MEMS 411: Design of a wiffle ball pitching machine

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Ball Spin

This project designs a wiffle ball pitching machine that would demonstrate the Magus Effect to the audience in St. Louis Science Center. Primarily made out of wood, this design is portable and able to pitch wiffle balls both indoor and outdoor. With two spinning wheels whose maximum spinning rate is 5044 rpm, this design is able to pitch balls with topspin, backspin, and no spin, and the trajectory of the traveling balls can be recorded by naked eye. The highest recorded traveling velocity of the pitched ball is 67 mph. Several function that would facilitate the demo process are included in this design: accurate pitching and angle adjusting–it is able to pitch balls at an angle range of 0 degrees to 90 degrees and in the testing trial, 12/12 balls are able to hit a 20' by 20' target placed 20 feet away from the machine. There are several risks that a user might take notice of when using the machine: the spinning wheels might scratch a user's hand when it gets too close; the wires connected to the motor would trip users; a user might be hit by a traveling wiffle ball; and if used improperly, a user may get electric shock. Warning signs are prepared on the device to prevent the such risks for happening.

WU, Julian
PARK, Steve
WU, Viola

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1 Introduction

Ball spin and the Magnus effect have been widely studied because of aerodynamics and baseball so our group wanted to create a science center demo, showing the effects of ball spin on ball drop [1]. The machine would utilize two spinning wheels at different speeds to create a specific spin on the ball, pushing air to flow over the ball in one direction, essentially creating an extra lift force on the ball as shown in Fig. 1.

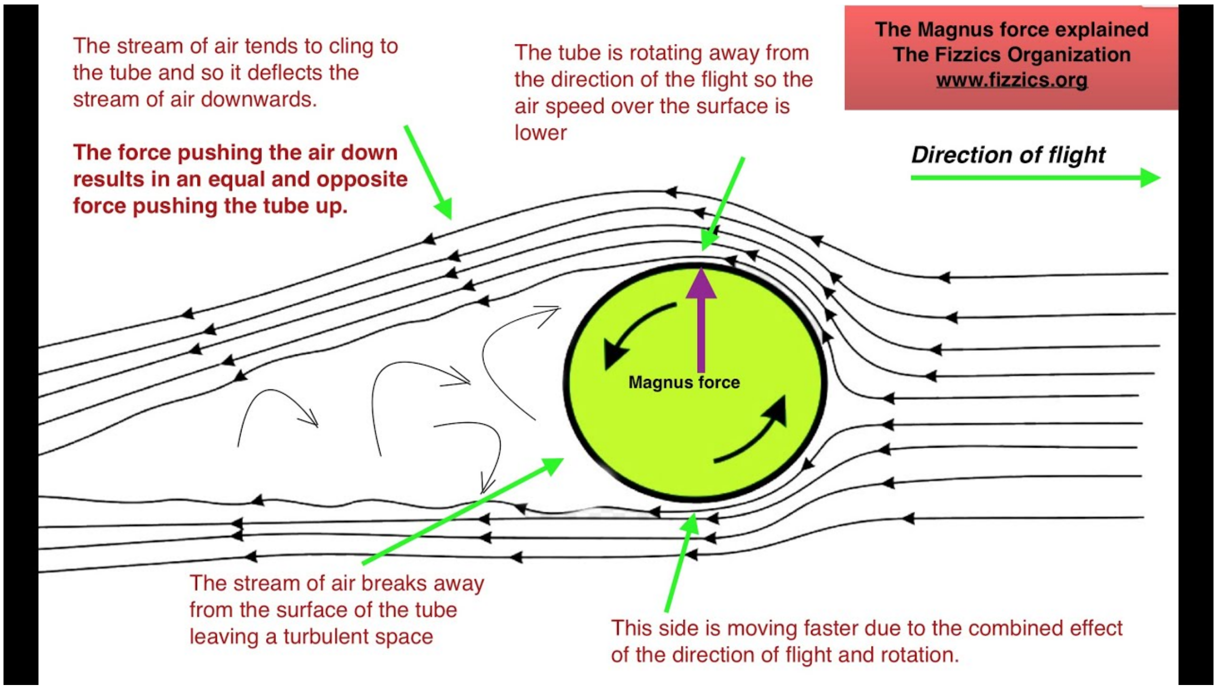


Figure 1: Magnus Force Diagram.

Dr. James Potter, Professor of Mechanical Engineering at Washington University in St. Louis, will use the Ball Spin demo as a proposal for the science center as there isn't an existing exhibit that shows the effect and also not one that is interactive.

The most recent plan for the Ball Spin demo is to utilize two grinder motors (high RPM, variable speed motors) and connect them to a frame that can be angle adjusted based on user input. Then there would be motor controllers to control both motor speeds at the same time to create different types of pitches. Finally a UI or panel will be built so the user can input specific speeds and spins on the ball to differ types of pitches. In this project, we will be using wiffle balls as they are safer for kids and aim for a maximum speed of 75mph to maintain safety for kids.

2 Problem Understanding

2.1 Existing Devices

Figures 2 -4 show the existing designs of softball pitching machines.

2.1.1 Existing Device #1: JUGS SMALL-BALL Pitching Machine

Figure 2: JUGS SMALL-BALL Pitching Machine (Source: hittingworld)

Link: https://www.hittingworld.com/Jugs-Small-Ball-Pitching-Machine-p/jugs-m7000.htm
Description: The JUGS SMALL-BALL Pitching Machine pitches the softball of interest by virtue of its acceleration tunnel and the two spinning wheels attached to it. The motor drives the wheels to spin, which, when contacting the softball released from the tunnel, pitch the ball to the user's desired directions. The height at which the user desires the ball to be pitched can be achieved by adjusting the configuration of the removable and retractable legs. The device is portable, weighing only 23 lbs, and can be fit to the trunk of an SUV car. The maximum pitching speed is 75 mph.

2.1.2 Existing Device #2: 2021 Hack Attack Junior Baseball Pitching Machine

Figure 3: 2021 Hack Attack Junior Baseball Pitching Machine (Source: pitchingmachinepro)

Link: https://www.pitchingmachinepro.com/2021-Hack-Attack-Junior-Baseball-Pitching-Machine-
102-1100.htm
Description: The Hack Attack Junior Baseball Pitching Machine has three throwing wheels that provide the necessary movements for the volleyball. The elevation control, fulfilled by an linear actuator, moves the pitch up and down and ensures user to select their desired elevation. Having a total weight of 75 lb, the machine achieves it portability by the wheels attached to its body and is able to fit into the trunk of a medium sized SUV car. To ensure safety, throwing heads and throwing wheel guards are set behind each throwing wheel–the former reduces recoil and the latter prevents the ball from sliding backwards. The range of pitching speed occurs between 30 mph and 70 mph.

2.1.3 Existing Device #3: BP®1 BASEBALL ONLY PITCHING MACHINE

Figure 4: BP®1 BASEBALL ONLY PITCHING MACHINE (Source: jugssports)

Link: https://jugssports.com/products/bp-1-baseball-only-pitching-machine.html
Description: The ball is placed manually through the channel where the user's hand can control its angle of attack. The motor drives the wheel to spin and push the softball with the desired flying speed. The supporting tripod ensures height adjusting mechanisms by their retractable feet and multi angle leg locks, thus rendering the user to adjust the height of the machine and its pitched softball. The allowed range of pitching speed is 15 mph to 70 mph.

2.2 Patents

2.2.1 Pitching machine (US20030195061A1)

This patent discusses the pitching machine's ability to release baseballs with different trajectory and velocity. When a baseball is placed in between a pair of rotating belts, the baseball is released in a preset direction and velocity. The horizontal and vertical inclination of the belts can be adjusted to change pitch types - from fastballs to breaking balls. Because of limited resources and budget, our group's wiffle ball pitching machine will be a much simpler version than this patent.

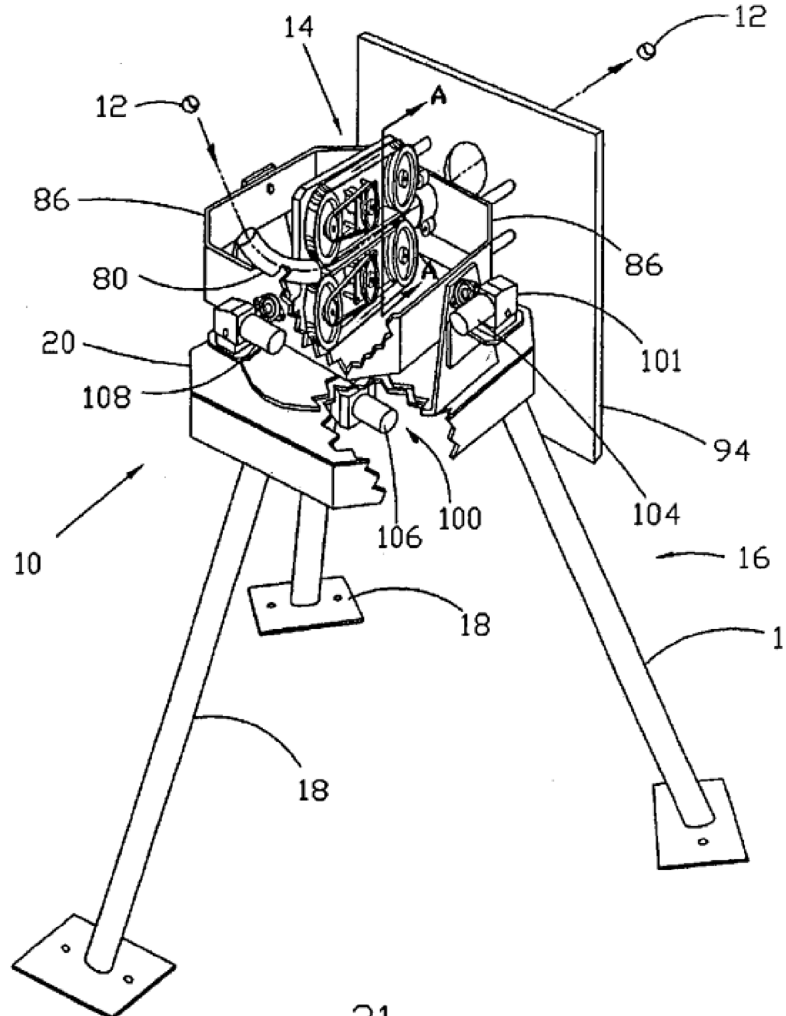


Figure 5: Patent image for pitching machine

2.2.2 Wiffle ball (Game ball) (US4930776A)

This patent discusses the material, weight, and dimension of wiffle ball. Baseball is extremely dense, and it travels with a high velocity. It can easily cause injuries for children, especially when they are untrained. Therefore, wiffle ball was invented to enable children to enjoy the sport with no risk of injuries. Knowing the dimension and the weight of wiffle ball is essential prior to designing a wiffle ball pitching machine. This pitching machine deviates from the baseball pitching machine because it throws a lighter and more delicate ball.

