2021 UC BattleBot Team
“Hash-Slinging Slasher”

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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Problem Statement

To design and manufacture a 1.5kg BattleBot that will compete in an internal UC Beetle Bot competition in the spring of 2021. The drive train component created by Sam Davison will be integrated with other BattleBot components such as the frame, armor, and weapon system which will be created by team members Kyle Pecenko and Trey Green, respectively.

Research

Background of the Problem

Due to the international Covid-19 pandemic and the BattleBot club budget cut, UC is hosting a beetle bot competition for all senior design BattleBot projects. Teams are tasked with designing, building, testing, and competing their bots. This event is held at UC with a soft competition date of April 2021. This event is based loosely around the BattleBots TV show that first aired in 2000. The description of this show according to IMDB is, "Remote controlled robots fight to the death in a Lexan-enclosed arena. Teams of robot builders come from all over the world with their creations to compete in head-to-head combat in four weight categories (Lightweight, Middleweight, Heavyweight and Superheavyweight)." (1) This TV show ran for only two year before being rebooted in 2015, but this show, and other similar shows, spawned fighting robots as a sport with rules and regulations. Regional competitions happen across the globe and the University of Cincinnati's BattleBots Club provides funding and guidance to many senior design teams each year.

Our team will compete against other bots and their teams (there are 3 other UC BattleBot senior design projects). The design of this bot will test our design skills, and practical assembly skills. The knowledge gained through this project will aid in the future of the battle bot club at UC and further UC's STEM credibility. According to Xtreme STEM: "Collegiate robotics teams have the upper hand at developing: STEM Skills, Teamwork, Leadership, and connections." (2) Xtreme STEM is another local BattleBot competition for 15lb robots.

The process of building a beetle bot is time-consuming, expensive, and dangerous. The official BattleBot's community says, "All-in-all be safe. Building, testing, and fighting a combat robot is dangerous." (3) Electrical systems pose an electrocution and fire threat, while the weapons systems are meant to incapacitate other bots. Our funding will come from the support of the battle bots club at UC, and we will dedicate time in and outside of classes to ensure we build a bot to the best of our abilities. We are limited to the funds and materials provided by UC and the BattleBots club to complete our bot, and we will need to finish our final design by the end of Spring Semester 2021.

Currently, bots can be tested with regards to the Fighting Robots Association build rules. There are 4 competition formats currently used by the FRA. Our robot will prepare for a knockout competition. In this competition points are awarded for knockouts, judge's decision, 2nd place, and participation. The winner is determined after all other opponents have received two eliminations. There are many rules to know prior to entering the competition, such as, the stuck rule. Each robot is allowed one release during the match, if they are stuck and it was not caused by the opponent, they can release their bot. If the bots are stuck on each other they can be released as many times as necessary. If your robot is unable to move, you will have ten seconds to get it to move again or the match is lost. This is one of the many college level competitions currently going on. Battle bots can come in many shapes and sizes, but according to the Bristol Bot Builders beetle bots must be, "1.5kg in weight, no size limit." (4) This means our team will be building a 3.3lb beetle bot. Due to the worldwide pandemic occurring, many BattleBot competitions are suspended until further notice. An internal competition is being created by Professor Dong with the assistance of the BattleBots club.

Each year different college teams build robots within the guidelines of the competition; our goal is to build an undefeated bot. There are 3 main features that differ between bots, each with their own pros and cons, these are the drive train, armor, and weapons systems. Our senior design battle bot will use the best of each of these and pass the tournament inspection. This inspection is described in the FRA internal build rules and regulations as, “Each event has safety inspections known as Tech checks. It is at the inspector’s sole discretion that your Robot is allowed to compete. As a builder you are obligated to disclose all operating principles and potential dangers to the inspection staff. (5) An inadequate solution would be a battle bot that fails inspection and is not allowed to compete. Our senior design project will aid in the continued learning of the robot building community at UC. We will work alongside our peers to challenge and create a new bot that uses the current best bot building strategies and pushes new innovations.

A full list of build rules and regulations can be found at the: (5), or in Appendix A. Our team will use these regulations to ensure a valid bot is created and entered to compete in the 2021 UC tournament. Some of the rules are what kinds of mobility is allowed, radio control requirements, whether or not human input is required, what kind of electrical power is allowed, battery types, internal combustion engines, pneumatic & hydraulic allowances, rotating weapon restrictions, spring and flywheel types, and weapon restrictions. Some important rules are that all bots are subject to safety inspections prior to competition. A locking bar must be used when powering up bots with spinning weapons to ensure that there is no accidental weapon operation. A failsafe device must be implemented into the electronic design that brings the system to a pre-set off position. A surface mounted power light must be installed on the robot as well. Matches will last three minutes or until a bot is defeated.

State of the Art

Frame:

The frame and armor are critical components and must work together effectively. The frame and amor can either be the weapon or must be designed around the weapon. BattleBots come in all different shapes and sizes but there are a few deigns that most people continue to innovate with due to their simplicity and versatility.

The wedge design is one of the simplest designs for a BattleBot. It consists solely of an inclined plane and uses it to slide under their opponents to push them into walls or other hazards. The main strength of this design is defense. Removing a weapon will also shed some weight from the bot that can then be used to reinforce some other weaker areas like the rear or sides. A very skilled driver and mobile bot is necessary for this design because the opponent will be very aggressive since there is no threat of damage to their bot from your own. The driver must be able to maneuver the bot and not allow the opponent to get behind since this is the major area of weakness with this design. Overall, a wedge design is very easy to design and build but requires a skilled driver and the lack of a weapons system can make it difficult to win any matches.

Figure 1: Wedge design

The box design is another very common and simple design to use. But unlike the wedge there will need to be a weapons system to have any chance of winning the match. The size, shape, and type of weapons system used is only limited by imagination, but the box dimensions must then be designed around it to ensure it works as intended. A box design allows for more room to place electronics and the drivetrain. Since there need to be armor on all sides and sometimes even the bottom, due to weight constrictions, the armor will not be able to be as protective and may require armor thinner in some places and thicker in others. The box design is can be a square, long and skinny, or anywhere in between. That is what makes it the most versatile frame design and one of the most common used in BattleBot competitions.

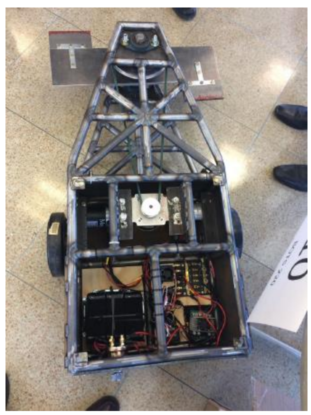


Figure 2: Box design

The spinning design is less common than the box or wedge but widely used. The design merges the abilities of the box and wedge together in some ways. Similar to the wedge it is defensively strong, not passively like the wedge with the strong armor but actively by having 360° threat of attack. The opponent will risk damage to itself by getting close to attack and all sides are protected weapons and armor alike. This design is very unique since it can attack from any angle. There are a few drawbacks for this design though, typically this design has most of its mass on the rotating outside to provide a greater force for the weapons system. However, that means that the tops are usually more vulnerable to bludgeoning or piercing damage. Also, this design is more difficult to control since it is in constant motion and if the rotation mass on the outside is not balanced it will wobble around out of control.

Figure 3: Spinning design

Weapon:

When choosing a weapon for your BattleBot it helps to consider what generally works best for past iterations of bots that have performed well at competitions. There are a handful of weapon systems that considerably outperform their counterparts: Drum Spinner, Horizontal Spinner or Vertical Spinner and Ring Spinner. (6)

Spinning Weapons

Spinning weapons have been used in BattleBot since the beginning and for good reason. There are many advantages to having a spinning weapon mounted to the front of your bot, the main reason being that it plays two sides of the same coin providing both offense and defense simultaneously as no other bot will be able to approach you without taking damage. This dual threat approach makes a spinning style bot a formidable component.

Drum Spinner

A Drum Spinner is a weapon consisting of a drum that has been teethed mounted to the front of the robot. The drum spinner is a great choice when considering a weapon because it is simple and reliable. A huge advantage, especially in light weight divisions is that you can design a drum spinner to drive while flipped and still be fully functioning. However, because the roller is only mounted to the front of the bot, it creates a limited striking zone. (6)

Figure 4: Drum spinner

Horizontal/Vertical Spinner

A horizontal/vertical spinner for your weapon of choice has huge upside, but it also has some negatives that are worth considering. Some positives for both spinners as that it is the ultimate form of what I mentioned earlier, offense and defense simultaneously. A horizontal/vertical spinner has great output of damage in a large striking zone that operates both when attacking or when being approached. (6) However, this is a glass cannon weapon, meaning that the robot will need to have a lot of added structure and support to ensure that it will not be self-destructive.

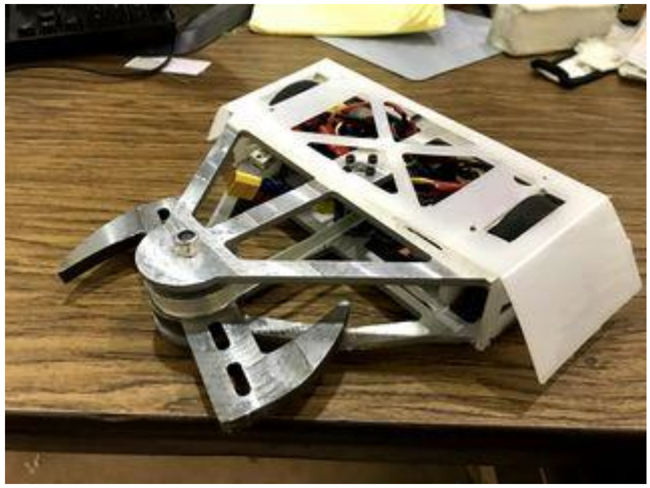


Figure 5: Horizontal/ Vertical spinner

Ring Spinner

A ring spinner is a weapon consisting of teethed metal that fully surrounds the entirety of the bot. (6) A few benefits from using a ring spinner as a weapon is that it has a complete 360-degree striking zone, making it a formidable opponent when trying to approach. This 360-degree design also makes it simple to design so that it can function while being flipped over. (6) However, this complicated system makes it very hard to design. Also, if the bot takes a hard blow from an opponent there is not much structural integrity from armor to back it up.

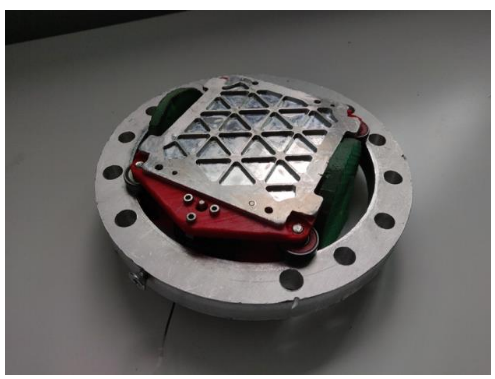


Figure 6: Ring spinner

Drivetrain:

The drivetrain component of 5 previous battle bot senior designs projects are shown below. While no previous senior designs have done BeetleBots, their drivetrain decisions will still suffice as references.

2016: This design uses a two-wheel drive with power supplied with a motor and gear box. The two-wheel drive was chosen to decrease drivetrain weight and allow for extra armor weight to be added. They used two AmpFlow F30-400 motors, and a three-stage chain-and-sprocket gearbox. These motors provide a peak horsepower of 3.0 and a reduction ratio of 8.3:1. They used these motors and gearbox to stay low cost while maintaining high torque. They chose to use two solid wheels with their drive motors positioned mirrored from one another to ensure no wheel punctures occur and help distribute weight evenly across the bot. Overall this design was well designed and executed. (7)

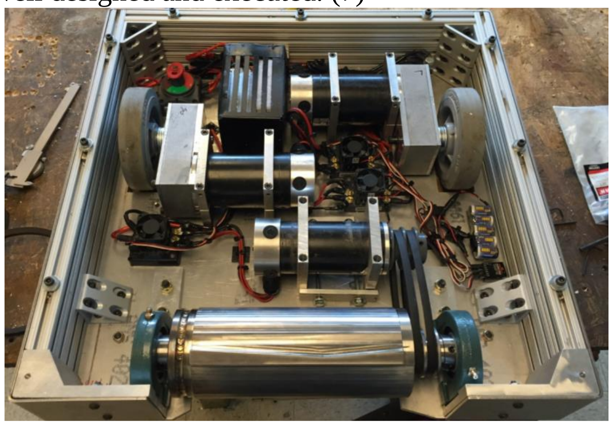


Figure 7: UC Senior Design BattleBot 2016

2017: This design uses a two-wheel drive to allow for quick turns and to continue facing their opponent. The motors used in this bot were S28-FP-150X MagMotor with gearboxes that both came from a 2011 BattleBot project. This bot features two eight-inch flat proof tires, and a caster wheel was also used to add stability. Improvements proposed included: larger wheels to allow for continued movement in the event of a flip, replacing the caster wheel with two ball bearings, and reorient the motors to conserve space. This design was adequate but had room for improvement. (8)

