Washington University in St. Louis
Washington University Open Scholarship

Mechanical Engineering Design Project Class | Mechanical Engineering & Materials Science

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2018 ASME Student Design Competition - Group T Senior Design Project

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Executive Summary

The American Society of Mechanical Engineers (ASME) hosts annual competitions for engineering students across the world. The ASME 2018 Student Design Competition is to build a robotic soccer team to compete in a FIFA World Cup style elimination tournament. We chose to take on the challenge and build our own robot to compete in the tournament. The Design Competition comes with a variety of rules and regulations that must be met to compete. Therefore, we had limitations on what we could design. The competition is not until spring of 2018, so for the purpose of this report, we set out to design, construct, and test a single robot that met all of the AMSE's competition criteria. Due to our design process being limited to the length of the fall 2017 semester, our prototype serves as a proof of concept for our design rather than a finished product. Despite the time constraint, we were able to design and build a functioning robot that can compete in the AMSE Student Design Competition. This paper will present you with an overview of our entire design and build process that took place over the past three months. This includes background/market research, design brainstorming, design selection, part orders, and our physical device embodiment.

MEMS 411: Senior Design Project

2018 ASME Student Design Competition

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1 INTRODUCTION AND BACKGROUND INFORMATION

1.1 INITIAL PROJECT DESCRIPTION

The 2018 ASME Student Design Competition challenges us to create a robotic "team" to compete against three other teams in a four-way soccer competition. We have the liberty to choose how "team" is constructed and how many devices we decide to use. There exists a long list of regulations and rules for this design competition, but basically, we must create remote controlled devices that, as a whole team, can fit in a 50 cm x 50 cm x 50 cm sizing box.

1.2 EXISTING PRODUCTS

Cambada Robot

The Cambada robot uses a PC visual system and sensors to function. It is a lot more sophisticated than the prototype we plan to construct, but there are interesting takeaways from this design – for example the roller wheels on the ball handling rods.

Tech United Robot

The Tech United has a similar overall design to the Cambada. They have rollers on the bottom the ball handling apparatus opposed to the top as with the Cambada. Otherwise, it is very close to Cambada in that is uses PC visualization systems and sensors to navigate. This is out of our scope for design, but offers some valuable design takeaways.

Carnegie Mellon Soccer Robot

This design has four wheels and uses rollers instead of wheels to handle the ball. Different from the previous two, it doesn't secure the ball when in possession. Less control is an option but would depend on how long we plan on possessing the ball. The general design shape isn't all that different from the other two.

1.3 RELEVANT PATENTS

Patent #: US12687126

This patent uses a computer vision and input processing device to control an object's movement by remote control. The uses of this system would be to play some variation of a remote-control sport, i.e. soccer. Possible application is to have a human controlled input compete against a computer-controlled input.

1.4 CODES & STANDARDS

Since this project was a design for a competition and not a design for a mass-producible product, this section did not directly apply to this project. Our design does however, abide by all ASME competition rules and requirements. If we were to sell this product, it would need to abide by electronic toy safety standards. The AS/NZS 62115:2011 is a sample electronic toy safety standard that we would follow.

1.5 PROJECT SCOPE

The goal of our design project is to design a robotic device that can be controlled remotely to propel a tennis ball into a goal – like a soccer player kicking a ball into the net. We plan to create an apparatus that can gain possession of the ball, move with the ball without losing possession, and then shoot the ball into a goal. This device will need to fit within the previously described sizing box, and it will need to be controlled with a remote control. We will use this device to compete against three other teams in a four-way soccer competition.

1.6 PROJECT PLANNING

Project planning is summarized in our Gant chart shown below in Fig.xxx. Time was scheduled for each component of the design and building process.

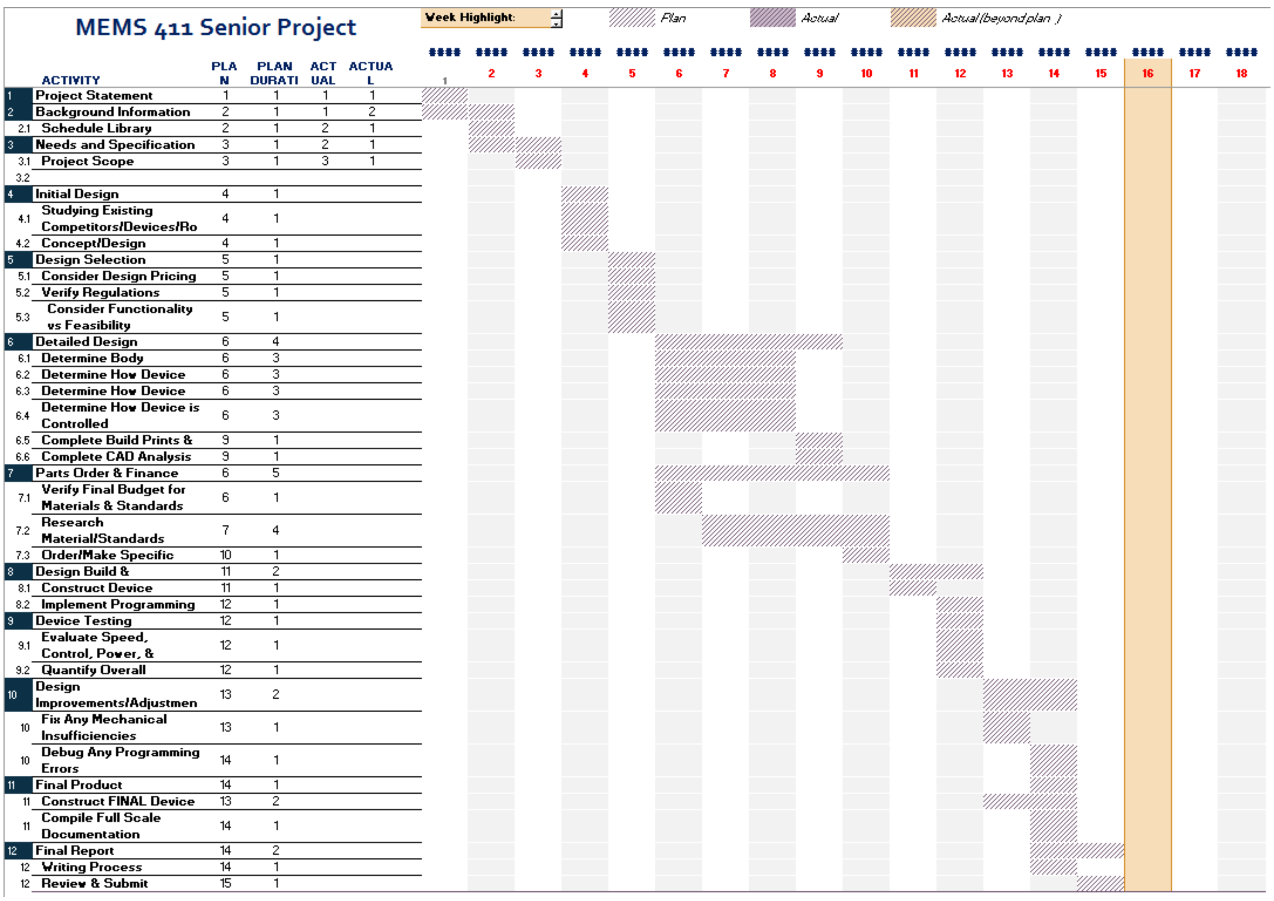


Figure 1: This is the Gantt chart we used to plan and establish timelines for our design process.

1.7 REALISTIC CONSTRAINTS

1.7.1 Functional

By ASME rules, the bot is constrained to a volume of 50cm x 50cm x 50cm. To meet our design goals for speed and shooting power, the bot must have large enough electric motors. To power large motors, the bot must have large enough batteries that a) can supply a high enough voltage and b) stay charged for five minutes.

1.7.2 Safety

The most relevant safety constraint we face with our design is the speed/power we use to shoot the tennis ball. Since there exists high power motors that would allow us to shoot a tennis ball more than 70 mph, we need to limit how fast our robot can shoot the ball. If it has too powerful of a shot, that would become a safety issue since the robot will be performing in a relatively small space.

1.7.3 Quality

The rules dictate that the competition will include multiple group round matches, each ten minutes in duration, followed by a semi-final, and then a final. Ideally, we would progress to the final so our design must have the quality to compete for potentially over an hour. This prompted us to consider high-quality materials and equipment in order for the robot to have a long life-span.

1.7.4 Manufacturing

Manufacturing constraints are not very applicable as we are not intending to mass produce our design.

1.7.5 Timing

We face timing constraints due to the nature of this course. Certain aspects of the project have specified due dates, and the project as a whole must be completed by December 8, 2017. On top of that, the ASME competition takes place in the spring of 2018, so if we intend to compete our design will need to be match ready by then.

1.7.6 Economic

The Senior Design course only offers a $230 budget for products so we are forced to limit the types of materials and equipment we use in order to stay under budget.

1.7.7 Ergonomic

The robot will be controlled using a hand-held controller. The controls need to be simple enough so that it does not become a hindrance during the competition. This prompted us to simply the driving controls to just forward, reverse, left and right, all on one joystick. Also, we eliminated any user input to the shooting wheel by leaving it on the whole time the robot is active.

1.7.8 Ecological

Our design has little to none ecological constraints on it as none of the materials we are using are potentially hazardous. The only potential issue is the used batteries so we will have to make sure to dispose of them properly.

1.7.9 Aesthetic

There are no aesthetic constraints for our design as we are not trying to appeal to consumers.

1.7.10 Life Cycle

There is the possibility of the robot needing maintenance during the competition. This is something we accounted for in the design by making the vital components easy to replace. Also, a lot of our parts can be recycled into other projects once the competition is over, reducing the waste from our design.

1.7.11 Legal

The bot must follow the ASME competition guidelines.

1.8 REVISED PROJECT DESCRIPTION

The purpose of this project is to create a single soccer playing robot to compete in the 2018 ASME student design competition. The robot, along with spare parts and all other devices must fit inside a 50x50x50 cm box. This robot must be able to traverse the field via remote control and have the ability to control a tennis ball and shoot it with sufficient force.