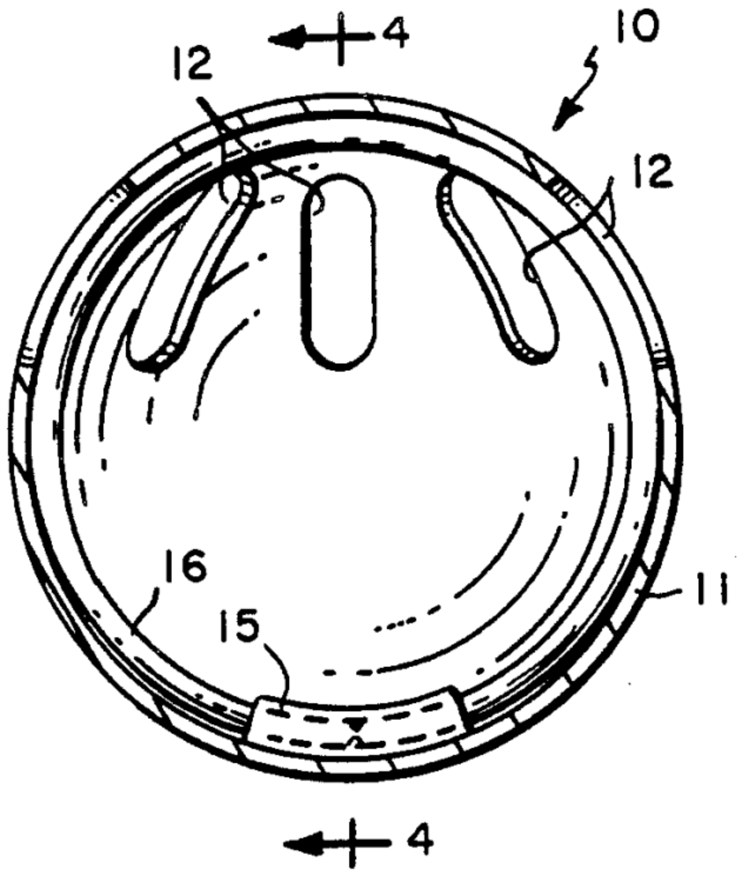


Figure 6: Patent image for wiffle ball

2.3 Codes & Standards

2.3.1 Safety and Health Regulations for Construction - Electrical - General Requirements (OSHA 1926.403)

Wiffle ball pitching machine is an indoor electrical device which needs caution when building and handling. This standard discusses the examination, installation, and use of the electrical equipment. It also addresses proper mechanical strength and durability of the equipment. This standard can be used to prevent safety hazards and malfunctioning when building an electrical device.

2.3.2 Motors and Generators (ANSI/NEMA MG 1-2021)

Wiffle ball pitching machine will include a DC motor to operate wheels for feeding. This standard provides information on choosing and operating the right motors and generators. Selecting the proper motor is extremely important for the design process because the incorrect selection of the motor can lead to safety and performance issues.

2.4 User Needs

This section summarizes the content of the interview between our group and our customer, Dr. James Jackson Potter.

2.4.1 Customer Interview

Interviewee: Dr. James Jackson Potter
Location: Zoom and Email
Date: September 9^{th}, 2022
Setting: We asked on zoom specific question regarding the maximum speed of the wiffle ball and the configuration of the wheels with drawings on Zoom whiteboard. Afterwards, we exchanged emails about the customer's expectations on ball retrieval and feeding, power source selection, and portability.

Interview Notes:
Feeding: what is a good way to feed/retrieve the balls

- Retrieval of the balls is not a top priority as it can be solved by having web behind home-base. Feeding can be achieved by letting gravity do the work–let balls roll down ramps when necessary.

What is the desired size and portability of the product?

- Although portability is not of the topmost concern as it is a demo, the footprint would be around 2' by 1' and reachable by children. The expected weight is 20 lb by maximum, but desirably falls between 10 lb and 15 lb.

What kind of power source should the design use?

- Having wires directly plug into the wall is preferred over using batteries because the former provide consistent power supply. Because portability is not the topmost priority, a battery is not chosen.

What is maximum exit velocity of the wiffle ball?

- 75 mph, and this number is the maximum velocity achieved by existing devices too.

What are the websites that provide good guidance on choosing the motors? What kind of motor is preferred? DC motor of AC motor?

- A good website horizonhobby.com. With the required maximum speed (75 mph), AC motors are preferred over DC motors as the former are geared for larger torques.

2.4.2 Interpreted User Needs

Table 1 shows the interpreted customer needs after interviewing our customer, Dr. Potter.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The softball pitching machine has continuous power supply	5
2	The softball pitching machine is safe for children	4
3	The The softball pitching machine occupies a reasonable amount of space (1' by 2')	4
4	The softball pitching machine is aesthetically pleasing	3
5	The velocity of the pitched wiffle balls is safe for children	3
6	The machine is able to pitch balls at user customized speed, angle, and elevation	3

2.5 Target Specifications

Based on the consumer needs and interpreted user needs, our group came up with target specifications of the product as shown below.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	2	Minimum user distance from rotating wheels	ft	> 1	< 3
2	3	Total area of the build	ft^2	< 6	< 2
3	4	Coolness factor		> 5	> 8
4	5	Maximum velocity	ft/s	< 120	< 110
5	5	Maximum weight	lbs	< 20	< 15
6	6	Maximum speeds	#	1	> 1

2.6 Project Management

The Gantt chart in Figure 7 gives an overview of the project schedule.

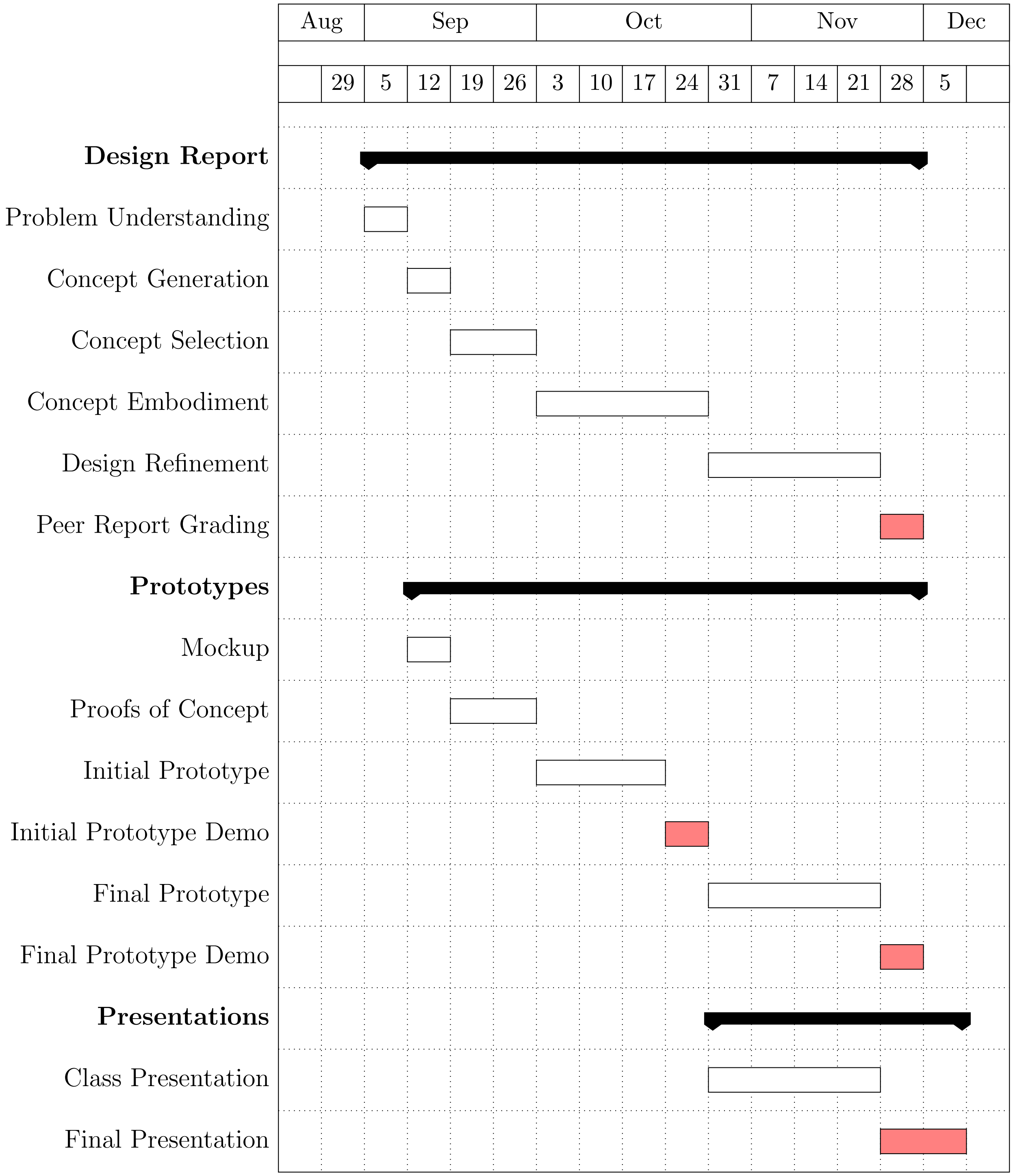


Figure 7: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

For the prototype, our group didn't have any motors to work with, so the best solution was to slap on some wheels and manually rotate them by hand to determine if the idea was viable. Doing different amounts of spins on the wheels, put different spins on the ball which is what our group was looking for. Additionally for the feeder, our group was looking for a feeder that could be used at every angle, so an angled piece of PVC was idea and if the design was tilted at a different angle, could still feed balls to the spinning wheels.

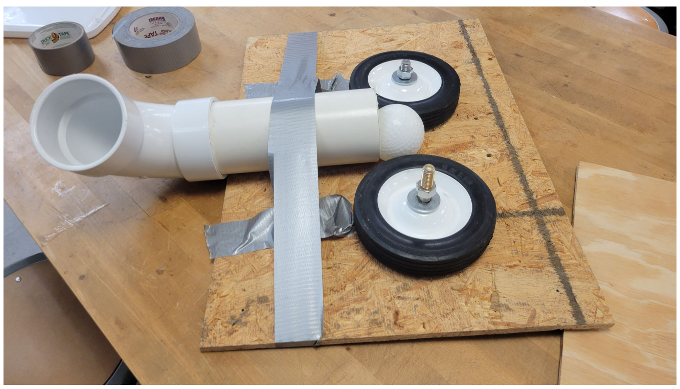


Figure 8: Angled-view mockup that our group made in class

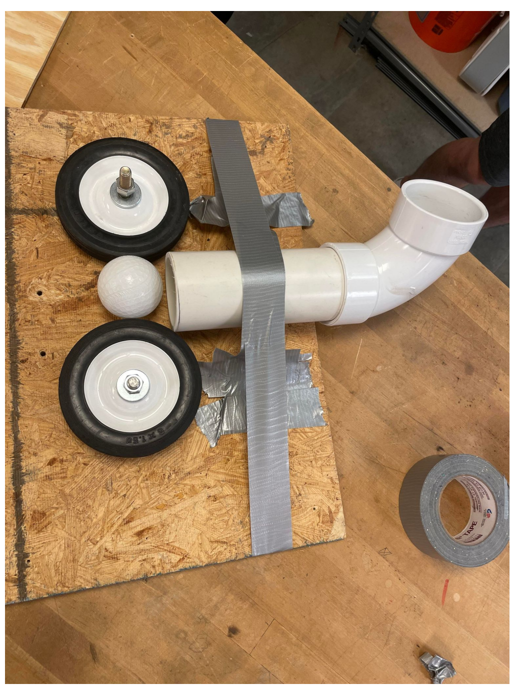


Figure 9: top-view mockup that our group made in class

Figure 10: side-view mockup that our group made in class

3.2 Functional Decomposition

For the function tree our group decided on six main sub functions: launching the wiffle ball, constant feeding, adjustable angle, adjustable speed, portable, and adjustable height. All the different sub functions together would combine to produce a wiffle ball pitching machine that is capable of producing different types of spins.

