2021 UC MET 1.5 kg Beetle Bot

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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ABSTRACT

This report shows the process our group took to design research and design a 1.5 kg beetle bot. This bot will compete in a school competition at the University of Cincinnati. The research as design were done as part of our MET senior design project. We researched and designed components for the frame/armor, weapon, drive train, and electrical parts. During the next semester, we will build, test, and compete with our beetle bot against other student teams.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

Design and build a combat beetle robot to compete with other UC student groups. The bot must disable opponents while protecting itself from attacks, while putting on an entertaining fight, and comply with safety standards set by the Fighting Robots Association.

Team Responsibilities:

Abby Hoying- Weapon Research and Design

Emely Casasola- Drive Train Research and Design

Alexandra Runyon- Frame/Armor Research and Design

RESEARCH

BACKGROUND AND SCOPE OF THE PROBLEM

Robot battling made its first appearance to the world in the mid 1990's [1]. Robot combat was reckoned to "become a true sport of the future" by Popular Science, 2013 [2]. It is a sport using new technology partnered with the classic elements of traditional sports, like using teamwork, thinking outside of the box, and being competitive. In the competitions, "two or more robots are entered into a ring (actually a bullet-proof cage) and let loose until there is only one robot moving-, kind of like ultimate fighting for robots." [1]. Now with this sport existing for over 20 years, competitors are challenged to create better designs than before. Teams need to consider robot mobility, bot control, weapons, configuration, component protection, and floor clearance in their designs.

Along with expanding innovation, more variations of battle bot competitions with different rules are being created. We are focusing on beetle bots, which is a new subdivision of battle bots. Beetle bots are smaller and lighter weight battling robots, which still compete in competitions. This subdivision was introduced to the sport in the last few years. For the UC Battlebot's club, we will be using rules from the Bristol Bot Builders (BBB) in the UK. The bot must comply with the Fighting Robots Association rules and safety features, such as a removeable link to power of the robot's electrical system, a power-on-light, and a fuse to prevent blown up components.

According to the BBB, "A UK beetle weight combat robot is a 1.5kg robot. The electrical components typically consist of, "a lithium polymer battery, receiver and transmitter, drive motors, connectors, battery eliminator circuit, and speed controllers. Unlike UK ant weights, there are no size restrictions, and unlike US beetle weights they have a lightly large weight at 1.5 kg instead of 3lb or 1.36kg. The bots do not have a size limit or weight tolerance but spinning weapons must not exceed 250mph. [3)]

Battle bots mainly impacts students entering battle bot robotics competitions. This can include students in high school, students in college, and general robotics enthusiasts who compete as a hobby. Competitions are held in many countries around the world, and they usually are associated with a school. The competitors usually consist of teams with a few people, who work towards making a working battle bot. According to a school in Hamilton, Ontario, the competitions are, “Not so much about the winning as it is about the learning, and helping to encourage an interest in further studies in science, technology, engineering and math - known as STEM.” [4]

The purpose of our project is to design and build a combat robot to compete in our local UC student competition. The bot must disable opponents while protecting itself from attacks, while putting on an entertaining fight, comply with safety standards, and stay within budget. The cost in fabricating and designing a robot can vary depending on the need of the robot. For the 2019-2020 year, our budget is $340. This will include costs for materials, electronics, and shipping fees. One of our goals is to design it cost effectively without losing important design features. The bot will need to perform safely since any piece of machinery can be hazardous to people. The weapon will need to be safe when handled and not harm others when hit. Specifically, banned weapons includes untethered projectiles and flames [5]. We will have two semesters to complete this project, which should allow us plenty of time to consider all design aspects of the bot and give us time for redesigns if necessary.

CURRENT STATE OF THE ART

Weapon:

2020 BattleBot Design, 15 lb Competition

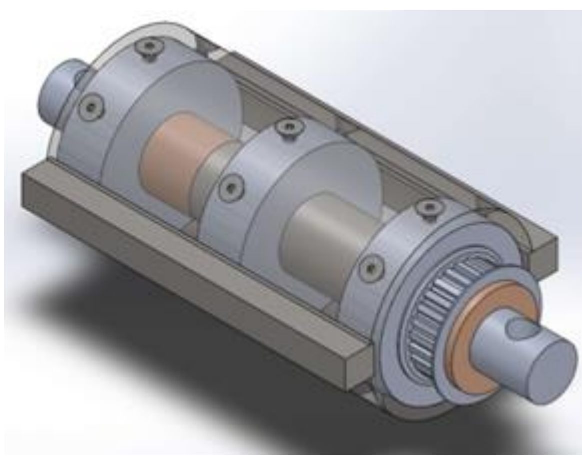


Figure 1. 2020 BattleBot Design, 15lb Competition [6]

The weapon selected for this project was a drum spinner. It consists of a rotating cylinder with protruding square edges. It has a strong offensive capability with a large area of attack. The weapon takes up the entirety of the front of the bot, which is beneficial when making attacks head on. On the downside, the drum can create a lot of inertia when spinning, which can cause it to potentially break. Extra support will need to be added to secure the bot, which can take up extra weight and space. When attacked, this weak spot might cause the robot to break. [6]

2019 BattleBot Design, 15 lb Competition

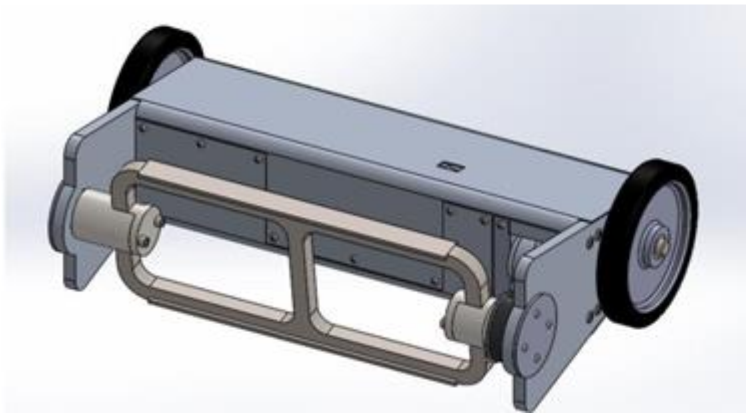


Figure 2. 2019 BattleBot Design, 15 lb Competition [7]

This team selected the vertical plate spinner with flared edges for their weapon. The weapon has a few connected bars which spin in a vertical direction. This is good for attacking, and it can flip approaching battle bots in competitions. The weapon is not buried in the frame which means it can be easily removed for repairs between matches. The weapon must be made from a tough material since it will be spinning rapidly, which will cost more. Also, the large metal weapon will add a lot of additional weight. This team used 4140 steel and 4340 steel for different sections of the weapon. [7]

2017 BattleBot Design, 220 lb Competition

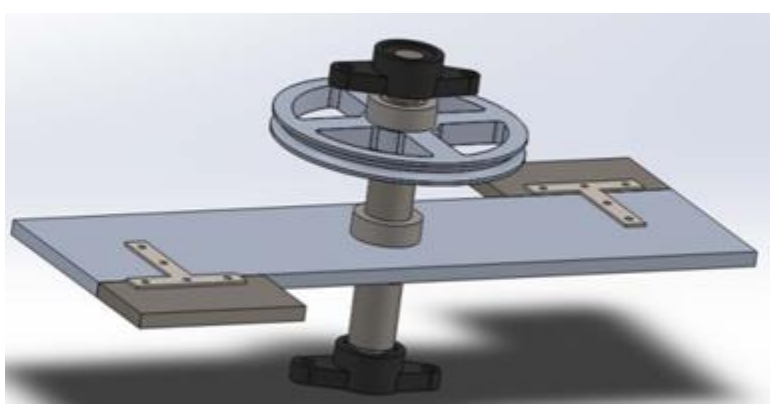


Figure 3. 2017 BattleBot Design, 220 lb [8]

This project used a horizontal blade for their weapon. This consisted of a shaft, motor, weapon drive system, and two blades. The blades are beneficial because if they were damaged during a round, they can be replaced easily by adding inserts and switching out the blades. The blade can be made from a 2024 aluminum sheet, which is low in cost, especially when needing to replace the blades. A con for the horizontal blade is it can only attack in one plane. This will make offensive attacks difficult. Also, the weapon will need to stick out from the rest of the bot, which can add stresses to the frame. [8]

Drivetrain System:

2017 UC Battlebot Team

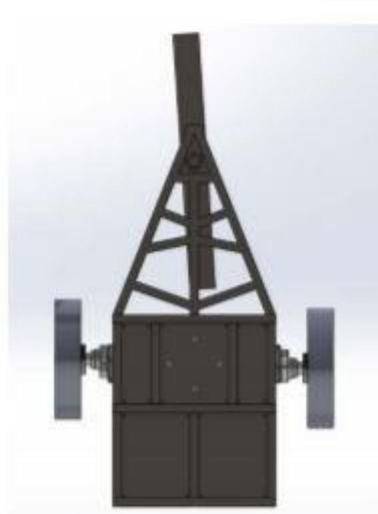


Figure 4. 2017 UC Battlebot Team [8]

This team prioritized maneuverability, which is why they chose a two-wheel design. Having two motorized wheels with gearboxes helps make quick turns and increase the torque. This was important to this team because it allows them to quickly reposition themselves to keep their opponent in front. For their wheel selection, they chose two fourteen-inch flat tires that were located towards the center of the robot which allowed the robot to torque itself over if flipped. However, with only having two wheels and a heavy weapon the robot creates a teetering effect on the robot. So, placement of the wheel with consideration of the overall robot weight was important. [8]

2020 UC MET 15 lb. BattleBot team “Mamba”

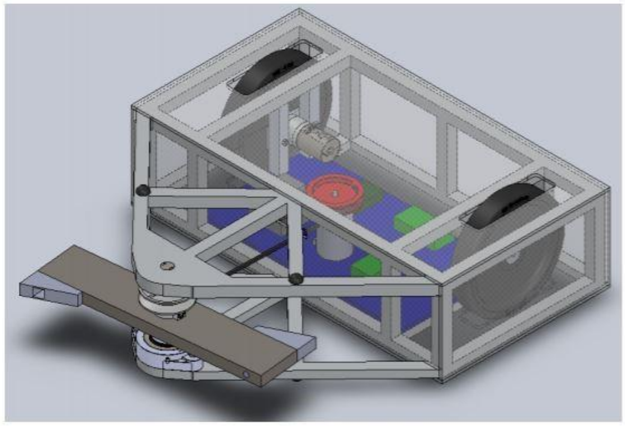


Figure 5. 2020 UC MET 15 lb BattleBot team "Mamba" [9]

This team prioritized simplicity and cost when designing their robot's drivetrain system. They picked two 4 and 7/8 inch diameter wheels each motorized by a DC motor and a gearbox. The motors came with the gear box used. They aligned the wheels to be symmetrical and located towards the rear end of the robot and encased by the frame and armor. Having the wheels positioned towards to back end helps give more room for the weapon in the front. Having the wheels enclosed helps protect the wheel and motors from damage. This robot was designed for the lightest weight class out of the different robot teams studied. This design was more relatable since it was closer in designing parameters since it was the closest to the design limitations of our competition. [9]

2018 UC Battlebot Team 60lb Competition

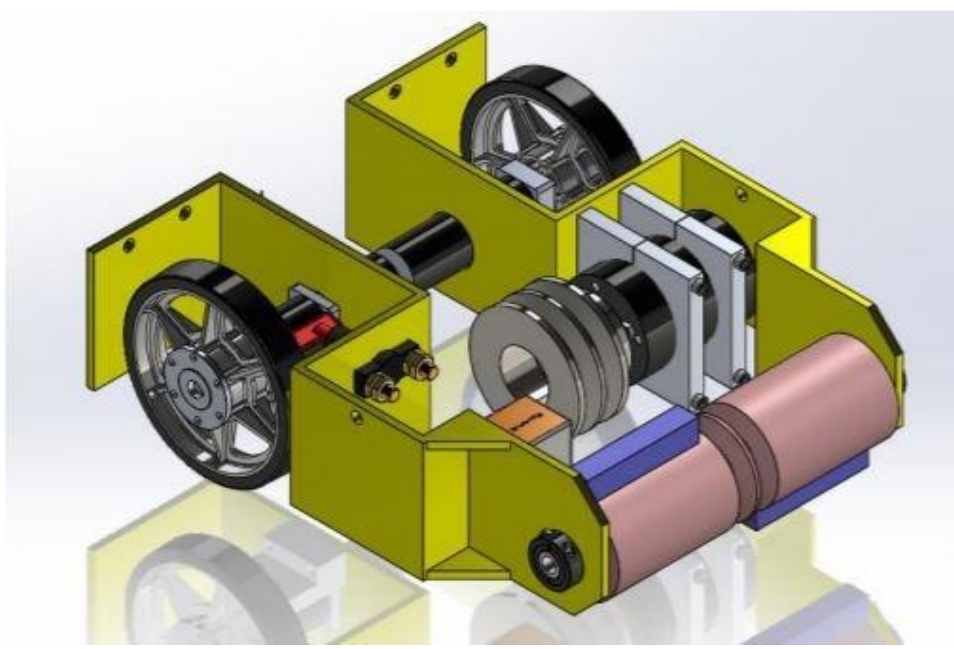
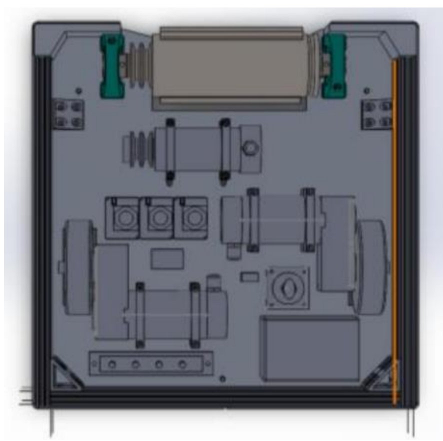


Figure 6. 2019 UC Battlebot Team 60 lb Competition [10]

This team also decided on the two-wheel design to help weight distribution. Using a direct drive system of motorizing each wheel allows for straightforward design which helps in robot repair time, and cost. Like the previous design from the 2020 team, the wheels are located towards the back. The adding weights to the rear combined with the location of the wheels helps increase traction. The wheels are placed within a wheel well, that helps proect the wheels from damage while having easy access to repair. [10]

Frame/Armor:

2016 UC BattleBot Team



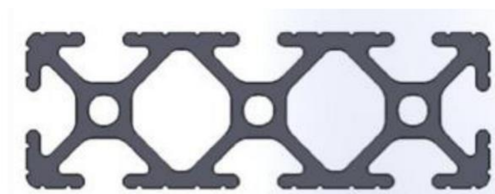


Figure 7. 2016 UC BattleBot Team Figure 8. 2016 UC BattleBot Team [11]

The 2016 BattleBot team utilized 1” thick extruded aluminum (right) to minimize weight while still maintaining strength behind the walls of the bot. Additionally, the top cover was made of one ½" thick sheet of Lexan. Lexan is a clever idea because it is extremely lightweight, however is still tough and durable, known for its high impact resistance. This choice might have become an issue with certain weapons that attack from the top, such as overhead saws and hammer bots, however those are uncommon in competition due to their ineffectiveness against many other more common weapons of choice. A Lexan sheet would likely hold up very well in competition while weighing much less than aluminum, though a thin layer of a harder material over it could possibly help protect against shearing forces. [11]

2018 UC BattleBot Team

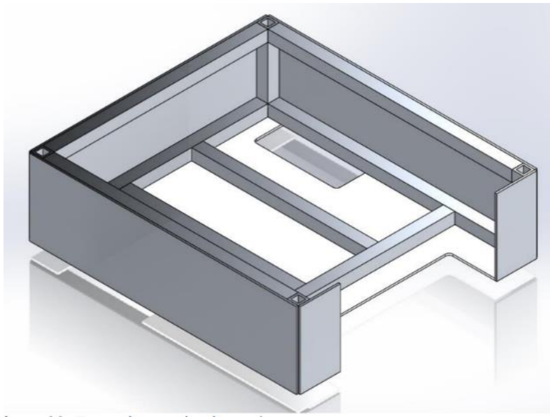
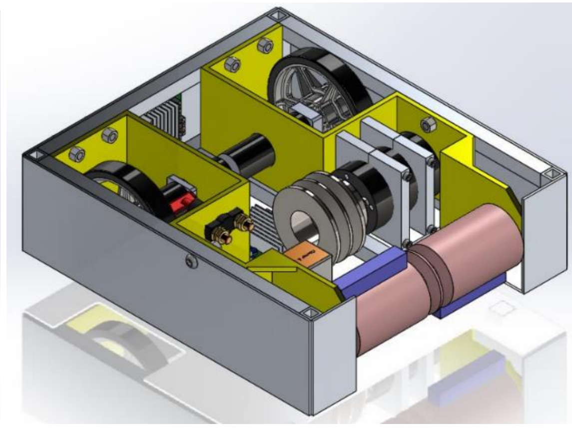