2 CUSTOMER NEEDS & PRODUCT SPECIFICATIONS

2.1 CUSTOMER INTERVIEWS

Table 1: Customer Needs Interview

Customer Data: Customer: ASME Robot Soccer Competitor

Address: Washington University Mechanical Engineering Department
Date: 9/18/2017

Question	Customer Statement	Interpreted Need	Importance
What is the primary goal of the robot?	Robot needs to be able to move around controlling tennis balls, score balls, and defend goals	S.R. should be able to move around field, collect and score balls	5
How will it be powered?	Has to be electric.	S. R. should be battery powered	5
How fast will it need to go?	Needs to be fast enough to get tennis balls before the other teams	S.R. should be able to move quickly and effectively	4
What are design limitations?	Must fit in a 50cm x 50cm x 50cm box	S.R. should conform to provided ASME guidelines	5
What is your strategy?	Offense, offense, offense!	S.R. should be designed to collect tennis balls and score them	3
How many robots will you use?	Probably just one, but maybe more later	S.R. should be easily replicable	3
What are safety guidelines?	Must be safe to operate, safe around children	S.R. should abide by toy safety standards	1

How will the robot be controlled?	Either remotely or with a tether	S.R. should be controllable from at least 5m (length of court) away	5
How far does the robot need to shoot the ball?	Ideally across the length of the court, which is 5 m.	S.R. should be able to shoot ball at least 5 m	4
What kinds of surfaces will the robot drive on?	Tile or carpet	S.R. should be able to move at desired speeds on carpet and tile	5
How should the robot be driven?	Electric DC or servo motors.	S.R. should use electric motors to power drive	4
Advantages and disadvantages of a large robot?	Advantage on defense but probably a disadvantage on offense because it needs to be quick and nimble.	Size of S.R. should be minimized to avoid incidental contact	3
Will the robot interact with other robots?	Incidental contact is likely but intentional contact is not allowed, so likely nothing too serious.	S.R. should have structural integrity to endure incidental contact	3
How will weight factor in?	There is no foreseeable advantage to the robot being heavy as it will likely be slow.	Weight of S.R. should be minimized so not to compromise functionality	3
How much are you willing to spend on this robot?	No more than $300 but ideally less than $230	Total cost of components should be under $230	3
How fast should the robot shoot the ball?	Ball should be able to shoot across court in 2 seconds.	S.R. should shoot ball at 2.5 m/s	4
How long should the battery last?	Robot should function for 5 min.	S.R. should be able to run for 5 min	4

2.2 INTERPRETED CUSTOMER NEEDS

Table 2: Interpreted Customer Needs

Need Number	Need	Importance
1	S.R. must be able to move around field, collect and score balls	5
2	S. R. should be battery powered	5
3	S.R. must be able to move quickly and effectively	4
4	S.R. should conform to provided ASME guidelines	5
5	S.R. should be designed to collect tennis balls and score them	3
6	S.R. should be easily replicable	3
7	S.R. should abide by toy safety standards	1
8	S.R. should be controllable from at least 5m away	5
10	S.R. should be able to shoot ball at least 5 m	4
11	S.R. should be able to move at desired speed on carpet and tile	5
12	S.R. should use electric motors to power drive	4
13	Size of S.R. should be minimized to avoid incidental contact	3

14	S.R. should have structural integrity to endure incidental contact	3
15	Weight of S.R. should be minimized	3
16	Total cost of components should be less than $230	3
17	S.R. should shoot ball at 2.5 m/s	4
18	S.R. should be able to run for 5 min	4

2.3 TARGET SPECIFICATIONS

Table 3: Target Specifications

Metric Number	Associated Needs	Source	Metric	Units	Acceptable	Ideal
1	4	ASME	Volume	cm^3	50x50x50	30x30x30
2	4	ASME	Set up time	sec	60	30
3	5	Customer	Drive speed	mph	5	5
4	6,1	Customer	Number of parts	integer	N < 150	N < 25
5	15,11,3	Customer	Weight	lbs.	W < 20	W < 15
6	17	Customer	Shooting speed	m/s	S > 2	S > 2.5
7	15	Customer	Battery life	min	5	T > 5
8	16	Customer	Cost	$	C < 300	C < 230

3 CONCEPT GENERATION

3.1 FUNCTIONAL DECOMPOSITION

The function tree below shows the necessary functions for the soccer robot.

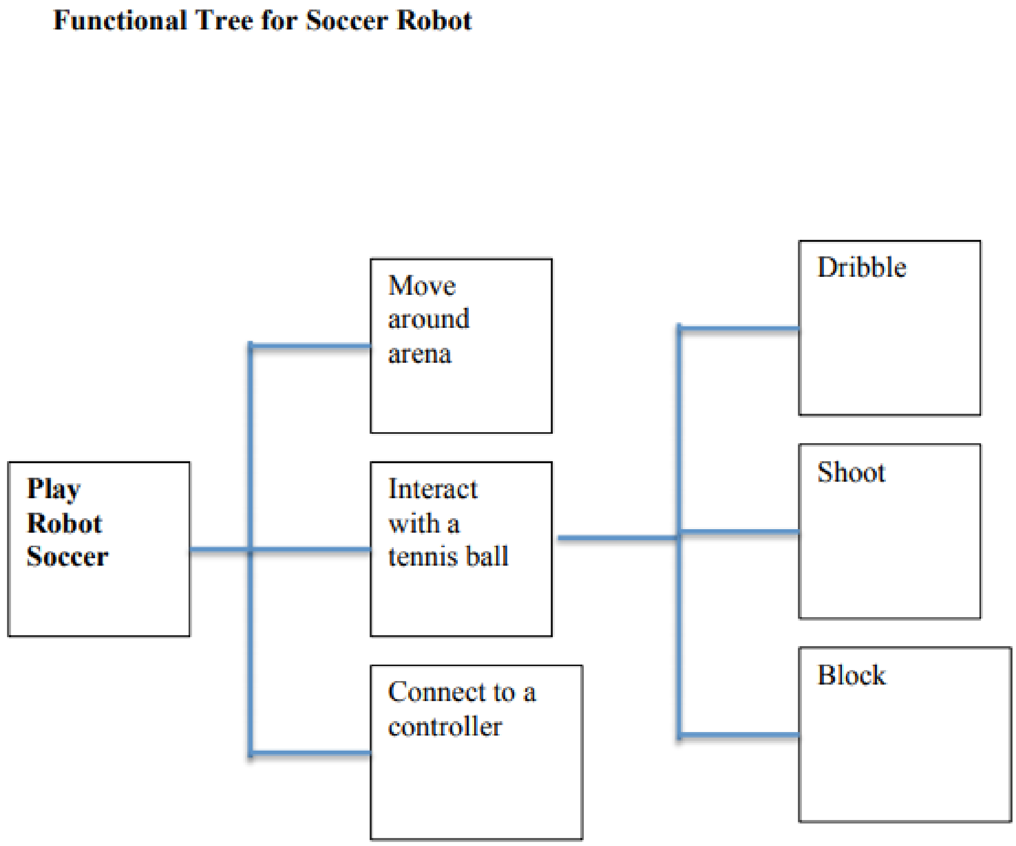


Figure 2: Function tree for soccer robot.

3.2 MORPHOLOGICAL CHART

The morphological chart below shows the initial design ideas of various functions.

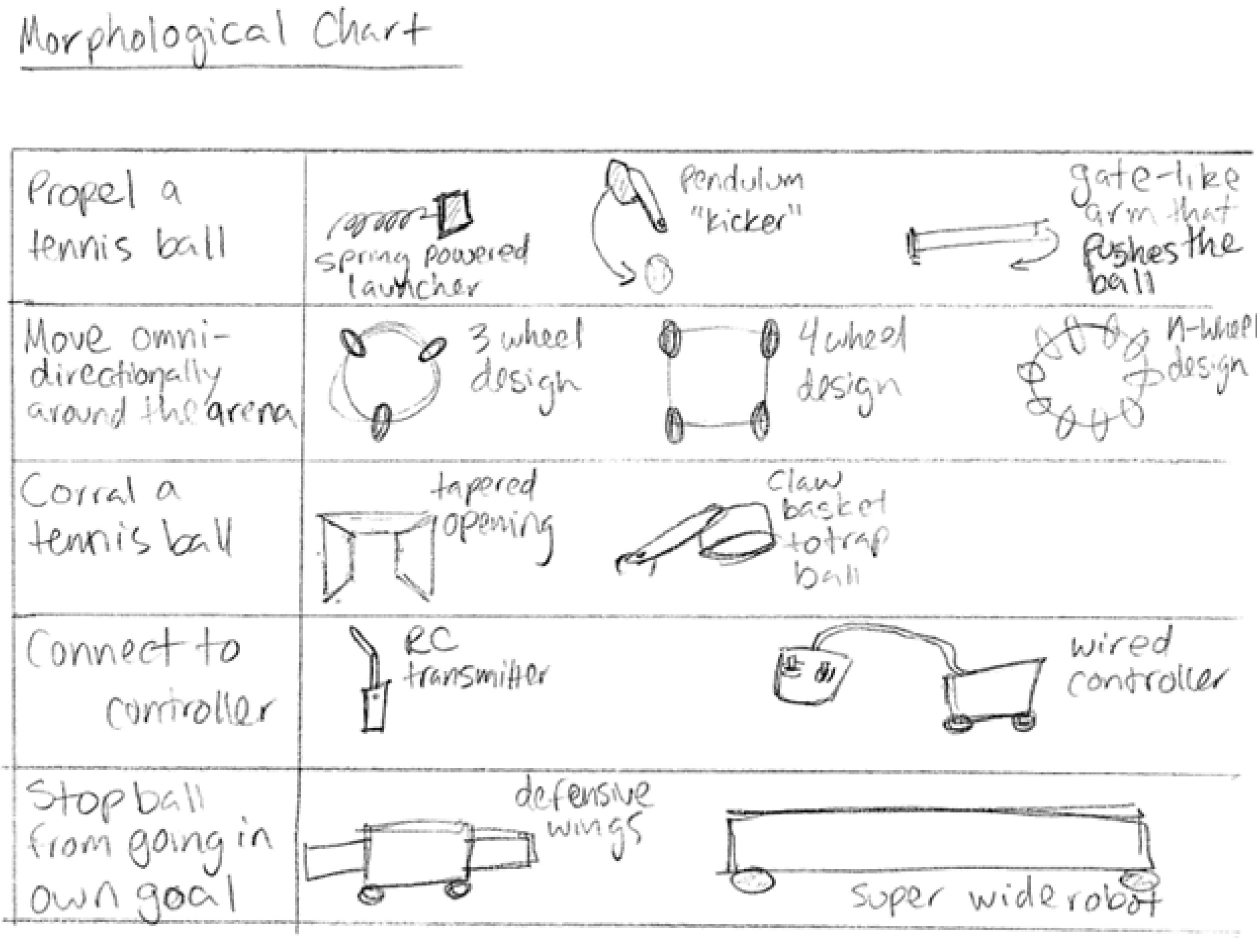


Figure 3: Morphological chart displaying our initial design ideas for a variety of necessary device functions.

3.3 CONCEPT #1 – "ROOMBA BOT"

The "Roomba Bot," shown below in Fig. A is a 3-wheeled RC robot that uses a spring powered shooter.