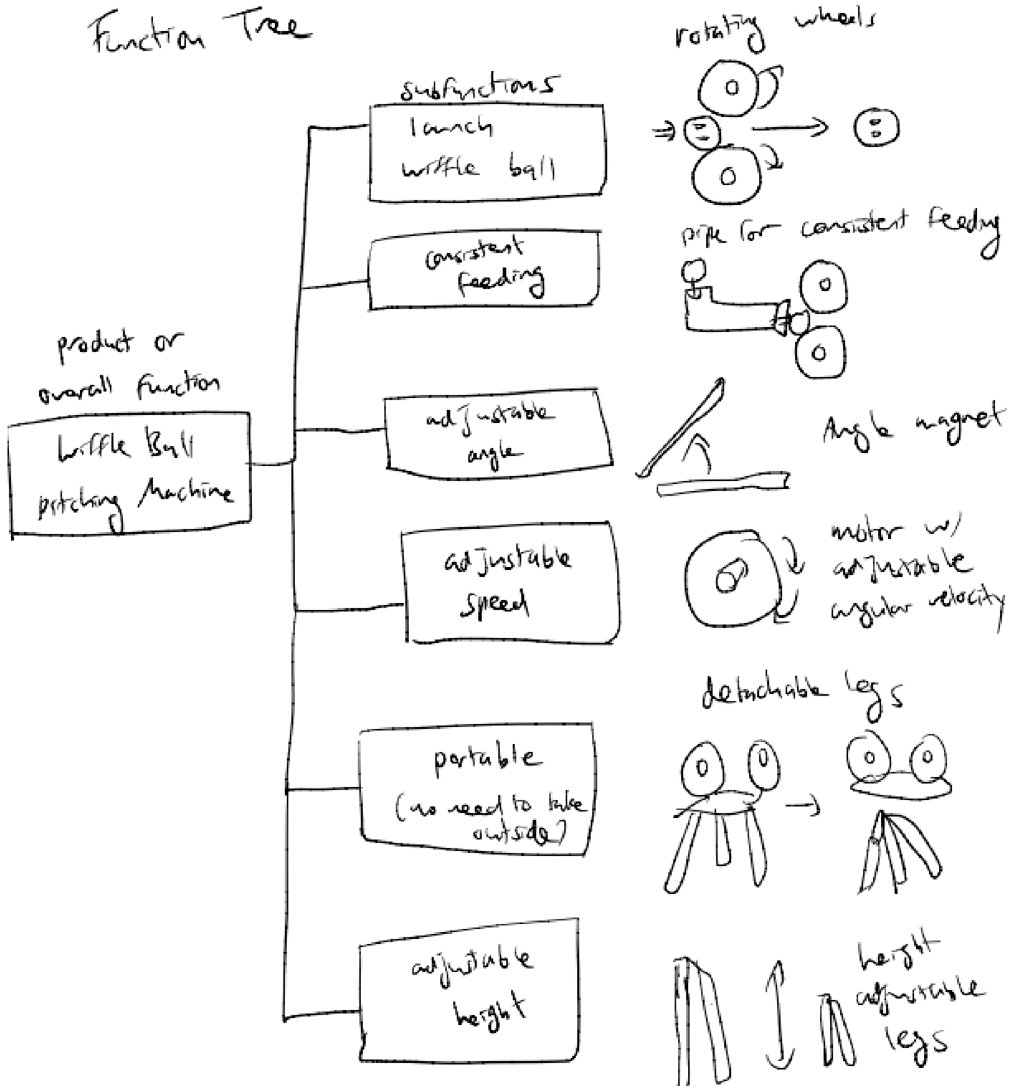


Figure 11: Function tree for Ball Spin Demo, hand-drawn and scanned

3.3 Morphological Chart

Figure 11 shows the morphological chart for the wiffle ball pitching machine. Each subfunction from the function tree has four different solutions. An ideal pitching machine should be able to launch the ball consistently with adjustable speed and angle. Therefore, our group will prioritize subsections 1, 2, 4 and 6 when building prototypes.

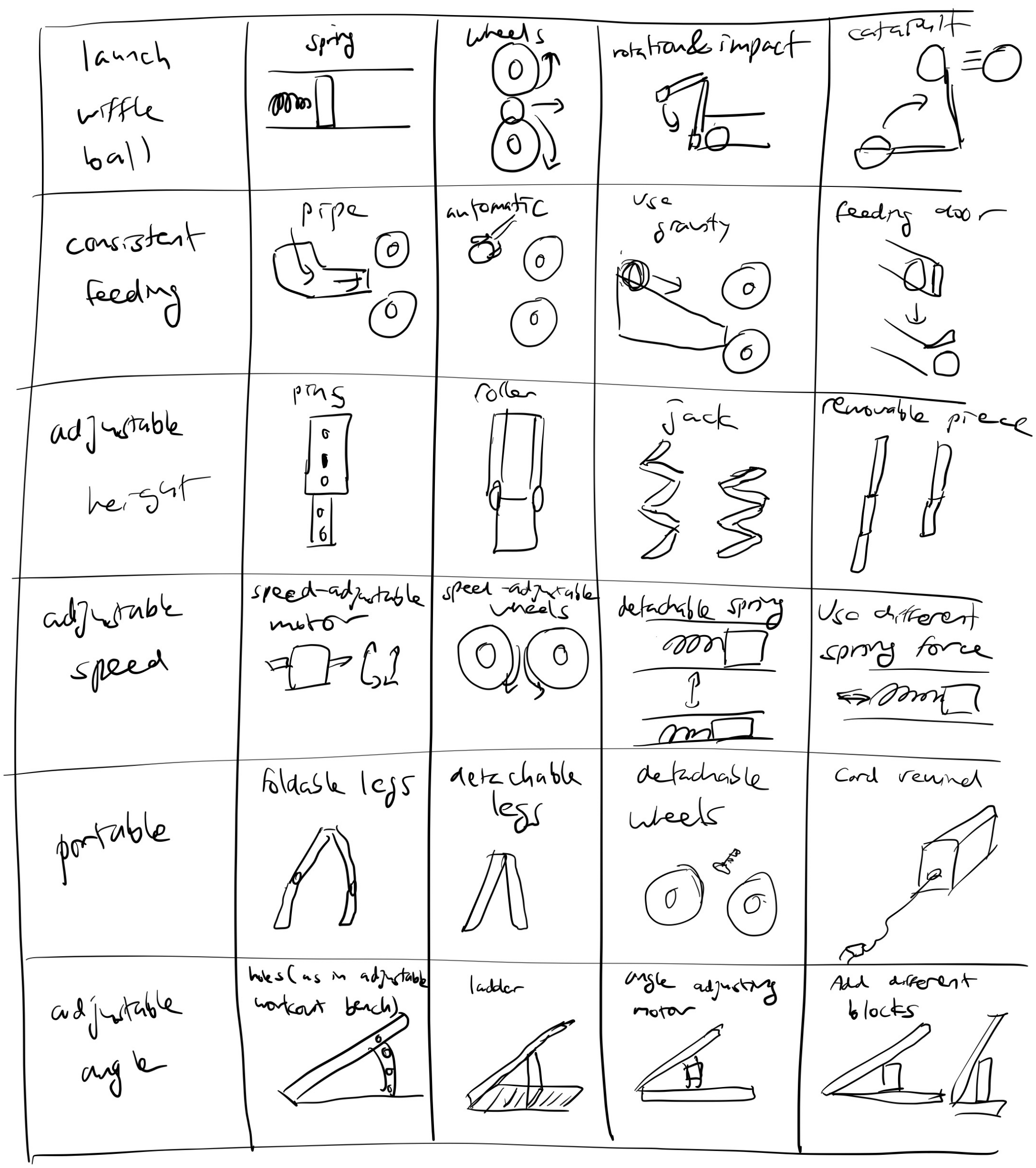


Figure 12: Morphological Chart for the wiffle ball pitching machine

3.4 Alternative Design Concepts

3.4.1 Concept #1: Medieval Shooter

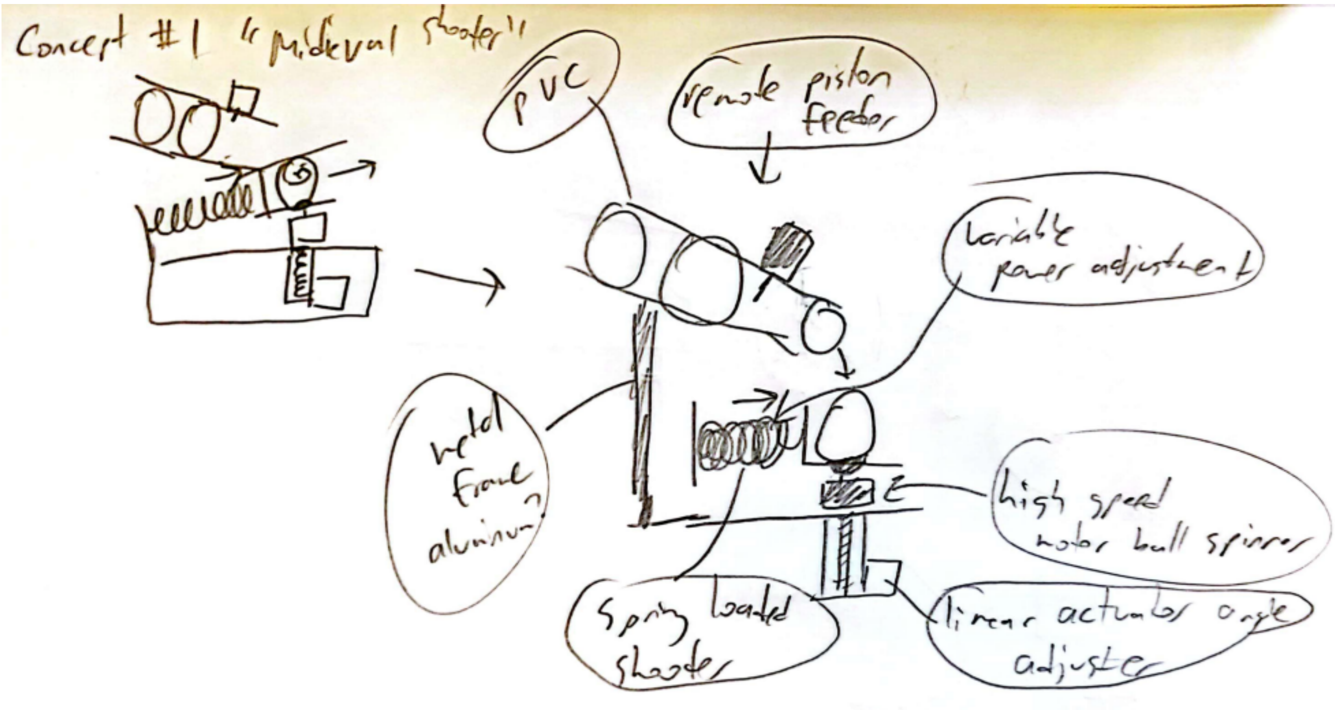


Figure 13: Sketches of Medieval Shooter

Description: The design "Medieval Shooter" feeds the ball using gravity and a piston cylinder suspended by an aluminum made frame, which when removed, the ball falls to the desired position to be pitched. The ball pitching process is achieved by a spring-mass system that gives linear motion. The high speed ball spinner gives rotational motion of the ball at the initial stage of pitching.