Figure 9. 2018 BattleBot Team *Figure 10. 2018 BattleBot Team [10]*

The 2018 BattleBot team chose to utilize an aluminum 6061 box frame made up of ¾" tubing covered in 1/8” plate with an additional ¼" aluminum internal rail assembly support system. The team added additional frame tubing mount to support and reinforce the internal rails. Overall, the internal rail did a great job holding everything in place and protecting individual components. It adds quite a bit of weight being ¼" sheet, but being in a 60lb weight class it became a worthwhile compromise. [10]

2019 UC BattleBot Team

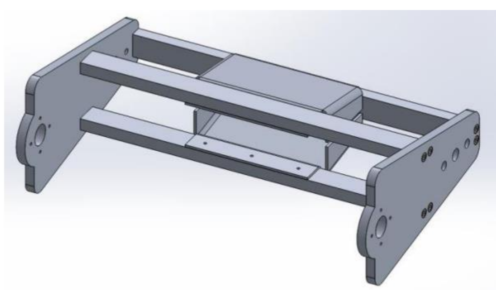
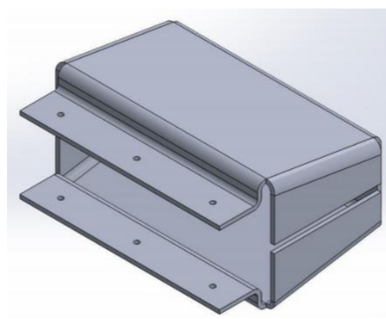



Figure 11.2019 UC BattleBot Team *Figure 12. 2019 UC BattleBot Team [7]*

The 2019 BattleBot team decided to go with a 7075-T6 frame and 6061-T6 armor. The team bolted it together to make it easier to access and swap out internal components easily. While it is important for consumable parts to be easily accessible, bolts can shear off relatively easily if the armor isn’t otherwise well attached and supported. Additionally, with the structure of the armor being essentially a 6061 outer shell, it is at high risk for bending or denting with impact. This could pose an issue not only to the internal components if it were to deform, but also could be easily jammed in such a way to make it difficult to remove in order to access components. This risk could potentially be minimized by making the armor consist of more than one piece so that in the event of a crash it can be removed in pieces rather than need to be pried off. [7]

END USER

For battle bot and beetle bot competitions, teams compete with their bots to see which bot has the optimal design. The teams consist of multiple members who will create their battle bot and use it in the competitions. Often teams will re-design past robots from previous competitions. Ultimately, the goal is to win the competition. The user will need to have a background in mechanical and electrical systems to design a successful bot. For our specific beetle bot, we are the end user, since we will make and compete with our bot. The competition will be held at UC, and we will compete with other teams in the battle bots club. We must design a bot to satisfy all design criteria, stay in budget, and put on a good show. Our goal is to win against the other 4-5 beetle bot teams.

CONCLUSIONS AND SUMMARY OF RESEARCH

For this project, our goal is to design the best beetle bot with the resources we are provided and win the UC Battle bot club's competition. We have studied past designs to understand what components work well and should be included in our design. Current solutions have not been successful because they often rely heavily on one specific weapon, which removes the focus on other parts of the bot.

Many of the weapons were too heavy or large which negatively affected the overall weight balance. The best way to optimize the design is to find a balance between the weapon and the overall design, so they successfully work together. Many past weapon designs consisted of some variation of drum spinner or a large wedge to flip the underside of opposing bots. The bots that performed better in competitions had a combination of the two designs, utilizing a mixture of smaller wedges and a large yet narrower drum spinner. Additionally, bots that did not perform well lacked components that can replaced during matches.

Many drivetrain designs are kept simple as seen above all three designs decided on using direct drive on two wheels. This is due to the nature of the competition to keep the robot easy to use. Making sure to keep it consistently reliable, easy to control and easy to repair keeping costs down on this aspect allowing to focus the resources more on the goal, destroying the opponents with the weapon.

In conclusion, with the advancement of technology and the aging of this sport there are many design decisions that must be made from collection of the currently applied techniques. However, most drive train design are kept simple and easy to allow costs and repair time to remain low. This allows the robots maneuverability to be easy to use and the robot to be reliable.

QUALITY FUNCTION DEPLOYMENT

Based on the survey we conducted on the week of September 21-28, we determined the importance and level of satisfaction for current beetle bot designs. We asked people familiar with battle bot and beetle bots to get accurate responses. Additionally, we asked a couple of specific technical questions for our design process. We received 31 responses to our survey, which helped determine customer features (see Appendix A for sample survey).

CUSTOMER FEATURES

Weighted on a scale from 1-5

1) Beetle Bot Safety - 5

2) Ease of use - 4

3) Maneuverability - 5

4) Durability - 5

5) Ease of repair between rounds - 4

6) Speed - 4

7) Size - 2.5

8) Cost - 3

9) Weight Distribution - 3

ENGINEERING CHARACTERISTICS

1) Beetle Bot Safety - Shut down time (Seconds)

    We will design a system to shut down within 3 seconds of turning off. This will allow a quick stop in case of an emergency. We can add an emergency stop switch to solve this problem.

2) Ease of use – Age of operation (Years old)

    This bot is designed to be user friendly. We will make the controls intuitive to the user. Ideally, users aged 13 and older should easily understand how to control the bot.

3) Maneuverability - Turnability (Degrees/Second)

    The bot will be designed to turn quickly when attacking other bots and defending itself. We will add an adequate motor to control the maneuverability. We aim to design the bot to turn 90 degrees per second.

4) Durability – Armor material toughness (Newtons)

We will design the bot to withstand attacks. To do this, will make sure the frame is secure by analyzing stresses in Solidworks. We will choose a strong but light material for the frame, like Lexan.

5) Ease of repair between rounds - Time to repair (Seconds)

Parts that will need to be replaced between rounds will need to be easily accessible. This will allow a quick turn over rate to change damaged parts. Our goal is to change out parts within 60 seconds.

6) Speed - Velocity (Meters/Seconds)

We will need a powerful motor to achieve our desired speed of 1 meter per second. We will choose one to fit this requirement.

7) Size – Volume (Cubic Centimeter)

There is no firm limit on size, but we will have to stay withing the 1.5 kg weight category. This means, out bot will have a smaller volume compared to past years battle bot projects. We will try to optimize space to avoid going over the weight.

8) Cost - Dollars ($ USD)

We have a budget of $340 for our beetle bot. To stay within budget, we will choose materials and electrical components wisely. Additionally, we will try to use free materials within the battle bot's club to save on costs.

9) Weight Distribution – Center of Mass (Centimeter)

Our weapon will have to remain balanced with the rest of the bot. To solve this problem, additional weight like the electrical components will be placed in the back of the bot to keep the center of mass in the middle of the bot.

10) Weight – Overall Weight (kg)

To meet beetle bot fighting criteria, we must stay within the weight limit, which is 1.5 kg.

11) Appearance – Number of Customizations

We will offer a couple of different customizations for the user. This can help improve the appearance of the bot. This will very in color and style.

12) Traction – Force (Newton)

With a smaller bot, we will need to make sure it has enough traction between the wheels and the floor. We can change this by trying different tire types to see which one has the best traction.

13) Weapon Speed (Revolutions/Second)

When picking a motor, we will choose one which can power the weapon powerfully. The weapon will need to spin at a high enough speed to disable the other bots.

House of Quality

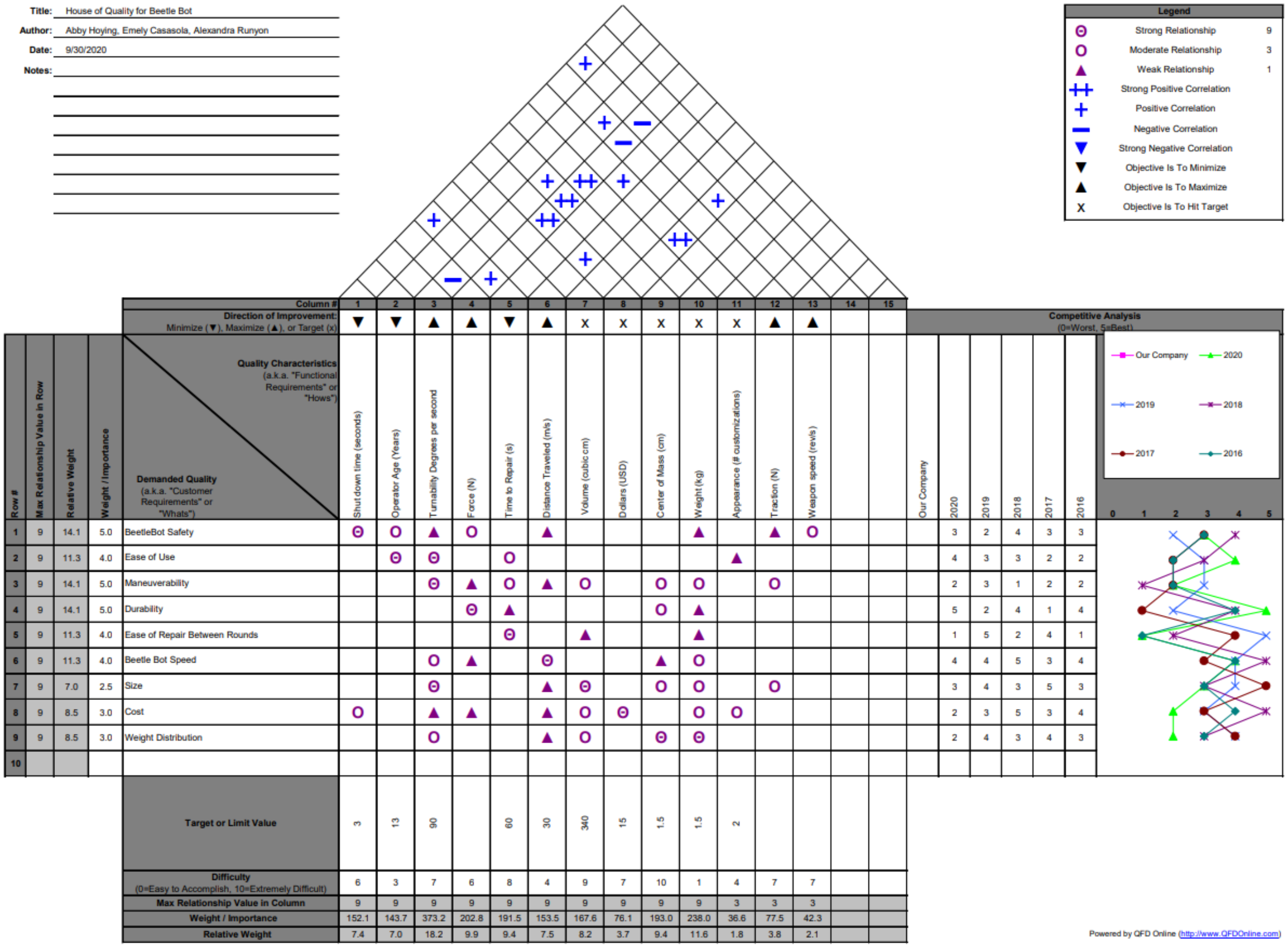


Figure 13. Full House of Quality

Product Objectives

1) Beetle Bot Safety - (7.4)

2) Ease of use - (7.0)

3) Maneuverability - (18.2)

4) Durability - (9.9)

5) Ease of repair between rounds - (9.4)

6) Speed - (7.5)

7) Size - (8.2)

8) Cost - (3.7)

9) Weight Distribution - (9.4)

10) Weight - (11.6)

11) Appearance - (1.8)

12) Traction - (3.8)

13) Weapon Speed - (2.1)

DESIGN

DESIGN ALTERNATIVES AND SELECTION

Concept 1: Drum spinner with wedged frame

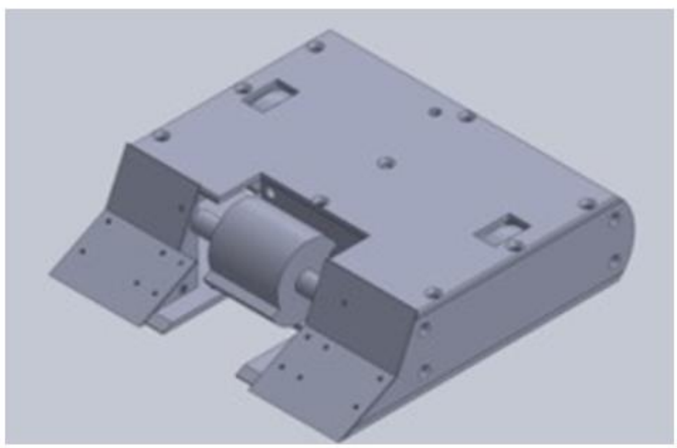


Figure 14. Concept #1

This concept has protected wheels, a wedged box frame, and utilizes a drum spinner. It is designed to combine a simple wedge with the main weapon, while still protecting the bot and creating maximum internal capacity for drive train components. This design prioritizes durability by truly blocking off all access points to the internal components of the bot. The overall short, flat shape maximizes even weight distribution to prevent flipping. The frame will be composed of 3D printed components to minimize material weight while maintaining durability.

While durability is the main strength of this concept, maneuverability could potentially be impaired by the additional armor that was added to protect the wheels from impact. The simplicity of the frame will make the manufacturing process easier and more cost effective, and the shape will make it much easier to quickly access internal components between rounds for repair. Out of the three concepts, this design scored highest on the weighted matrix.

Concept 2: Horizontal spinner

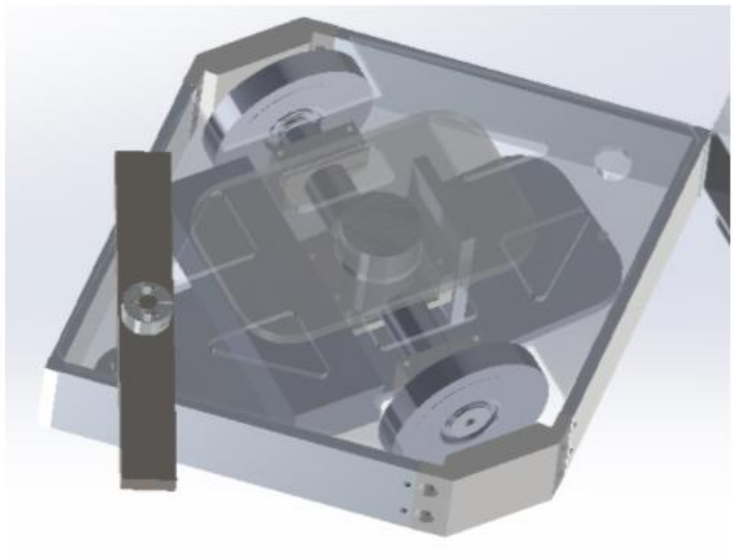


Figure 15. Concept #2

Our second concept has encased wheels, a triangular frame, and a horizontal spinner for the weapon. There are two wheels which are fully encased withing the frame. This was intentional to prevent damage to the wheels by other beetle bots. The drive train is also fully encased withing the bot. The frame is triangularly shaped to target the opposing bots head on, with the horizontal spinner at the tip of the triangle. Additionally, this shape will help the bot escape tight spaces, if pushed by an opposing bot. Originally, the horizontal spinner has pointed ends, but after considering the small size of the beetle bot, we decided it will add too much extra weight without adding enough offense capabilities. The bar will be machined and made from aluminum. The frame will be 3D printed using PLA filament, and it will be printed in a high in-fill percent. This will allow the frame to be dense and sturdy, but not add too much weight, since PLA is used.

This concept scored lower on maneuverability because you must hit a bot head on to cause damage. It could be difficult to turn around, and it always must face the other bots. Additionally, it is not very durable because the weapon can easily be damaged, since it sticks out, and broken off the frame. There are concerns with weight distribution since the spinner and drive train are towards the front of the bot. Extra weight must be added the backside to evenly distribute weight. The bot can have a high speed since the spinner acts as a gyroscope, accelerating the bot. Overall, this bot scored the lowest compared to our other concepts and it was not chosen for our final design.