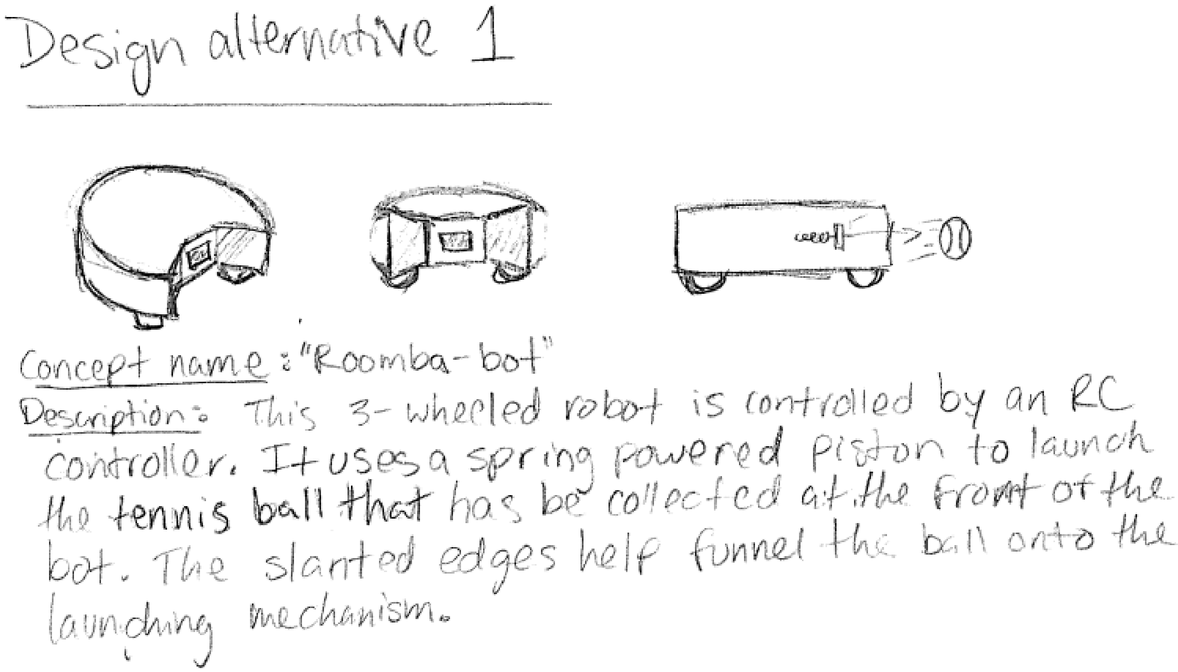


Figure 4: "Roomba Robot"

3.4 CONCEPT #2 – "PENDULUM BOT"

The "Pendulum Bot," similar to the "Roomba Bot" in its size and function, has four wheels and a swinging lever arm to shoot the ball (Fig. B).

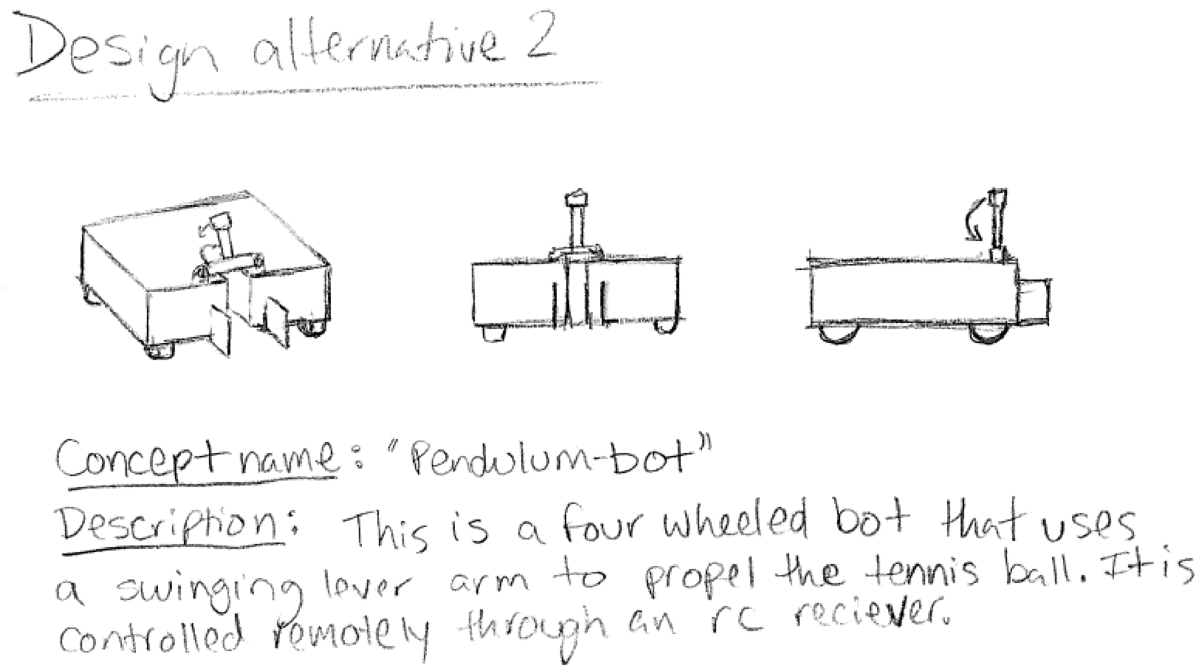


Figure 5: "Pendulum Bot"

3.5 CONCEPT #3 – "SPIN - LAUNCHER"

The "Spin Launcher" affectionately known as the Caterpillar was designed to launch tennis balls above defenders into the goal using a rotating spiral tube (Fig. C).

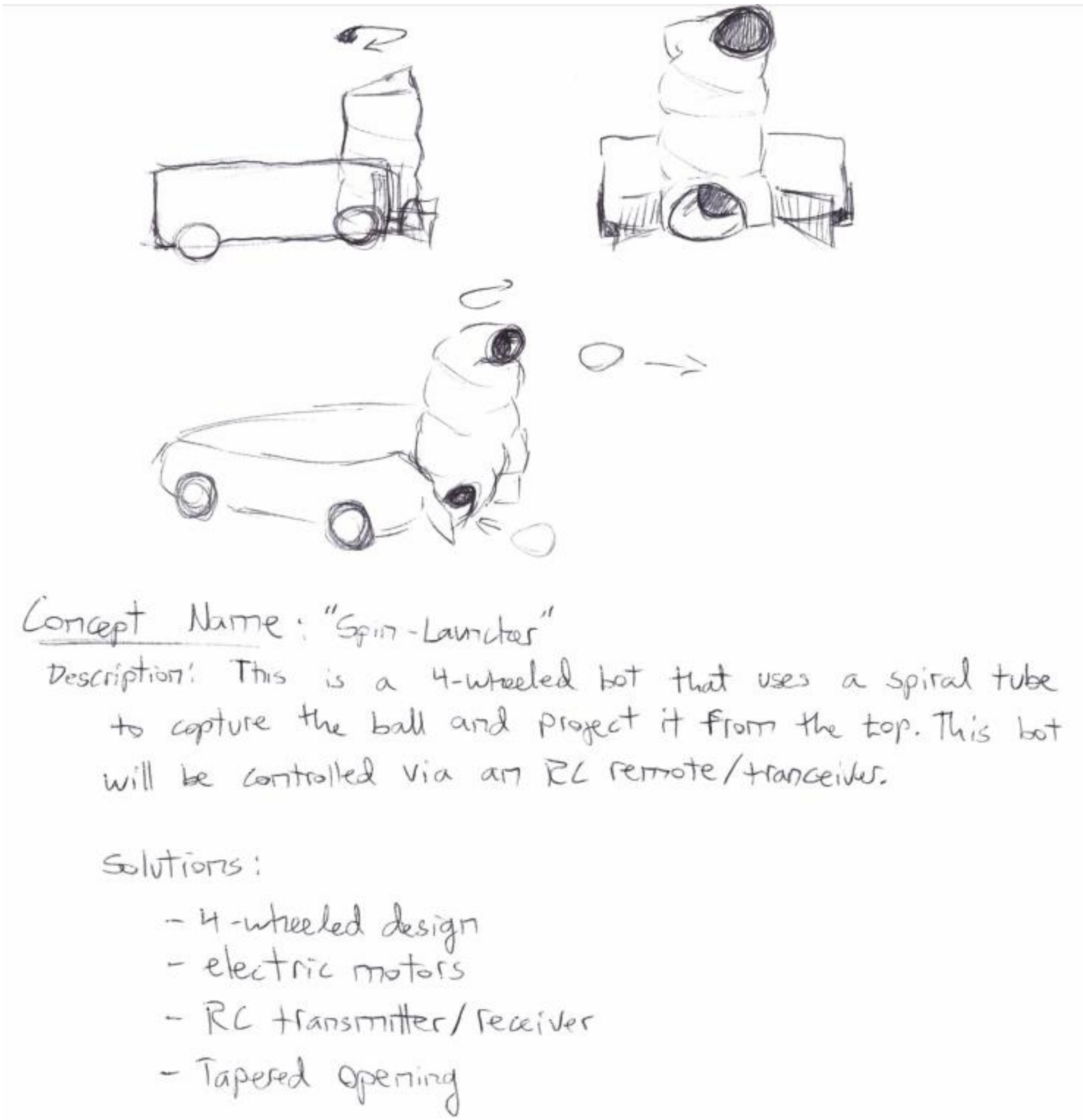


Figure 6: "Spin Launcher / Caterpillar"

3.6 CONCEPT #4 – "TANK BOT"

The "Tank bot, shown below in Fig. D was designed to move like a traditional RC race car and to be able to pick up tennis balls and launch them like a tank through the air.