3.4.2 Concept #2: Angle-Adjustable Ball Pitch

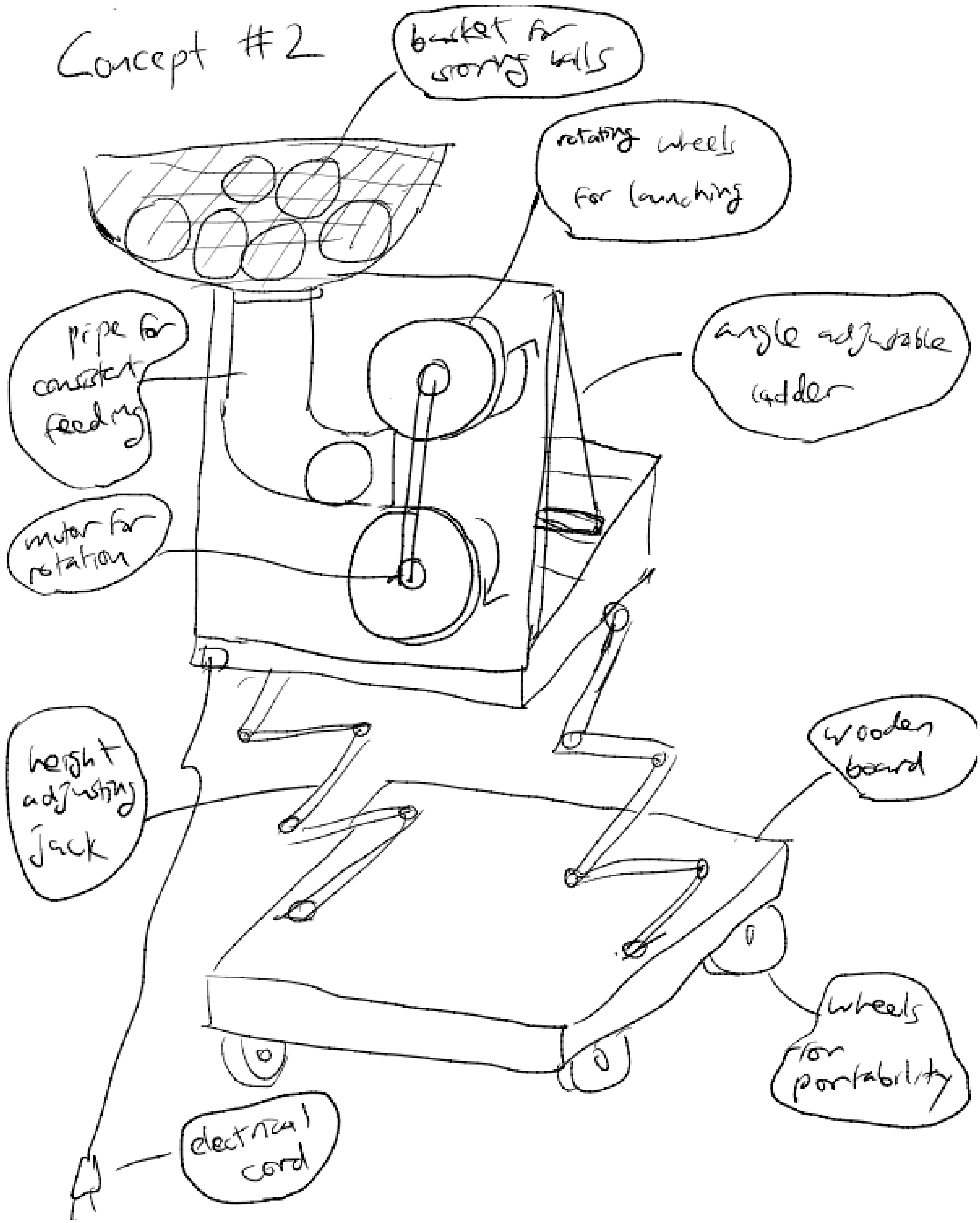


Figure 14: Sketches of Medieval Shooter

Description: The Angle Adjustable Ball Pitch ensures that the user can adjust the pitching elevation through the frame. The balls are fed through a downward sloping pipe connected to a bucket of reservoir where all the balls stay. Then the ball go through the rotation wheels which gives the ball linear and rotational motion. The angle at which plate at which the ball stays is adjustable to produce various shooting angles.

3.4.3 Concept #3: Ball Pitch with Web

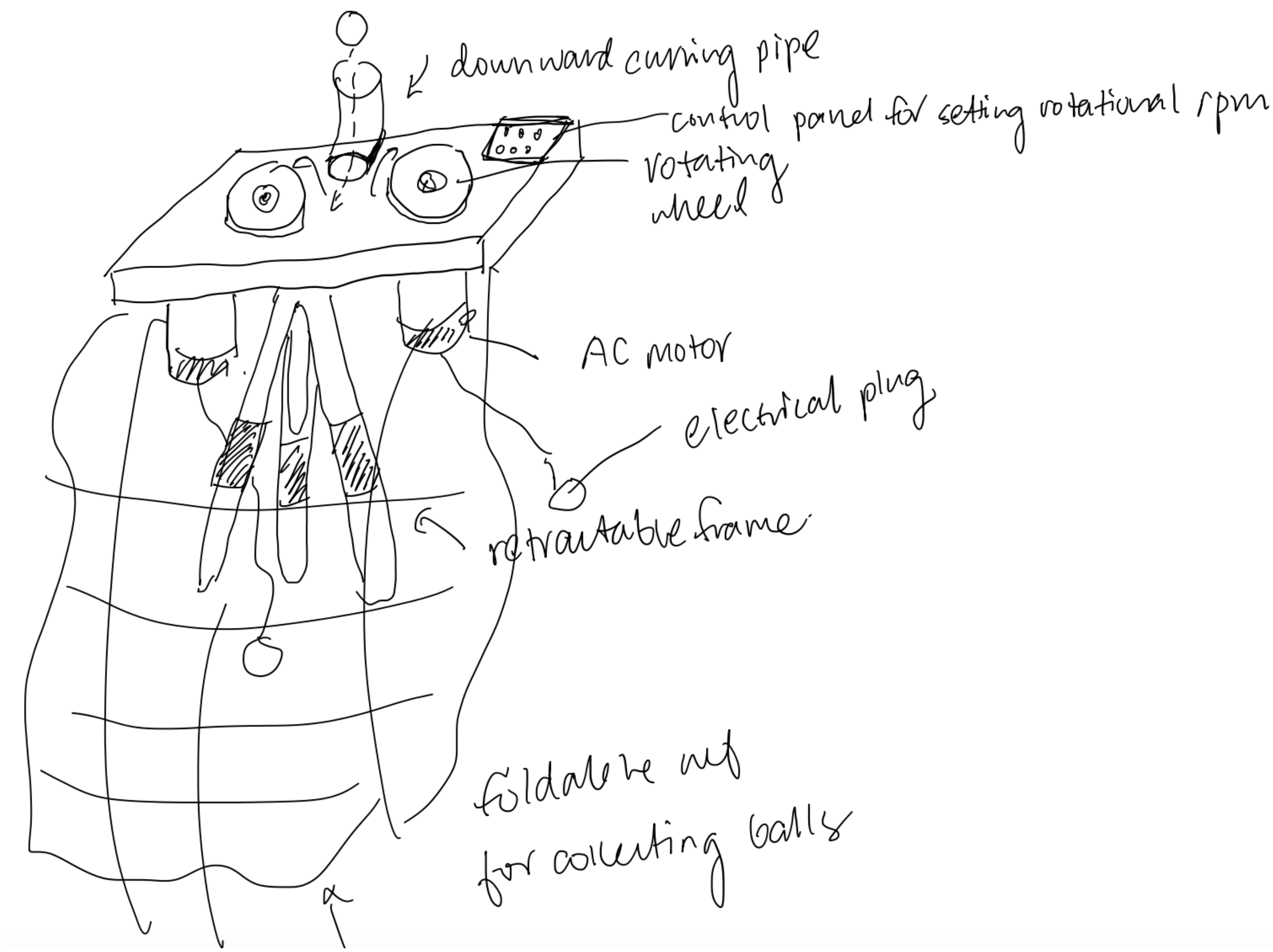


Figure 15: Sketches of Medieval Shooter

Description: The balls are fed by user and go through a pipe that transmits the ball to the desired location for pitching. When the motor is turned on, they push the ball with adjustable rotating speed, controlled by the panel on the upper-left corner. The height of pitching is adjustable through a tripod frame. After all balls are pitched, a foldable net attached to the body of the ball pitch collects all the balls fell to the ground.

4 Concept Selection

4.1 Selection Criteria

Figure 16 shows the analytic hierarchy process (AHP) table. Out of five criteria, safety and easy to retrieve & launch have the highest weight.

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5		Row Total	Weight Value	Weight (%)
Affordability of Parts	**1.00**	0.10	0.25	1.00	3.00		5.35	0.13	13.15
Safety (mech & elec)	10.00	**1.00**	1.00	3.00	3.00		18.00	0.44	44.24
Easy to Retrive & Launch	4.00	1.00	**1.00**	1.00	3.00		10.00	0.25	24.58
Aesthetics Appeal	1.00	0.33	1.00	**1.00**	1.00		4.33	0.11	10.65
Portability	0.33	0.33	0.33	1.00	**1.00**		3.00	0.07	7.37
						Column Total:	**40.68**	**1.00**	**100.00**

Figure 16: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

Figure 17 shows the weighted scoring matrix (WSM) table for the concept selection process. Based on the matrix result, Concept #3 was chosen to be our design model.

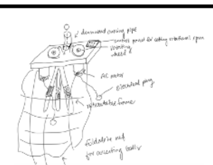
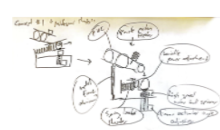
Alternative Design Concepts		**Concept #1**		**Concept #2**		**Concept #3**	
							
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Affordability of Parts	13.15	4	0.53	5	0.66	4	0.53
Safety (mech & elec)	44.24	4	1.77	4	1.77	4	1.77
Easy to Retrive & Launch	24.58	3	0.74	2	0.49	4	0.98
Aesthetics Appeal	10.65	3	0.32	4	0.43	4	0.43
Portability	7.37	2	0.15	1	0.07	3	0.22
	Total score	**3.500**		**3.419**		**3.926**	
	Rank	**2**		**3**		**1**	

Figure 17: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

After going through the whole design process, we determined that based on the 5 factors we chose, (affordability of parts, safety, how easy to retrieve and launch balls, aesthetics appeal, and portability) Steve's shooter design would be the best choice. It was compared to one of Viola's designs and one of Julian's designs and although it was pretty close, Steve's design won over from the portability appeal and the aesthetics of the design. The reason those two categories were considered was because if it was a real public demo, it would require it to look very safe as well as be very portable in case it needed to be moved to a different location. It didn't make a large difference because the designs were mostly similar so it came down to minute details in differences. In terms of the most important categories like safety and how easy it is to launch and retrieve balls, Steve's design was slightly better than the other two.

4.4 Engineering Models/Relationships

Three models that help to quantify the performance of our design are attached as Figures 18 to 20.