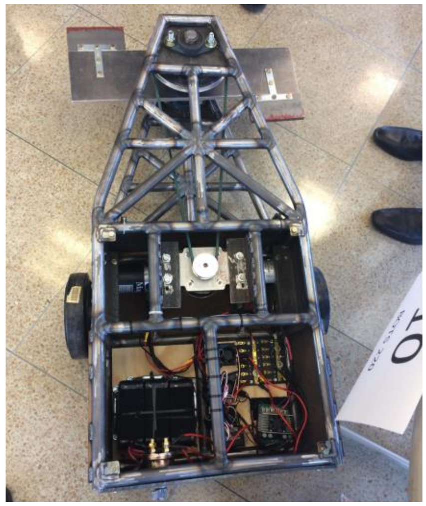


Figure 8: UC Senior Design BattleBot 2017

2018: This design aimed for maneuverability and to be lightweight. They went with a four-wheeled bot with two driven wheels and cogged belts connected to the other two wheels. This design is lightweight, thanks to the exclusion of gears and chains, and with only two driven wheels the bot could be driven like a skid. The extra weight loss would also allow for extra armor to be added to the bot. This design worked well with the other features designed within the bot, but decisions were made to spend time and money elsewhere and this can be seen in the final results of the competition. (9)

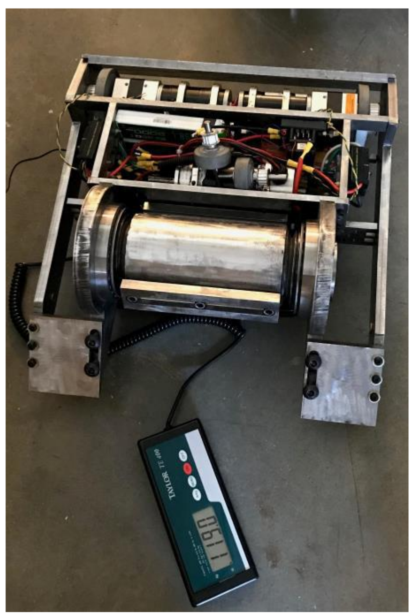


Figure 9: UC Senior Design BattleBot 2018

2019: This design uses 2 RS-540 sized motors and a 20:1 gearbox reducer. They chose this to be low cost and efficient. This design is simple and effective, and they reflect on their drivetrain choice as being successful for maneuverability. (10)

Figure 10: UC Senior Design BattleBot 2019

2020: This design uses a two-wheel drive with two brushed DC motors and an attached gearbox with a ratio of 47:1. This design was chosen due to overall weight, simplicity, and cost. A single DC motor controller was used and communicates easily with the remote controller. As this robot was never manufactured, final comments were not available, but overall their design is simple yet effective. (11)

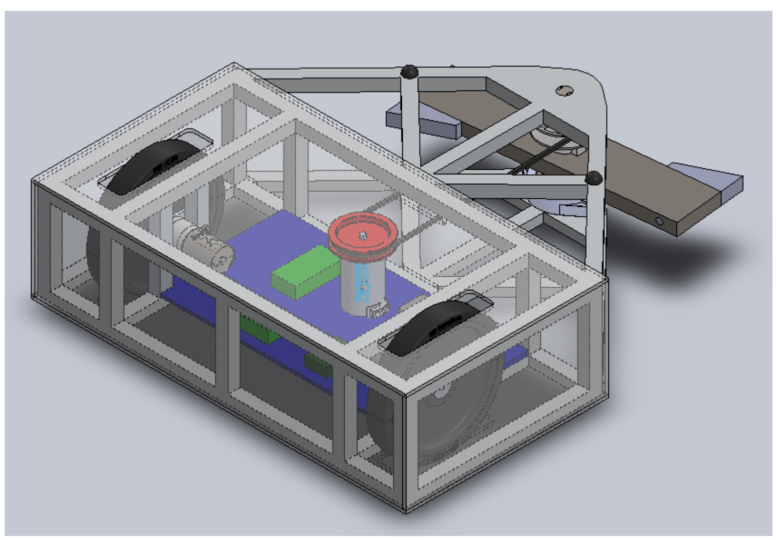


Figure 11: UC Senior Design BattleBot 2020

End User

The user of this robot will be a member of our senior design team whose responsibility is to control the robot during the competition. The user must use a remote control to remain mobile while inflicting damage on the opponent. The end user must abide by the Code of Conduct set forth by the FRA (12). This event is a timed combat event. The user will be required to make quick decisions, be familiar with controls and bot movement, and follow all competition rules outlined in the FRA Competition Regulations (13).

Summary of Research

These are just three of the more common options of frame and armor design but there are numerous others and hybrid designs mixed in. As mentioned before the frame should be built around the weapons system so that will be a driving factor on how the frame and armor are implemented into the final design.

When having to come to the final conclusion for the best weapon for the bot it was a hard choice, but after considering all the pros and cons as well as the successes and failures of past bots we have come to the conclusion that a drum spinner would be best suited for the job. This is because of the simplistic design and reliability factor given to the bot especially with a 3lb limit.

Regardless of the size difference between the state-of-the-art designs and our own beetle bot, it seems that using wheels is a superior drive method to legs or a tread. Using legs requires many servo motors and complex wiring that is not within the budget allowance of our team. A tread is also expensive due to the complexity of the design. Using wheels will give us high mobility and accuracy to line up our weapon and dodge the opponent's weapon. Having a two-wheel drive system also seems to be a good balance for weight and torque. Each motor will require a gearbox or a motor with a built-in gearbox for the two drive wheels. We want to ensure that the gears are metal and not plastic to prevent slippage or breaking. Even though, solid tires seem superior to regular RC tires, these tires will be adequate and better suited for our bot design. The bot will be designed so that, in the event of a flip, the wheels will stick up on the top side and allow for continued mobility.

Quality Function Deployment

Customer Features

Price of Bot, Safety, Bot Maneuverability, Damage Output, Armor Durability, Drivetrain Efficiency, Recoverability

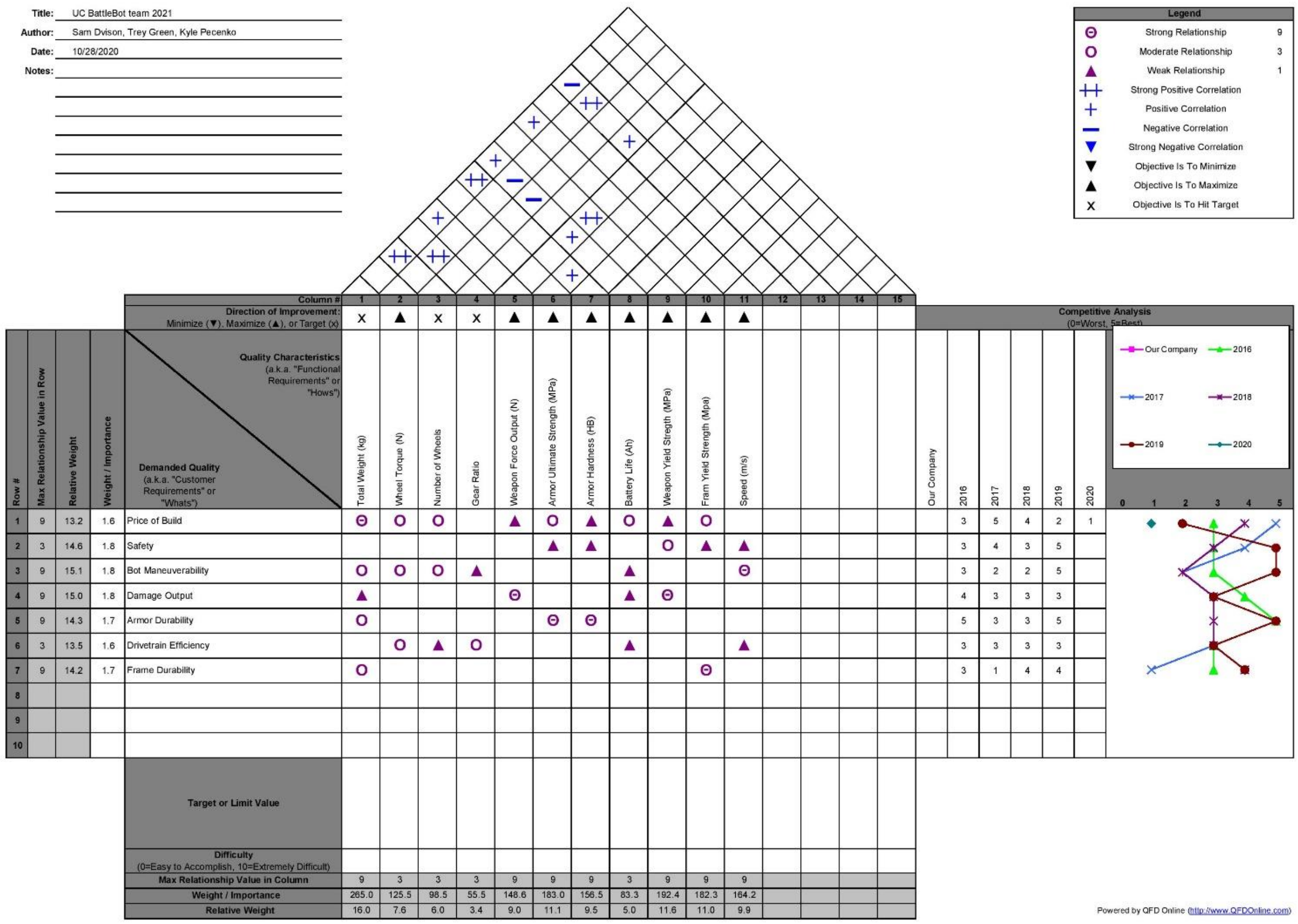
These features were derived using survey data. Our team created an online survey that was posted to multiple BattleBot/ robotics related forums and filled out by 38 people. The survey asked the responder to determine how important each category was on a scale from one to five. It can be viewed in its entirety in Appendix B. The categories are as follows: overall cost of build, bot safety, bot maneuverability, damage output, armor durability, drivetrain efficiency, and frame durability. These importance weights were averaged and added to the HOQ.

Engineering Characteristics

Total Weight (kg), Wheel Torque (N), Number of Wheels, Gear Ratio, Weapon Force Output (N), Armor Ultimate Strength (MPa), Armor Hardness (HB), Battery Life (Ah), Weapon Yield Strength (MPa), Frame Yield Strength (MPa), Speed (m/s).

These characteristics were chosen to best represent each customer feature in a measurable quantity. Each characteristic will affect the final design of the bot and using the HOQ they can be ranked from most to least important.

House of Quality



Title: UC BattleBot team 2021
Author: Sam Dvison, Trey Green, Kyle Pecenko
Date: 10/28/2020
Notes:

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Total Weight (kg)	2 Wheel Torque (N)	3 Number of Wheels	4 Gear Ratio	5 Weapon Force Output (N)	6 Armor Ultimate Strength (MPa)	7 Armor Hardness (HB)	8 Battery Life (Ah)	9 Weapon Yield Stregth (MPa)	10 Fram Yield Strength (Mpa)	11 Speed (m/s)	12	13	14	15	Our Company	2016	2017	2018	2019	2020
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	▲	x	x	▲	▲	▲	▲	▲	▲	▲										
1	9	13.2	1.6	Price of Build	Θ	O	O		▲	O	▲	O	▲	O							3	5	4	2	1
2	3	14.6	1.8	Safety						▲	▲		O	▲	▲						3	4	3	5	
3	9	15.1	1.8	Bot Maneuverability	O	O	O	▲				▲			Θ						3	2	2	5	
4	9	15.0	1.8	Damage Output	▲				Θ			▲	Θ								4	3	3	3	
5	9	14.3	1.7	Armor Durability	O					Θ	Θ										5	3	3	5	
6	3	13.5	1.6	Drivetrain Efficiency		O	▲	O				▲			▲						3	3	3	3	
7	9	14.2	1.7	Frame Durability	O									Θ							3	1	4	4	
8																									
9																									
10																									
				Target or Limit Value																					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)																					
				Max Relationship Value in Column	9	3	3	3	9	9	9	3	9	9	9										
				Weight / Importance	265.0	125.5	98.5	55.5	148.6	183.0	156.5	83.3	192.4	182.3	164.2										
				Relative Weight	16.0	7.6	6.0	3.4	9.0	11.1	9.5	5.0	11.6	11.0	9.9										

Table 1: House of Quality

Product Objectives

The weighted ranks of each Engineering Characteristic were determined from the HOQ and listed below in descending order. These values show which characteristic is most important toward our design. These will be focused on throughout our design process.

Total Weight (16.0)

Our weight must not exceed 3kg.

Weapon Yield Strength (11.6)

A high yield strength means our weapon system can deliver more hits before deforming.

Armor Ultimate Strength (11.1)

A high ultimate strength for our armor material will enable our bot to take more hits without breaking and/or exposing our vital insides.

Frame Yield Strength (11.0)

A high yield strength for our frame means that our bot will last longer after taking damage, and function properly.

Speed (9.9)

A high speed will allow our robot to move its weapon within range of the opponent and avoid the opponent's weapon.

Armor Hardness (9.5)

Along with the ultimate strength, hardness will prevent opponent weapons from damaging our robot.

Weapon Force Output (9.0)

A high damage output will decrease the number of hits we need to land on the opponent and decrease the time of matches.