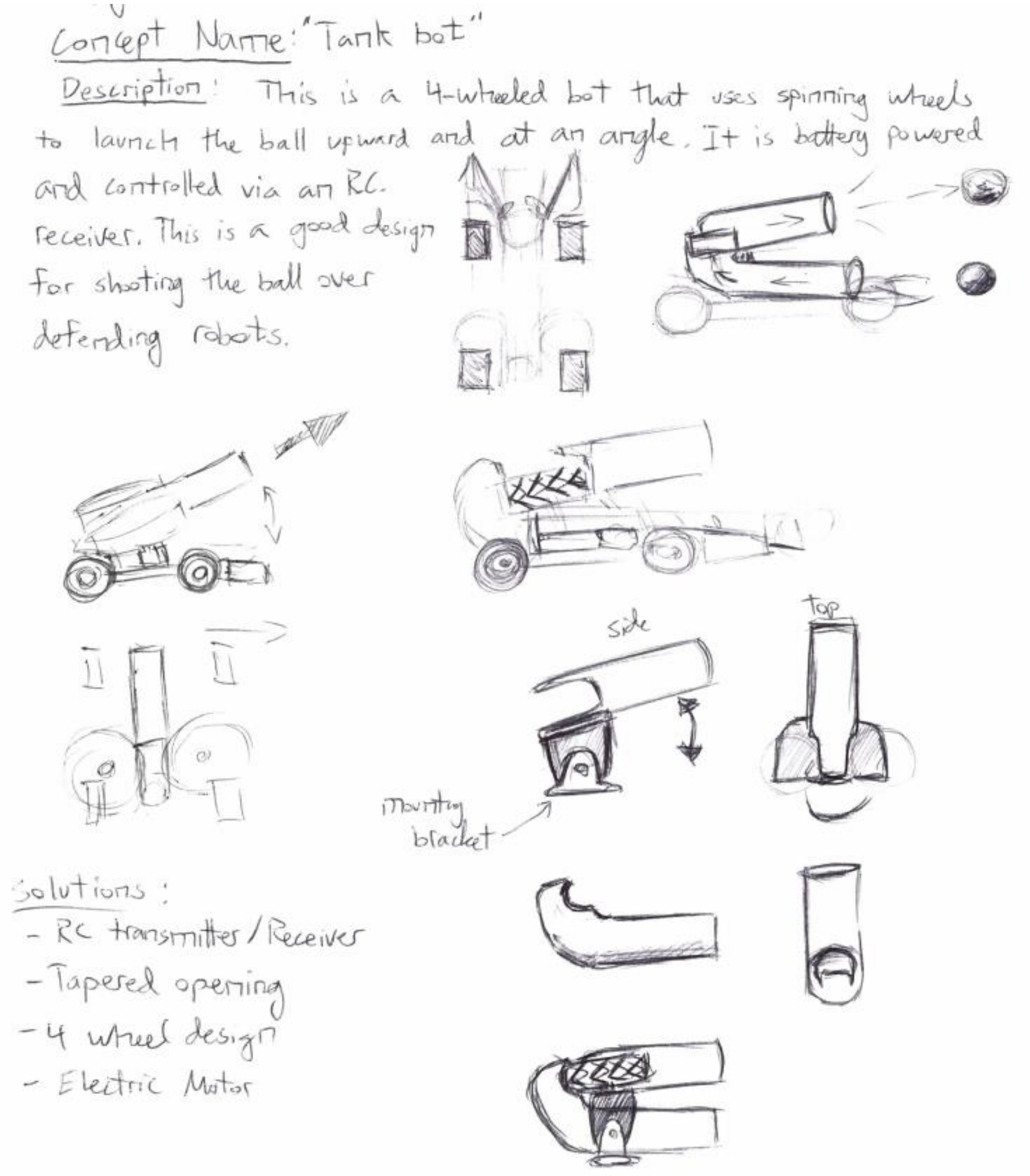


Figure 7: "Tank Bot"

3.7 CONCEPT #5 – "REVERSE SHOOTER"

The "Reverse Shooter," shown below in Fig. E was designed to collect the ball from one end, then move to where it is able to shoot, then shoot the ball using spinning wheels similar to a batting cage.

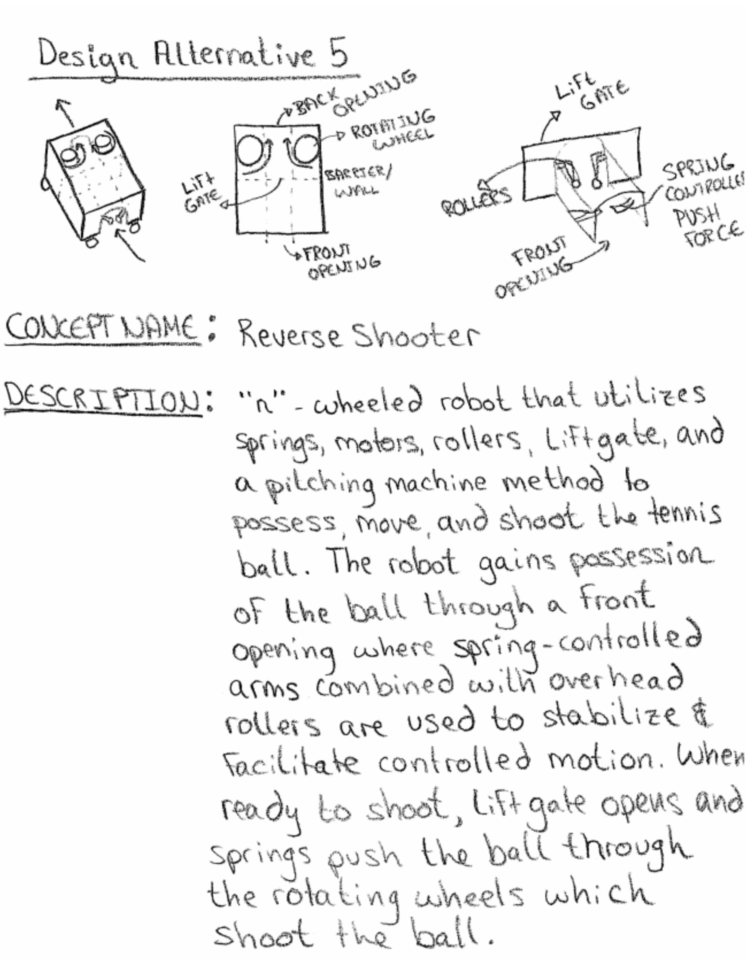


Figure 8: "Reverse Shooter"

3.8 CONCEPT #6 – “THE NOTCHED ROLLER”

The "Notched Roller," shown below in Fig. F used three wheels to move, and used a spinning roller with a notch to shoot kick the tennis ball.

Figure 9: "Notched Roller"

4 CONCEPT SELECTION

4.1 CONCEPT SCORING MATRIX

To help determine which design to use for our project, we compared the designs to each other by using a weighted scoring matrix. By weighing our essential criterion and scoring how each design performed in each category, we could establish the design that best suited our needs. Below is our weighted scoring matrix for the six design concepts our team generated followed by brief discussion regarding the top three designs.

Table 4: Weighted Scoring Matrix for Selected Design Concepts

		Alternative Deisgn Concepts											
		Roomba		Pendulum		Spin launcher		Tank bot		Reverse shooter		Notched roller	
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Mechanical safety	2	4	0.08	3	0.06	2	0.04	2	0.04	4	0.08	1	0.02
Cost of components	8	3	0.24	3	0.24	1	0.08	1	0.08	2	0.16	4	0.32
Manuverability	10	4	0.40	3	0.30	3	0.30	3	0.30	3	0.30	4	0.40
Shot Power	10	3	0.30	2	0.20	3	0.30	5	0.50	5	0.50	4	0.40
Shot Accuracy	12	2	0.24	3	0.36	2	0.24	4	0.48	3	0.36	2	0.24
ASME size guidelines	20	4	0.80	3	0.60	1	0.20	2	0.40	4	0.80	4	0.80
Ability to posses tennis ball	12	2	0.24	3	0.36	3	0.36	3	0.36	5	0.60	1	0.12
Energy Consumption	8	3	0.24	3	0.24	2	0.16	1	0.08	2	0.16	3	0.24
Physical Appearance	4	4	0.16	2	0.08	5	0.20	5	0.20	3	0.12	3	0.12
Ease of setup	14	5	0.70	4	0.56	3	0.42	3	0.42	3	0.42	4	0.56
	Total score	3.400		3.000		2.300		2.860		3.500		3.220	
	Rank	**2**		**4**		**6**		**5**		**1**		**3**	

4.2 EXPLANATION OF WINNING CONCEPT SCORES

Reverse Shooter

With a score of 3.5 from the weighted scoring matrix, the reverse shooter came out on top following our concept design analysis. The strengths of this design coincided with some of the more heavily weighted criterion, which helped it generate such a favorable score. For example, the reverse shooter scored the highest possible rating in both shot power and ability to possess the tennis ball - two criterion that we value significantly. On the other hand, this design's weaknesses appeared in areas that had some of the lowest weights - i.e. physical appearance, energy consumption, and cost of components. The reverse shooter offers us a design that excels at shooting and possession, but unfortunately may be a bit too involved. Although it was the highest ranked design, we have concluded that some changes will need to be made to reduce the complexity (and therefore reduce costs as well). The current design has two spinning wheels used to shoot the ball. A simplified design could be used by eliminating one of the wheels, and rotating the orientation of the wheel. Another reduction could be made to the divider between the ball introduction area to the shooting apparatus. We have decided to work around some of these unnecessary complexities and see how simple we can make the design without compromising performance.

4.3 EXPLANATION OF SECOND-PLACE CONCEPT SCORES

The Roomba Bot

The Roomba bot came in second in the concept selection process with a total score of 3.4. It scored a 4 in mechanical safety because all the mechanical components are inside the housing of the bot so there would be a low chance of the user being injured during operation. Shot power was one of the lower scores of the Roomba bot with a 2. The shooting apparatus is a spring-powered pusher and this will only propel the ball in a straight line. If the ball is slightly off center of the pusher or the bot is not aimed correctly then the shot will be inaccurate. The Roomba bot scored highest on ease of setup. This is a very important category as we will only have one minute to setup the bot during competition. The Roomba bot scored a 5 in this category because there are no mechanical components to set, once the robot is powered on it will be ready to go.

4.4 EXPLANATION OF THIRD-PLACE CONCEPT SCORES

Notched Roller

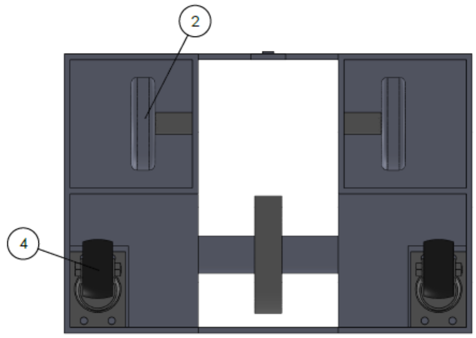
The Notched Roller scored a 3.220 overall. While it had a low cost of components, was highly maneuverable, had high shot power, and was easy to set up, it scored poorly with regards to mechanical safety, shot accuracy, and ability to possess a ball, which were highly important categories. The Notched Roller only had a rotating flipper on the front in order shoot the ball, so it had no way to move with the ball, and shooting accuracy was unlikely to be any good. Since the design of the notched roller was so compact, the maneuverability of the bot would be very high with low energy consumption due to low weight.

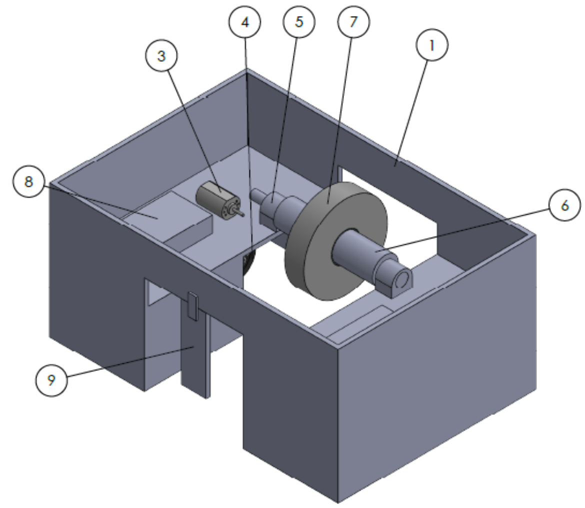
4.5 SUMMARY OF EVALUATION RESULTS

Through the weighted scoring matrix, we determined that the Reverse Shooter was the best design. We focused highly on size of the robot, ease of setup, and shooting ability, as those criteria would help us be most successful in competition and the Reverse Shooter was highly rated in those categories. Overall the concepts were determined to be #1 Reverse Shooter, #2 Roomba Bot, #3 Notched Roller, #4 Pendulum, #5 Tank Bot, and #6 Spin Launcher.