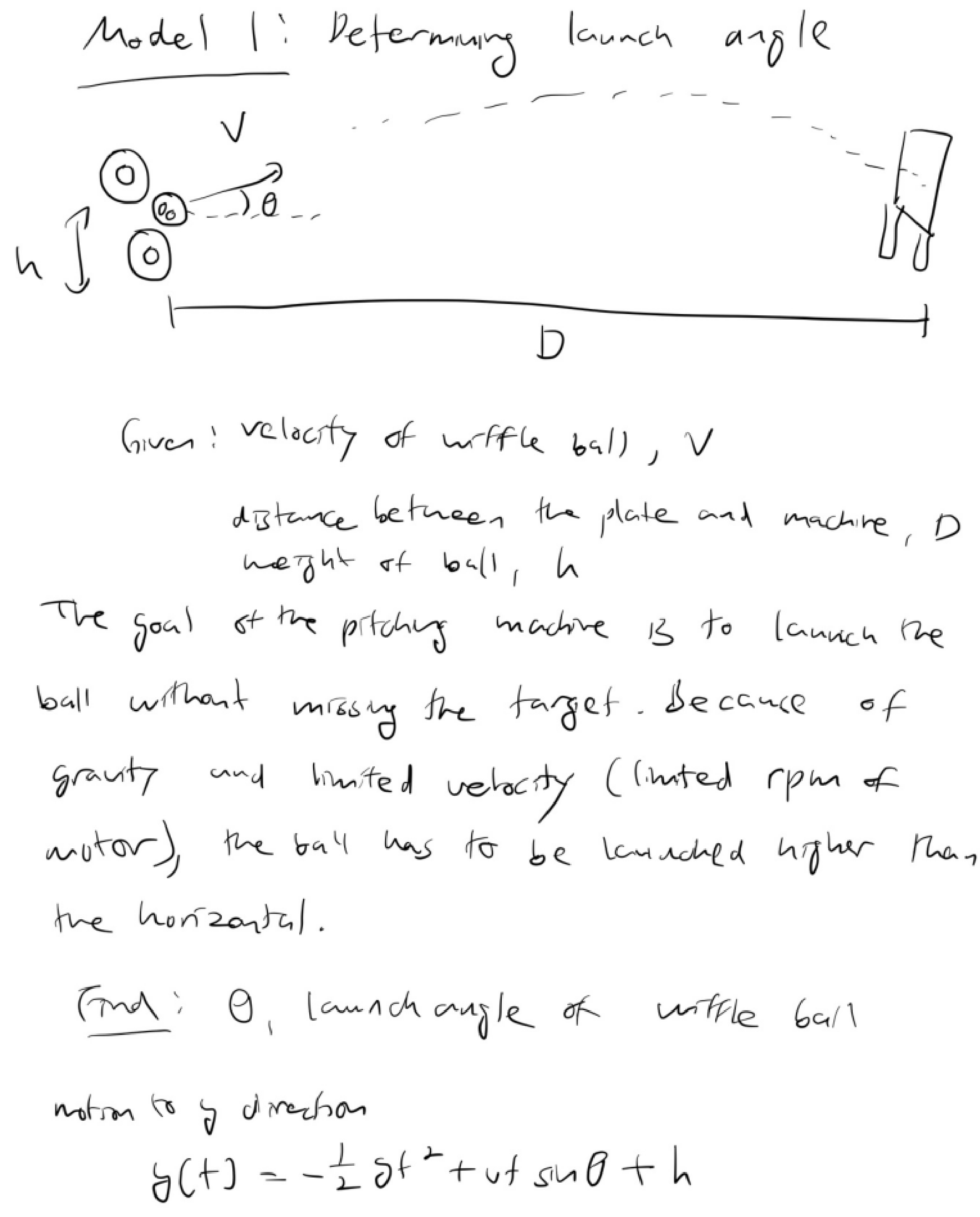


Figure 18: Pitching Angle Model

Model 1 is useful because it tracks the vertical movement of the wiffle ball with the assumption that the wiffle ball is a moving particle experiencing negligible drag and lift force. It is an approximation of the trajectory of the wiffle ball after pitched so that with this relation, the speed of the wiffle ball can be adjusted and quantified to create different pitching elevations and angles, which are useful parameters for users to study the Magnus effect.

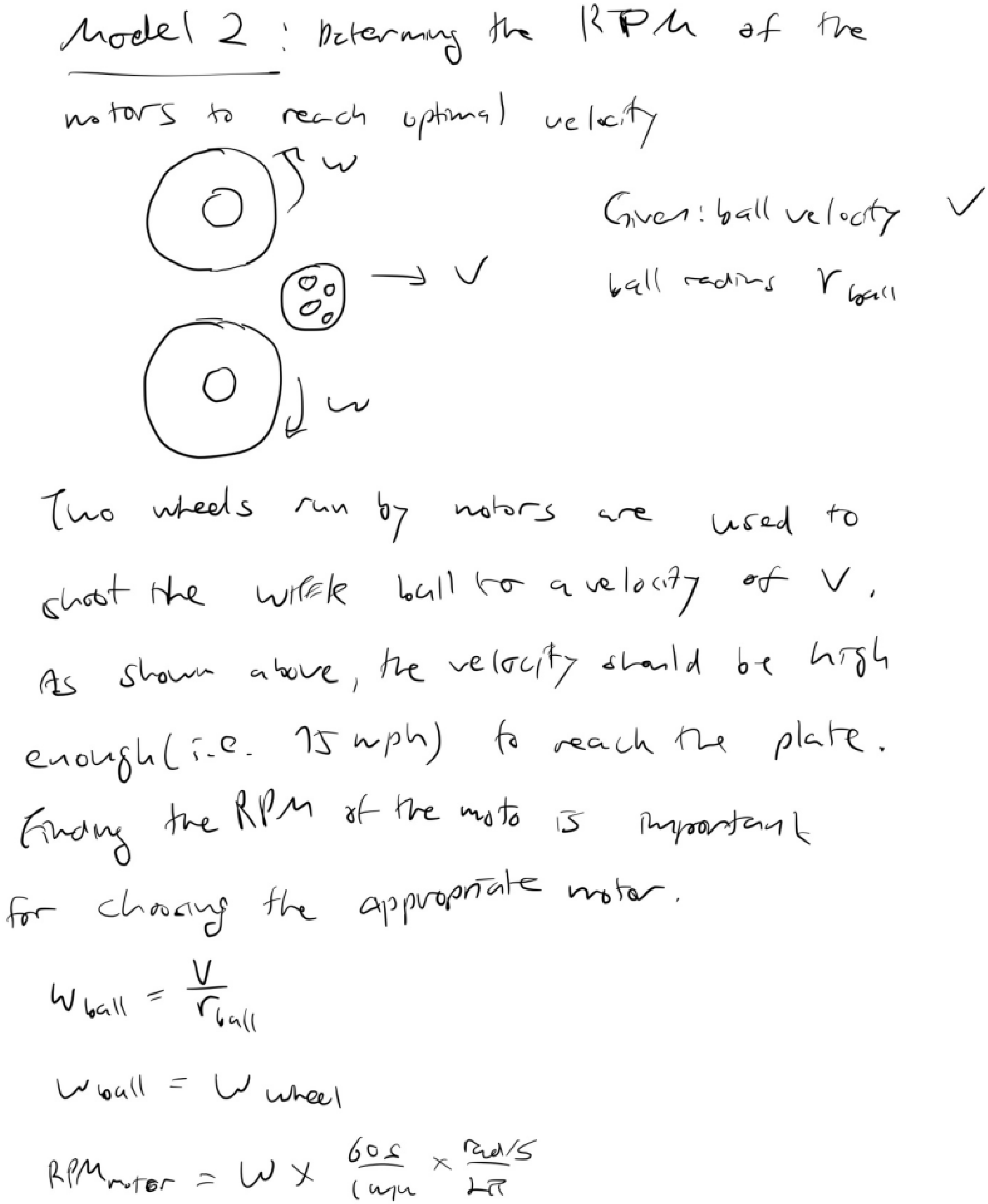


Figure 19: Motor Model

Model 2 is included because it relates the customer's need for the maximum pitching speed to the motor's spinning rate. The spinning rate of motor should be quantified during designing and testing because it helps to select the type of motor radius and to create a user interactive interface where the motor spins at the user's designated spinning rate.

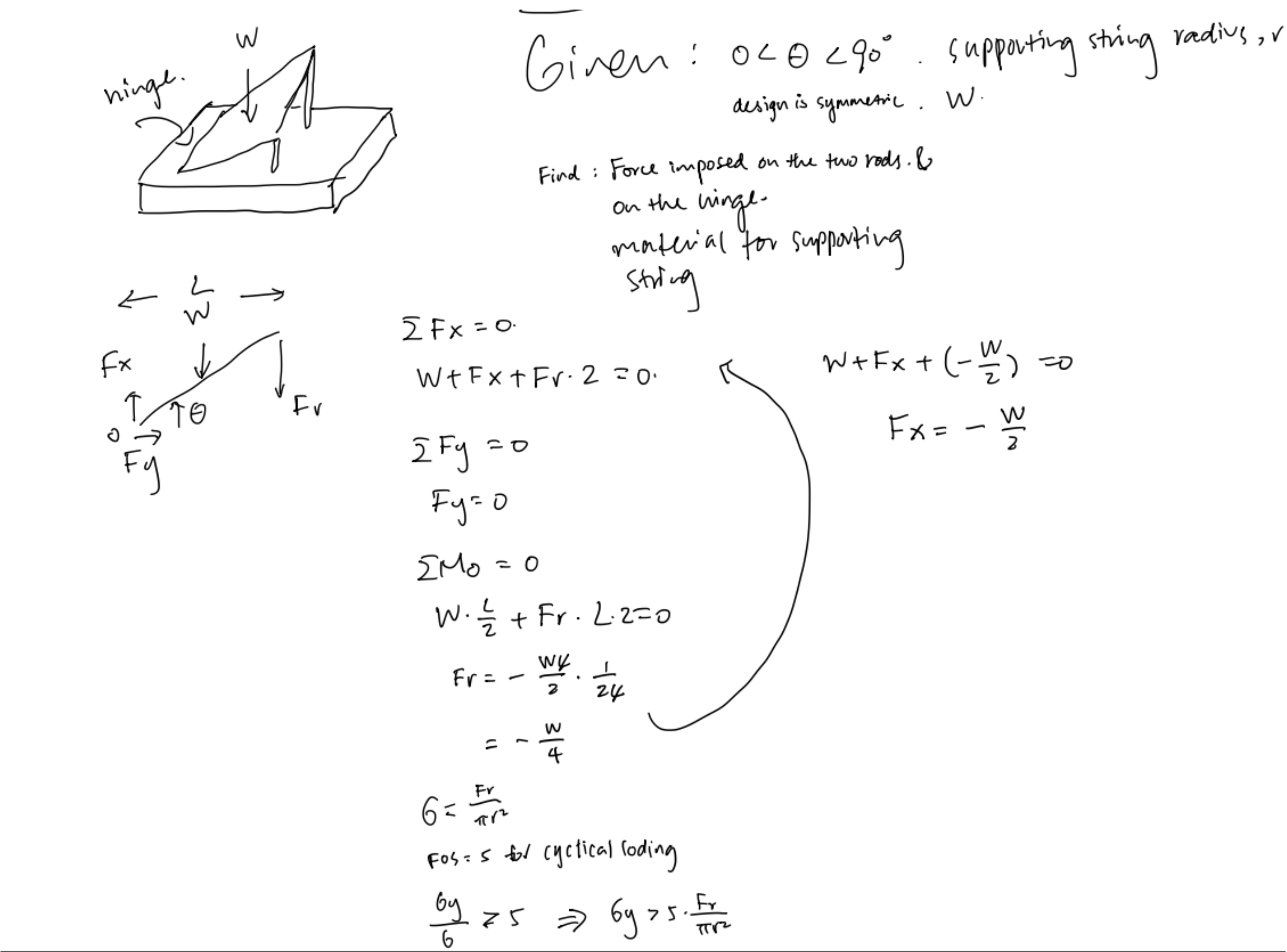


Figure 20: Material Selection Model

Ideally, the material selected for supporting the weight of the plate and its geometry should withstand cyclical loading. To prevent material failure during continuous loading of the angle adjustment mechanism, model 3 is selected because in material selection process, factor of safety under cyclical loading, yield stress, and toughness should be considered because the failure of pitching machine can cause unexpected safety issues, for instance, the machine hits a pedestrian.

5 Concept Embodiment

5.1 Initial Embodiment

Figure 21 shows the design with all dimensions. Figure 22 shows the design in isometric view. Figure 23 shows the isometric view with a bill of material (BOM) callout. The goals that this prototype is supposed to achieve are: it is able to pitch ball at a maximum velocity of 60 mph; it is able to pitch balls with significant topspin, backspin, and no spin; and 90% of the ball pitched are able to hit a 3'x3' square target more than 20 ft horizontally placed from the device.