Wheel Torque (7.6)

We desire a high torque on our wheels to ensure our bot stays mobile, to avoid the opponent's weapon system, and stay within our own weapon range.

Number of Wheels (6.0)

Our wheel number will depend on our frame design, and weapon system. We will use either 2 or 4 wheels.

Battery Life (5.0)

Our battery needs to last the duration of multiple matches, and testing periods.

Gear Ratio (3.4)

Having a high gear ratio will give us higher toque output on our weapon and drive systems.

Concepts Drawings

Concept 1: Spinner

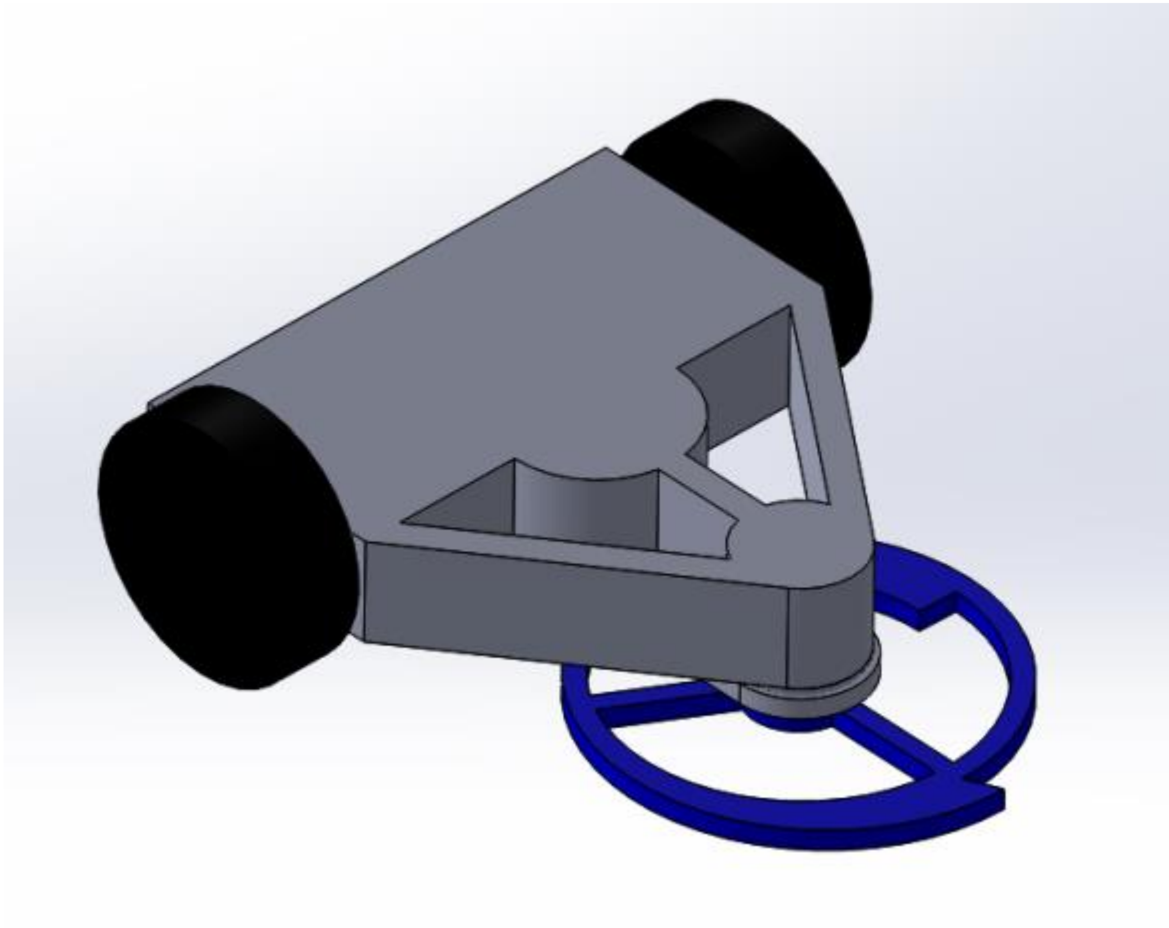


Figure 12: Design Concept 1

Concept one consists of a main body, housing all electronics and motors, and an external spinner weapon. This design features a two-wheel drivetrain with individual motors for each wheel with a third motor set in the front for the weapon. The weapon will be made of a low-weight, high-strength metal such as titanium and will be belt driven. The frame is simple yet robust in the strong shape of a pentagon. This shape will leave few weak points for the enemy to exploit while providing enough room to house all the internal components. The size of the wheels compared to the frame allows for continued use if flipped over. The weapon shape above has a large impact surface with a counterbalance opposite. This allows the weapon to be spun rapidly without risk to the bot itself.

Concept 2: Drum Roller

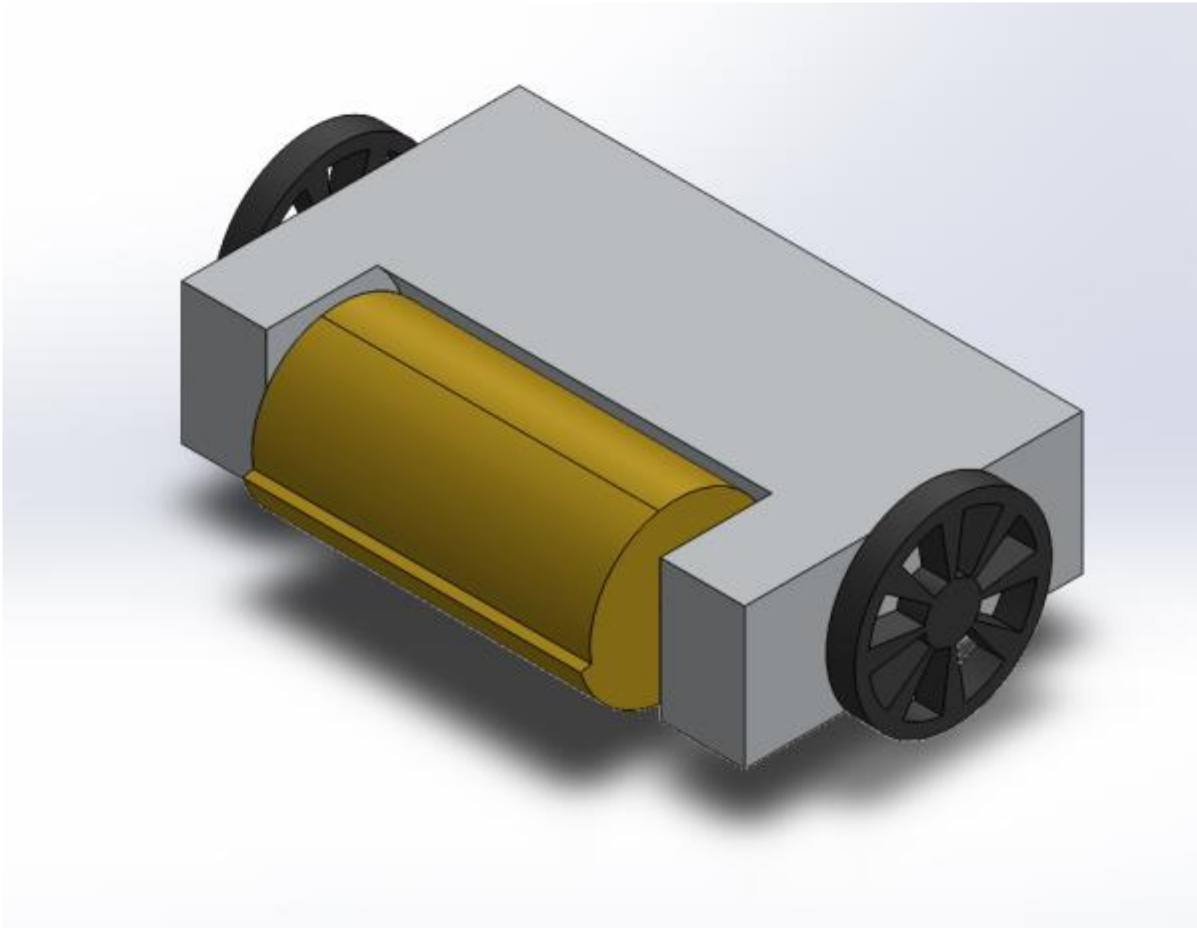


Figure 13: Design Concept 2

Concept two consists of a main body with an embedded drum roller. The roller has two striking edges (one can be seen pointed straight out) and these will allow for damage potential twice per rotation of the roller. In the orientation shown above, the drum will spin clockwise and deal damage low on the opponents bot. If flipped the wheel clearance on the top will allow this design to stay effective and continue to deal damage by reversing the drum rotation. The two-wheel design is common for drum rollers as the drums rotation also aid in maneuverability of the bot. The simple square frame allows for maximum utilization of space within the housing for internal components and with iterative designs the weak points can be shaped to minimize opponent weapon damage.

Concept 3: Wedge Design

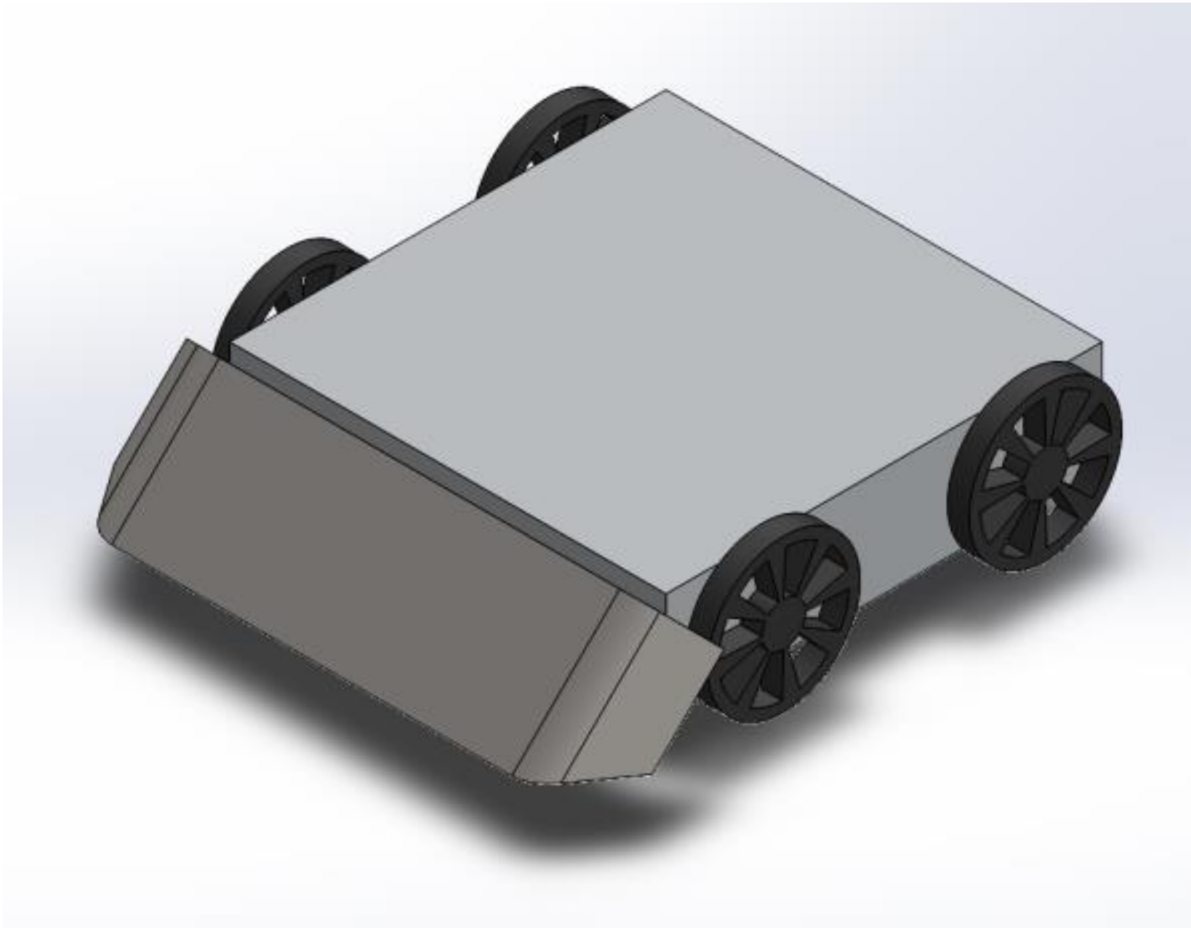


Figure 14: Design Concept 3

Concept three consists of a four-wheeled drive train on a simple square frame with a downward sloped wedge. Using a four-wheel design opens up the available options for power transmission methods. This design can use four separate motors to increase maneuverability, one motor for the left and right halves to decrease weight and decrease power consumption, or a single driveshaft to decrease weight further and decrease cost. The wheel clearance allows for continued use if flipped but would render the weapon ineffective. The wedge is simple but provides protection to the internals of the bot and the wheels from a head on attack. Speed is very important with this design and this design has the best defensive ability comparted to the other two design.