Concept 3: Wedge

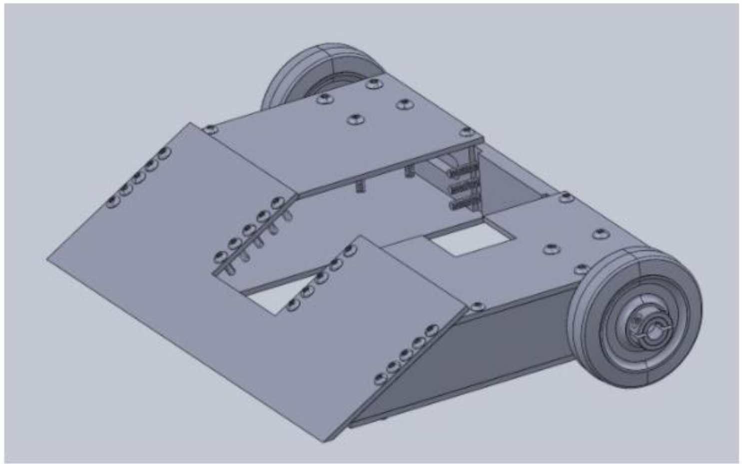


Figure 16. Concept #3

The third concept uses a simple wedge as the primary weapon. This is designed to slide under the opponent causing them to flip and/or lose control of their robot. All internal components are protected from damage by the outer armor. It would primarily be made from plastic panels to keep costs down and make the manufacturing process easier. The wheels are located outside of the frame, making repairs easier during competitions if needed. The wheels would be a hard plastic with rubber treads. This design would keep the weight minimal while maximizing traction.

This design scored in the middle because the simplicity of the design increases the safety factor. It has less room for error, is easy to repair, and simple to operate. While this design is very practical, the weapon design does not cause as much damage to opposing bots but rather plays a defensive role in competitions. Additionally, this design results in difficult maneuverability, which can become a large hinderance in fast paced competition.

Rating	**Value**
Unsatisfactory	0
Just Tolerable	1
Adequate	2
Good	3
Very Good	4

Decision Factor	**Weighted Importance**	**Drum Spinner w/ Wedge and Encased Wheels**		**Horizontal Spinner w/ Encased Wheels**		**Wedge with Wheels on Outside**	
-	-	Ratin g	Weight Rating	Rating	Weight Rating	Rating	Weight Rating
Beetle	0.141	3	0.423	2	0.282	4	0.564

Bot Safety							
Ease of Use	0.113	3	0.339	3	0.339	3	0.339
Maneuverability	0.141	3	0.423	2	0.282	2	0.282
Durability	0.141	1	0.141	1	0.141	4	0.564
Ease of repair between rounds	0.113	2	0.226	2	0.226	1	0.113
Speed	0.113	4	0.452	3	0.339	2	0.226
Size	0.07	3	0.21	1	0.07	1	0.07
Cost	0.085	3	0.255	3	0.255	2	0.17
Weight Distribution	0.085	3	0.255	2	0.17	2	0.17
Total	1	NA	2.724	NA	2.104	NA	2.498

Table 1. Selection Matrix

Looking at the decision matrix, concept 1 has the largest score. This concept incorporates the use of two weapons, protected wheels and flat box shaped frame with small wedges. The use of a drum and wedges allows the robot to be versatile. It can play offensively by causing damage with the drum and play defensively with the wedges. The drive train consist of two wheels each power by its own motor which allows the operator to individually control each wheel making it easy to drive. Since the frame is a flat box it helps evenly distribute the weight and the direct drive give the robot great maneuverability. The frame completely protects the robot and is made of different panels of material that are secured to the frame by screws. Repairs will be smooth since the panels can quickly be removed by a power drill. The armor will be made of 3D printed panels that keeps costs low while having the luxury of painless personal customization.

Design Drawings

Beetle Bot Design

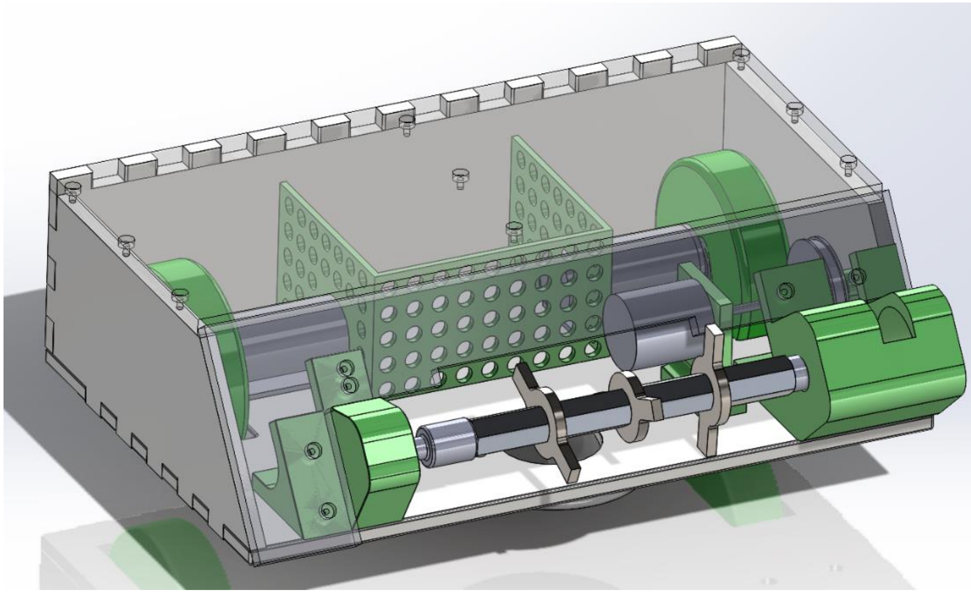


Figure 17. Final Beetle Bot Design

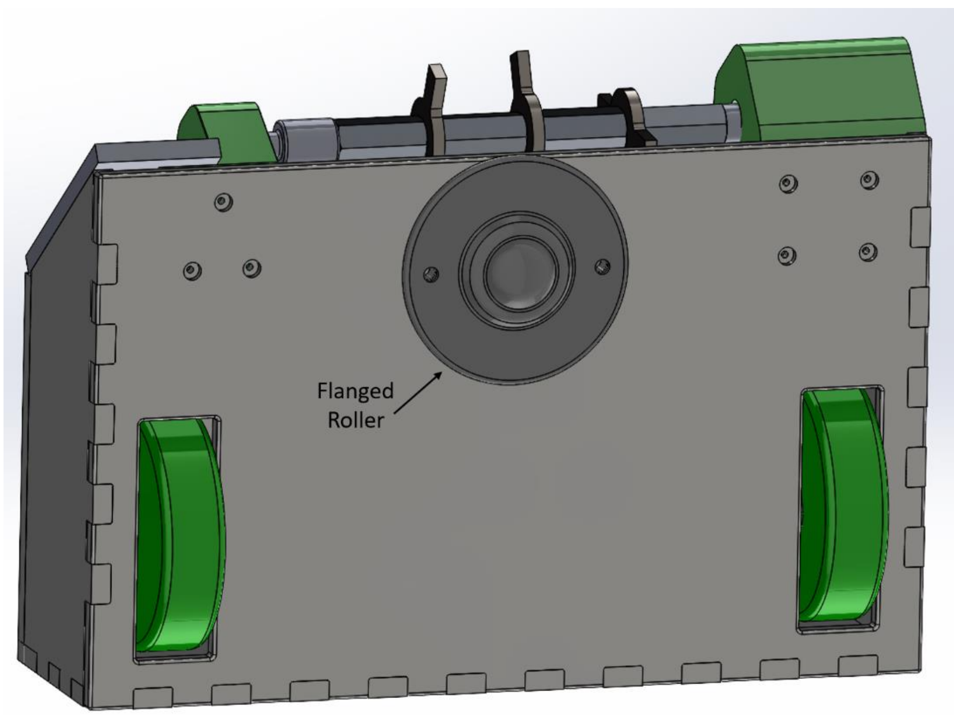


Figure 18. Final Beetle Bot Design Bottom Side

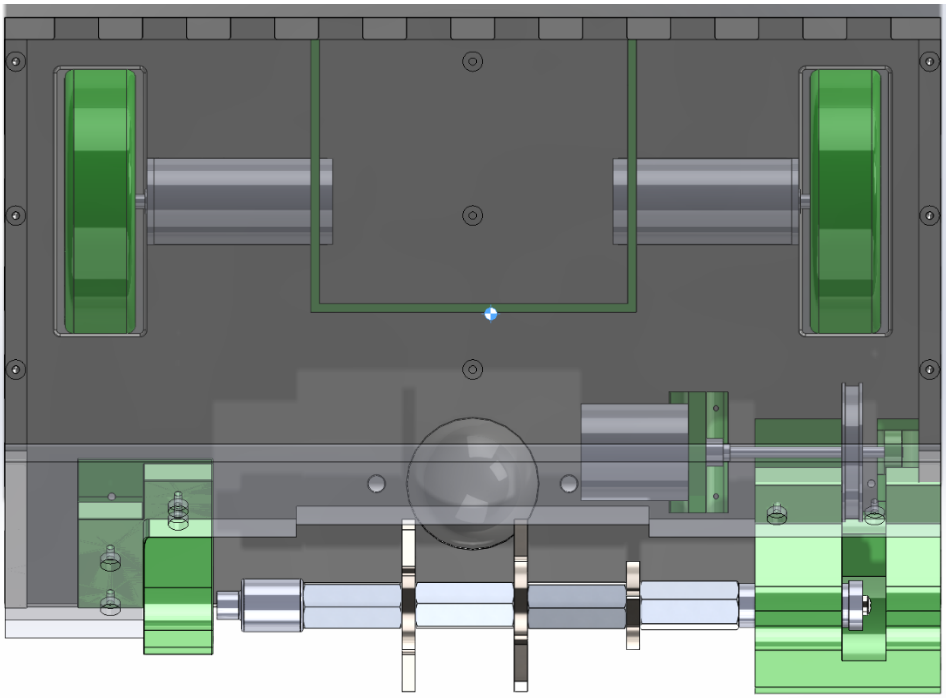


Figure 19. Center of Mass

The final design for our beetle bot is shown in *Figure 17* and *Figure 18*. *Figure 17* shows the bot while looking at it from the front left view, and *Figure 18* shows the underside of the bot. The final design includes a drum spinner combined with a wedged frame, and encased wheels within the frame. The wheel placement was decided on after researching other designs and finding that it is common for wheels to be damaged in competition from side impact. All the other components are safely stored in an internal structure away from impact as well as any internal moving parts. *Figure 19* shows the center of mass for the beetle bot. The components were balanced in a way such that the center of the mass is towards the middle of the design, minimizing the risk of being overturned during impact.

Weapon

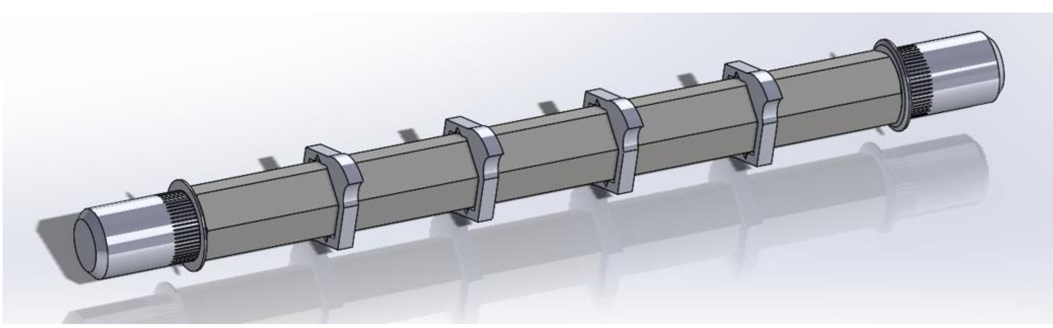


Figure 20. Original Weapon Design

The weapon selected is a modified drum spinner, seen in *Figure 20*. For the shaft, it is made up of 5 hex coupling nuts. There is a threaded screw running through all 5 shafts which connects them together. To ensure the screw does not move, we will apply an epoxy between the screw and the hex coupling nuts. The epoxy is specifically designed to bond pieces of aluminum together. For the part of the weapon that will apply damage, there are 4 blades which slide onto the shaft. The blades will be strong enough the withstand high stresses. To keep the blades in place, they will have a small cutout between the blade and the hex coupling nut where several small keys will be inserted. This will ensure the blades do not move and are fully secured.

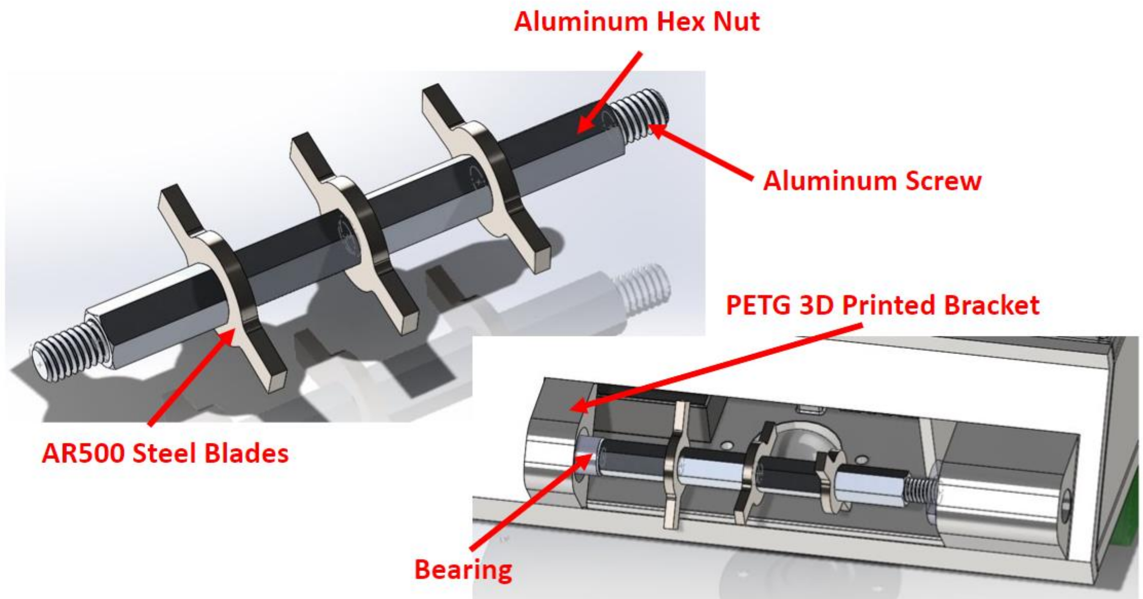


Figure 21. Weapon Re-Design

A few modifications were made to the weapon design. I felt the weapon blades did not stick out enough to attach opposing bots, so I extended the length of the blades. Additionally, I was concerned about the pointed tip of the original design fracturing if hit on the tip, so I created a more supportive design in Solidworks. Since this used more steel, which weighs more, the number of blades was reduced to three and the number of hex coupling nuts was reduced to four to keep the weight in range.