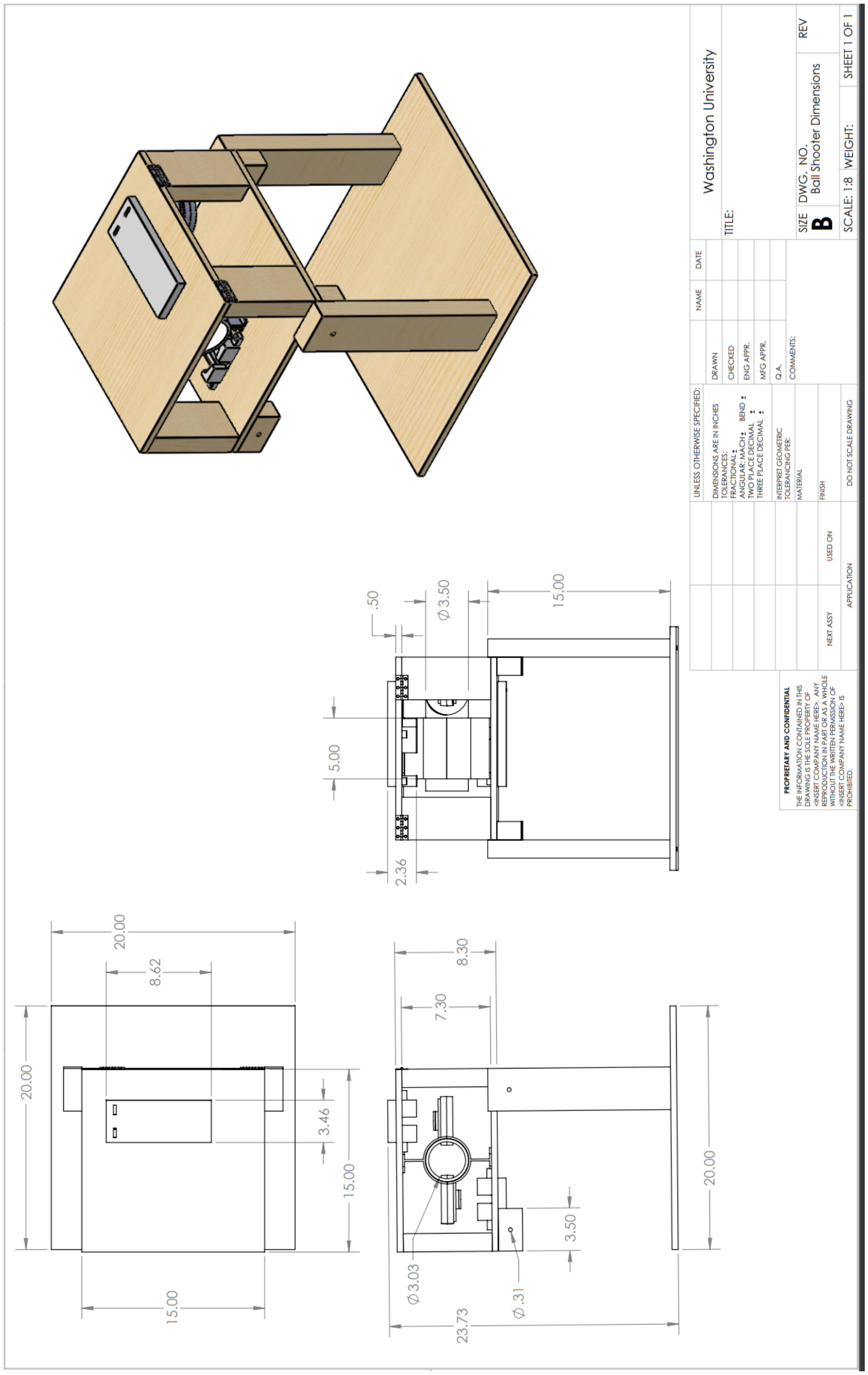


Figure 21: Assembled projected views with overall dimensions

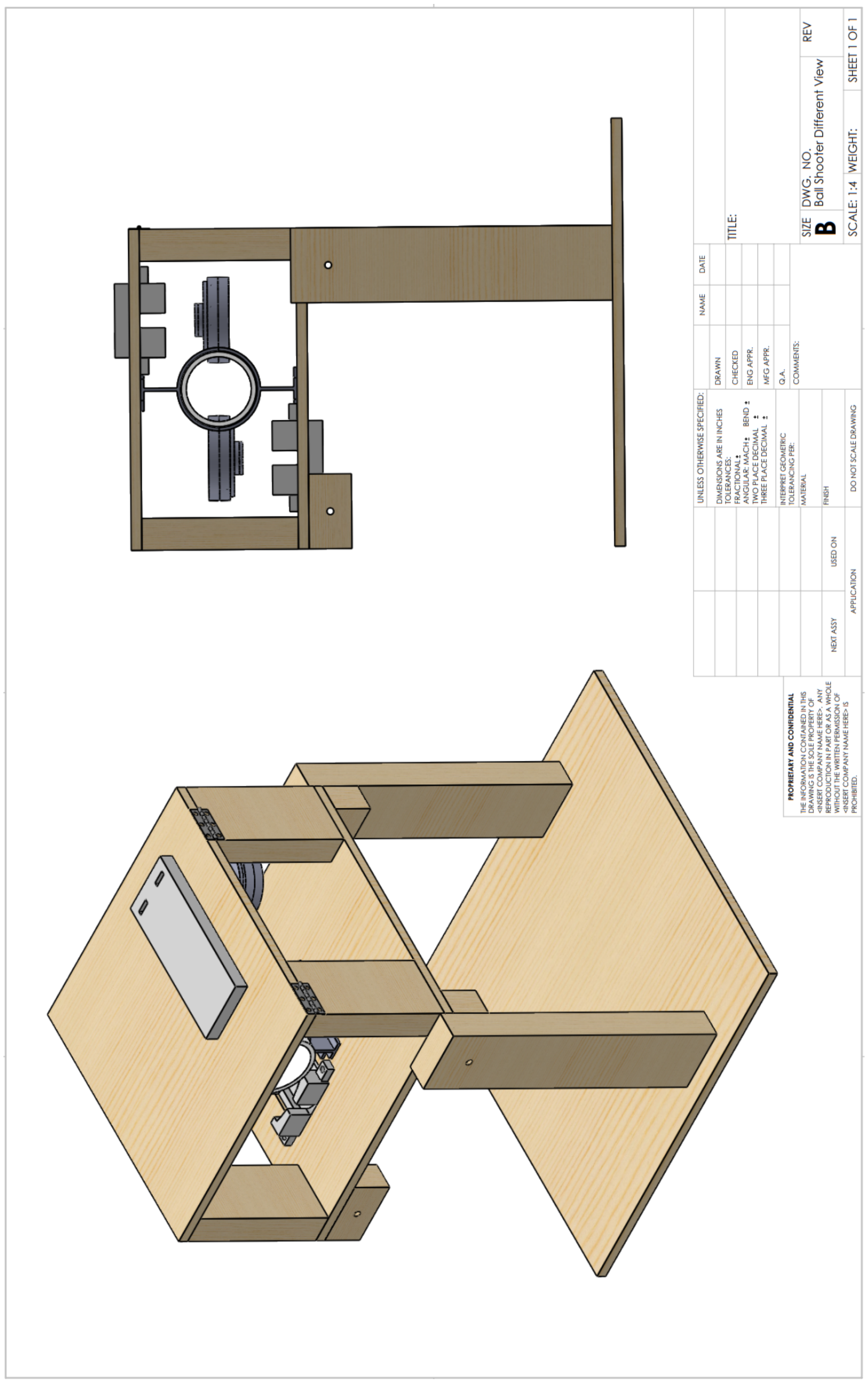
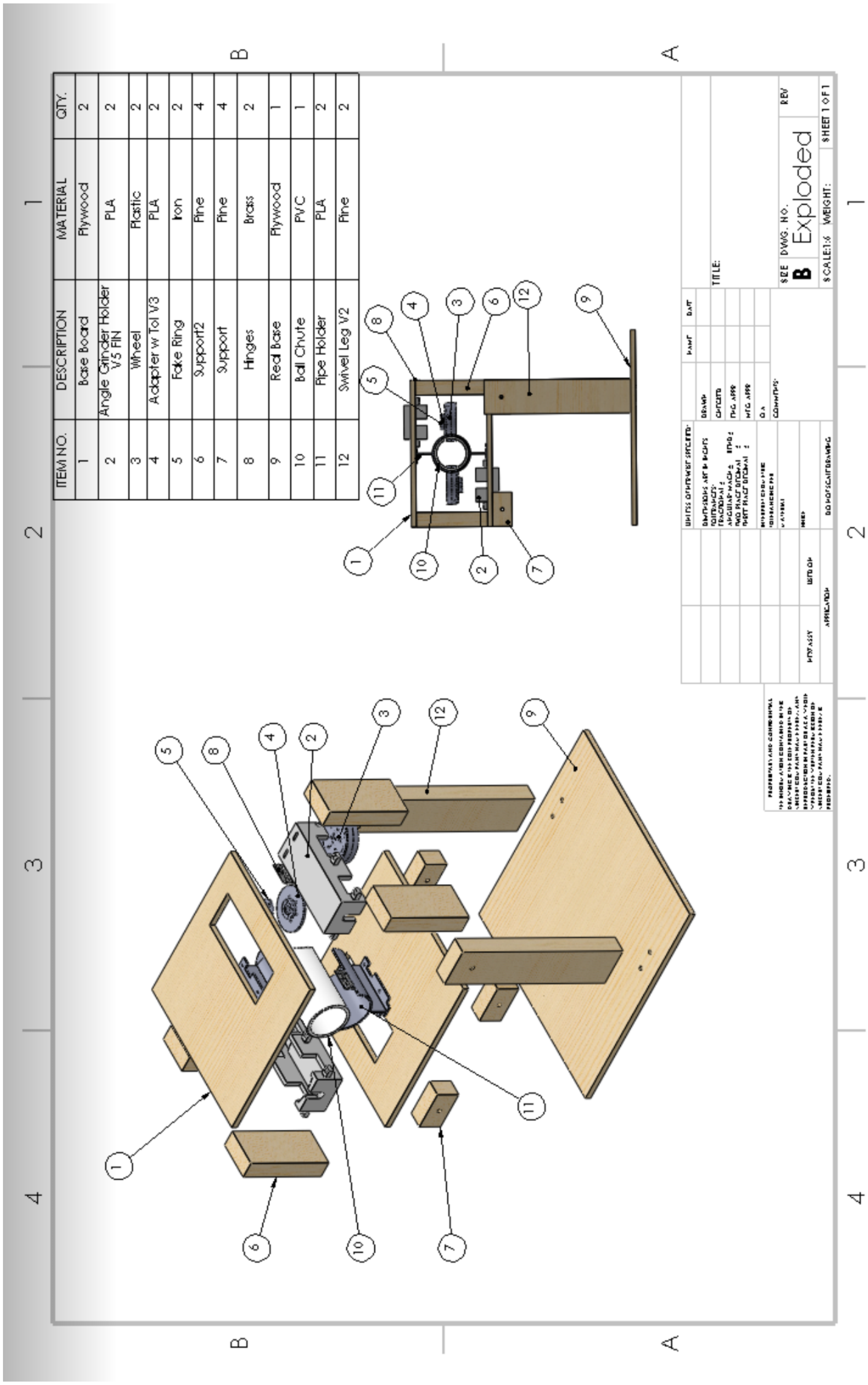


Figure 22: Assembled isometric view



ITEM NO.	DESCRIPTION	MATERIAL	QTY.
1	Base Board	Plywood	2
2	Angle Grinder Holder V5 FIN	PLA	2
3	Wheel	Plastic	2
4	Adapter w Tol V3	PLA	2
5	Fake Ring	Iron	2
6	Support2	Pine	4
7	Support	Pine	4
8	Hinges	Brass	2
9	Real Base	Plywood	1
10	Ball Chute	PVC	1
11	Pipe Holder	PLA	2
12	Swivel Leg V2	Pine	2

Figure 23: Exploded view with callout to BOM

5.2 Proofs-of-Concept

The design of the wiffle ball pitching machine before the proof of concept had two angle grinders facing upwards. After the Proof-of-Concept testing, we realized that the angle grinder could only rotate in one direction, so one of the angle grinders had to face downwards. In other words, one should rotate clockwise, and the other should rotate counterclockwise to release the wiffle ball forward. Also, before the proof of concept, the design had both the angle and the height adjustment. After building the initial prototype, we removed the height adjustment function from the prototype. We decided that the angle adjustment function already includes what the height adjustment function can achieve. The angle adjustment is still in progress.

5.3 Design Changes

Below are the design changes made in the prototype.

- Mentioned in section 5.2, the most pronounced difference is the flipped orientation of the motor, or angle grinders, which can only rotate in one direction. To ensure that they are able to pitch balls, they are positioned upwards and downwards respectively instead of placed in parallel. Also because of this reason, the two angle grinders are contained in a semi-open chamber for the purpose of aesthetics.

- Because of material availability, the frame of our prototype is built primarily using wood bricks rather than cast iron, the envisioned material.