Decision Matrix:

		Spinner		Drum Roller		Wedge	
Criteria	Weight %	Rating (1-3)	Weighted Rating	Rating (1-3)	Weighted Rating	Rating (1-3)	Weighted Rating
Offensive Capability	2	3	6	2	4	1	2
Defensive Capability	1.75	1	1.75	2	3.5	3	5.25
Speed	0.75	2	1.5	1	0.75	3	2.25
Cost	1.5	3	4.5	1	1.5	2	3
Usability	1	3	3	2	2	1	1
Ease of build	1.5	2	3	1	1.5	3	4.5
Total			**19.75**		**13.25**		**18**

Table 2: Decision Matrix

Rankings
1- worst
2- middle
3- best

Table 3: Decision Matrix Ratings

Design Model

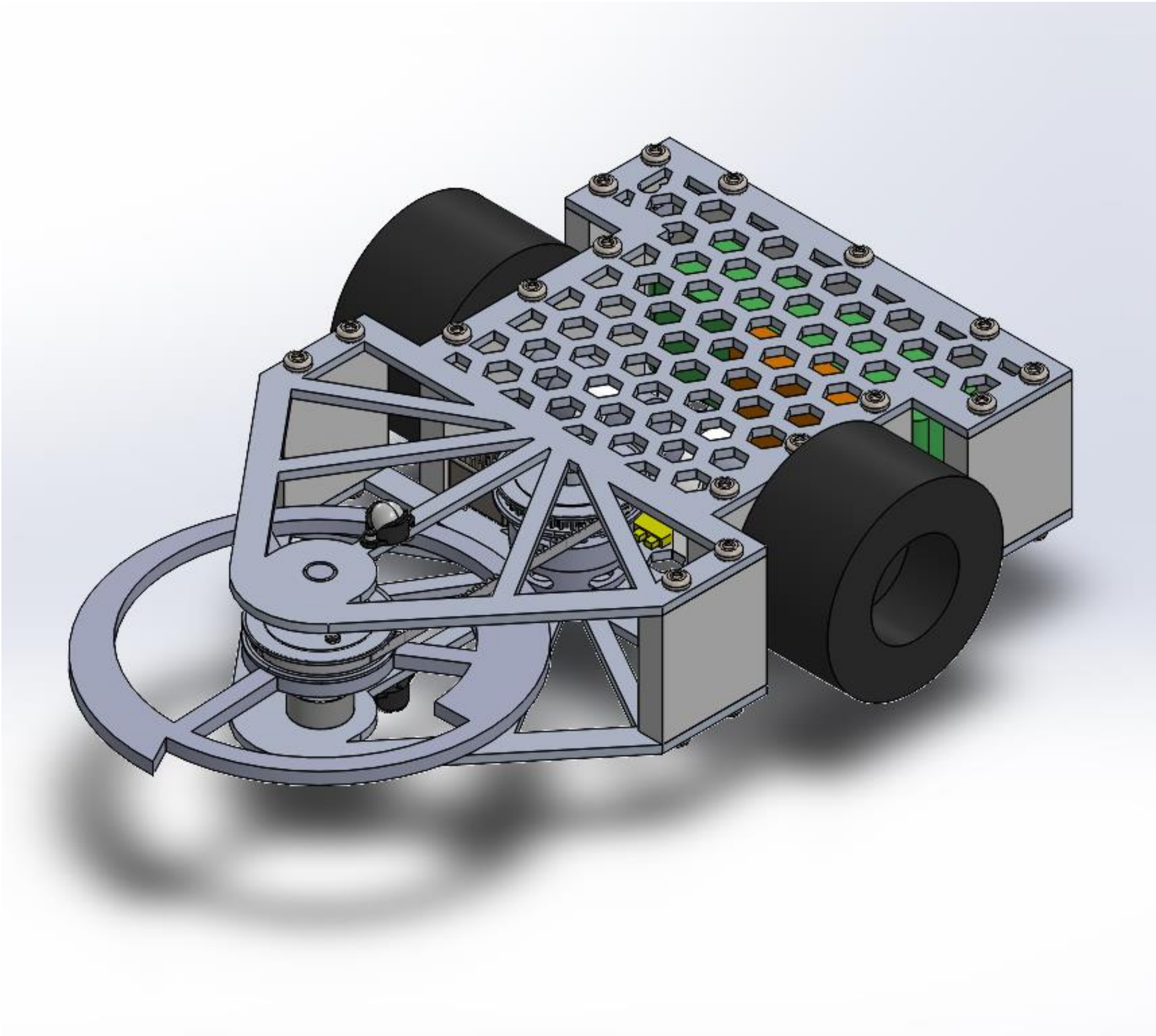


Figure 15: Isometric View of Bot

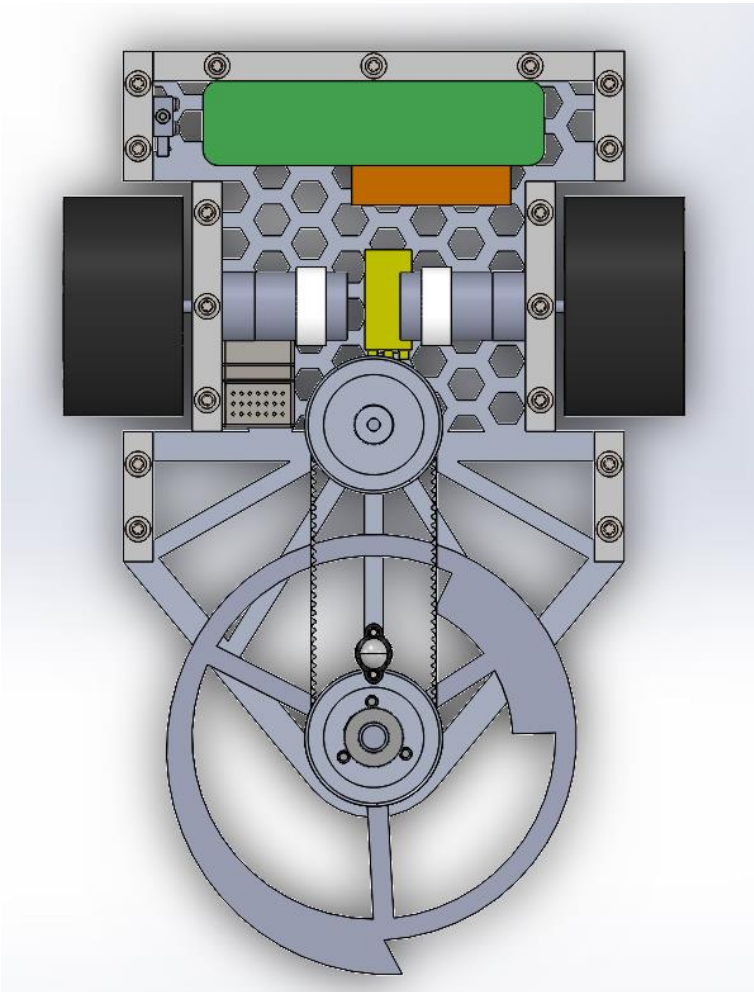


Figure 16: Inside View of Bot

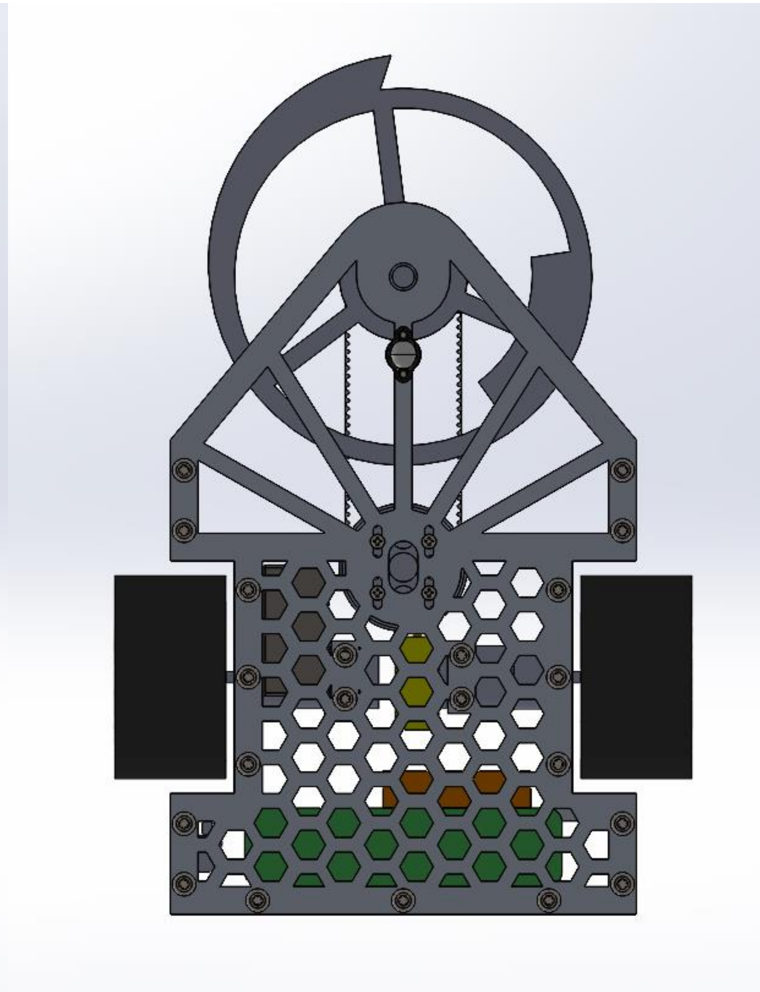
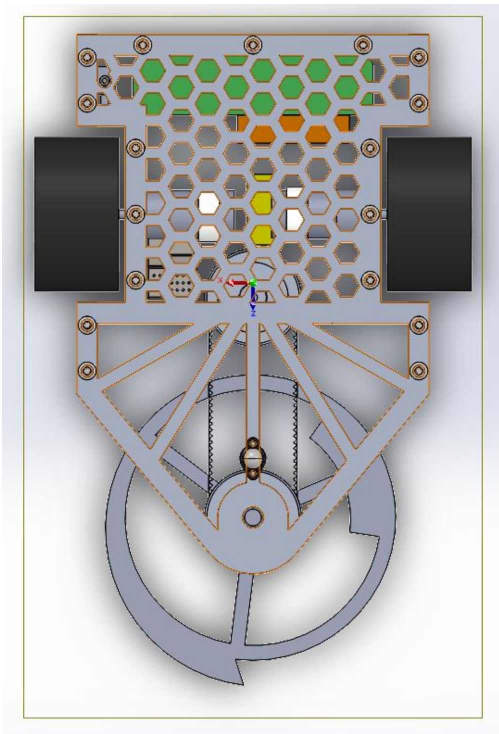


Figure 17: Underside of Bot

Center of Gravity



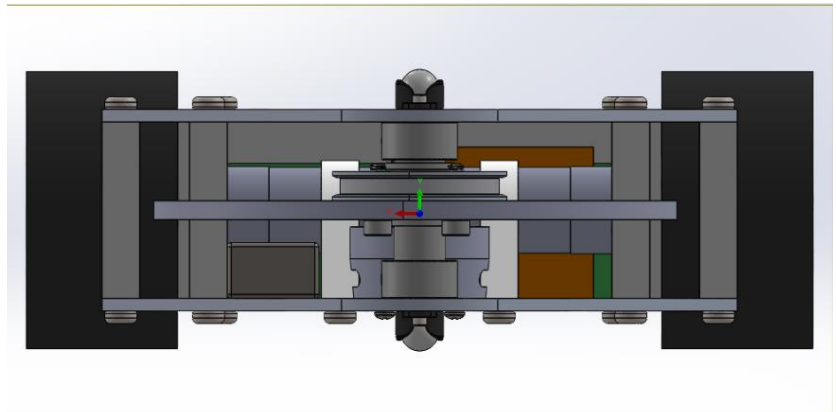


Figure 19: Center of Gravity- Front View

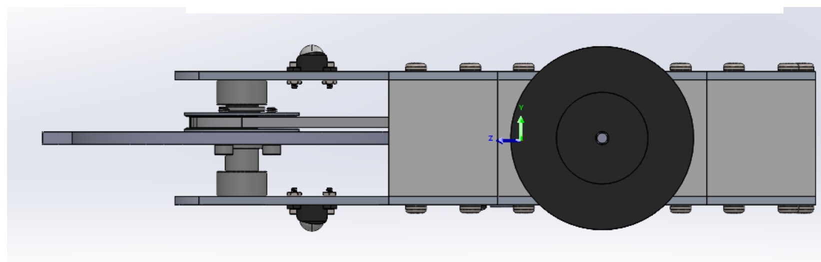


Figure 18: Center of Gravity- Top Down View

Figure 20: Center of Gravity- Side View

Frame and Armor Analysis

Frame and Armor Calculations

Measured Characteristics:

Weapon Mass: 0.2907 kg

Radius of Weapon: 0.0762 m

Speed of Bot: 2.2 m/s

Assumptions:

Motor RPM: 500 rpm = 52.4 rad/s (ruleset limitation)

Impact Time: 0.05 s

Estimated Expected Hitting Force-

KE of rotating weapon:

$$I = mr^2 = (0.2907\ kg) * (0.0762\ m)^2 = 0.00168\ kg * m^2$$

$$KE_{rotation} = \frac{1}{2}Iw^2 = 0.5 * (0.00168\ kg * m^2) * \left(52.4\ \frac{rad}{s}\right)^2 = 2.31\ J$$

KE of moving bot:

$$KE_{moving\ bot} = \frac{1}{2}mv^2 = 0.5 * (1.5\ kg) * \left(2.2\ \frac{m}{s}\right)^2 = 3.63\ J$$

Combined KE:

$$KE_{total} = KE_{rotation} + KE_{moving\ bot} = 2.31\ J + 3.63\ J = 5.94\ J$$

Speed of bot after impact:

$$KE_{total} = \frac{1}{2}mv_f^2\ ; 5.94\ J = 0.5 * (1.5\ kg) * v_f^2\ ; v_f = 2.81\ m/s$$

Momentum:

$$Momentum = m * v = (1.5\ kg) * \left(2.81\frac{m}{s}\right) = 4.22\ kg * \frac{m}{s}$$

Force acting on bot:

$$F_{avg} * \Delta t = momentum\ ; F_{avg} = \frac{\left(4.22\ kg * \frac{m}{s}\right)}{(0.05\ s)} = 84.4\ N$$

Frame and Armor FEA Simulation

The stresses analyzed here are direct normal stresses and fall into the design stress guidelines chart from the sixth edition of Robert L. Mott's textbook: Applied Strength of Materials. (14)

TABLE 3–2 Design stress guidelines: Direct normal stresses.