Mechanical Power Transmission Systems

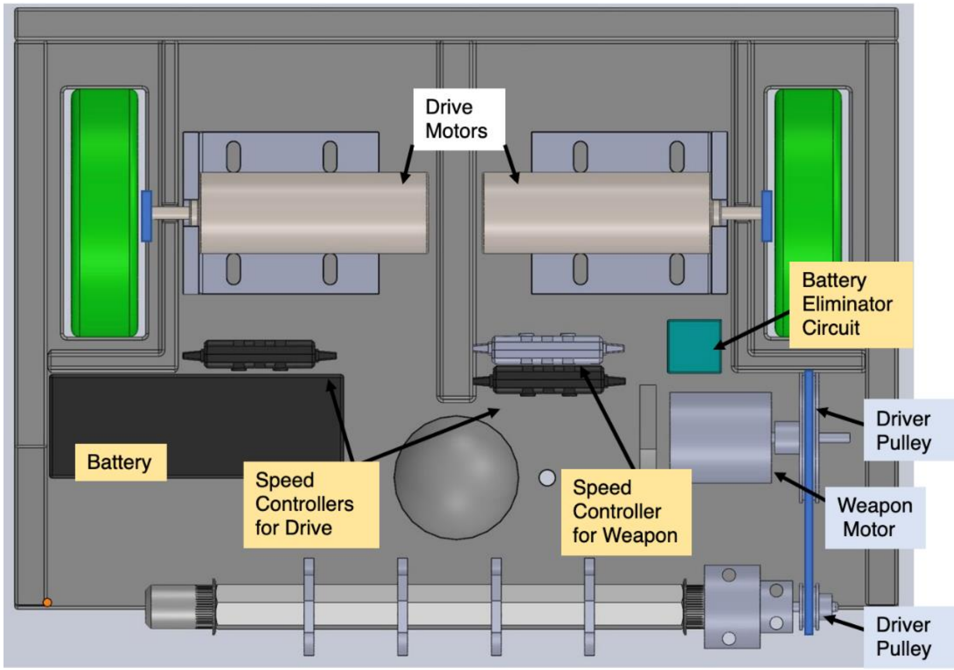


Figure 22. Drive Train Design

The drive train for this robot is a simple design that maintains balance and weight distribution through three points of contact. The two-driving wheels are located towards the rear-end of the robot's body, each is powered by a 12V DC 1000 RPM motor. The wheels have tire treads made of a rubbery plastic material with cut outs which helps grip and increase traction. The third point of contact is from a Hudson bearing, specifically a flanged ball transfer that rotates freely. The white boxes show the drive motors. The yellow boxes are the main electronic components used to electrically power the drive train which is then transferred into mechanical power to drive the robot.

The light blue boxes are the main mechanical components of powering the weapon of the robot. The weapon is powered by a brushless motor that is connected to a pulley system. The pulleys have a 2:1 ratio where the driver pulley is a little more than twice the diameter of the follower pulley. This is to increase the RPMs of the weapon to get the highest speed of the end tip of the weapon without exceeding the competitions design constraint of 250 mph for weapon tip max speed.

Frame

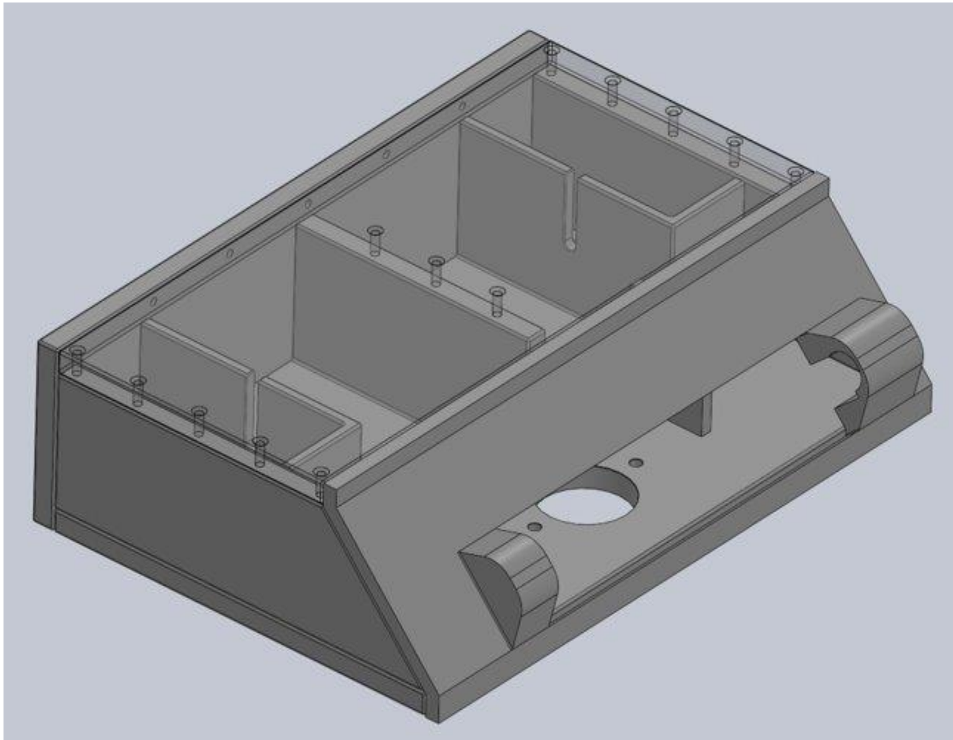


Figure 23. Original Frame Design

For our original design (shown in *Figure 23*), our group decided to go with a box frame with internal wheels and a slight integrated wedge. The boxed frame provides the most efficient space for internal components, and the concealed wheels will keep the bot mobile despite any side impacts. Partitions were added throughout the main area of the bot to help separate and secure components as well as add additional reinforcement to the outer panels. The bottom plate and partitions were determined to be made in one large for structural integrity, with fillets at the base of each partition to eliminate any unnecessary stress concentration.
The outer shell of this frame was decidedly a simple paneled design to allow easy access to internal components between rounds, as well as make manufacturing as easy and cost effective as possible. Countersinks were added to prevent concentrated stress to the frame at attachment points and unnecessary hang-ups during competition due to any protruding hardware.

On this initial design our group decided to go with 3D printing as our primary manufacturing strategy. This was decided due to two of our group members owning 3D printers at home, making our workspace safe and accessible during the COVID-19 pandemic. For filament, we decided to go with PETG as opposed to PLA due to its higher strength and greater impact resistance.

Once manufacturing of the panels was underway, an issue was discovered when 3D printing the panels. As the printer worked at the extreme area limits of the print bed, complications arose resulting in distortion and poor print quality. This was a major issue because these areas would create weak spots at the seams in the paneled assembly. One possible solution was to break up the panels into smaller sections, but this was quickly ruled out due to the reduced durability. To solve this problem, we decided to change our manufacturing method from 3D printing to machining due to the accuracy and durability of the completed product as well as the convenience of having CNC and knee mills at our disposal despite the pandemic. This change in manufacturing method resulted in several design changes.

Due to the nature of switching from additive to subtractive manufacturing, our material needed to be purchased in solid panels instead of filament. This opened our options up, resulting in our primary material switching from PETG to polycarbonate due to the drastic increase in strength and durability, slight decrease in weight, and maintained easy machinability. Additionally, our design would need to change for assembly and machinability purposes. Slots and tabs were added to the edges of each panel to distribute applied forces and reinforce the seams, with the intention of adding plastic bonding epoxy. The biggest redesign, however, would be required in the front panel. The contours of the initial design would've been tricky to print, but were nearly impossible to machine using conventional methods. To fix this issue, we decided to use our already purchased PETG filament to create weapon caps to mount and secure the weapon in place at each end. These would also double as mounting brackets to secure the front panel to the rest of the frame, which would have been difficult to do with slots and tabs while maintaining the wedged shape. This change allowed our front panel to be created out of polycarbonate sheet as well. Working with sheet stock also required our internal support structures to be divorced from the bottom panel, however due to the added strength of the new design we decided to replace the structures with one lightweight 3D printed unit to contain the electrical components. All these changes culminated in the final frame design, shown in *Figure 24*. Note that all polycarbonate components are represented in grey, and all 3D printed components are shown in green. Top, front, and left panels are made transparent for clearer view of bottom plate and internal structures.

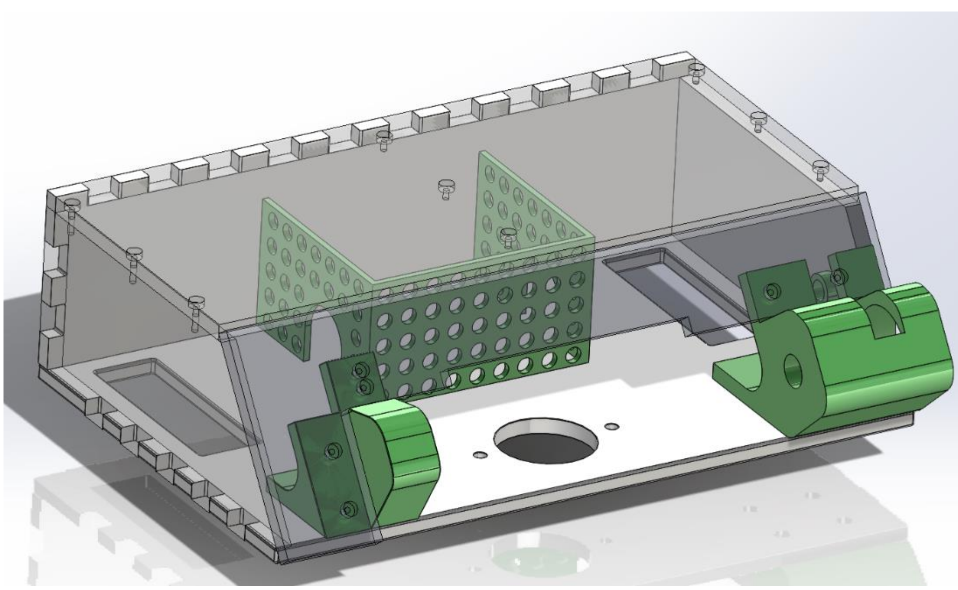


Figure 24. Final Frame Design

Component Selection
Weapon Components


Figure 25. Screw

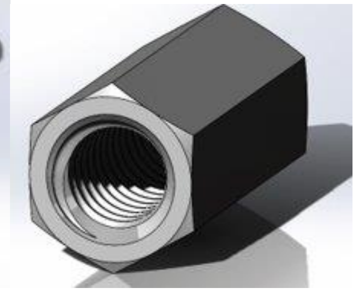


Figure 26. Hex Coupling Nut

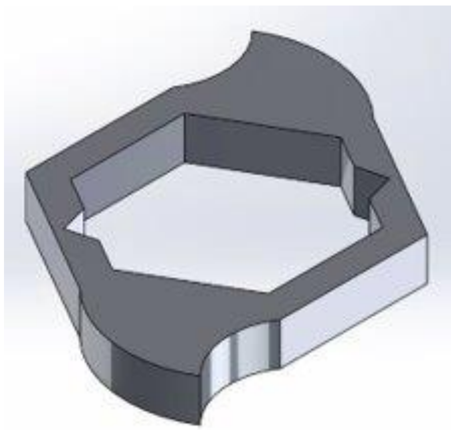


Figure 27. Blade

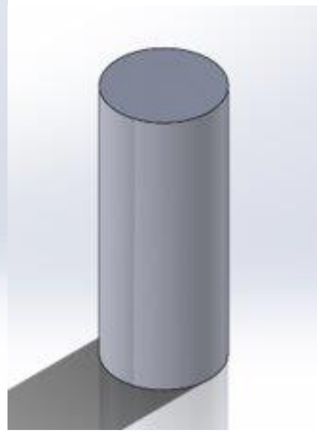


Figure 28. Key

There are 4 different components which will be assembled to form the weapon. Aluminum coupling nuts will be used as the drum's body as seen in *Figure 26.* Each hex coupling nut is 28.57 mm, and we will use 5 nuts in our design equaling a weapon length of 142.87 mm. The drum's diameter equals 12.7 mm, which is thin enough to fix well on the frame. Aluminum was chosen as the metal since it is strong but lightweight. Since we are restricted with a weight limit, choosing aluminum allowed us to save weight overall. The nuts will be connected by a long 152 mm screw, seen in *Figure 25.* The nuts are threaded so the screw will easily screw in and secure the nuts. The blades (*Figure 27.)* will slide onto the outside of the nut, and they will be made from steel. Steel was chosen because it is stronger than aluminum, and we decided since larger forces will be applied to the blade, a stronger material should be selected. Lastly, the key (*Figure 28.*) will be inserted between the blade and the nut. This will secure the blade and ensure it will not move while spinning.

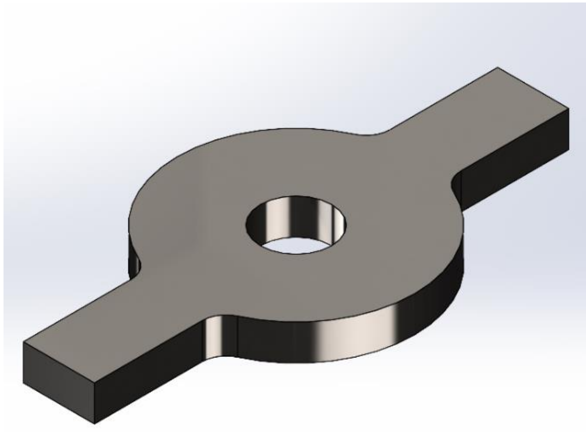


Figure 29. Blade Re-Design

In the weapon re-design, the blade in *Figure 29.* was used to replace the blade in *Figure 27*. With the change in weapon blade design, the key was no longer needed and was not used.

Mechanical Power Transmission Systems

Drive Train System

Figure 30. Motor

Figure 31. Shaft Mount

Figure 32. Wheel

Figure 33. Custom Wheel Hub

Figure 34. Hudson Ball Transfer

The drive train of the robot has five main mechanical components. The motor shown in *Figure 30.* is a 12V DC motor, with 1000RPM. The wheel shown in *Figure 32.* is a rubbery plastic wheel with hollow sections through the tire tread. This design allows the wheel to flex with applied force of the robot and increases traction. The wheel and motor are connected by the shaft mount shown in *Figure 31.* and the custom wheel hub shown in *Figure 33. Figure 34.* is the Hudson ball transfer that is located in the front of the robot mounted to the bottom plate to give the robot a third point of contact.

Weapon Power Transmission System

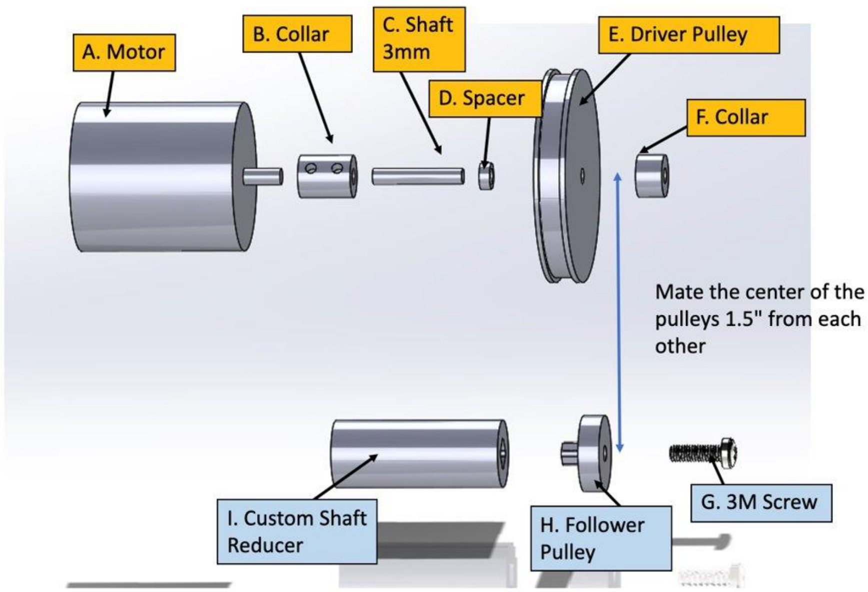


Figure 35. Exploded View of Weapon Power Transmission

The weapon is connected to the custom shaft reducer shown in *Figure 36 as part I.* This piece must be custom made for the robot because this pulley system is connecting to the weapon. The entire weapon itself is an original piece using a mixture of stock components parts from McMaster and custom parts. This figure shows how the motor is connected to the drive pulley system. The weapon power transmission system is powered by a DC brushless motor that gives 11,000 RPMs at the shaft. We want the weapon speed as fast as possible to cause the most amount of damage to opponents. The pulley system has a ratio of a little over 2 which will help double the RPMs delivered to the weapon.