5 EMBODIMENT & FABRICATION PLAN

5.1 ISOMETRIC DRAWING WITH BILL OF MATERIALS





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Soccer Robot housing	This is the main body of the robot.	1
2	Soccer Robot drive wheel	These are the main propulsion wheels.	2
3	6331K21 - Motor	These are the motors that will power the drive wheels and the shooting wheel.	3
4	78155T11 - Caster Wheels	These are caster wheels on the back of the cart that provide support.	2
5	Axel support	These pieces secure the axel rod to the housing and allow it torotate.	2
6	Axel rod	This rod supports the shooting wheel and connects to the motor for rotational power.	1
7	2476K7 - Shooting Wheel	This is the shooting wheel that will propel the tennis ball.	1
8	Battery/assorted electronics	The battery that will power the motors.	2
9	Ball tab	This is a tab at the ball entry point that opens to allow the ball into the center of the cart and prevents the ball from rolling back out.	1

Figure 10: Isometric view of our Robot with BOM

5.2 EXPLODED VIEW

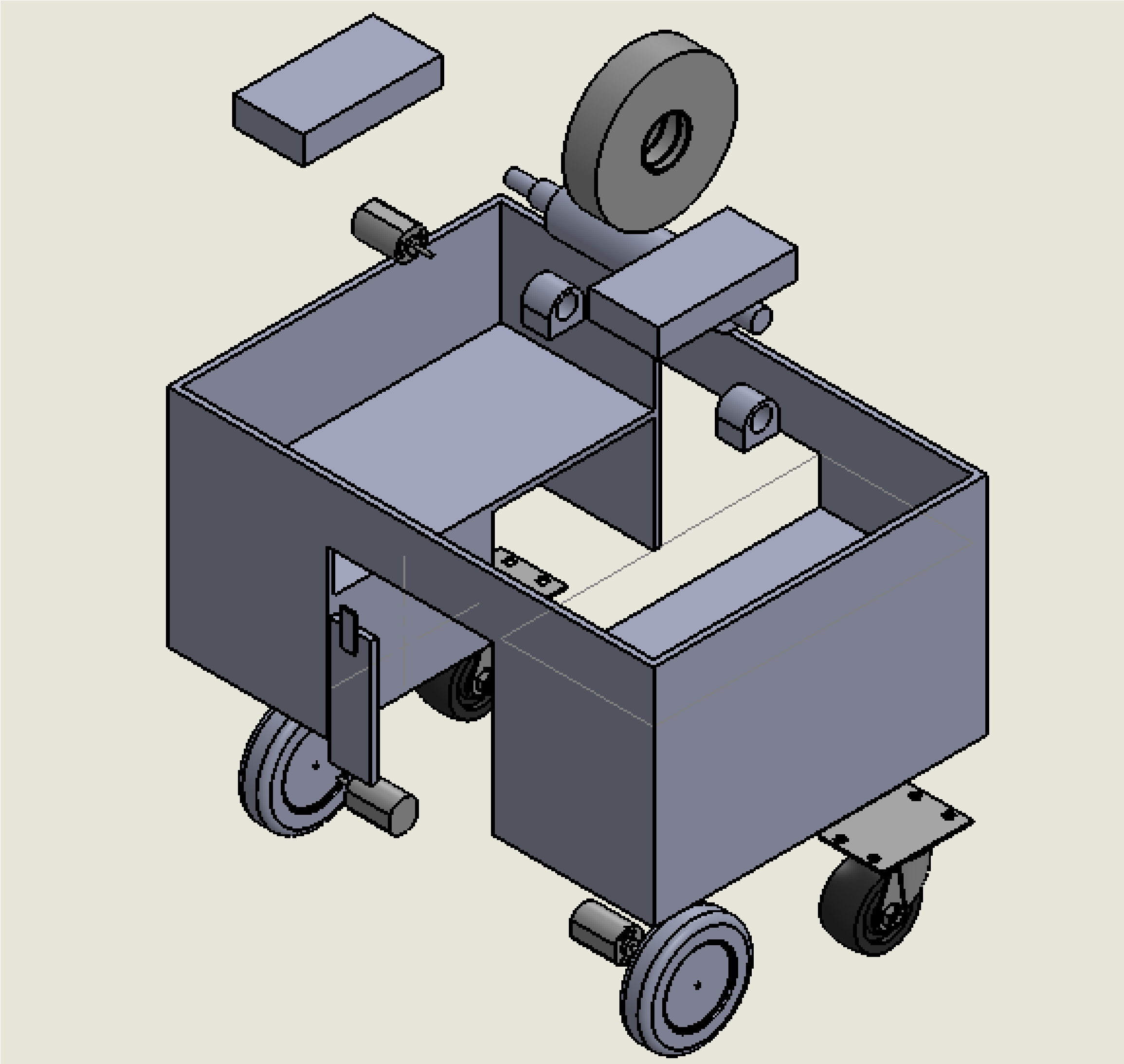


Figure 11: Exploded view of prototype

5.3 ADDITIONAL VIEWS

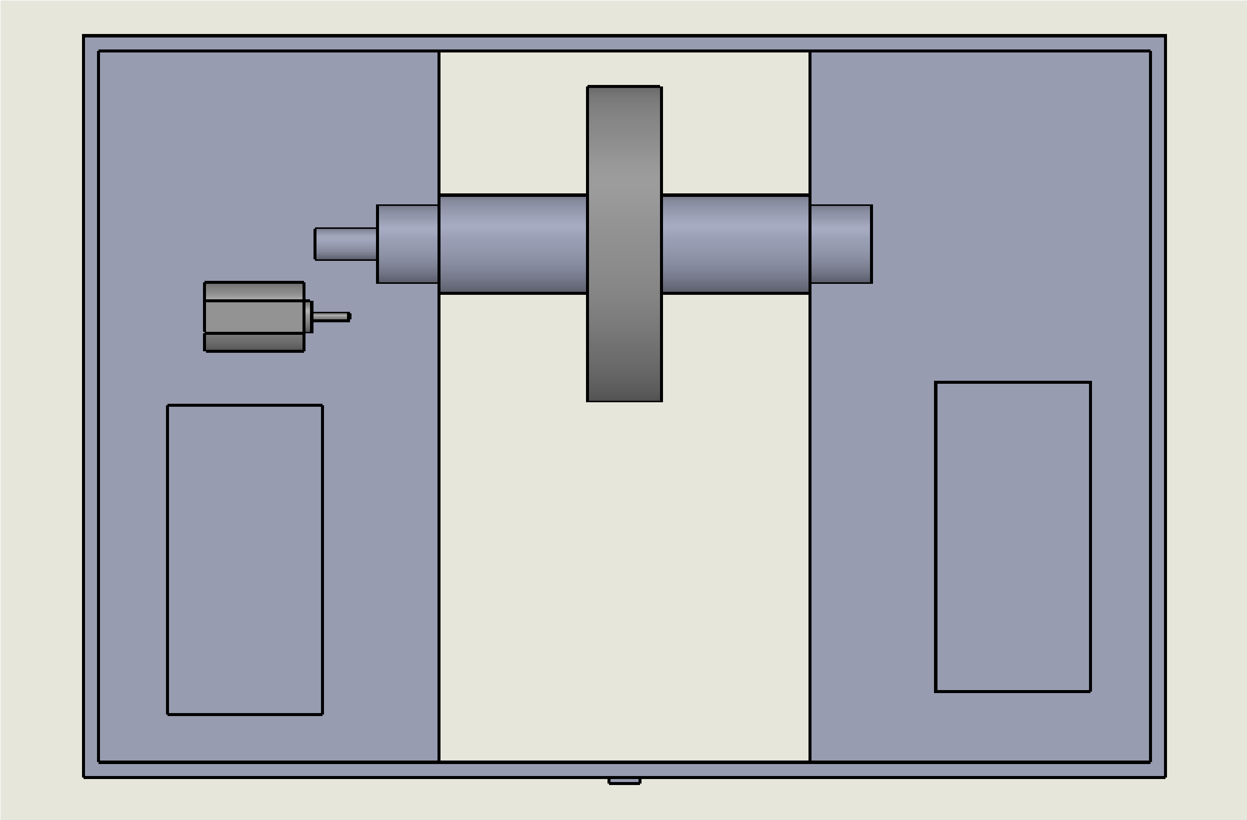


Figure 12: Top view of model

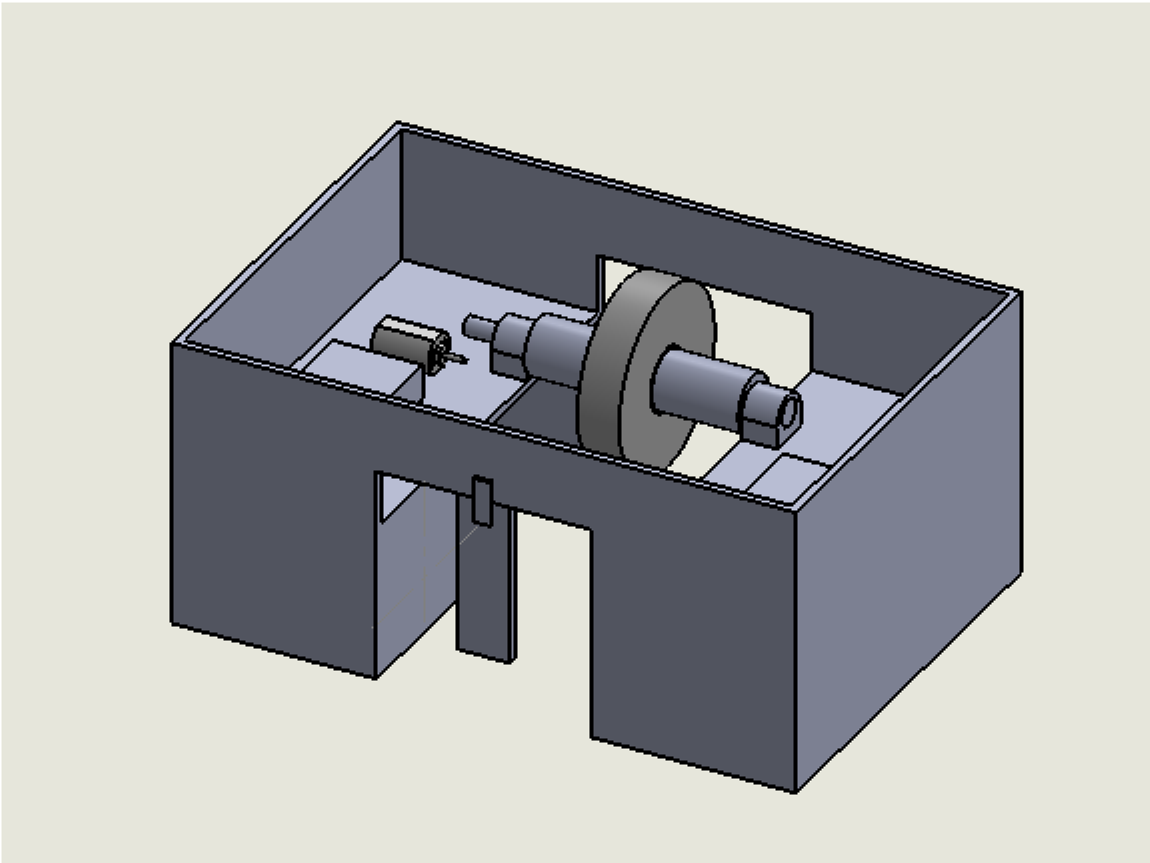


Figure 13: Trimetric view of model

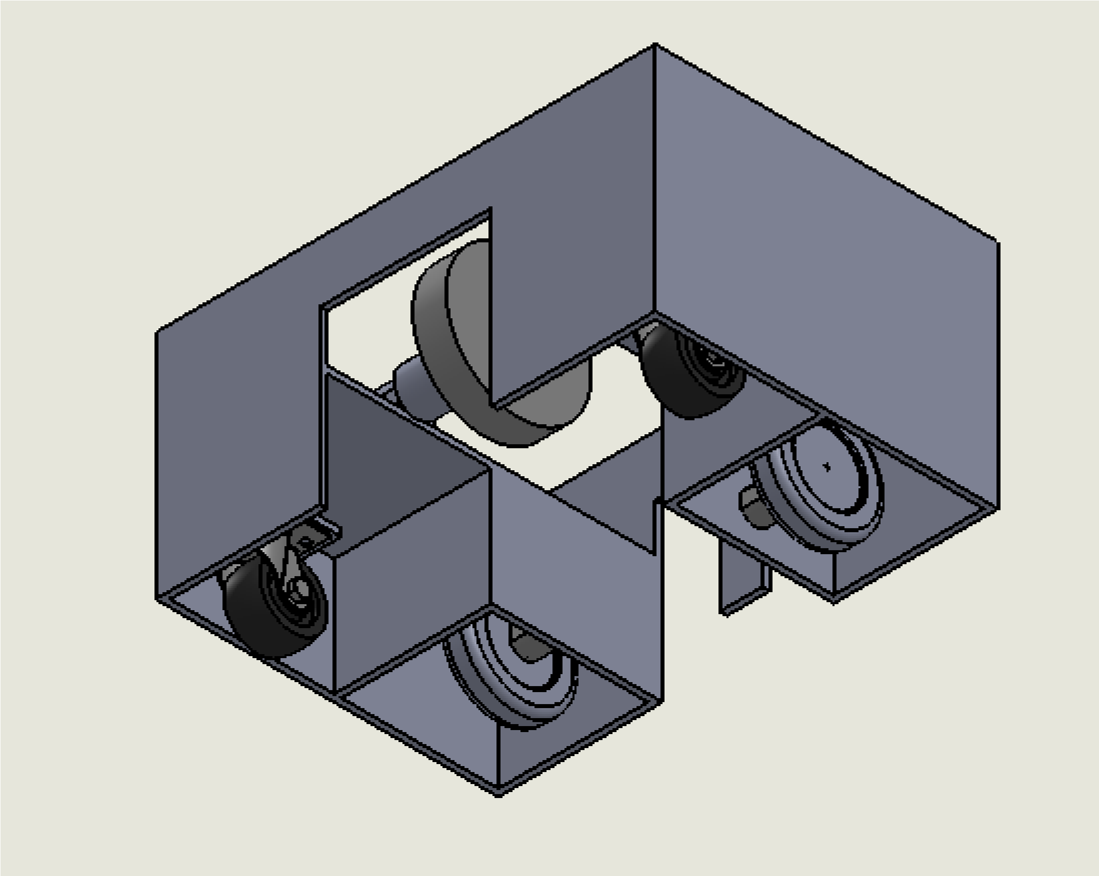


Figure 14: Underside view of model

6 ENGINEERING ANALYSIS

6.1 ENGINEERING ANALYSIS RESULTS

6.1.1 Motivation

The most relevant analysis that was necessary for our design process was to determine what motor speed would be sufficient, when paired with our design, to shoot a tennis ball a minimum of 2.5 m/s. Ideally, we would want our device to the shoot the ball faster than 2.5 m/s, but the motivation behind our analysis was to establish the base minimum motor speed that would be required to meet our performance goals. The goal of this process was to establish a formula where we could simply input motor speeds and receive a good approximation of how fast the device will shoot the tennis ball.

6.1.2 Summary Statement of the Analysis

We pursued our analysis through the use of conservation of energy. This method assumes that no energy is added or lost to the system throughout the process. Although this is physically unrealistic, the formulas should still present us with a good approximation. Additionally, we made two assumptions. First, we assumed that non-slip conditions exist while the tennis ball passes under the spinning wheel. Second, we assume that applying this formula to one of our wheels (despite using a dual wheel system) will be sufficient. We went on to prove that while the second wheel aides our device in terms of gripping and aiming the ball, the effects of the second wheel are negligible when it comes to shooting speed. Below are the relevant equations that we used to solve our theoretical analysis.

ω_i = initial angular velocity of the wheel $\left(\frac{\text{radians}}{s}\right)$

ω_f = final angular velocity of the wheel $\left(\frac{\text{radians}}{s}\right)$

m = mass of the tennis ball (kilogram)

v = final linear velocity of the tennis ball $\left(\frac{m}{s}\right)$

r = radius of our wheel (m)

I = moment of inertia of our wheel $(\text{Kg} - m^2)$

$$I = I_{\text{hub}} + I_{\text{rim}} + I_{\text{spokes}}$$

$$I_{\text{hub}} = \frac{1}{2} * m_{\text{hub}} * \left(r_{\text{hub }0}^{\ 2} + r_{\text{hub }i}^{\ 2}\right)$$

$$I_{\text{rim}} = \frac{1}{2} * m_{\text{rim}} * \left(r_{\text{rim }0}^{\ 2} + r_{\text{rim }i}^{\ 2}\right)$$

$$I_{\text{spokes}} = n * \left(\frac{1}{12} * m_{\text{spoke}} * L^2 + m_{\text{spoke}} * D^2\right)$$

$$E_{\text{sw}} = \frac{1}{2} * I * \omega^2$$

$$E_{\text{mo}} = \frac{1}{2} * m * v^2$$

$$v = \omega_f * r \text{ (no} - \text{slip assumption)}$$

$$\frac{1}{2} I * \omega_i^{\ 2} = \frac{1}{2} I * \omega_f^{\ 2} + \frac{1}{2} * m * v^2$$

$$v = \omega_i * \sqrt{\frac{I}{m + \frac{I}{r^2}}} \text{ (Final Equation)}$$

$$m_{\text{rim}} = \rho_{\text{Polyutherane}} * V_{\text{rim}}$$

$$m_{\text{hub}} = \rho_{\text{Al}} * V_{\text{hub}}$$

$$m_{\text{spokes}} = \rho_{\text{HDPE}} * V_{\text{spoke}}$$

$$V_{\text{rim}} = \left(\frac{4}{3} * \pi * a * b * c\right) - \left(\pi * r_{\text{rim }i}^{\ 2} * h\right); \text{ (Volume of Ellipsoid - Volume of Cylinder)}$$

$$V_{\text{hub}} = \left(\pi * r_{\text{hub }o}^{\ 2} * h\right) - \left(\pi * r_{\text{hub }i}^{\ 2} * h\right); \text{ (Volume of Cylinder - Volume of Cylinder)}$$

$$V_{\text{spoke}} = \text{Width*Length*Height; (Volume of Rectangular Prism)}$$

$$\text{RPM}_{\text{wheel}} = \text{RPM}_{\text{motor}} * \frac{90}{62}$$