Manner of loading	Ductile material	Brittle material
Static	$\sigma_d = s_y/2$	$\sigma_d = s_u/6$
Repeated	$\sigma_d = s_y/8$	$\sigma_d = s_u/10$
Impact or shock	$\sigma_d = s_y/12$	$\sigma_d = s_u/15$

Table 4: Safety Factor Table for Multiple Loading Conditions

Acceptable safety factor for impact or shock load on ductile material: 12

Acceptable safety factor for impact or shock load on brittle material: 15

Due to the nature of the competition and how determine our opponent's weapon to function, we consider our expected manner of loading against our bot to be impact or shock.

Frame Stress Analysis 1:

A 84.4 N force was applied to the rear of the armor plate upper frame.

Maximum observed stress: 18.6 MPa

Yield Strength of 6061 Aluminum: 276 MPa

Meets Safety Factor of 12 for Ductile Materials

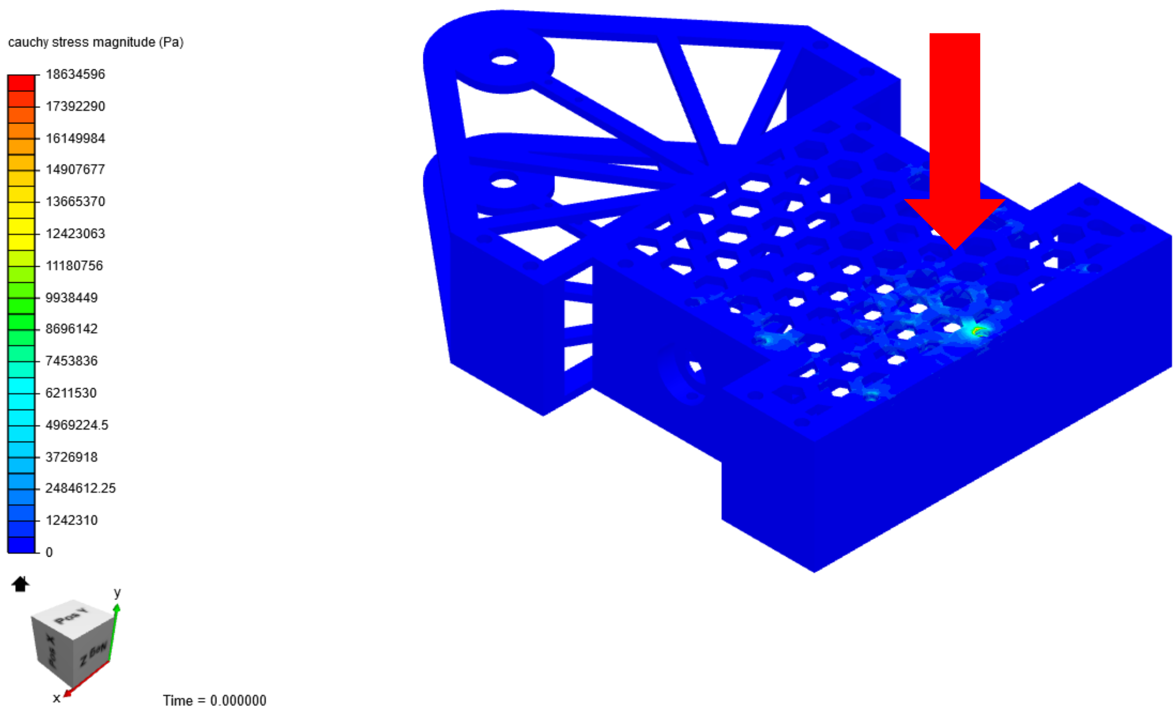


Figure 21: Frame Stress Analysis 1

Frame Displacement Analysis 1:

A 84.4 N force was applied to the rear of the upper frame.

Maximum observed displacement: 0.00000657

% Elongation of 6061 Aluminum: 12.5%

% Elongation calculated: $\frac{(0.003175+0.00000657)-0.003175}{0.003175} * 100 = 0.207\%$

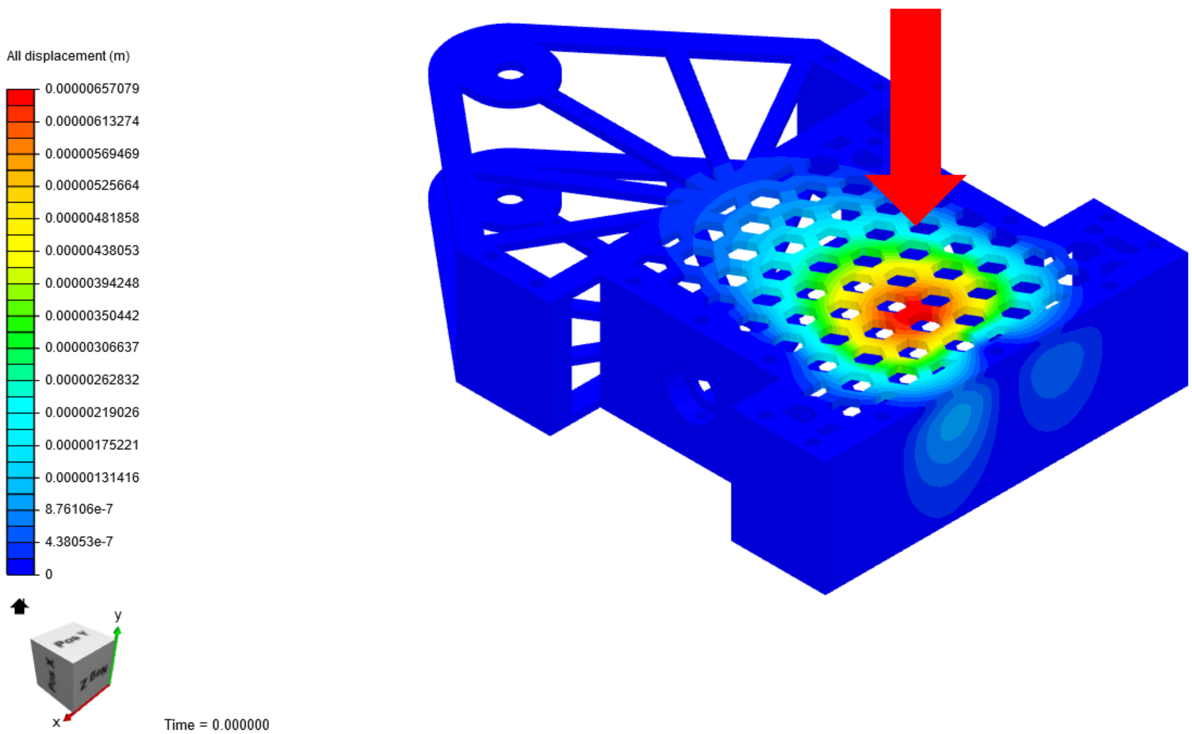


Figure 22: Frame Displacement Analysis 1

Armor Stress Analysis 1:

A 84.4 N force was applied to the front of the side armor plate.

Maximum observed stress: 0.426 MPa

Yield Strength of Nylon 12 Plastic: 33.4 MPa

Meets Safety Factor of 15 for Brittle Materials

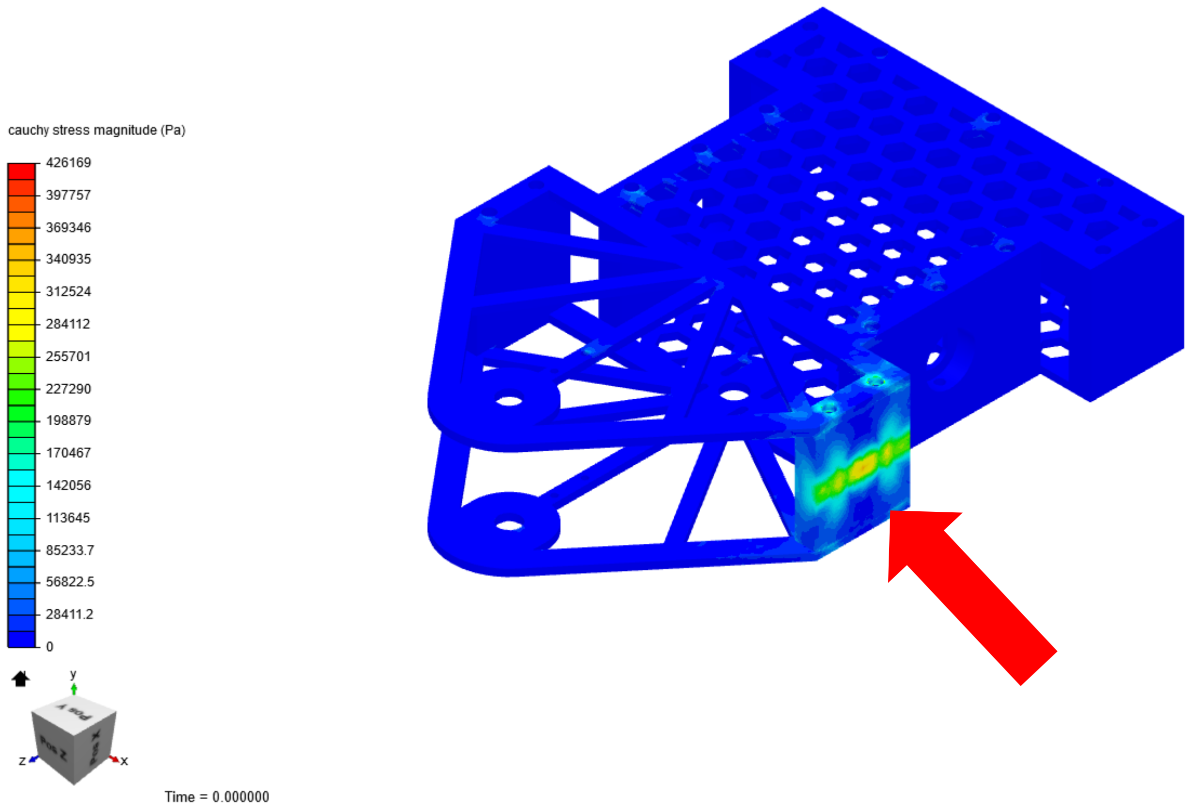


Figure 23: Armor Stress Analysis 1

Armor Stress Analysis 2:

A 84.4 N force was applied to the rear of the side armor plate.

Maximum observed stress: 0.396 MPa

Yield Strength of Nylon 12 Plastic: 33.4 MPa

Meets Safety Factor of 15 for Brittle Materials

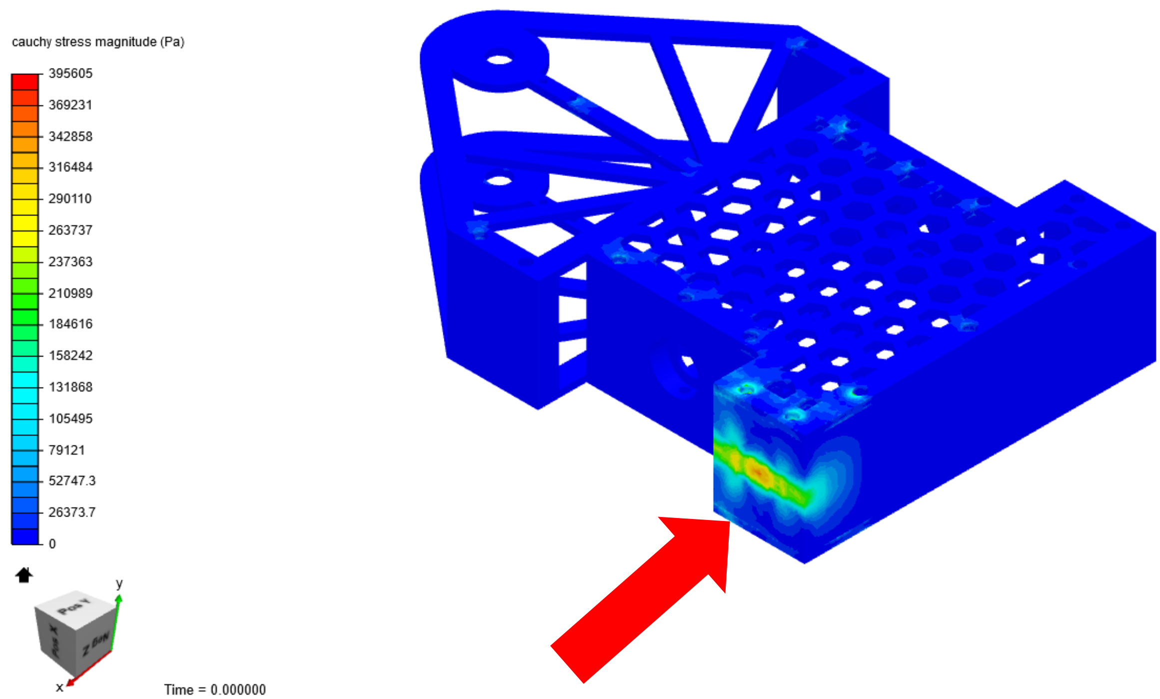


Figure 24: Armor Stress Analysis 2

Armor Stress Analysis 3:

A 84.4 N force was applied to the rear corner of the side armor plates.