To accomplish this system there were three components that were custom made from aluminum to keep costs and weight down. Part B in the figure connected the motor shaft which had an outer diameter of 3.175mm to the driver pulley shaft which had an outer diameter of 3mm. The next components were connecting the follower pulley shaft to the weapon shaft. Part I the custom shaft reducer had three designs concepts. The first design idea was having two parts that clamp onto the weapon shaft and the pulley shaft. The two halves are secured by screws and nuts that feed through the holes. The issue with this design is that it does not prevent slippage, which would result in a crucial failure of the entire purpose of this pulley system. This design is also bulky which adds weight to our robot. Since we are working with the beetle weight criteria of 1500 grams every little component makes a significant contribution. Concept 2 is a simpler design which transmits power by locking the pulley together with custom shaft reduce using a key. The collar of the pulley fits into the shaft reducer and it held in place by a key. Since we are working with small components a worry that the stressed produced by spinning the weapon would cause the key to break within the parts or creating a fracture in the pulley collar. It is also difficult to mill the key slot in the pulley collar because it was such a small cut out. Concept 3 is the final design that we went with. The pulley collar is milled from the original circle shape to a square. The shaft reducer has a square hole which the pulley interlocks to. By doing this there is no need for a shaft since the pulley is mechanically locked into place to the shaft reducer. There is a taped hole on where the square hole is milled to insert a screw after the pulley is fixed to secure the two parts together. On the other side of the shaft reducer is another taped hole that threads onto the weapons threaded shaft. This design was picked because it was the simplest, which meant most cost efficient and lightest.

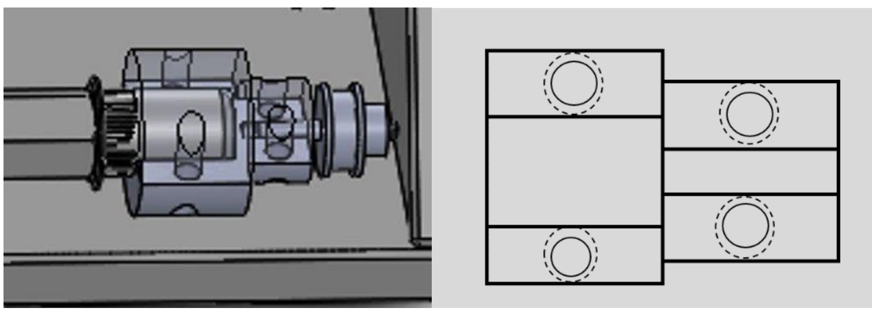


Figure 36. Custom Shaft Reducer – Concept 1

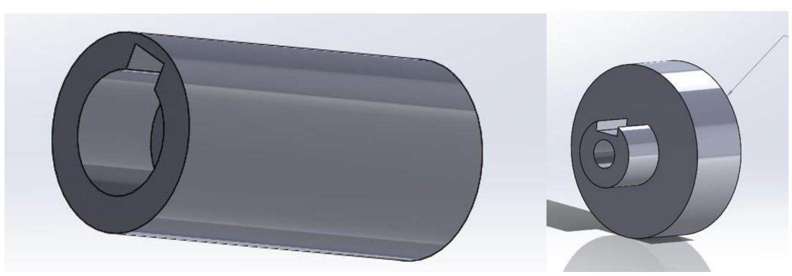


Figure 37. Custom Shaft Reducer – Concept 2

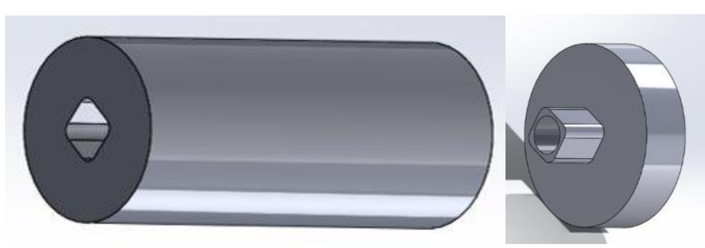


Figure 38. The Final Custom Shaft Reducer Design – Concept 3

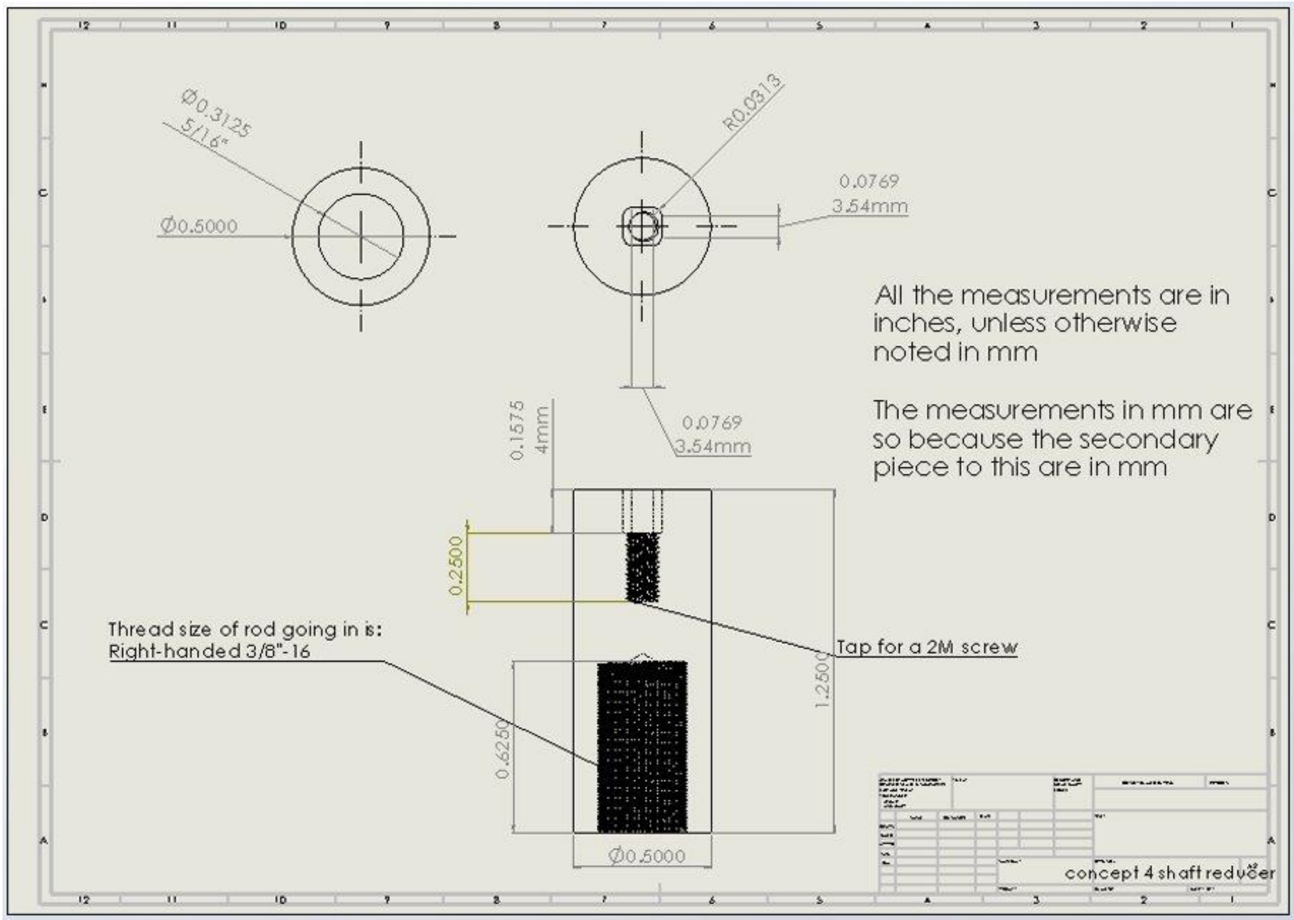


Figure 39. Drawing of Final Design for Part I

A brushless motor was selected for our weapon power transmission system because it operates more efficiently. A brushless motor functions through a magnetic field that pulls current from the battery to power the motor. Because of this it can handle kickback very well. It adjusts to any inference the motor might experience which helps prevent damage to the internal components. Compared to a brushed motor which is more susceptible to stripping when it experiences damage because it does not adjust it continues pulling power. Since our weapon will be experiencing consistent damage, brushless motor was the best option for us.

Remote Controller Components

There are other electrical components which are not included in the drive train but are in the remote controller. These components include the battery eliminator circuit, the receiver, and transmitter. The remote controller is our transmitter, which allows us to control the bot. The RC controller has a 4-channel transmitter, so we can control the beetle bot in 4 different way. We only 3 of the channels, which control each wheel motor, and the weapon motor. The channels are connected to the ECS which change each motor’s speed. Our circuit is at 11.1 V and the receiver needs to between 4-6 V, so we are using a battery eliminator circuit to bring the voltage down to 5 V. This allows us to safety use the RC controller. In the electrical diagram in Figure 30, it shows how we will wire the electrical components.

Electrical Diagram

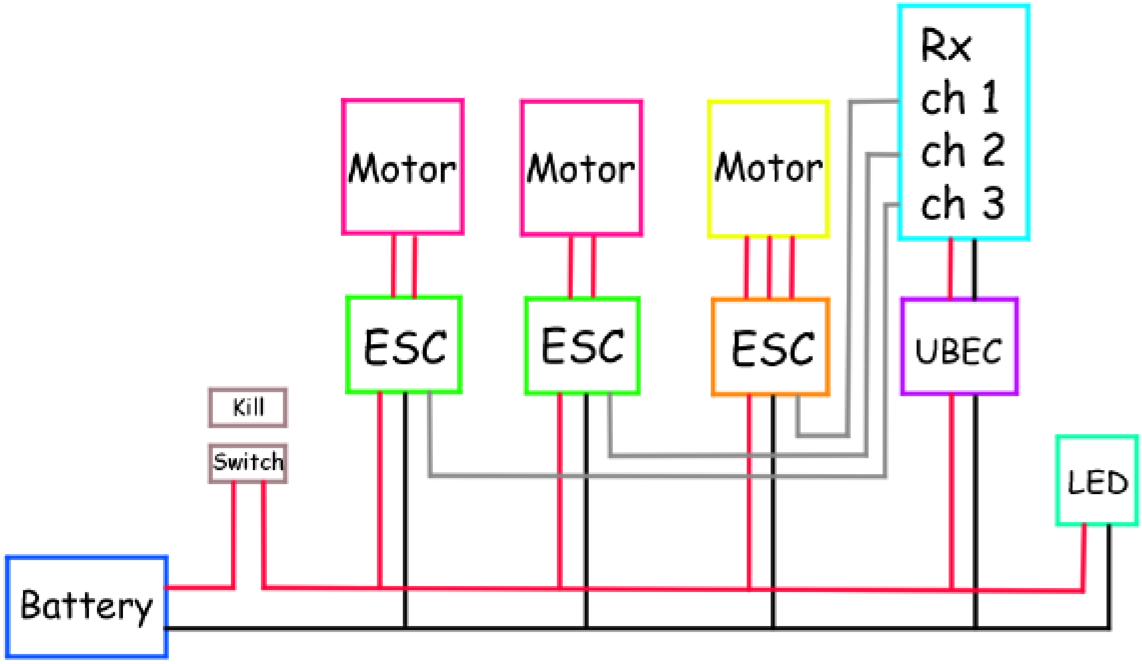


Figure 40. Electrical Components

Safety Components
There are several safety features which we must include in our design. To verify the beetle bot is full turned off, and there is no risk of it turning on and injuring someone, we are including a kill switch. We are using the FingerTech 40A Mini Power Switch by Finger Robotics. This switch is designed for small and lightweight applications. It can be turned on and off by twisting a screw which disconnects the two metal sides and kills the circuit. This will allow us to turn off the bot by using an Allen key, which means we do not have to take apart the bot every time we want to fully kill power. Another safety feature we included is an LED light to notify anyone that the beetle bot has power and is on. This is meant to be a visual to notify anyone going near the bot that it is on and could potentially hurt you. Lastly, we must include a lipo bag to safety store our lithium polymer battery when it is not in use. The battery is rechargeable, so it must be taken out of the bot when the battery is low. To assure the battery does not explode or catch on fire, it must be kept in the lipo bag, which is fireproof.

Frame Components

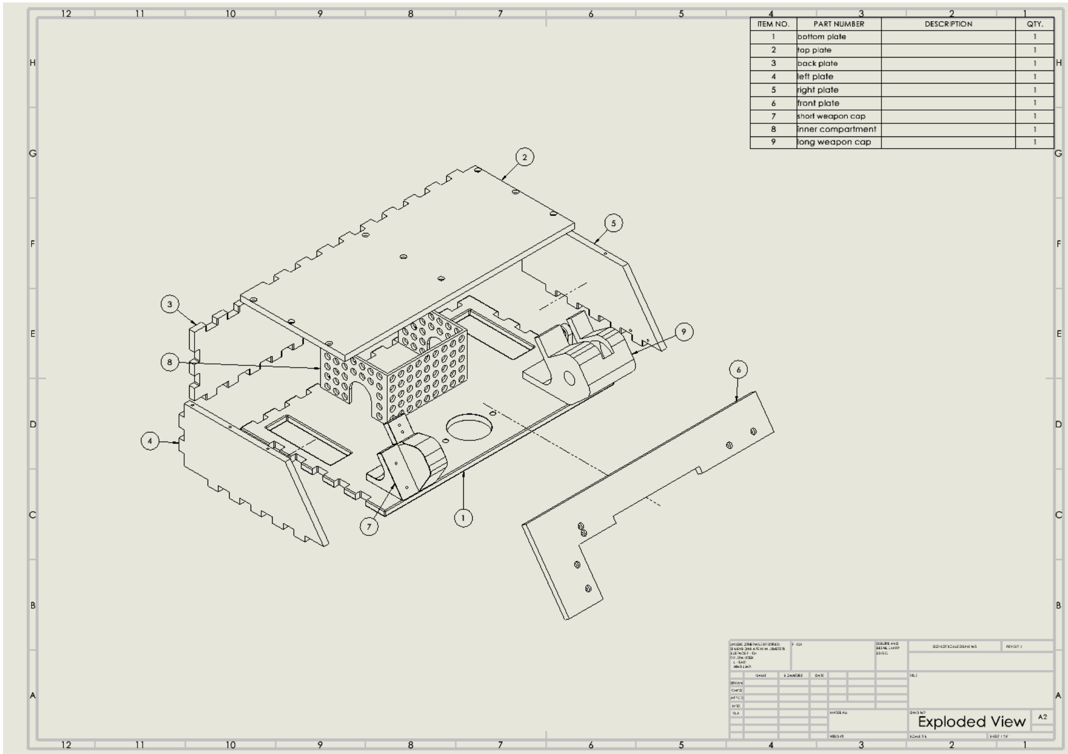


Figure 41. Frame Exploded View

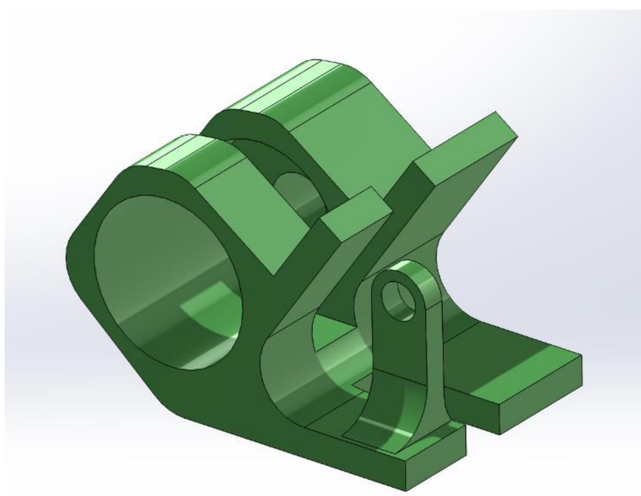


Figure 42. "Long Weapon Cap"

The frame of the robot can be broken down into 9 main components as shown in the exploded view drawing in *Figure 41*. Components 1-6 as listed in the bill of materials are outer panels that were milled out of Lexan Polycarbonate. They were fitted together using slots and tabs that were reinforced with JB Weld Plasticweld epoxy. The top plate, rather than being epoxied to the other plates was screwed on using zinc plated #4 torx screws so that it could be removed and reattached between rounds to make repairs to internal components. Components 7 and 9 were the two weapon caps. Due to the intricate design, they were not readily machinable and thus were 3D printed from PETG and doubled as mounting brackets to attach the front panel to the robot. The “long weapon cap” (component 9) went through several design iterations, eventually resulting in a cutout for the drive pully, a large counterbore to hold a weapon bearing, and was integrated with a mounting bracket that held the shaft between the drive pully gear and the motor. This integration held proper tension on the belt and drastically increased the durability of the bracket.

