Paddle Rod Assembly and Exploded View

IX. Conclusions

After going through many designs, different struggles, and various team setbacks the final design that the team settled on is a lesson in simplicity and functionality. Through persistence and diligent collaborative thinking the team has created not only a design that will win, but a design that will do it simpler, faster, and cheaper.

During the course of this Project, trying not to get sidetracked was the biggest challenge overall. Because of this many late nights were spent because the team needed a simple solution to a problem that could have been finished in class or during lab hours. This did not end up ruining any progress or throw the team into any situations where we were going to miss a key deadline. The only ill consequence of our easily sidetracked behavior came in the form of stress. But stress in this case seemed to have made a strong diamond out of our final design.

The team's overall performance has been consistently on the edge of the seat and the final design is exactly how it was expected to be. The one performance tip that could have been changed for the next project would be the team's ability to keep and stick to a task schedule like the gantt chart. With a task managing system like a gantt chart the team has a much better road map as to who will be doing the assignments and when they will get done. That though is a small change to an overall successful team journey and one to continue improving into project 3.

X. References

[1] Dym, Clive L. “Engineering Design: A Project Based Introduction (4th Edition)”. *Wiley*, 2014

[2] Hackerspace trento, director. *Arduino (Easy DIY) Catapult*. *YouTube*, YouTube, 29 July 2014, https://www.youtube.com/watch?v=YX0409FM3Yw. Accessed 2 Oct. 2022.

[3] HappyElectricCircuit, director. *Arduino Controlled Catapult*. *YouTube*, 27 Apr. 2012, https://www.youtube.com/watch?v=R8D8ZZJyCLA. Accessed 2 Oct. 2022.

[4] Sui, Tianbo, director. *Arduino Catapult*. *YouTube*, YouTube, 11 June 2013, https://www.youtube.com/watch?v=lf_crj2tL5c. Accessed 2 Oct. 2022.

[5] *Arduino Catapult*. *YouTube*, YouTube, 14 May 2016, https://www.youtube.com/watch?v=K3U2OlnTnME. Accessed 2 Oct. 2022.

[6] David Michael Nugent, Tadeusz W Keska, “Rapid fire toy launch apparatus,” US9958230B1, Dec. 30, 2016.

[7] Douglas B. Campbell, Jeff J. Campbell, Adam T. Pan, “Basketball Training System,” US10315090B2, Mar. 10, 2015.

[8] Jerrold M. Dobbins, Gerald Dobbins, “ Compressed gas gun,” US10024626B2, Jul. 17, 2018.

[9] Eric A. Ward, “Automatic ball launcher,” EP3206483B1, Sept. 25, 2019.

[10] Finio, B. (2017, October 16). *Launch Time: The Physics of Catapult Projectile Motion.*

[11] Science Buddies Staff (n.d.). *The Engineering Design Process.* Science Buddies.

[12] Khan Academy, *Build a Ping Pong Ball Launcher. https://www.khanacademy.org/science/physics/discoveries/projectile-launcher/v/build-a-ping-pong-ball-launcher*