Maximum observed stress: 1.09 MPa

Yield Strength of Nylon 12 Plastic: 33.4 MPa

Meets Safety Factor of 15 for Brittle Materials

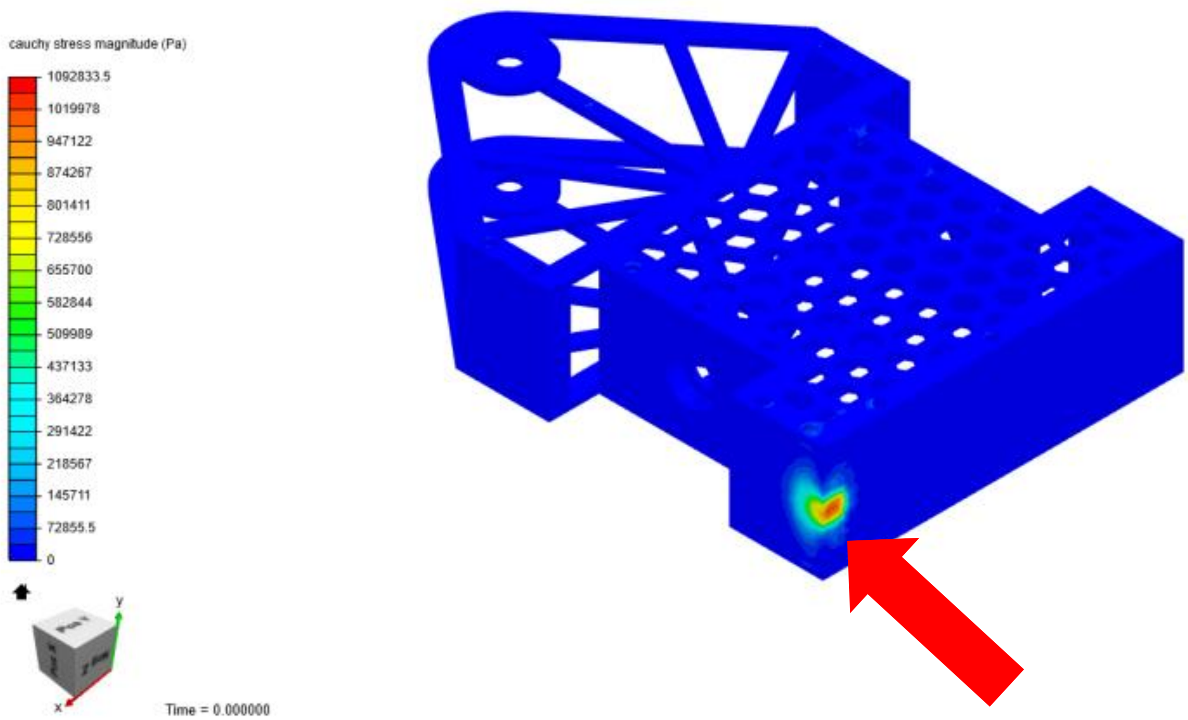


Figure 25: Armor Stress Analysis 3

Armor Displacement Analysis 1:

A 84.4 N force was applied to the front of the side armor plate.

Maximum observed displacement: 0.000025

% Elongation of Nylon 12 Plastic: 12.7%

% Elongation calculated: $\frac{(0.009525+0.0000025)-0.009525}{0.009525} * 100 = 0.026\%$

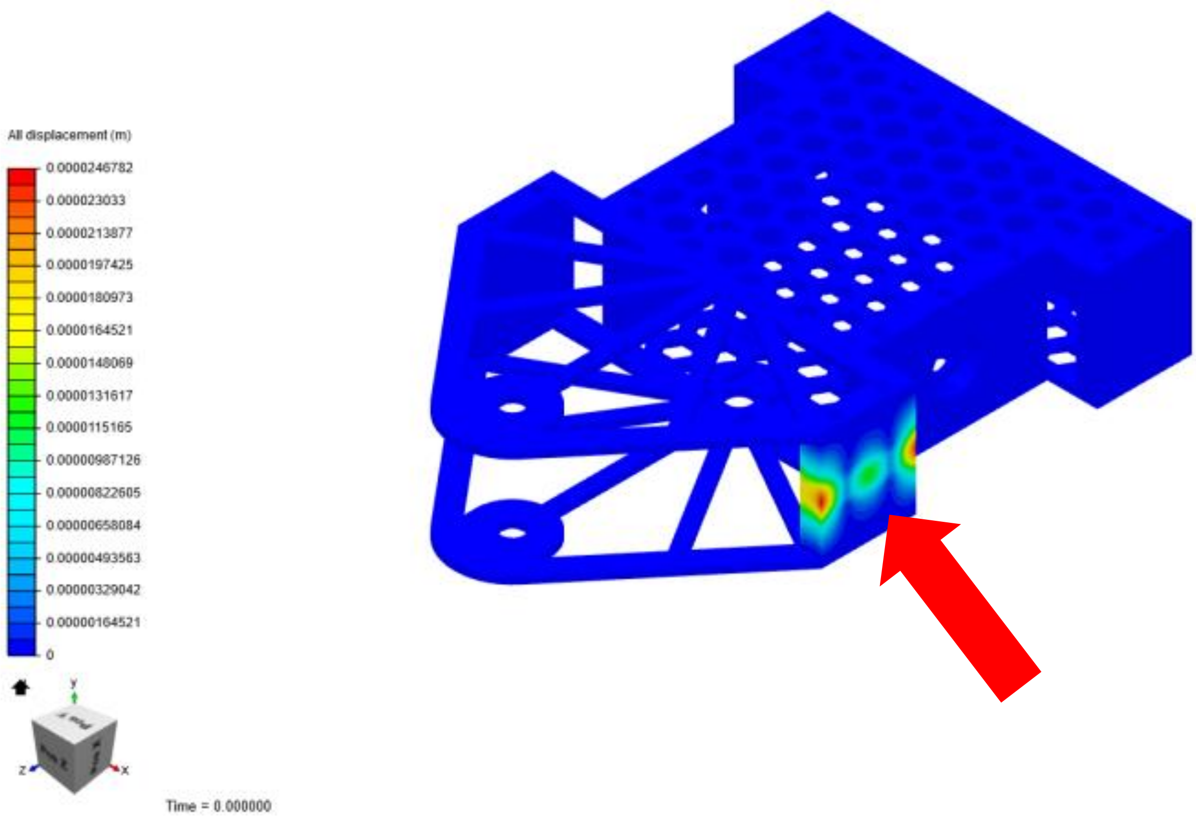


Figure 26: Armor Displacement Analysis 1

Frame and Armor Material Selection

Using a maximum allowable impact safety factor of 12 for ductile materials and 15 for brittle materials, along with the material properties of our armor and frame materials below, we expect to find that all of our calculated safety factors from our FEA analyses for our armor to exceed 12 and our frame to exceed 15.

Brittle Material < 5% elongation < Ductile Material

1/8” thick Aluminum 6061-T6 plate- Ductile

Percent elongation: 12.5%

3D Printed Nylon 12- Brittle

Percent elongation: 12.7%

All FEA analyses provide worst case scenario prevention. We would not expect to encounter these stresses unless an opponent has our bot pinned to the wall and all the energy from its moving hit going directly into our frame or armor. After reviewing the results of our FEA analyses, we can confidently say that the materials we chose for our frame and armor have high enough yield stresses to be effective in our bot.

Our displacement analyses were used to calculate expected % elongation. Comparing this value to the % elongation of our material determined if our material would withstand permanent deformation. Our chosen materials successfully passed this analysis.

Weapon System Analysis

Weapon System Calculations

$$Max\ Horse\ Power = \frac{339W}{746\frac{W}{HP}} = .454\ HP$$

$$Torque = \frac{HP*5252}{RPM} = \frac{.454HP*5252}{2000} = 1.19\ Nm$$

$$0.5I\omega^2 = 0.5mv^2$$

$$500\ RPM = 52.4\ rad/s$$

$$I = mr^2 = .2907(.0762^2) = .00168\ kg*m^2$$

$$0.5(.00168)(52.4^2) = 0.5(.2907)(v^2)$$

$$v_{blade} = 3.98\ \frac{m}{s}$$

$$F_{avg} = \frac{Impulse}{\Delta t} = \frac{.2907kg*3.98\frac{m}{s}}{.05s} = 23.1\ N$$

Weapon System FEA Simulation

Weapon Stress Analysis 1:

A 23.1 N force was applied to the striking surface of the weapon blade.

Maximum observed stress: 27.9 MPa

Yield Strength of AR500: 1,370 MPa

Meets Safety Factor of 12 for Ductile Materials

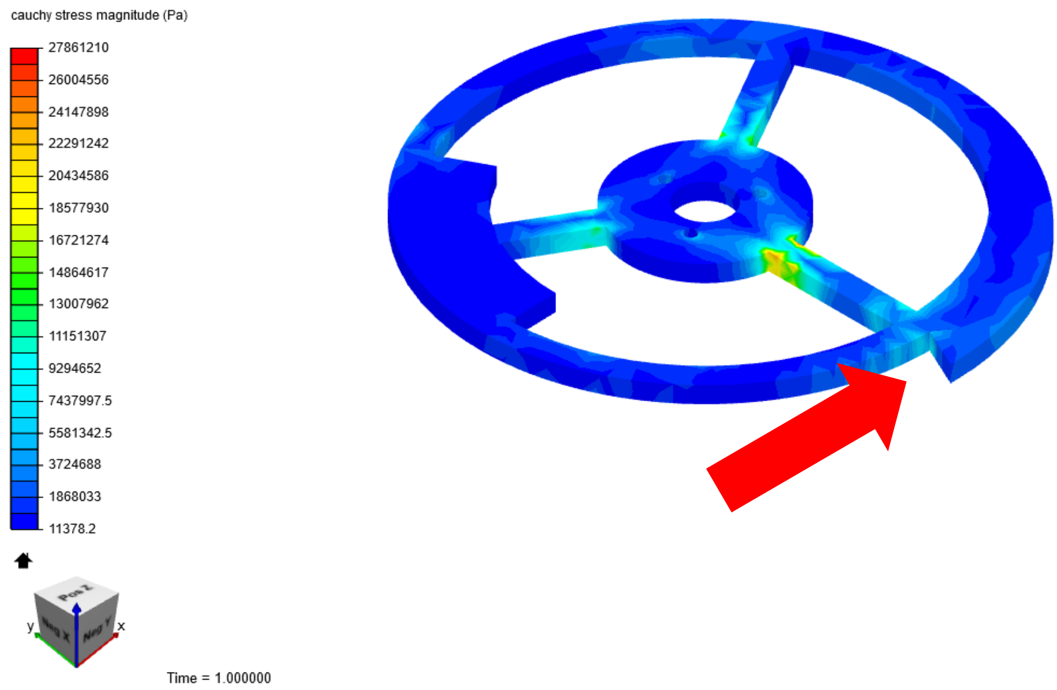


Figure 27: Weapon Stress Analysis 1

Weapon Stress Analysis 2:

A 84.4 N force was applied to the side of the fixed weapon shaft.