Stress Analysis

Frame

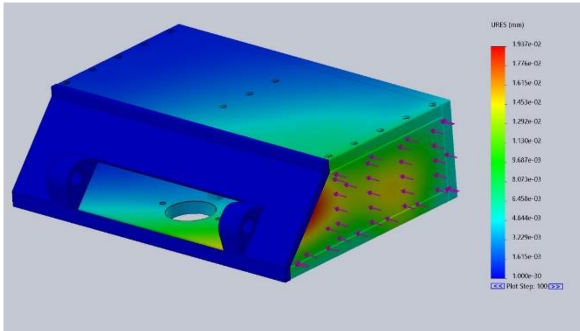


Figure 43. Frame Stress Analysis- Right

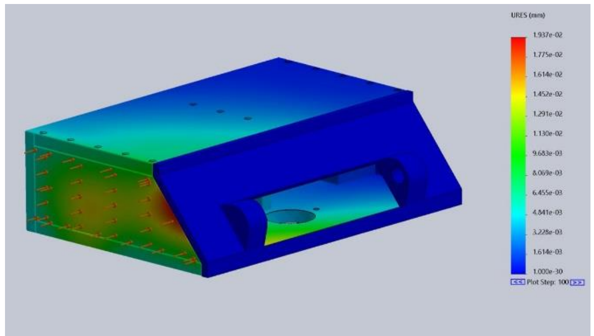


Figure 44. Frame Stress Analysis- Left

The applied stress on the robot’s frame was estimated by considering the weight of a potential competitor’s bot multiplied by acceleration. This came out to approximately 7.84 N. This was applied to the bot assembly using Solidworks’ Stress Analysis simulation, creating the deformation diagrams shown in *Figure 43* and *Figure 44*. Analysis was done on both the left and right sides with the side opposite the forces fixed, simulating the bot becoming pinned against a wall by the competing bot.

Weapon

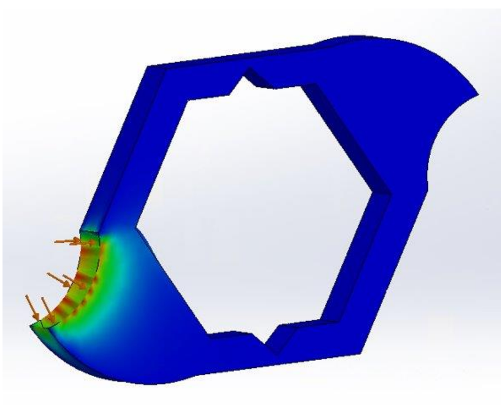


Figure 45. Weapon Blade Stress Analysis

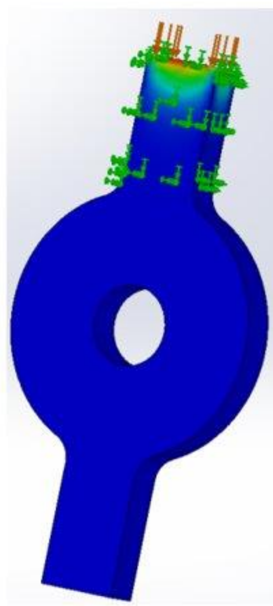


Figure 46. Weapon Blade Re-Design

For the weapon stress analysis, we calculated how large of a force an opposing bot could apply on our bot. We calculated the weight of the other bot multiplied by its acceleration. This equaled 7.84 N. Using the Solidworks' simulation, we applied the force onto the edge of the blade, where it would be hit. *Figure 45* shows the result when the force is applied. We calculated the safety factor of the design when aluminum and steel are used for the weapon. For aluminum, the safety factor is 11.5. For steel, the safety factor is 13.3. Since these are in range or greater than the FOS of heavy-duty shafting (FOS 10-12), we find them acceptable and will use this design for our beetle bot. For the re-design, the same force was applied to the new design as seen in *Figure 46.*

ENGINEERING CALCULATIONS

Loading Conditions
Tensile Strength Steel = 420 MPa
Yield Strength Steel = 350 MPa

Tensile Strength Aluminum = 310 MPa
Yield Strength Aluminum = 276 MPa

Tensile Strength PETG = 68.9 MPa
Yield Strength PETG = 58.6 MPa

Impact force on Weapon

$$Force \ = 0.8\ kg * 9.81\ \frac{m}{s^2}$$

$$= 7.848\ N$$

Force per Square Meter

$$P = \frac{((0.8kg * 9.81\ \frac{m}{sec^2})N}{0.001\ m^2}$$

$$= 7848\ Pa$$

Material Selection
The inner compartment as well as the weapon caps were 3D printed using PETG filament. PETG (Polyethylene Terephthalate Glycol) is a thermoplastic polyester that is commonly used in 3D printing due to its low forming temperatures and high-cost effectiveness. This material was selected due to its relatively high strength and low hardness, resulting in high impact resistance and low risk of cracking. It has low rates of shrinkage when cooling, meaning that when printed, the final product will very close to the specified dimensions.

The outer panels were cut from Lexan, which is a polycarbonate resin thermoplastic. This material was selected due to its ability to undergo significant deformation and withstand heavy impact without cracking. It is very machinable and slightly less dense than PETG, making it both the lighter and stronger choice.

Drive Train Power & Torque Calculations

$Total\ robot\ weight$: $M_r = 1.5\ kg$

$Max\ load$: $M_l = 0\ kg$

$Nominal\ Speed$: $V_n = 5\ \frac{m}{s}$

$Max\ speed$: $V_l = 6\frac{m}{s}$

$Maximum\ slope\ incline$: $k = 0.15$

$Acceleration\ time$: $t_a = 0.2\frac{\frac{m}{s}}{s}$

$Gravity$: $g = 9.81\frac{\frac{m}{s}}{s}$

$Wheel\ Diameter$: $D_w = 0.0762\ m$

$Robot\ Wheel\ RPM$:

$$N_t = \frac{60 * V_n}{\pi * D_w}$$

$$= \frac{60 * 5}{\pi * 0.0762} = 1253.8$$

$Traction\ Force$:

$$F_t = g * k * (M_r + M_l)$$

$$= 9.81 * 0.15 * (1.5 + 0) = 2.27N$$

$Mechanical\ Power$:

$$P_u = F_t * V_n$$

$$= 2.27 * 5 = 11.036\ W\ (total\ for\ both\ wheels)$$

$$P_u\ per\ wheel = \frac{11.036}{2}$$

$$= 5.518\ W = 0.0074\ HP$$

$Torque\ for\ wheels$:

$$t_t = 0.5 * F_t * \frac{D_w}{2}$$

$$= 0.5 * 2.27 * \frac{0.0762}{2} = 0.042\ Nm$$

Pulley Distance Calculations

$$\begin{aligned}&Belt\ Length: && L_b = 0.18m\\&Driver\ Pulley\ Diameter: && D_d = 0.04\\&Follwer\ Pulley\ Diameter: && D_f = 0.0143\end{aligned}$$

$L_b = 0.5\pi\left(D_d + D_f\right) + (2Center\ Distance)$ ***Rearrange to equal center distance***

$$Center\ Distance = \frac{L_b}{2} - \left(\frac{\pi\left(D_d + D_f\right)}{4}\right)$$

$$= \frac{0.18}{2} - \left(\frac{\pi(0.04 + 0.0143)}{4}\right) = 0.0473\ m$$

Battery Calculations

$$\begin{aligned}Max\ current\ Drawn\ &= 3A * 3\ motors * 1000\\&= 9{,}000\ mA\end{aligned}$$

$$Battery\ Usage\ = 9{,}000mA * \frac{3\ min}{60\ sec} = 450\ mAh$$

This is the lowest mAh rating for a potential battery. We selected a battery rated 1,000 mAh since it was the lowest mAh rated battery with the connector plug we needed.

Factors of Safety

$$\begin{aligned}Safety\ Factor\ Aluminum &= \frac{breaking\ load}{effective\ load} = \frac{maximum\ stress}{applied\ force}\\&= \frac{276\ MPa}{24\ MPa}\\&= 11.5\end{aligned}$$

$$\begin{aligned}Safety\ Factor\ Steel &= \frac{breaking\ load}{effective\ load} = \frac{maximum\ stress}{applied\ force}\\&= \frac{420\ MPa}{17\ MPa}\\&= 13.3\end{aligned}$$