$$\text{RPM} = 0.104719755 \ \frac{\text{radians}}{s}$$

Figure 15: Engineering Analysis for the Shooting Wheels

Once we had acquired all of the necessary formulas, we needed to obtain all the relevant measurements and dimensions. We were able to easily record all of the required dimensions of our wheel using a caliper. Using a standard scale, we found the mass of both our tennis ball and our wheel. To find the masses of the individual parts that make up the wheel, we had to solve for the volume and multiply that by the material density. The formulas used can be seen in the previous section. The rim is made of Polyurethane elastomer, which has a density of 1121 kg/m^3. The hub is aluminum, which has a density of 2700 kg/m^3. Lastly, the spokes are made of high-density polyethylene, which has an average density of 970 kg/m^3. We then plugged in our values and were able to calculate theoretical results.

To test our theoretical calculations, we physically ran our motor/wheel setup and recorded how fast the wheel was rotating as well as how fast the tennis ball was shot. This way, we could easily plug in the wheel's angular velocity and see if our equation gave the same ball velocity as we measured physically. We used a slow motion camera and a stop watch to record the shooting apparatus. We were able to analyze the slow motion video and see how long it took the large gear (which was closest to the camera) to complete a full rotation. From that, we found what RPM our motor was operating at. We then used our gear ratio formula, which can be seen in the previous section, to calculate how fast the smaller gear (and therefore the wheel) was rotating. Similarly, we marked the one meter mark and recorded how long it took for the ball to reach the marker once shot out from under the wheel. By converting RPM to rad/s, we plugged our wheel angular velocity into our final equation and compared the resulting ball velocity to the physical velocity measured from our slow motion recording analysis.

6.1.4 Results

When calculating our masses of the wheel components, we took great caution to be as accurate as possible. When adding our theoretical masses together, we had an output of 200.25g. We then measured the physical wheel and found it to be exactly 200g. This means we had a 0.125% error, which is incredibly accurate. We could not have asked for a better approximation. Since our mass measurements were so precise, we have great confidence that our theoretical value for the moment of inertia of the wheel is a worthy approximation.

Using the slow motion recording, we found our driving wheel completed a full rotation in 0.24 seconds. This means the larger gear was rotating at 250 RPM. Using our gear ratio, we found our wheel was rotating at 362.903 RPM or 38 rad/s. Plugging this value into our equation gave us a ball speed of 1.98572 m/s. When reviewing the tape, we calculated that the ball took 0.48 seconds to travel a meter. This means the tennis ball shot out at a velocity of 2.0833 m/s. Our equation had a 5% error. All things considered, our equation was proven fairly accurate.

6.1.5 Significance

Now that we have proven that our approximations and assumptions resulted in an equation that operates within 5% error, we can confidently solve for what motor speed is needed to shoot the tennis ball at a minimum velocity of 2.5 m/s. We found that as long as our motor operates at least 315 RPM, we will meet our performance goal. The previous motor we were using only rotated at 250 RPM when connected to a 9 volt battery. This means we have to find a faster, stronger motor before the final product is ready for submission.

6.2 PRODUCT RISK ASSESSMENT

6.2.1 Risk Identification

Risk Name: Battery Explosion

Description: The batteries used to power the drive wheels and the shooting wheel are lithium polymer (LiPo) batteries. These batteries can have very disastrous failures if they are not handled properly. Things like overcharging, punctures, internal damage, short circuiting and heat can cause LiPo batteries to fail and potentially explode.

Impact = #: 5. This risk is a 5 impact because of the possibility of an explosion.

Likelihood = #: 2. This risk is a 2 likelihood because the catastrophic failure of a LiPo battery can be easily avoided with proper care and handling.

Risk Name: Collision

Description: During the operation of the soccer robot there is the potential for the robot to collide with a bystander causing injury.

Impact = #: 2. The robot will not be moving at a high speed so any damage sustained by a bystander during a collision will likely be minimal.