- The angle adjusting mechanism is implemented not on the place where the motors are attached but on the body of the frame, as the configuration of motor incorporates a more complicated design. In other words, the wooden frame itself is able to rotate.

- There is no more panel on top of the chamber to adjust the angular velocities of motors, because the angle grinders all have their own speed adjusting panel on their electric cord, which factors into the velocity adjusting mechanism of the system.

- There are no more wheels attached at the bottom of the frame. Consider the recoil that the frame experiences after pitching balls, the sliding balls are removed because that makes the frame more unstable.

- Because our goal in the Initial Prototype is to make sure the design is able to pitch spinning balls, we did not prioritize height adjusting mechanism on the supporting frame. The frame consists of four wooden rods. Our future plan for achieve this goal is to use sliding channels with nuts and bolts to adjust the height but not the height adjusting jack, which is more budget friendly.

6 Design Refinement

6.1 Model-Based Design Decisions

Engineering models are applied to better quantify our design. Models 1 and 2 are the same ones listed in section 4.4. Model 1, shown as Fig 24, predicts the location relative to the ground at which the ball hits the target, in the situation where no spinning occurs. The height, speed, design dimensions, are all from measurements during our real time simulations. The predicted hitting position is 0.54 m above the ground.

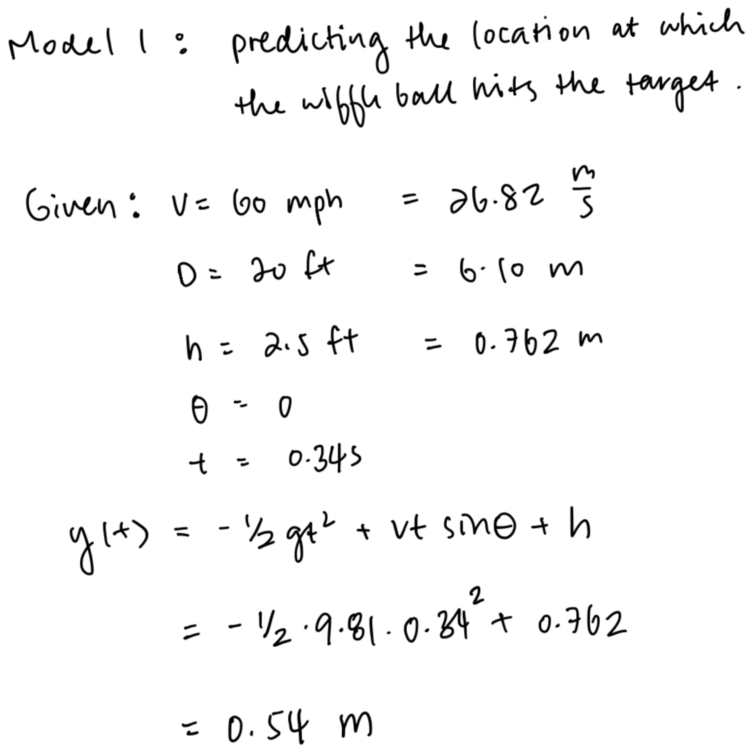


Figure 24: Model 1 with calculations

Because the angle grinders' velocity adjusting panels show no numeric rotating speed, it is necessary to use engineering models to calculate its spinning rate. Model 2, shown as Figure 25, predicts the rotating speed of the two motors when they pitch a wiffle ball whose traveling velocity is 60 mph with no spin. The values given are the dimension of the wiffle ball and the wheels, which come from measurements during testing. The predicted value is 5044 rpm for each angle grinder.

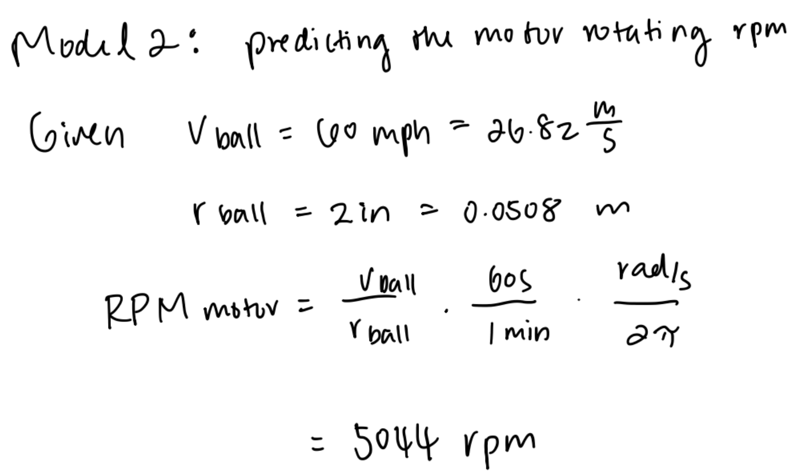


Figure 25: Model 2 with calculations

Due to the update of our design on its angle adjusting mechanism, Model 3 from 4.4 is also slightly adjusted to better conform to the functionality of our design. The redefined figure is shown in Fig 26 where the model predicts the maximum shear and normal stress applied on the supporting frame leg. The dimensions of the rod and weight of the system supported come from measurements during testing. The maximum normal stress endured by the model is 28.73 kPa; the maximum shear stress is 4.31 kPa.

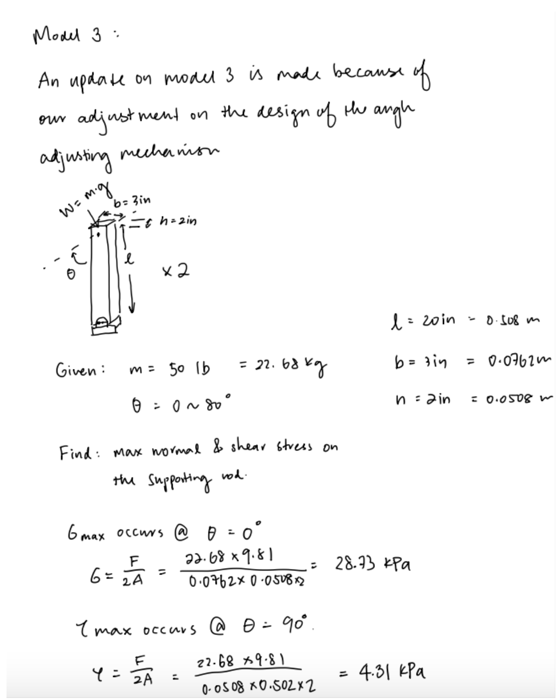


Figure 26: Model 3 with calculations

6.2 Design for Saftey

Below lists the risks that a user might encounter with our design.

6.2.1 Risk #1: User gets tripped by wire

Description: The wires attached to our angle grinder are long, and if unnoticed one can step on the wires get tripped.

Severity: Marginal. The level is set to be marginal because one can stabilize himself/herself after they feel the wire underneath his/her feet; even getting tripped will not immediately be fatal.

Probability: Occasional. The wires are fairly noticeable as they are all black. However, there is the chance that a pedestrian does not notice it when they walk.

Mitigating Steps: The wires can be organized and confined to a certain place rather than placed randomly on the ground. This configuration will help pedestrian to notice their existence.

6.2.2 Risk #2: User gets electric shock

Description: There is a chance that the insulation wears out and the interior of the wires get exposed to the air; any touching of that part by the user is considered a risk when the design is connected to electricity.

Severity: Catastrophic. Because of the high voltage applied on the device, it will damage the skin of the user and even put their life in danger.

Probability: Seldom. The insulation around the wires are thick enough, albeit there is a chance that over the years, they will wear off.

Mitigating Steps: Set up annual check when the device is off from electricity to make sure the coating covers the entirety of the wires.

6.2.3 Risk #3: User gets hit by wiffle ball

Description: When the machine pitches the ball, a user might be hit by the ball if they are in the way of the ball trajectory.

Severity: Marginal. Although the maximum velocity of the wiffle ball is 60 mph, its light weight will not physically harm a pedestrian unless he/she is a toddler.

Probability: Likely. Because our design require coordination between the one who picks up the ball and the one that pitches the ball, which cannot be assumed as achievable for all cases, hitting by a traveling wiffle ball is likely.

Mitigating Steps: Set up notice boards to indicate the importance of coordination and set up better feeding and retrieving mechanisms.

6.2.4 Risk #4: User gets hit by design parts

Description: When the design reaches the point of its mechanical failure, the parts will fall apart and would hit a user if they are around.

Severity: Marginal. The heaviest parts of our design are the angle grinder, which are 25 lb for each. The other parts are made of wood and are light weight. Moreover, the height of the design would be approximately 3 feet above the ground, making it unlikely to cause any fatal disasters even if the angle grinder hit a user.

Probability: Unlikely. The materials used for design are strong enough to withstand all the loads, and this is testified during our testing.

Mitigating Steps: Set up annual check to ensure the structural integrity of our system.

6.2.5 Risk #5: User's hand hurt by rotating motors

Description: When the motors rotate at high speeds, when a user place their hand/any body parts close to the motor, they will get hurt.

Severity: Marginal. The motor running on high speed will scratch one's skin; immediate first aid will be needed to prevent inflammation though surgical aid will not be needed.

Probability: Seldom. Because of the distance between the pipe and the motors, as long as the pitch feed their ball at a distance, their hand will not get hurt. However, it is possible that one place their hand around the wheels without getting to know its spinning rate.

Mitigating Steps: Set up notice boards to indicate the danger associated with the spinning wheels. Figure 27 shows the heat map of the risks associated with our design.

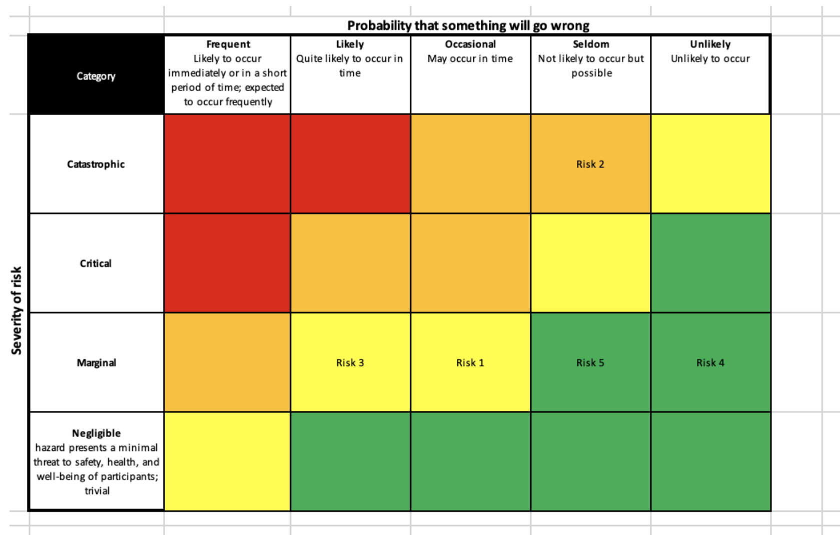


Figure 27: Heatmap of Risks

Risk 2 is the most prioritized one because of its catastrophic effect, which is fatal for a user to touch an electric powered bare wire with no insulation. Even though the chance of happening is seldom, the severity related to risk 2 makes it the one that the design should avoid the most. Risk 3 and risk 1 are ranked the same, because their severity is marginal and the possibility are likely and occasional, respectively; both, if happened, will not engender a life-costing danger. Finally, risk 5 is ranked the least because although the severity is marginal, the same as risk 3 and risk 1, it has a smaller chance of happening–only seldom. Therefore it is ranked the lowest by the heat map.

6.3 Design for Manufacturing

The current design has 33 parts and 36 threaded fasteners. The list below shows the Theoretically Necessary Components (TNC) in the design.

1. Angle Grinder Holder: This is an essential component to keep the angle grinder in place. It cannot be a part of the wooden frame because because it should be durable enough to withstand the vibration from the rotating angle grinder.

2. Wheels: Wheels are necessary to launch the wiffle ball, and they should be a separate component because they should be capable of rotating at high RPMs.They are high friction wheels capable of gripping the balls a lot better at higher RPMs without fear of slipping.