MANUFACTURING DRAWINGS

Weapon

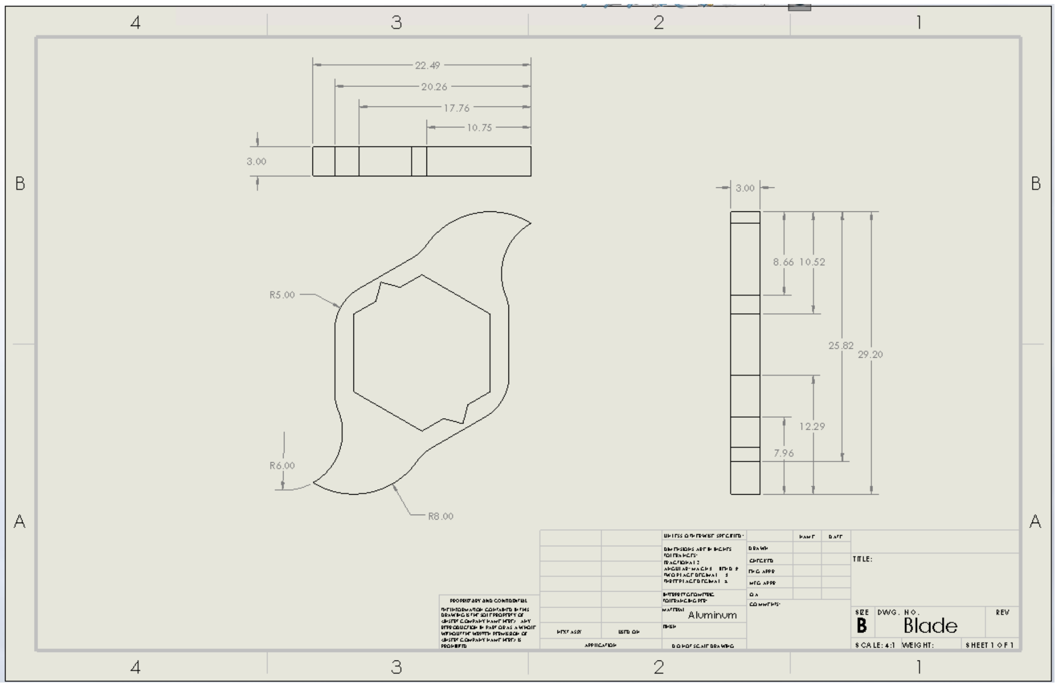


Figure 47. Blade Manufacturing Drawing

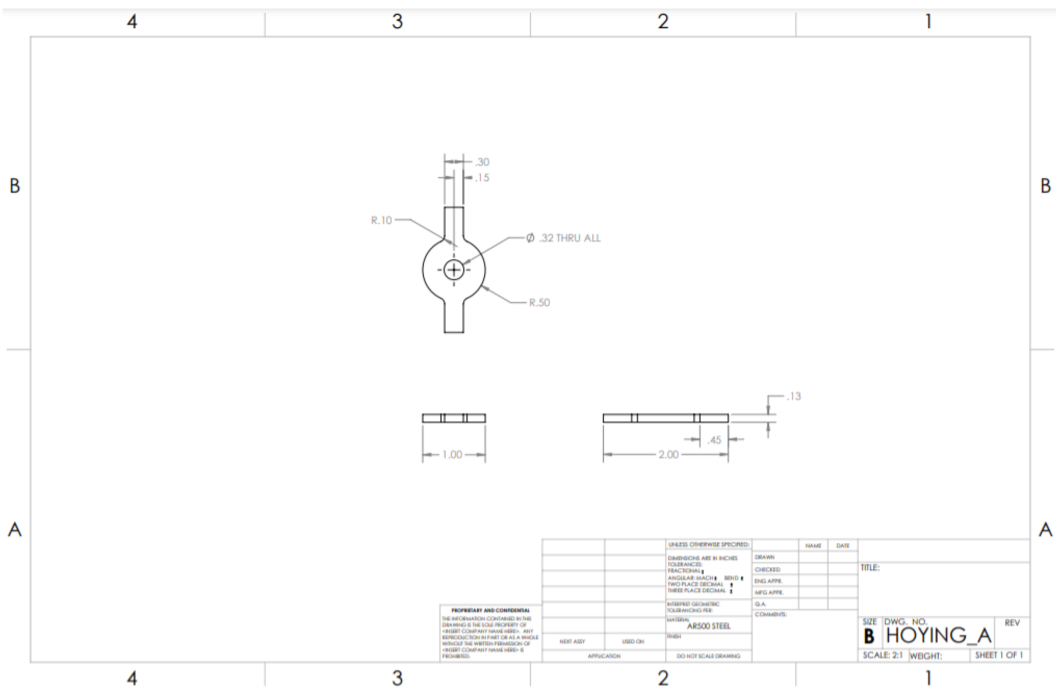


Figure 48. Blade Manufacturing Re-Design Drawing

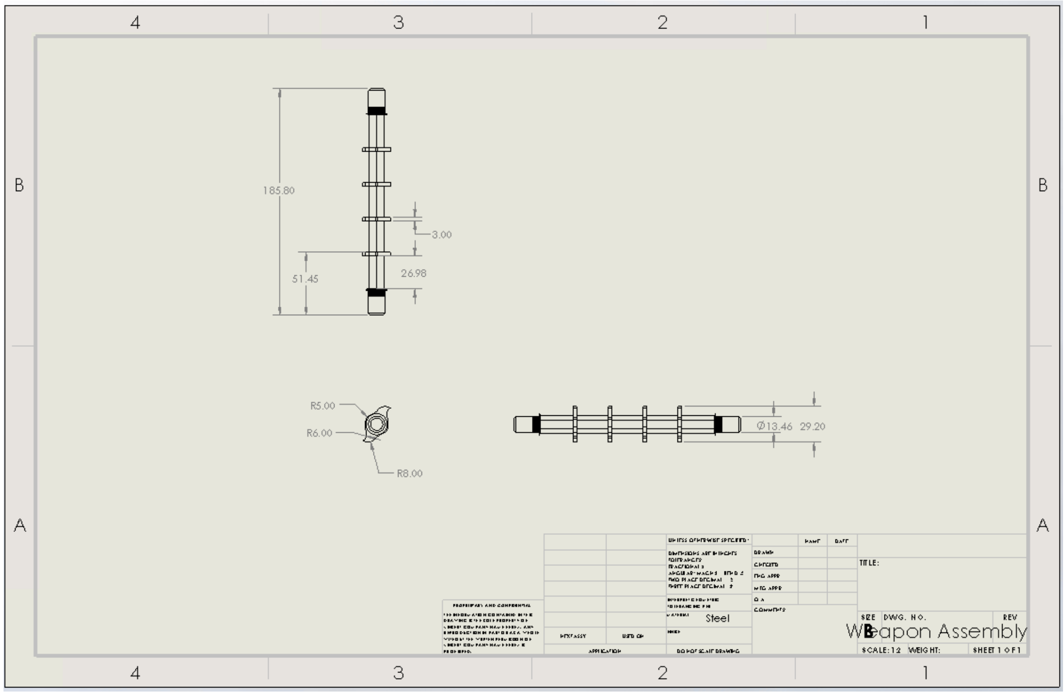


Figure 49. Weapon Manufacturing Drawing

Weapon Power Transmission

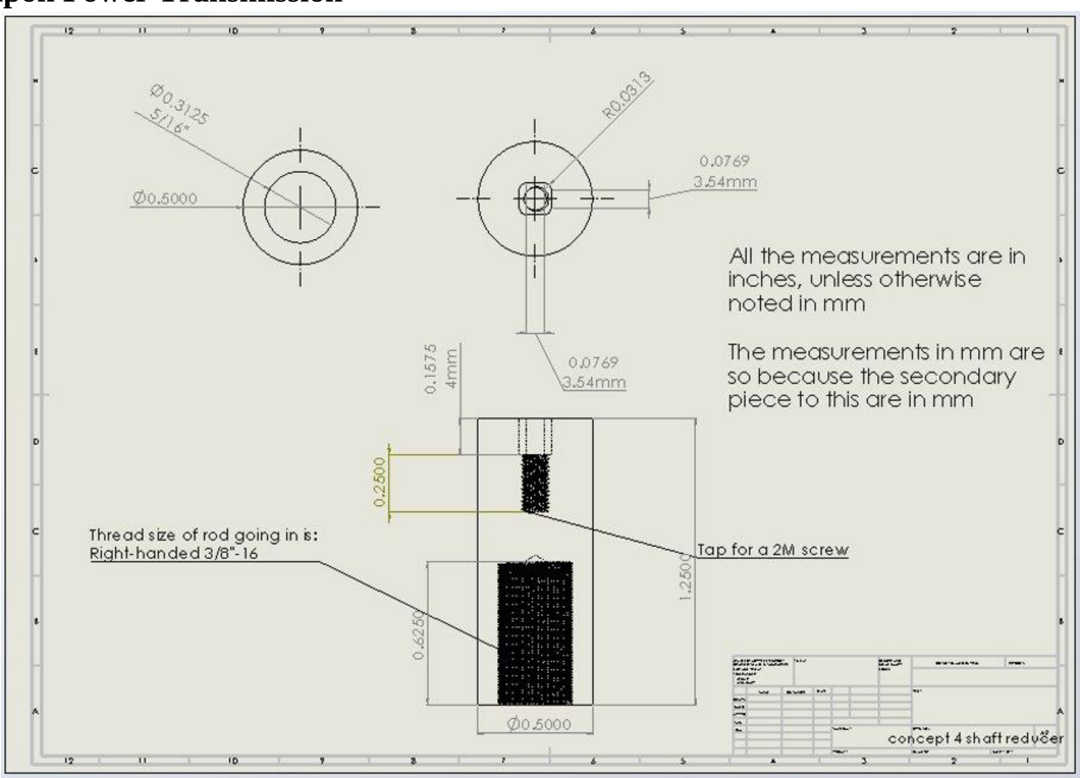


Figure 50. Weapon to Pulley Shaft Reducer Manufacturing Drawing

Frame

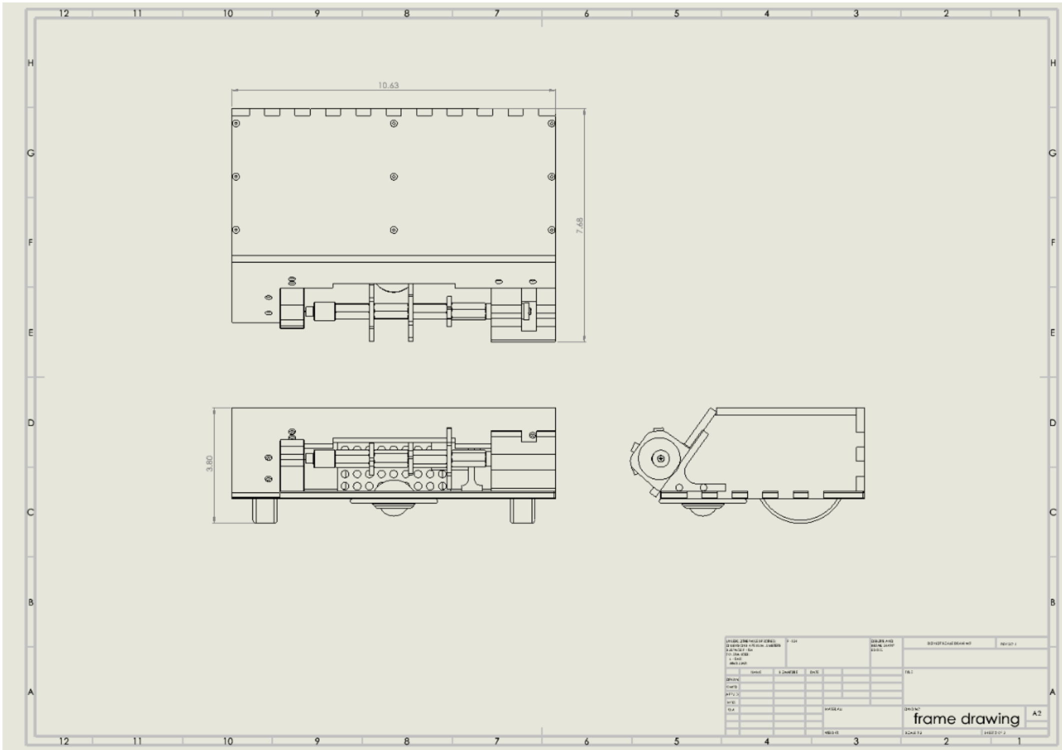


Figure 51. Full Assembly Manufacturing Drawing

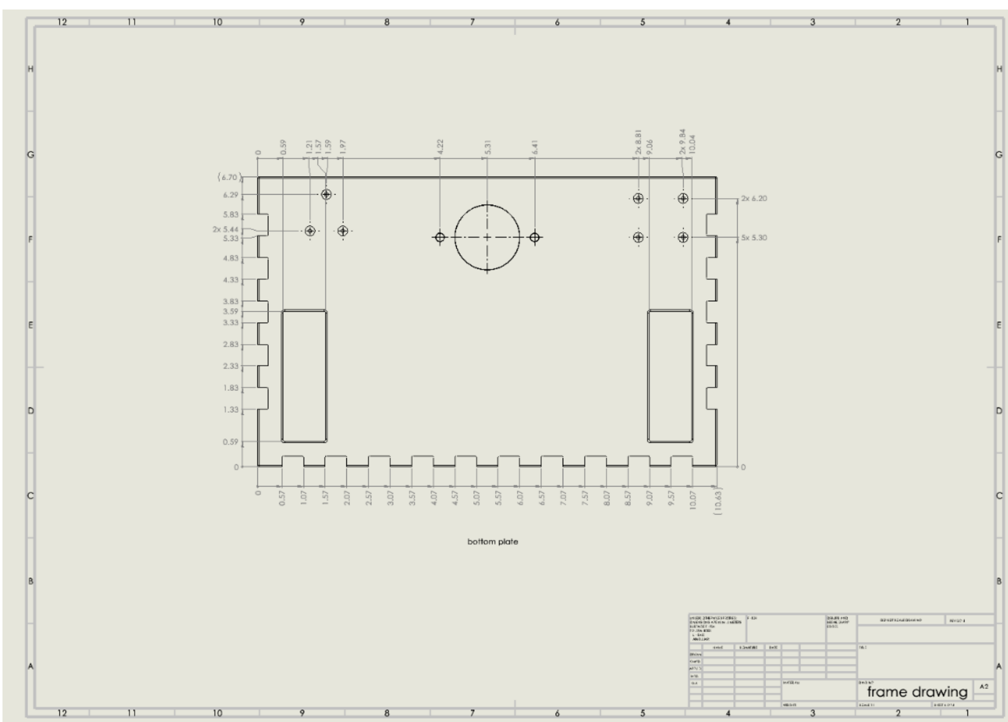


Figure 52. . "Bottom Plate” Manufacturing Drawing #2

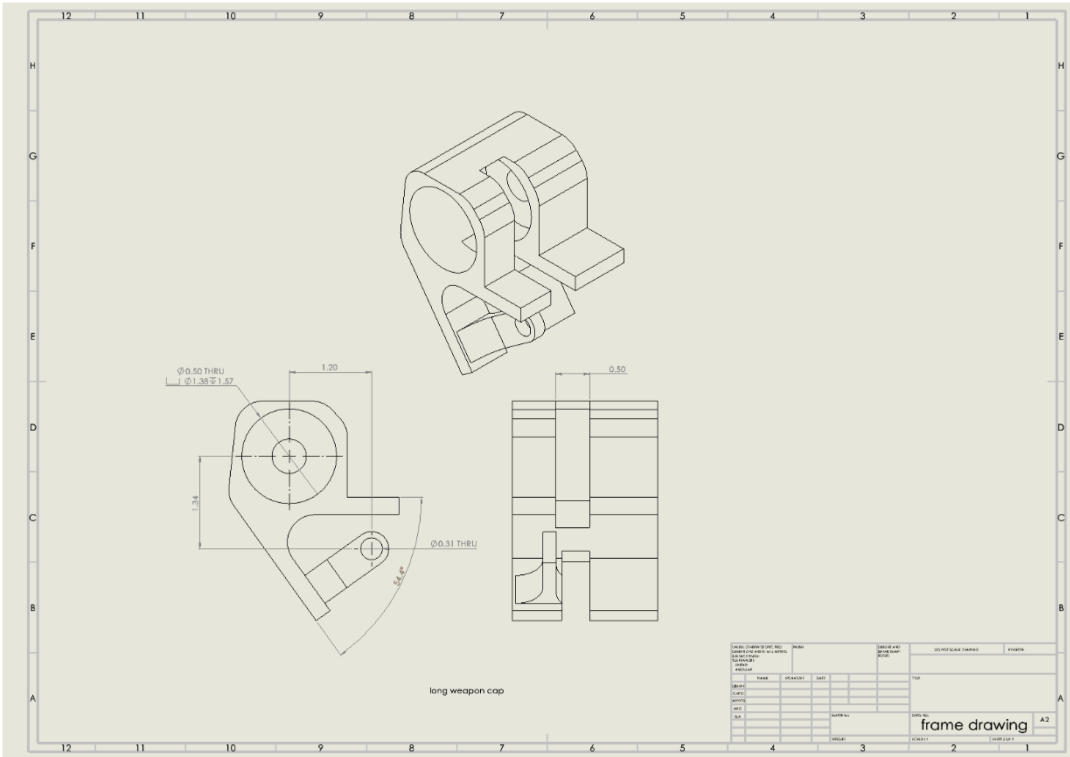


Figure 53."Long Weapon Cap" Manufacturing Drawing #3

BILL OF MATERIAL

Description	Quantity	Price Per Unit	Total Cost
3mm Shaft Collar	1	4.46	$4.46
Spacers	1	4.41	$4.41
Recessed Flange-Mount Ball Transfer	1	9.99	$9.99
Connector for Speed Controller	1	7.99	$7.99
Batteries for RC controller Eight AA Alkaline Cells	1	10.48	$10.48
Stainless Steel Nuts and Bolts Assortment Package	1	17.99	$17.99
Dean Plug for Lipo Battery to Charge	1	7.98	$7.98
Resin	0	0	$0.00
Wheel Motor	2	9.51	$19.02
3mm x 100mm Shaft	1	1.95	$1.95
Weapon Brushless Motor	1	13.55	$13.55
Ball Bearings	1	4.68	$4.68
Brushless Speed Controller for Weapon Motor	1	10.59	$10.59
Speed Controller for Drive Motor	2	12.93	$25.86
Lithium Polymer Battery	1	13.81	$13.81
Battery Eliminator Circuit	1	4.42	$4.42
Receiver/Transmitter	1	27.2	$27.20
Connector for Battery	1	3.41	$3.41
Filament 1.75mm PETG	1	8.46	$8.46
Heat Shrink	1	0.7	$0.70
Lipo Bag	1	2.58	$2.58
Hex Drum	5	5.56	$27.80
Steel AR 500 Material	1	26.13	$26.13
Threaded Rod	1	9.13	$9.13
Key (3 in)	1	5.39	$5.39
Power on light LED	1	0	$0.00
Driver Pulley	1	6.9	$6.90
Follower pulley	1	4.35	$4.35
V-Belt	1	2.17	$2.17
Wheel mounting hubs	2	4	$8.00
Wheel Motor Mounts	2	7.45	$14.90
Wheels (Includes Hub)	2	4.25	$8.50
Kill Switch	1	6.78	$6.78
3mm Shaft Collar	1	8.26	$8.26
Spacers	1	8.7	$8.70
Recessed Flange-Mount Ball Transfer	1	9.99	$9.99
3mm x 100mm Shaft	1	5.29	$5.29
Speed Controller for Drive Motor	2	12.93	$25.86
1819 Cost for Weapon	1	24	$24.00
1819 Cosat for Drive Train	1	84	$84.00
Frame Material	1	30	$30
Bearing	1	7	$7
Total Cost			$522.68

Table 2. Bill of Materials

BUILD AND TEST

DISCUSSION OF THE MANUFACTURING PROCESSES UTILIZED

Weapon

The hex nuts and screw were purchased online since they are standard parts. The steel blades are the only parts which will need to be manufactured. The blades were designed in Solidworks, and we sent asked UC's 1819 Innovation Hub to cut our parts using a water jet machine. This cost a total of $12 for the three blades. The finished cut can be seen in *Figure 54.* Originally Alex was going to thread the blades so they could be screwed onto the long screw throughout the weapon, but due to the strength of the material they could not be tapped without damaging tooling. To overcome this, is sent another job to 1819 with a larger through hole, so they blades would slide over the screw. To secure the hex nuts and blades, JB weld was applied to all parts and threads on the screw. When this dried, it created a sturdy weapon which could effectively hit other bots without breaking.

Figure 54. Weapon Blades cut from 1819 Innovation Hub

Weapon Power Transmission

Everything was first 3D modeled to plan the dimensions, placement, and arrangement of the pulley system. Since we were working with tight parameters this helped experience conflicts before building, yet there were some things that did not go as planned. *Figure 55* shows problems we faced during the build that we did not anticipate. Since we have access to a 3D printer, we were able to experiment with protyping. This was the first print of the long cap component of the armor that was used as a mounting bracket and as a mount for the weapon transmission system. After building we noticed that the original cut made for the pulley was not wide enough so we the space bigger by melting material away until we got it to work well and added material till it created the perfect amount of support. After these modifications we added the changed into SolidWorks shown in *Figure 42* to create the final long cap shown in *Figure 56.*

Figure 55. 3D Printed Bracket

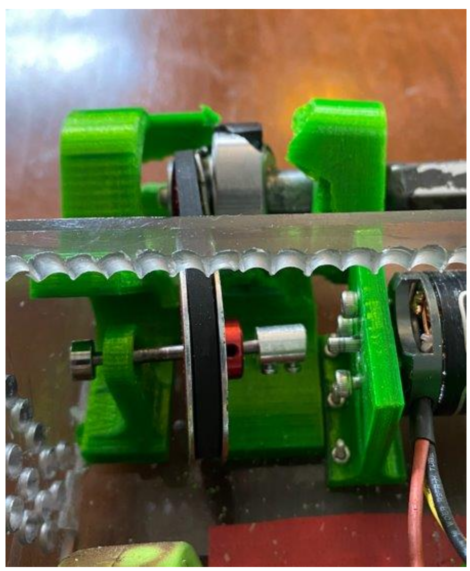


Figure 56. Final 3D Printed Bracket

Frame

When discussing the fabrication options for the robot frame, the team primarily considered 3D printing due to the accessibility of 3D printers despite the COVID-19 pandemic. While this was very useful for the internal structures and weapon caps, the design change to the outer panels meant that each polycarbonate component had to be machined. Rather than pay 1819 to manufacture components which would consume the majority of the budget, Alex was able to program and run all frame components on CNC machines at her work, as well as mill the main power transmission shaft to size with added flats for the set screws via a manual knee mill. Small modifications were made to custom threaded parts at work by hand tapping at the shop, and internal components as well as the weapon caps and inner mounts and brackets were 3D printed on Alex's home printer.

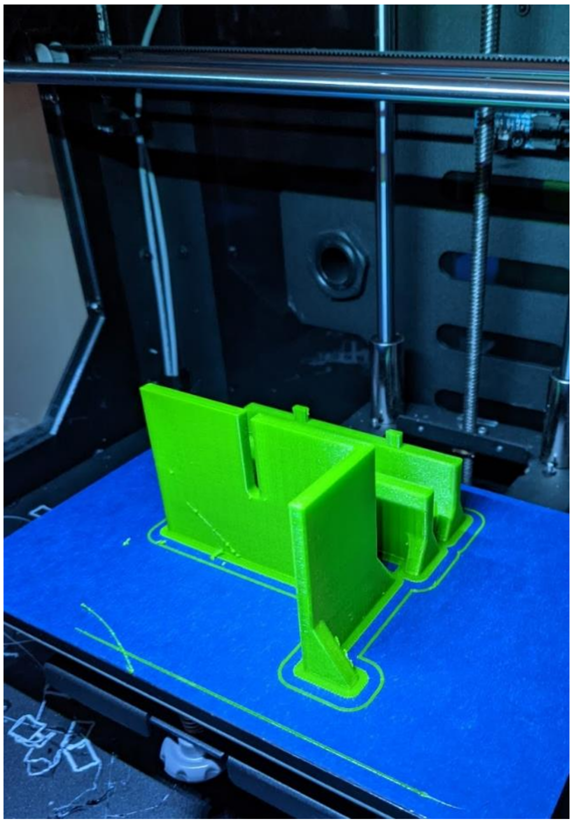


Figure 57. 3D Printing Components

Figure 58. Milling Frame Panels

Electronics

For the electronics, each part was soldered according to the electrical diagram in *Figure 59.* To comply with safety regulations, electrical tape was wrapped around any exposed wires. Additionally, when turning on our battery, we stored in it our lipo fireproof safety page incase the battery exploded.