Maximum observed stress: 6.0 MPa

Yield Strength of : 550 MPa

Meets Safety Factor of 12 for Ductile Materials

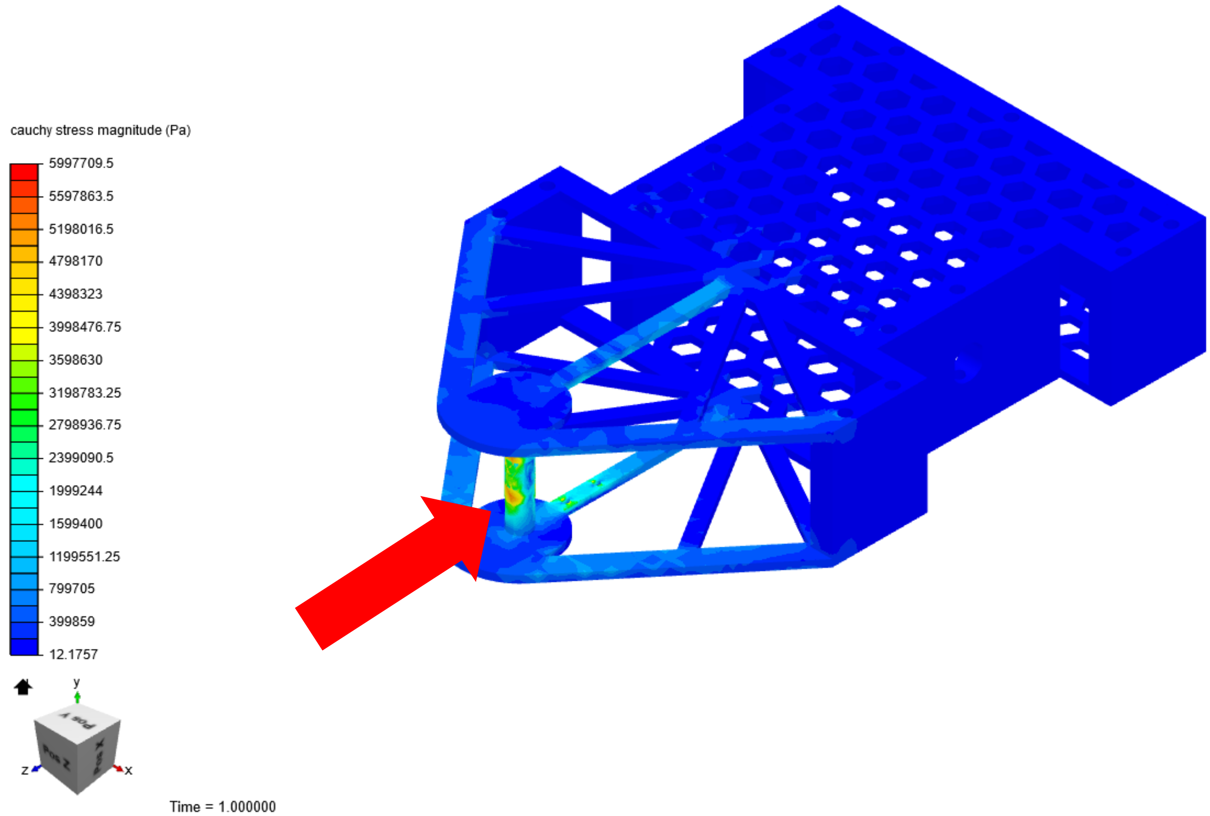


Figure 28: Weapon Stress Analysis 2

Weapon System Material Selection

The material we chose for the weapon blade is AR500. It has a yield strength of 1370 MPa, a tensile strength of1740 MPa, and 8% elongation in 50.8mm gauge. It is a medium carbon, manganese alloy with moderate Brinell hardness.

The material we chose for the shaft is 1566 Hardened Steel. It has a yield strength of 550 MPa, a tensile strength of 880 MPa, and 15% elongation.

Weapon Motor Selection

For our motor we selected a Turnigy Aerodrive SK3 3530-1150kv Brushless Motor. According to the BBB, there is a limit on the tip speed of all spinning weapons at 250 mph. This motor allows for the tip speed to be well under the limit. The operational voltage range is in line with the battery. The burst current is less than the battery and weapon motor ESC. Lastly, this motor was selected to minimize the weight and overall cost of the bot.

Drivetrain Analysis

Drivetrain Calculations

Speed of BeetleBot:

Measured Characteristics:

Rated load: 0.54 kgf-cm

Rated-load Speed 602±60 rpm

Max. Stall Current: 4.9A

Wheel Diameter: 2.75” = 0.06985 m

$$Speed\ of\ Beetlebot\ = RPM * \frac{2 * pi}{60} * wheel\, radius = 602RPM * \frac{2 * pi}{60} * \frac{0.06985}{2} = 2.2\, m/s$$

Torque to Overcome Static Friction:

Assumed Coefficient of Friction between Wheels and Steel Floor: 0.6

$$Wheel\ load:\ \frac{Weight}{2\, Wheels} = \frac{1.5kg * 9.81}{2} = 7.36N$$

$$Friction\ Force\ on\ Wheels = 0.6 * 7.36N = 4.42N$$

$$Wheel\ Friction\, Torque = Friction\ Force * wheel\, radius = 4.42N * \frac{0.06985\, m}{2} = 0.15\ Nm$$

Rated Drive Motor Torque: 0.294 Nm (greater than force to overcome load)

Turn Radius:

$$Wheel\ Spread = \ 0.160\, m$$

$$Arc\ length\ of\ a\ 180°\ turn = \frac{circumference}{2} = \frac{\pi * (0.160) * 2}{2} = 0.5024\, m$$

$$Time\ to\ complete\ 180°\ turn = \frac{Turning\ Arc\ Length}{Beetlebot\ Speed} = \frac{0.5024\, m}{\frac{2.2\, m}{s}} = 0.23\ s$$

Electronics Analysis

Wiring Schematic

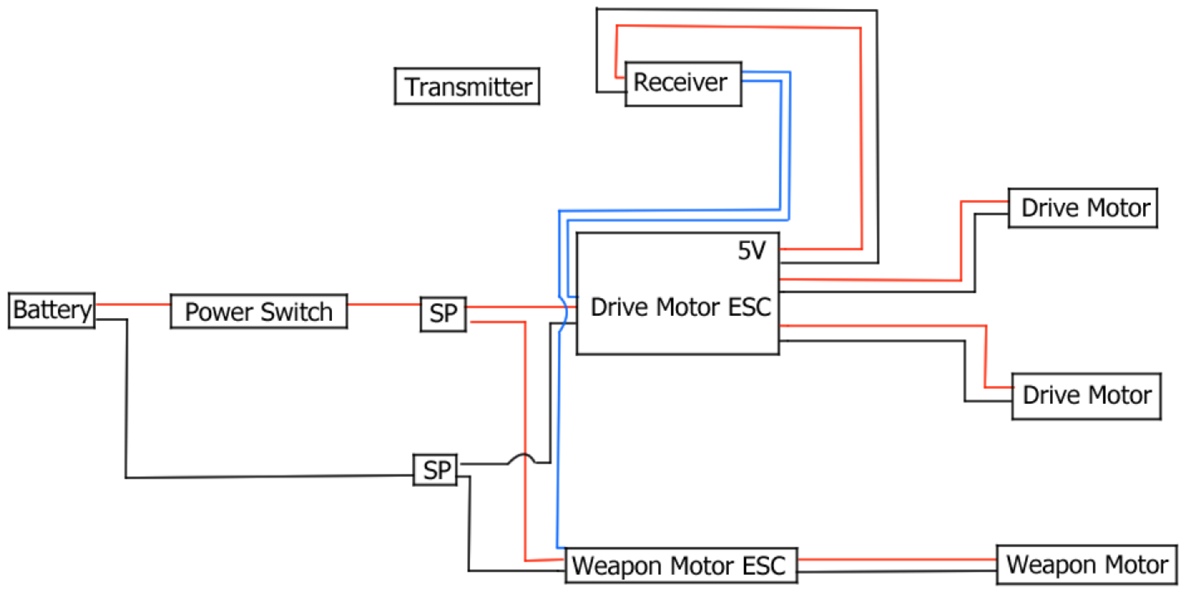


Figure 29: Wiring Diagram

Red – positive

Black – ground

Blue – signal

Battery Capacity Calculations

Measured Characteristics:

AC Weapon Motor Amperage: 45 mA

DC Drive Motor Amperage: 650 mA

Battery Capacity: 2200 mAh

Combined Motor Draw:

$$Combined\ Motor\ Amperage = Weapon\ Motor + 2 * Drive\ Motor = 45\ mA + 2 * 650\ mA = 1345\ mA$$

Battery Life:

$$2200\ mAh = 1345\ mA * hrs\ ; 1.64\ hours$$

Match Length= 3 minutes

Our battery will last 32.7 matches

Estimated Total Weight

This is the summation of all of our component weights. Solidworks mass properties feature was used to determine the weight of non-commercial or fabricated materials. This total weight of 1443.06 grams excludes the weight of wires and connectors. The extra 57g will provide adjustments to errors in real weights and the addition of wires and connectors.

	System Component	Weight	Quantity	Total Weight
Frame & Armor	Armor materials	180.5	1	172.2
	Frame materials	357.5	1	292.72
	Ball caster	0.8	2	1.6
	Body screws	1.86	38	70.6
	Ball caster bolts	0.3	4	1.2
	Ball caster nuts	0.2	4	0.8
Weapon	Weapon motor	71	1	71
	Weapon motor controller	9.6	1	9.6
	belt	3	1	3
	pully	26.3	2	52.6
	Weapon material	230	1	230
	Bearing	5.1	1	5.1
	Shaft	28.2	1	28.2
	Shaft bushing top	2	1	2
	Shaft bushing bottom	4.5	1	4.5
	Shaft collars	15.65	2	31.3
	AC motor hardware	0.39	4	1.56
	Weapon to pulley hardware	2.11	3	6.33
Drive Train	Drive motor controller	17	1	17
	Drive motor	73	2	146
	Wheels	24	2	48
	Wheel hubs	10	2	20
	Motor mounts	4	2	8
Electronics	Communication	13	1	13
	Batteries	196	1	196
	wires		N/A	
	Cable to splice in power switch		1	
	Power splitter connector		1	
	LED	4	1	4
	Power switch	2	1	2
	Power switch mounting hardware	2	2	4
	Weapon ESC to motor connectors	0.25	3	0.75
	Total Weight			1443.06

Table 5: Total Component Weight

Final Total Weight

Figure 30: Final Weight: 1431g

Proposed Fabrication

For our frame plates, armor plates, and weapon plate we will be purchasing sheets of material. We will need to cut these into shape and one possibility is to use the waterjet at 1819. Waterjets provide superior edge quality compared to plasma cutting or machining, they are cost effective, and can cut precise internal cutouts. This is important for our frame plates, as we have lots of screw holes, and our mesh design on top needs to precise in order to properly distribute forces. An alternative for the armor plates is to 3D print them. This would be more cost effective, but take longer, and can lead to warping or improper extrusions.

Our design features drive motors that are not face-mountable. We designed motor mounts that hold the motors in place from the body. These will need to be 3D printed at 1819.

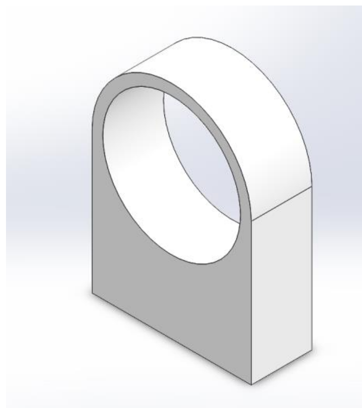


Figure 31: Motor Mounts

Our bushings, shaft, and pulley will need post process fabrication to meet our design requirements. This will be possible on the bandsaw at 1819. These cuts need to be precise so care will need to be taken to ensure dimensions are correct.

Actual Fabrication

For the Fabrication of the bot, we decided to use the 1819 Innovation hub. The top and bottom aluminum plates only needed to be cut out with the CNC waterjet. The AR500 steel plate was also able to be cut out with the waterjet. We originally wanted to tap the three mounting holes of the AR500 so that it would secure to the pulley. In the process 1819 broke their tap inside the first holes. The part needed to be redesigned and more material needed to be ordered, thankfully the people at 1819 ordered more of the AR500 plate free of charge. The weapon design had to be revised with the three mounting holes being enlarged to 4.5mm and act as thru holes for the 4mm bolts. This change did not affect any other part of our bot. Originally, we decided to make our side walls out of HDPE (High density polyethylene) but during our consultation at 1819 it was decided to change our sides walls to a 3D printed nylon 12 material. We decided to change to 3D printing at the advisement of a makerspace technician who told us that it would cost more money and take more time to have these parts manufactured. We decided to use a more expensive material, nylon 12, due to its high impact resistance. The only problems we ran into with the 3D printed materials was with the tight tolerances in the motor mounting side walls, but this was to be expected with 3D printing. We had to use a Dremel to shave off some material to get our motors to fit the way we wanted. The final fabricated parts were parts that were purchased and had to be changed to fit our design. We also had our motor mounts 3D printed with a basic PLA material. PLA was chosen because it was a very cheap option and there would be very little force on these mounts. These parts also had to be shaved down to fit the motors. Our weapon shaft was 3" long and got turned down to 2". We had two oil embedded brass flange bushings. These needed to be turned down to two different sizes to fit into our system. The first needed to be turned down to a final length of 13/32" and the second needed to be a final length of 3/16". The weapon pulley needed to be drilled out to match the 3/8" diameter of the weapon shaft, the collar needed to be turned down flush to save space on our shaft and finally the three mounting holes needed to be drilled and tapped. Finally, our AC motor pully hole was originally 2mm in diameter and needed it to be drilled out to 4mm to fit over the AC motor shaft. Unfortunately, a mistake was made at 1819 and the pully was drilled out to 5mm diameter. Due to international shipping, we were unable to get a new pully. We decided to work with the oversized pulley hole, but this proved to be difficult. The pulley only had two set screws, so the pully was very difficult to center properly. The results of this will be explained further in the testing section.