Likelihood = #: 1. Both the operator and bystander should be able to react quickly enough to avoid a collision.

Risk Name: Motor Failure

Description: During operation the drive motors and shooting motor could become burnt out though overuse. This would cause the motor to cease working and render the soccer robot useless.

Impact = #: 4. A burnout motor, either drive or shooting, would result in the loss of one of the robot primary functions.

Likelihood = #: 2. The robot will be active for five-minute periods of time so the chance of a motor overheating and burning out should be low.

Risk Name: Receiver Connection

Description: The receiver that links the controller to the drive motors could lose its function due to a lack of power from the battery or a poor connection with the controller.

Impact = #: 3. This would render the controller useless as it would be unable to communicate with the drive motors. The robot would be unable to drive, like with a burnt-out motor, but it should be an easier fix than a burnt-motor.

Likelihood = #: 3. Receivers can be finicky and could drop a connection due to interference.

Risk Name: Laceration

Description: The body of the soccer robot is made from aluminum and plastic with potentially sharp edges. These edges could cause harm to someone trying to handle to robot.

Impact = #: 3. Any cut should be fairly small and not life-threatening.

Likelihood = #: 3. There a lot of machined parts on the soccer robot so the is a decent likelihood of a laceration occurring.

Risk Name: Timing Belt

Description: The timing belt connecting the shooting motor and the shooting wheel could fail, either from fraying or from losing contact with the timing pullies.

Impact = #: 4. A failed timing belt would mean that the shooting wheel would not be driven by the motor making one of the main features of the soccer robot useless.

Likelihood = #: 2. The timing belt in good condition and there are guards on the timing pullies to prevent the belt from drifting so it should operate correctly.

6.2.2 Risk Heat Map

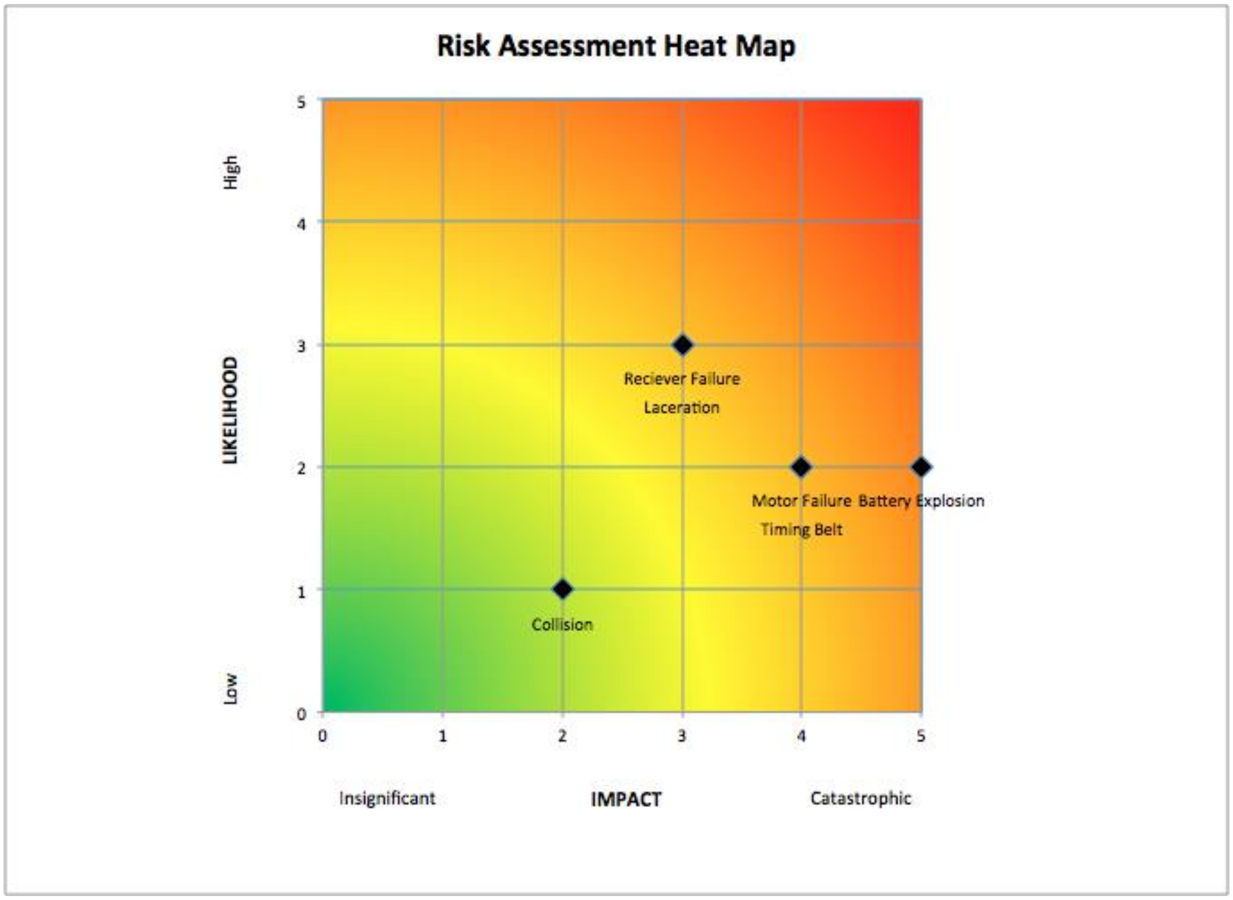


Figure 16: Risk Assessment Heat Map Comparing Impact to Likelihood

6.2.3 Risk Prioritization

Our first priority for risk is battery explosion. Since it has the greatest impact it should be what we focus on eliminating first. Motor failure, timing belt failure, receiver failure and lacerations are all at the about the same level of risk so those would be our second priority. Collision is not a large concern and since the competition rules dictate that only incidental contact is allowed, this would be our third priority.

7 DESIGN DOCUMENTATION

7.1 PERFORMANCE GOALS

1. Ability to weave in and out of buckets spaced a machine width and a half apart

2. Battery life for 5 mins of activity

3. Drive 5 mph forward

4. Shoot tennis ball a minimum of 2.5 m/s

5. A shot from 5 m does not deviate more the 25 cm side to side

7.2 WORKING PROTOTYPE DEMONSTRATION

7.2.1 Performance Evaluation

We were able to successfully meet three of our five performance goals, numbers 2, 4, and 5. The batteries for the drive wheels and the shooting wheel lasted for more than five mins, the average shot speed was 2.84 m/s, and we scored three out of three shots from 5 m. We were not able to meet goals 1 and 3 due to poor motor performance. After further testing of goal 3, it was concluded that 5 mph might have been an unrealistic expectation. Currently the robot drives at around 1 mph, and while this is relatively slow, we do not think the robot needs to be five times faster in order to be successful in the competition. A goal of 2.5 mph or 2 mph seems much more realistic and achievable. For both goals 1 and 3 simply implementing more powerful motors would allow us to reach the desired performance.

7.2.2 Working Prototype – Video Link

Below is a video summarizing our project.

https://www.youtube.com/watch?v=i6OtpnxOjWc

7.2.3 Working Prototype – Additional Photos

Below are a couple of pictures showing what our working prototype looked like. As you can see in the figures below, the design allows for a sturdy structure without weighing the robot down unnecessarily. The inside also features a sufficient amount of room to add/improve in the future.

Figure 17: Photos of our finished prototype

8 DISCUSSION

8.1 DESIGN FOR MANUFACTURING – PART REDESIGN FOR INJECTION MOLDING

8.1.1 Draft Analysis Results

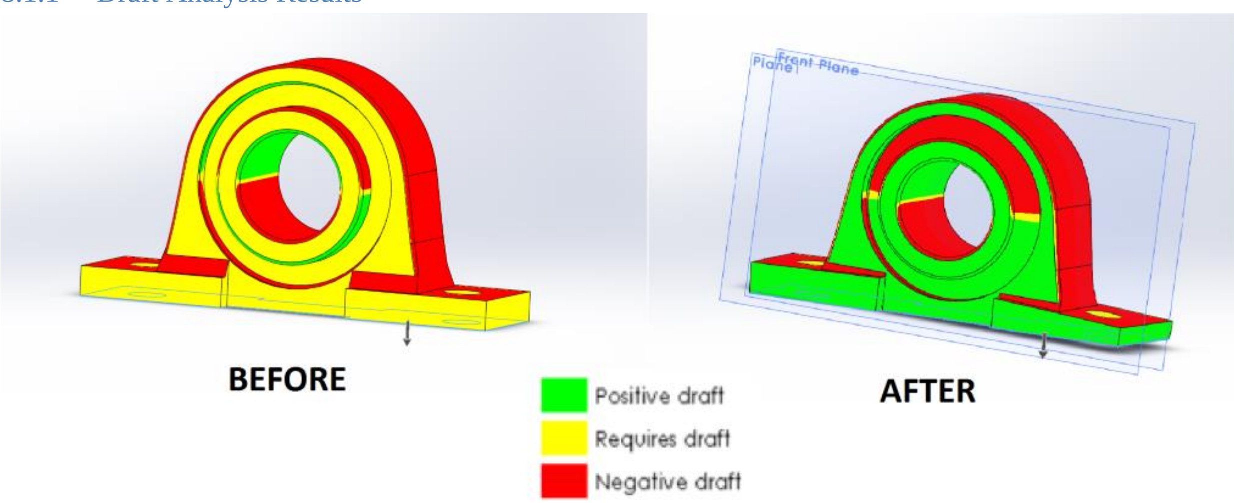


Figure 18: SolidWorks Draft Analysis

8.1.2 Explanation of Design Changes

A draft analysis was performed on the bottom of our bearing housing because it is the most important side to be flat so that it will fit flush with any other flat surface it rests on. Draft is important during injection molding to ensure clean edges as well as to withstand molding stresses. The results of this are shown in the “before” picture below. In order to incorporate draft on a majority of the flat surfaces, a draft angle of 3 degrees was created using Solidwork’s draft wizard which automatically makes the surface slightly angled for optimum molding. The inner rings proved to be more difficult, so a chamfer was added to take up the flat space within the bearing housing. This added a non-flat edge while preserving its functionality. The holes for the bearing and screws were not attempted to be drafted as these could easily be completely filled in during a molding step and machined out after. Our final result is shown in the “after” picture below.

8.2 DESIGN FOR USABILITY – EFFECT OF IMPAIRMENTS ON USABILITY

8.2.1 Vision

Red-green color blindness or presbyopia should not have a significant effect on the usability of our design. No part of the design is color dependent, and the controller can be controlled by touch without much need of sight. If someone with a vision impairment needed to troubleshoot the device, they may need reading glasses to see part numbers, and a colorblind person may struggle to identify correct wire colors – however these are unavoidable problems from the designer's perspective. People who are significantly shortsighted or legally blind should not use our product for safety reasons.

8.2.2 Hearing

Hearing impairments should not have a significant effect on the usability of our design as there are no design elements that are hearing dependent.

8.2.3 Physical

Our device is operated using a hand-held remote controller. This could create user issues for people with physical impairments of their hands, as they would not be able to operate the controls effectively. Any impairment that limits the use of ones' hands would, in turn, limit the use of our device.