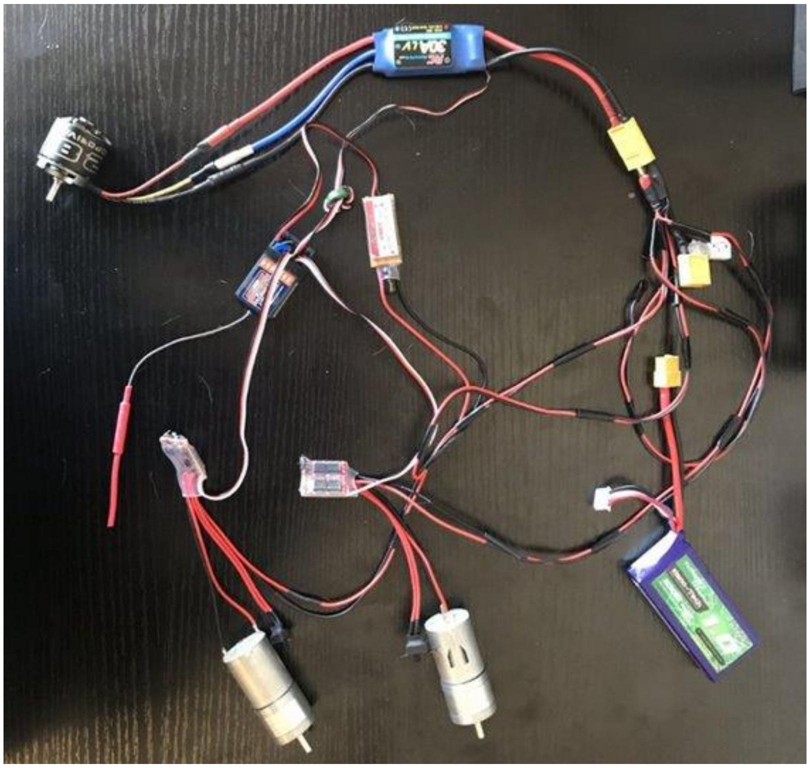


Figure 59. Electronics Assembly

TEST PROCEDURE AND CRITERIA

Before we assembled our beetle bot, we first tested the electrical components. To do this, we combined the components in a circuit and turned it on. This involved soldering and wiring the components together to the motors, battery, EDC, UBEC, and receiver, kill switch, and LED. This test allowed us to make sure all the components run as expected, and if not, we could easily troubleshoot any problems. This follows our highest rated product objective from our QFD which is beetle bot safety. When the circuit ran correctly, we secured the parts in the frame.

To test the PETG 3D printed frame, we ran an impact test to test the frame. This helped us determine if our stress analysis modeling in Solidworks correctly modeled our design. We also tested our frame against different types of weapons to determine if we have weak points. At any weak points in either test, we modified the CAD file and re-printed another frame. We had enough 3D printing filament to print several frames. This follows our durability product objective from our QFD.

Lastly, we tested the weapon to make sure if it will be powerful enough in the competition. To do this, we connected the weapon to the electrical components and run it to determine if it is spinning at an optimal speed. Due to issues in the drive train, we were not able to see the motor driving the weapon. Ideally, we would have ran the weapon for 3 minutes, which is the max duration of a competition round. This will assure us that the weapon can effectively run for a round without any complications. This follows our weight distribution and weapon speed product objective from our QFD.

TEST RESULTS AND FINDINGS

For the weapon, we made sure we met our product objects and voice of the customer. We wanted to make sure the weapon could meet safety requirements and ideal weapon speed, so testing was critical to make sure the weapon did not break upon impact. We knew the coupler between the weapon shaft and bearing was a weak point (*Figure 60.*), so we performed a drop test on that part. As a result, the 3D printed resin coupler broke (*Figure 61.*), and a new solution had to be created. As an alternative to using the coupler, we used a grinding wheel to shave down the shaft diameter and directly insert the shaft into the bearing. This guaranteed the weapon would be strong enough to use in the UC student competition.

Figure 60. Weapon Drop Test Before

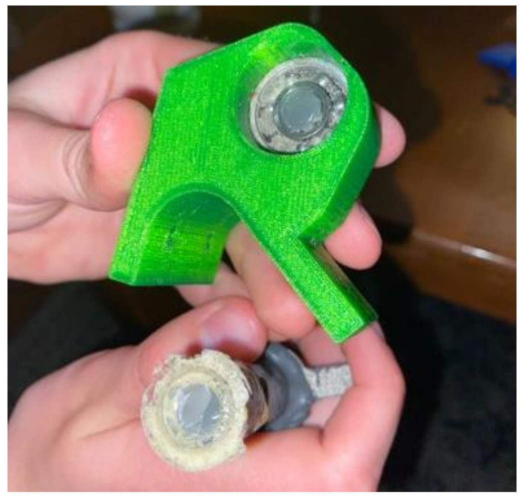


Figure 61. Weapon Drop Test After

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

Description	Quantity	Price Per Unit	Total Cost
3mm Shaft Collar	1	4.46	$4.46
Spacers	1	4.41	$4.41
Recessed Flange-Mount Ball Transfer	1	9.99	$9.99
Connector for Speed Controller	1	7.99	$7.99
Batteries for RC controller Eight AA Alkaline Cells	1	10.48	$10.48
Stainless Steel Nuts and Bolts Assortment Package	1	17.99	$17.99
Dean Plug for Lipo Battery to Charge	1	7.98	$7.98
Resin	0	0	$0.00
Wheel Motor	2	9.51	$19.02
3mm x 100mm Shaft	1	1.95	$1.95
Weapon Brushless Motor	1	13.55	$13.55
Ball Bearings	1	4.68	$4.68
Brushless Speed Controller for Weapon Motor	1	10.59	$10.59
Speed Controller for Drive Motor	2	12.93	$25.86
Lithium Polymer Battery	1	13.81	$13.81
Battery Eliminator Circuit	1	4.42	$4.42
Receiver/Transmitter	1	27.2	$27.20
Connector for Battery	1	3.41	$3.41
Filament 1.75mm PETG	1	8.46	$8.46
Heat Shrink	1	0.7	$0.70
Lipo Bag	1	2.58	$2.58
Hex Drum	5	5.56	$27.80
Steel AR 500 Material	1	26.13	$26.13
Threaded Rod	1	9.13	$9.13
Key (3 in)	1	5.39	$5.39
Power on light LED	1	0	$0.00
Driver Pulley	1	6.9	$6.90
Follower pulley	1	4.35	$4.35
V-Belt	1	2.17	$2.17
Wheel mounting hubs	2	4	$8.00
Wheel Motor Mounts	2	7.45	$14.90
Wheels (Includes Hub)	2	4.25	$8.50
Kill Switch	1	6.78	$6.78
Shipping Hobby King Estimation	N/A	$0.00	$42.00
Shipping Robot Shop Estimation	N/A	$0.00	$5.00
3mm Shaft Collar	1	8.26	$8.26
Spacers	1	8.7	$8.70
Recessed Flange-Mount Ball Transfer	1	9.99	$9.99
3mm x 100mm Shaft	1	5.29	$5.29
Speed Controller for Drive Motor	2	12.93	$25.86
International Shipping Fee	1	3.49	$3.49
International Shipping Fee	1	0.75	$0.75
International Shipping Fee	1	0.71	$0.71
1819 Cost for Weapon	1	24	$24.00
Replacement ESC	1	11.96	$11.96
Replacement ESC	1	11.99	$11.99
1819 Drive Train Parts	1	84	$84.00
Frame Material	1	30	$30
Bearing	1	7	$7
Estimated Cost			$319.58
Total Cost			$598.58

Table 3. Proposed vs Actual Spending

Our actual spending was very different from our proposed cost. We estimated we would spend \$319.58, but we actually spent \$598.58. The differences in cost came from needing to buy replacement electronics since some of our parts became fried, shipping fees for parts, new parts for re-designs, and additional labor costs for jobs at 1819. After subtracting the \$340 budget the club supplied, we ended up spending \$258.58 out of pocket, which was \$86 per person.

SCHEDULE, PROPOSED /ACTUAL

Below is our schedule for completing our beetle bot project. We started the project in Senior Design I, which started in August. We researched the weapon, drive train, and frame, and in October 2020, we reported our research. To gain an understanding of our customer's desires and expectations, we created a survey and 31 people filled it out. With the data we collected, we were able to make a QFD and concept drawings. Then, in senior design II, we calculated values for our beetle bot which helped us select components and materials. We created our final design and presented our findings from Senior Design I and II in December 2020. In Senior Design III, we fabricated, assembled, and tested our final design. We competed in the UC student competition on April 17th and presented our findings at the Tech Expo on April 20th.

Item	**Due Date**	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Senior Design I	9-Oct								
Background Research	4-Sep								
Final Design	18-Sep								
Final QFD	2-Oct								
Concept Drawings	9-Oct								
Senior Design II	6-Dec								
Senior Design Presentation	1-Dec								
Senior Design II Report	6-Dec								
Senior Design III	1-Apr								
Fabrication & Assembly	1-Feb								
Test	1-Mar								
Tech Expo	1-Apr								

Table 4. Overall Schedule

Item	Due Date	Jan	Feb	Mar	Apr
Senior Design III	25-Apr				
Order Parts	31-Jan				
Cut AR 500 Steel	14-Feb				
Solder Electronics	28-Feb				
Test Electronics	14-Mar				
Test Weapon	14-Mar				
Order Replacement Parts	16-Mar				
Assemble Weapon Hardware	28-Mar				
Tech Expo	1-Apr				
Competition	17-Apr				

Table 5. Weapon Proposed Schedule

Item	Due Date	Jan	Feb	Mar	Apr
Senior Design III	25-Apr				
Order Parts	31-Jan				
Cut AR 500 Steel	14-Feb				
Solder Electronics	28-Feb				
Test Electronics	14-Mar				
Test Weapon	14-Mar				
Order Replacement Parts	16-Mar				
Assemble Weapon Hardware	28-Mar				
Tech Expo	1-Apr				
Competition	17-Apr				

Table 6. Weapon Actual Schedule

For the weapon manufacture, assembly, and test, I proposed the schedule in *Table 5.* We faced on issue in January and February because we expected the parts to have arrived by that time. The parts did not arrive until March, which caused the rest of the schedule to be pushed back as seen in *Table 6.*, which shows the actual schedule followed.

SUSTAINABILITY AND MATERIAL USAGE

If the project were to be redone, we would have made the bot overall much narrower and shallower in order to minimize materials used. This would have also lowered the total weight of the bot, allowing more room for reinforcements or modifications. The electronics could have been soldered with lead-free solder which is non-toxic and better for the environment. For the weapon, the screw was cut by 6 inches, so a shorter screw rod could have been purchased to save material and cost.

CONCLUSIONS

For the weapon, I was able to effectively meet our initial problem statement to build a combat beetle robot which competed against other UC student groups. Additionally, it complied with all safety standards set by the Fighting Robots Association. Past senior project weapon designs were researched, and I modeled my concepts from a drum spinner, vertical spinner, and horizontal spinner. Additionally, I looked at incorporating a wedge design in our robot's final design. From the QFD, we decided to focus on safety, weight, and weapon speed for the weapon design. We chose the drum spinner for our weapon and used AR 500 steel for the blades. The rest of the weapon was made from aluminum to keep weight under 1,500 grams. Using a waterjet machine to cut the blades allowed us to create a very smooth finish that was able to strictly stay within tolerance. Since safety is such an important factor in our weapon design, I completed several tests to make sure the weapon safety operates correctly. For the weapon, I believe it met our product objectives, but to improve on the design, I would have a metal coupler fabricated from 1819 instead of trying to 3D print the design. Also, since I was not able to have the blades threaded, I would have picked a softer steel, which could be threaded, so the weapon could have extra support.

Looking at the parts that I led in design and build I am very proud of my work. The drive train was simple so I knew that would not be an issue. But making the weapon work was the hard part of my responsibility. After competition and having our long cap become broken, the weapon worked. This showed that the components that were chosen worked, but that the design could have been better. Somethings I would change if I had a second change to do this is design a way of mounting the pulley system so the tension in the belt could be adjusted to get a better fit. There was a lot of friction within the weapon and pulley system which caused our weapon to not function. I think if we used a 1 to 1 ratio it would have helped increase the torque applied to the weapon.

For the frame, initial criteria were met in all aspects. The frame was able to withstand impact from competition while fully supporting and accommodating all internal components and mounting requirements. If the project were to be done again, our group would likely create the frame with a smaller profile, which would open up more options within the weight constraint for reinforced panels.

During the UC student competition on April 24, we competed against 3 MET groups and one EE group. Our bot finished in fourth place overall. In the initial competition against our first bot competition, we did not win, and we moved onto the secondary bracket. We competed against the robot Hash Slinging Slasher, and after the first collision, both weapons broke on the bots. On our bot, our bearing was cracked, which made it hard for our weapon to spin.

WORKS CITED

1. **John-David Warren, Josh Adams, Harald Molle.** *Arduino Robotics .* [Ebook] New York, NY : Springer Science+Business Media, 2011.

2. **Atherton, Kelsey D.** Technology. *Popular Science.* [Online] Popular Science, June 19, 2013. [Cited: July 28, 2020.] https://www.popsci.com/technology/article/2013-06/elaborate-history-how-wedges-ruined-battlebots/.

3. Robot Build Guides and Rules. Bristol : s.n., 2018.

4. *Battle of bot gets students excited for future; Hamilton high school hosts international competition celebrating tech talents.* **McNeil, Mark.** Hamilton, Ontario : CNW Group Ltd. - Toronto Start Newspaper, 2018.

5. **extremestem.** Colleigate Clash. *xtremestem.* [Online] February 2020. [Cited: Septemeber 1, 2020.] https://www.xtremestem.org/collegiate-clash.

6. **Isabella Long, Fred Schroeder, Mathew Itapson.** 2020 UC MET battlebot team 15 lb bot. Cincinnati : University of Cincinnati, 2020.

7. **Markus Cheslock, Justin Giese.** 2019 UC MET battlebot team - 15 lb. combat bot design. Cincinnati : The University of Cincinnati, 2019.

8. **Nathan Hunt, Reginald Glossett, Dan Schaefer, Benjamin Schenck.** 2017 UC battlebot team. Cincinnati : The University of Cincinnati, 2017.

9. **Nicholas D'Angelo, Evan Rithsatz, Daniel Wittmann.** *2020 UC METS 15lb BattleBot Team "Mamba".* Cincinnati : University of Cincinnati, 2020.

10. **Ryan South, & Carson Burben.** *2018 UC Battlebot Team 60lb Competition.* Cincinnati : University of Cincinnati, 2018.

11. **Daniel Sizemore, Lance Stahler, Matthew Mideros, Brenton Cates.** *2016 UC BattleBot Team.* Cincinnati : University of Cincinnati , 2016.

APPENDIX A

Survey Sample

Hello! I and 2 other people are working on building a Beetlebot for our senior project at the University of Cincinnati. Right now, we are conducting a quick survey to gather info on what we should we focus and the weight of importance for different aspects of our project. We would really appreciate your input!

How important is each feature to you in a beetle bot?

Please select the appropriate answer. 1=Low importance 5=high importance

1) Beetle Bot Safety
2) Ease of use
3) Maneuverability
4) Durability
5) Ease of repair between rounds
6) Speed
7) Size
8) Cost
9) Weight Distribution
10) N/A

How satisfied are you with current beetle bot technology?

Please select the appropriate answer. 1=very Unsatisfied 5=very satisfied

1) Beetle Bot Safety
2) Ease of use
3) Maneuverability
4) Durability
5) Ease of repair between rounds

6) Speed

7) Size

8) Cost

9) Weight Distribution

10) N/A

How much would you be willing to invest in a beetle bot?

$50 -$100, $100 -$200, $200 -$300, $300-$400, $400-$500, $500+

At least one master switch is required, but how many would you recommend?

1,2,3,4,5, Other

Which out the choices would you recommend for master switches

- Complete Shut off
- Mobility System
- Weapons System
- Frame System
- N/A

Which weapon design do you prefer:

- Drum Spinner
- Horizontal Spinner
- Vertical Spinner
- Ring Spinner
- Wedge
- Hammer
- N/A