3. Hinges: These are important components for the user to open up the trap door and safely turn on the angle adjusters. The hinges should be a separate component to ensure that the flap rotates with no obstruction. It is also made out of brass, as opposed to a wooden frame.

4. Angle Adjustment Base: This is necessary to adjust the angle to create different types of spins on the balls.This should be a separate component because it is a 3D printed polymer. It should be removable in case a different angle is necessary.

5. PVC Tube Holders: These are necessary to keep the PVC in place for safe feeding of the balls. This also needs to be a separate piece because it should be removable to uninstall the angle grinder holder.

If reducing the number of components is necessary, we can remove the PVC pipe and the PVC pipe holder. We can hand-feed the wiffle ball to the machine instead, though it might increase the risk of an injury. In addition, the two pieces of the PVC pipe holder can be merged into one piece; however, this will reduce the adjustability and portability of our design, as opening the cap will be harder because of this. Also, the angle adjustment function of the pitching machine can be discarded. It is possible to adjust the angle by hand, although it might not be as precise as using the angle adjustment base.

6.4 Design for Usability

The list below describes the factors that can influence the usability of the design.

- Vision Impairment: This impairment might cause the user to have trouble inserting the wiffle ball into the PVC pipe properly. It can also cause injuries if a user with a vision impairment accidentally makes contact with a fast spinning wheel. Ways to modify this disadvantage is that during designing, we figure out what colors painted on the assembly will not confuse our users. We can also stick labels with braille that describe the parts to help those who are visually challenged to know our design in detail.

- Hearing Impairment: The angle grinders generate a loud noise when they are turned on, which functions as an audible warning. The user with a hearing impairment may not notice that the angle grinders are on, which can be a safety hazard. To eliminate the chance such a risk might occur, we can print our manuals to warn them beforehand of the potential injuries the angle grinders might cause to users. We can also provide visual warning when the angle grinders are in motion.

- Physical Impairment: The angle adjustment function requires a decent amount of strength to lift the machine and move to a desirable location. A person with the physical impairment might not have sufficient strength to use the angle adjustment function. Moreover, those whose limbs activities are confined might not be able to feed the ball. The way for them to experience this mechanism would be to have people who are capable to feed balls and adjust angles around them to visualize the functionalities of our design. Pre-recorded videos could also be made available for them to see the wiffle ball trajectory.

- Control Impairment: For the angle adjustment, the user should carefully place the leg onto the angle adjustment base. One with the control impairment might not have the stability to implement the angle adjustment function. Also, similar to the vision impairment, one might not be able to insert the ball into the PVC pipe correctly. To bring these issues to resolution, the design can incorporate wheels and materials that reduce friction to facilitate the process. Having those who are able to adjust angles and insert balls around them will also demonstrate them the functions of our design.

7 Final Prototype

Figures 28 and 29 display the full and inside view of the final prototype.

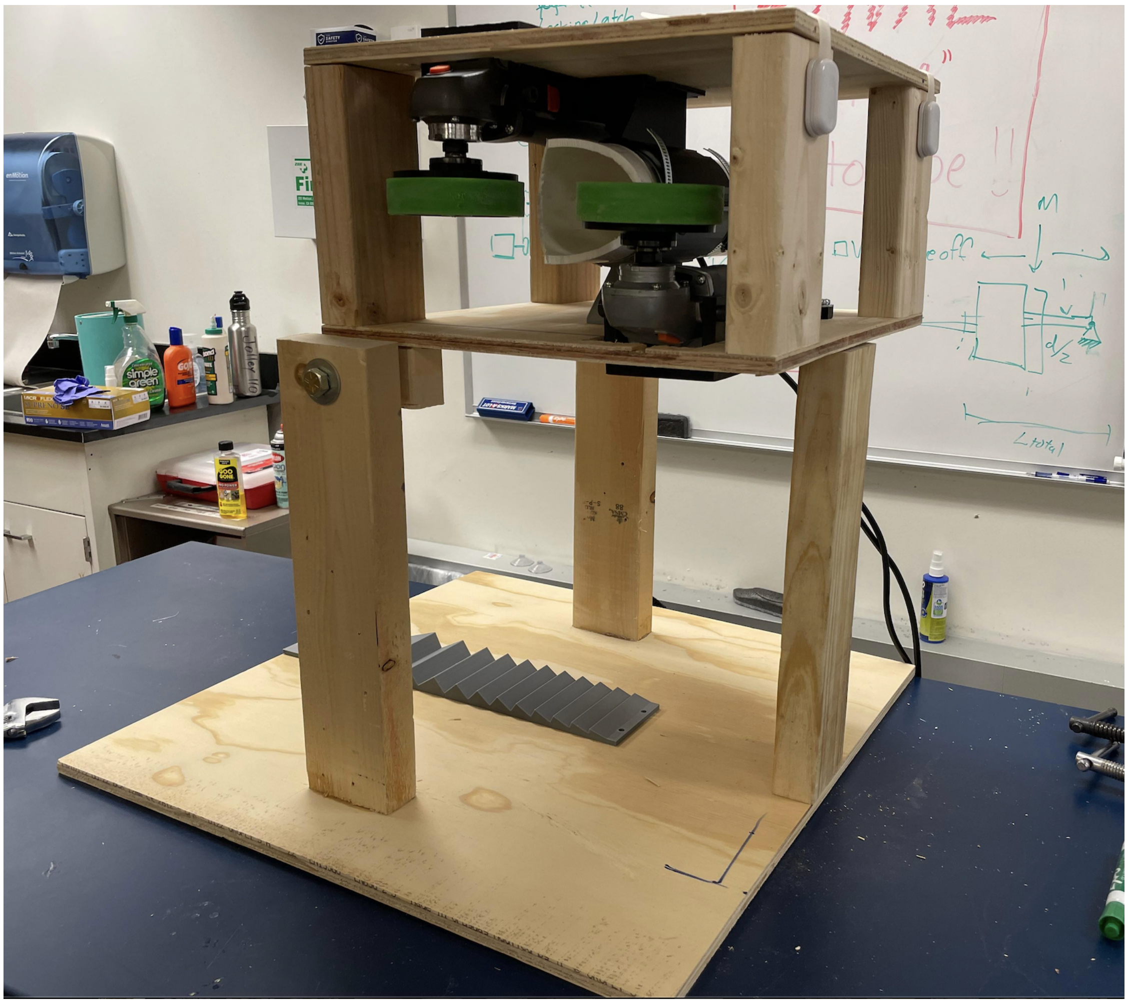


Figure 28: Full view of the final prototype.

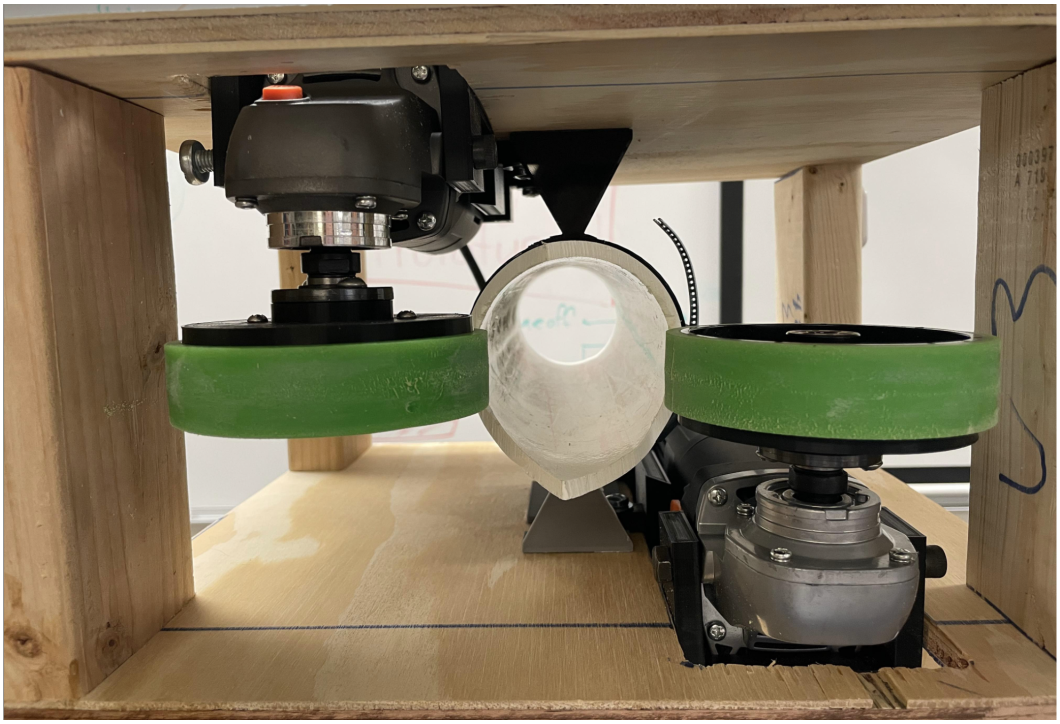


Figure 29: Inside view of the final prototype.

Figure 30 describes each component of the final prototype.

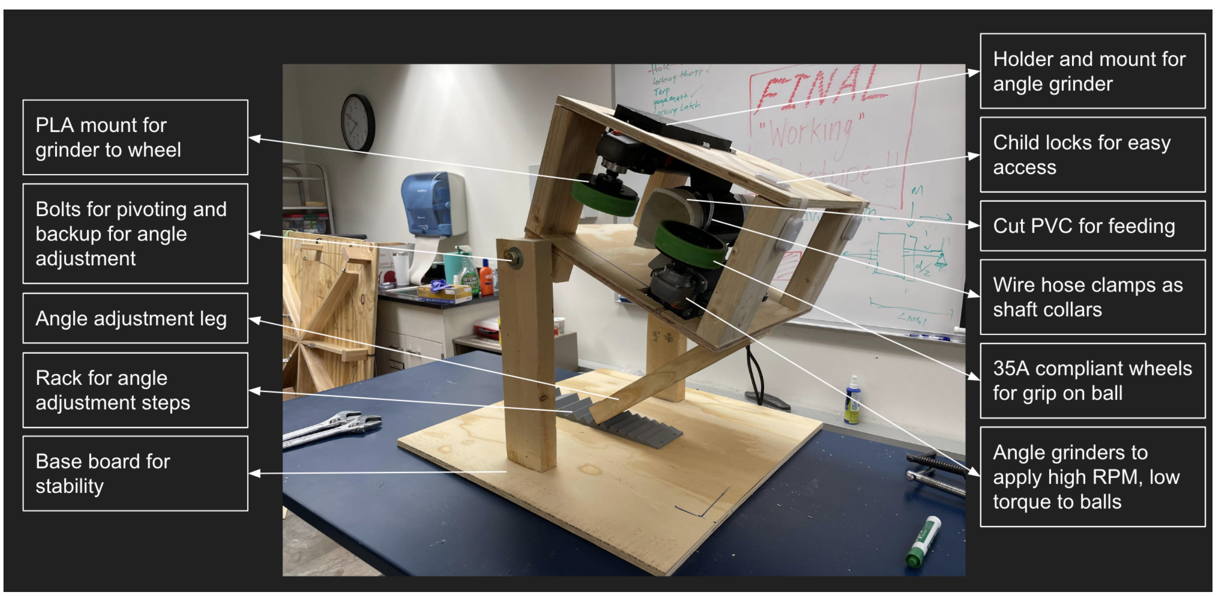


Figure 30: Components explanation of the final prototype.

Overall, we were able to satisfy all of the prototype performance goals. The final prototype was able to launch the wiffle ball with different spins (backspin, topspin, no spin). Also, the pitching machine was able to consistently hit the target. Out of 12 tries, the pitching machine hit the target 12 times from 20 feet away. Lastly, the machine could generate a velocity of up to 67 mph, which exceeded our initial goal of 60 mph.

Bibliography

[1] Britannica. *Magnus effect*. Encyclopedia Britannica, 2020.