8.2.4 Language

A language impairment will have little to no effect on the usability of our device. The controls are fairly simple, two joysticks, so anyone, with any language background should be able to operate our device effectively.

8.2 OVERALL EXPERIENCE

8.2.1 Does your final project result align with the initial project description?

The initial project goal was construct a robot that could play "soccer" and fit the ASME provided guidelines and our final project result is in line with that. We can confidently say that we were able to construct a robot that meets our initial project description

8.2.2 Was the project more or less difficult than you had expected?

The actual construction of the robot was less difficult than we expected, but we were under a significant time crunch due to part ordering which was not expected. We wish our driving motors and wheel setup was better designed, but due to difficulties with part orders, we were left without much time to improve on the robot's deficiencies. Therefore, the most difficult part of this project was getting the right parts we needed.

8.2.3 In what ways do you wish your final prototype would have performed better?

The driving performance was not great; the robot does not go as fast or turn as well as expected. In the future, we would have to significantly improve our robot's ability to navigate smoothly via remote control. The shooting apparatus and overall structure of the device was a success.

8.2.4 Was your group missing any critical information when you evaluated concepts?

No, we covered all the necessary information when evaluating concepts.

8.2.5 Were there additional engineering analyses that could have helped guide your design?

An engineering analysis on the drive motor could have helped us realize that we could use more powerful motors. Additionally, it would have been wise to have looked into existing driving systems that exist and work to model our design after those. Instead, we tried to do it ourselves and found out the hard way that this was the wrong approach. In the future, better engineering practices would be used and a more in-depth analysis of the best way to set up the drive motor and wheels would be performed.

8.2.6 How did you identify your most relevant codes and standards and how they influence revision of the design?

ASME competition rules and requirements were the primary design constraints that we followed because the robot was not meant to be mass-produced. Had we been following the toy safety standard, "AS/NZS 62115:2011" more closely, we would have needed to think about moisture resistance, more protection of electrical wiring, resistance to heat and fire, softer edges and removing extruding screws.

8.2.7 What ethical considerations (from the Engineering Ethics and Design for Environment seminar) are relevant to your device? How could these considerations be addressed?

We use a few batteries to power components in our design, so we need to be conscious of the disposal of these as there are potential hazards.

8.2.8 On which part(s) of the design process should your group have spent more time? Which parts required less time?

We should have spent more time on the detail of the concept embodiment. A detailed understanding of the design and a manufacturing plan would have cut down on our assembly times. We spent more time than required on part ordering due to uncertainty of what parts to purchase.

8.2.9 Was there a task on your Gantt chart that was much harder than expected? Were there any that were much easier?

Again, parts ordering was harder to complete due to our own uncertainty, but the actual report requirements were easier to meet.

8.2.10 Was there a component of your prototype that was significantly easier or harder to make/assemble than you expected?

The shooting apparatus was particularly difficult as the wheel height needed to be just right to properly propel the tennis ball. Also, the shooting motor need to be at the right distance from the shooting wheel so the timing bet was taunt and everything rotated correctly.

8.2.11 If your budget were increased to 10x its original amount, would your approach have changed? If so, in what specific ways?

We would have been less conservative on our purchases. We ordered a lot of cheaper items or tried to use items we found in the workshop and that caused some issues. For example, we found casters in the basement that we planned to use opposite our drive wheels, but the turned out to be poor quality and limited to motion of our design. Having a larger budget would have allowed us to purchase the exact wheels we needed without concern for cost.

8.2.12 If you were able to take the course again with the same project and group, what would you have done differently the second time around?

We would have created a more thorough manufacturing plan in order to eliminate unnecessary delays during construction. Additionally, we would have approached our driving motor and wheel design completely differently. As mentioned above, we would instead use the approach of modelling after optimized examples that already exist rather wasting time trying to do it ourselves with whatever scrap motors and wheels we could find laying around. That was poor engineering.

8.2.13 Were your team member’s skills complementary?

Our team member skills were complementary. We are all friends, so we are comfortable working with each other. Also, since we have had previous experience working together, it was easy to be open and forward with each other. Conflict could easily be addressed without any major problems to our team chemistry.

8.2.14 Was any needed skill missing from the group?

No one in our group had that much experience with the electrical components needed in this project, so someone with those skills would have helpful.

8.2.15 Has the project enhanced your design skills?

We all feel more comfortable with the design process and know what areas we need to improve on. Now we can build on those things going forward.

8.2.16 Would you now feel more comfortable accepting a design project assignment at a job?

Yes! With our current experience, we of course are not experts, but we are at least competent enough with regards to the actual design process. The necessary skills and experience will come with time, but since we have been through the process, we are confident we could handle a project assignment.

8.2.17 Are there projects you would attempt now that you would not have attempted before?

I believe that since we now have experience working with a time constraint, we are more willing to take on personal projects in the future. Before, a big worry is knowing how to manage our normal school workload along with a side project. Thanks to this experience, we know have the tools to properly manage our time and set appropriate goals and timelines to reach.

9 APPENDIX A - PARTS LIST

Table 5: Parts list

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Tax ($0.00 if tax exemption applied)	Shipping	Quantity	Total price
1	Frame	Machine Shop		Aluminum	$0.00	$0.00		1	$0.00
2	2' x3' Aluminum Sheet (for body)	https://www.lowes.com/pd/Stelworks-24-in-x-3-ft-Aluminum-Sheet-Metal/3057473	42279	Aluminum	$19.88	$1.99	$0.00	1	$19.88
3	Drive Motor	https://www.amazon.com/dp/B072R5G5GR?th=1	B072R5G5GR	12V	12.99	1.299	2.52	2	$30.50
4	Shooting Motor	https://www.amazon.com/dp/B072R5G5GR?th=1	B072R5G5GR	12V	$12.99	$1.30	$0.00	1	$12.99
5	Battery Pack	HobbyKing.com	T2200.3S.25	11.1V	$10.99	$1.10	$3.95	3	$48.12
6	Battery Charger	Maker Space	0	12V	$0.00	$0.00	$0.00	1	$0.00
7	Tether	Maker Space		Black	$0.00	$0.00	$0.00	1	$0.00
8	Misc. Wiring	Maker Space		Red, Yellow	$0.00	$0.00	$0.00	1	$0.00
9	Casters	Jolley Basement		Plastic/Aluminum	$0.00	$0.00	$0.00	1	$0.00
10	Drive Wheels	Maker Space		3" Orange	$0.00	$0.00	$0.00	2	$0.00
11	Motor Driver LN298	https://www.sparkfun.com/products/9479	COM-09479	Silver	$2.95	$0.30	$2.00	1	$5.25
12	Wheel Mounting Brackets	Machined		Aluminum	$3.00	$0.00	$0.00	2	$6.00
13	Controller	Maker Space		Black	$0.00	$0.00	$0.00	0	$0.00
14	Shooting Wheel	Jolley Basement		9"	$0.00	$0.00	$0.00	1	$0.00
16	Arduino Uno	https://www.sparkfun.com/products/11021?gclid=EAIaIQobChMI_qHJ5YHu1gIVBFmGCh0-MgUrEAAYASAAEgLck_D_BwE			23.95	2.395	4.79	1	$23.95
Total:									$146.68

10 APPENDIX B - CAD MODELS

Figure 19: CAD drawing of the body

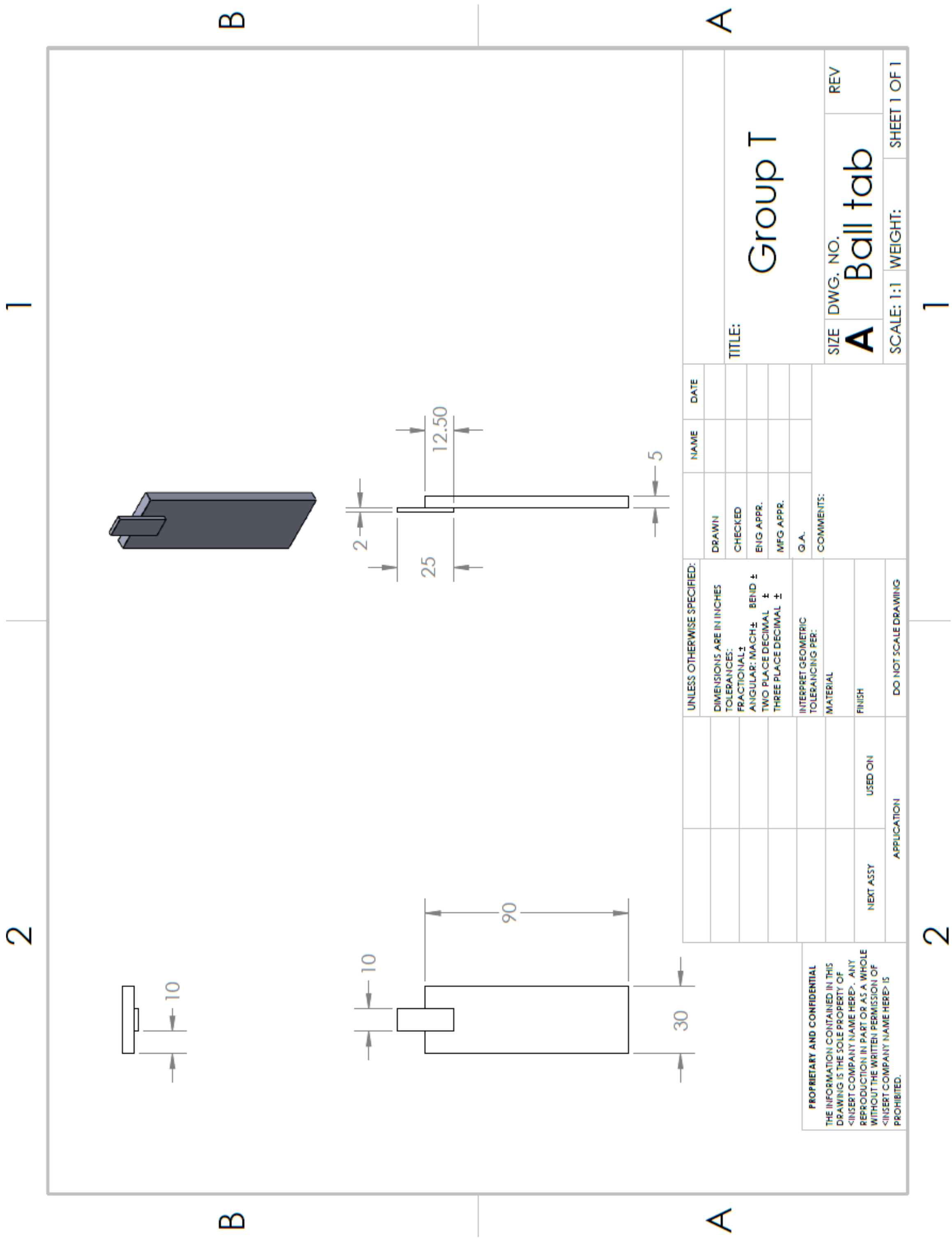


Figure 20: CAD drawing of the ball control tab

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