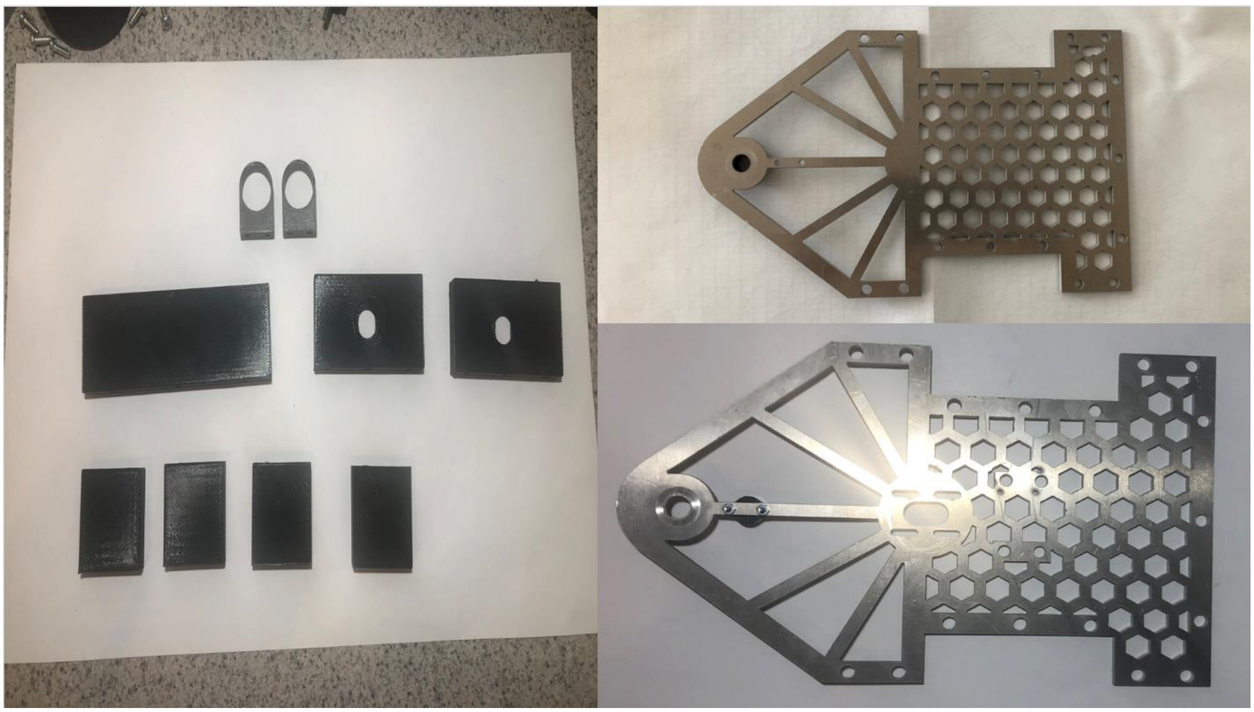


Figure 32: 3D Printed Parts & Aluminum Frames

Proposed Assembly

Frame and Armor

1. Start with bottom frame.
2. Then screw on side walls with plastic screws.
3. Assemble and install weapon and drive systems inside of frame.
4. Attach the top frame with plastic screws.

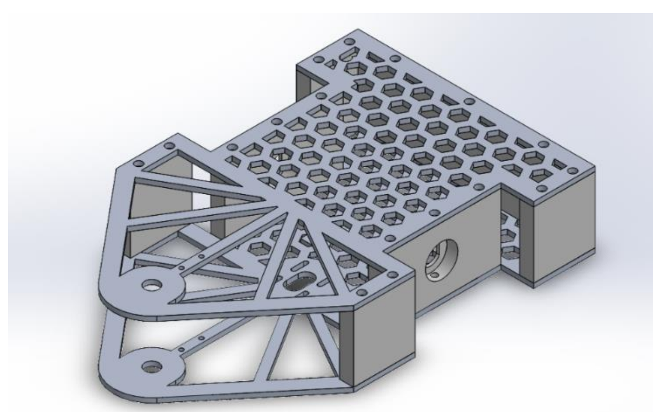


Figure 33: Frame and Armor

Weapon System

1. Install shaft into bottom frame hole. Add bottom collar and bushing onto shaft
2. Add bearing to center of weapon and attach pulley to top side of weapon.
3. Add weapon, top bushing, and collar to shaft.
4. Add the pulley to the drive motor and install screws loosely.
5. Add belt around pulleys and tension before adding top plate.

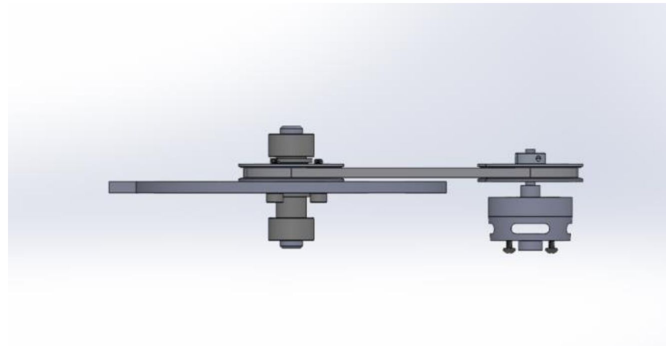


Figure 34: Weapon System

Drivetrain

1. Motor mounts will be added to bottom frame and attached with plastic screws.
2. Motors will be inserted, and hubs will be attached to the motor shaft.
3. Wheels will be affixed to hubs.
4. Drive ESC will be mounted inside bot.
5. Power and signal wires will be run from the drive motors to the ESC which will be connected to the battery and receiver.

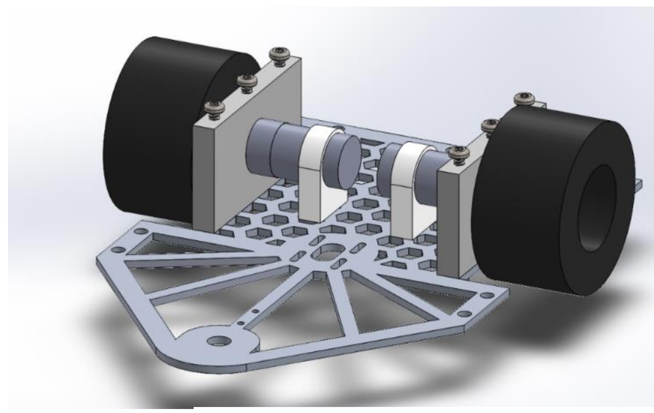


Figure 35: Drivetrain

Electronics

1. Battery will be secured inside of bot.
2. Battery XT60 output will connect to XT60 to Dean Plug adapter.
3. Plug Adapter will attach to splice adapter which is connected to power switch.
4. Power is then split using another adapter to power both ESCs.
5. Receiver is powered using 5V supply from Drive ESC and signal wires are connected to both ESCs.
6. LED is powered using 5V supply also and is attached to outside of bot.

Actual Assembly
Wiring

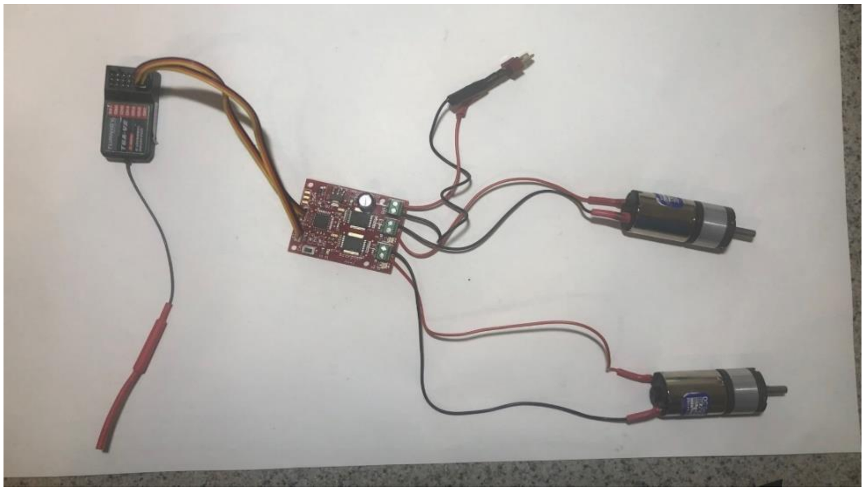


Figure 36: Starting assembly: Scorpion Mini ESC, 6Ch Receiver, LED Power Indicator Light, (2) DC Motors

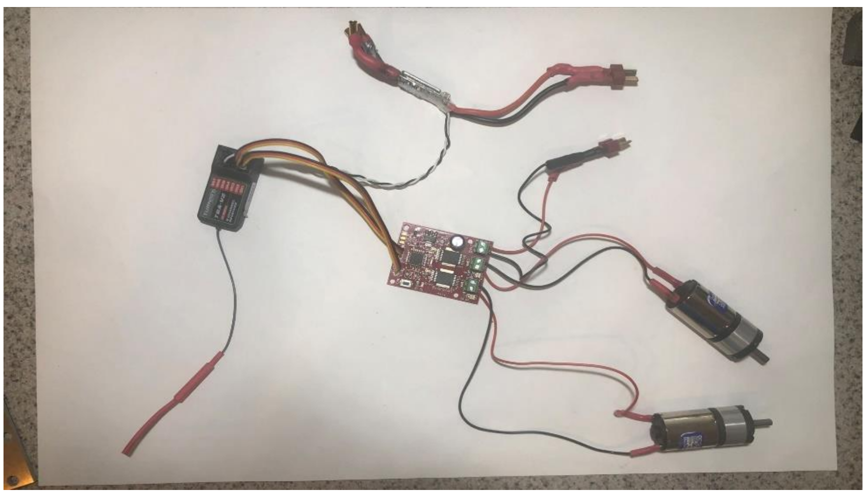


Figure 37: Addition: Turnigy MultiStar 40A BLHeli-S Rev 16 ESC 2~4S V3 (Opto)

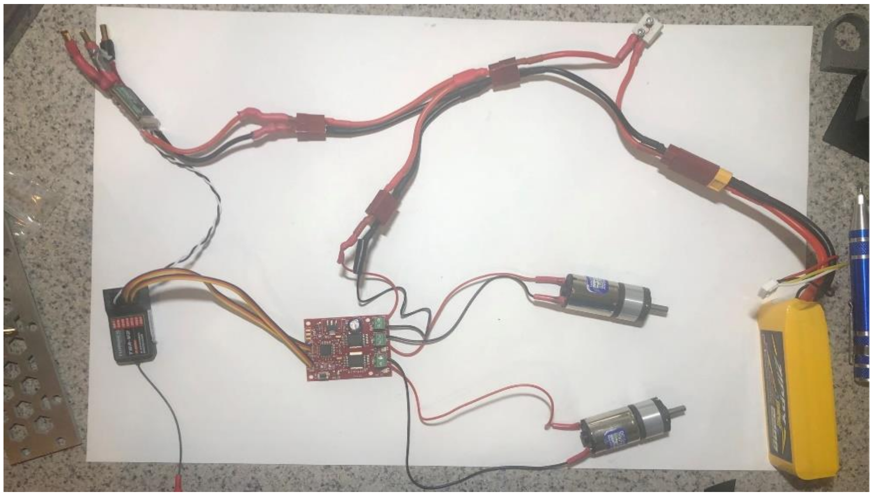


Figure 38: Addition: 3s Lipo Battery, Mini Power Switch

Weapon

Figure 39: Components: AR500 Blade, Weapon Shaft, (2) Collars, 42T Pulleys, 107T Belt

Figure 40: Finished Weapon Assembly

Full Assembly

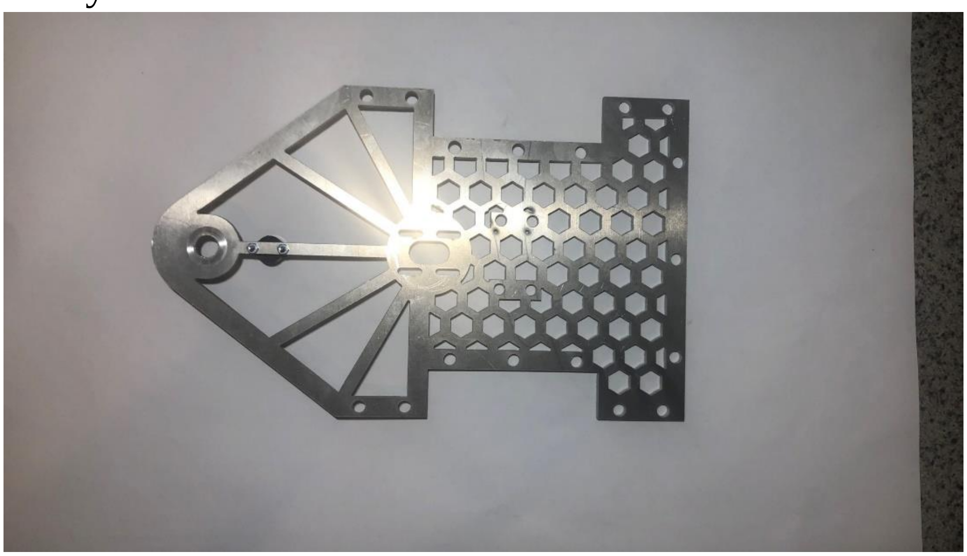


Figure 41: Starting Assembly: Bottom Aluminum Frame, Caster

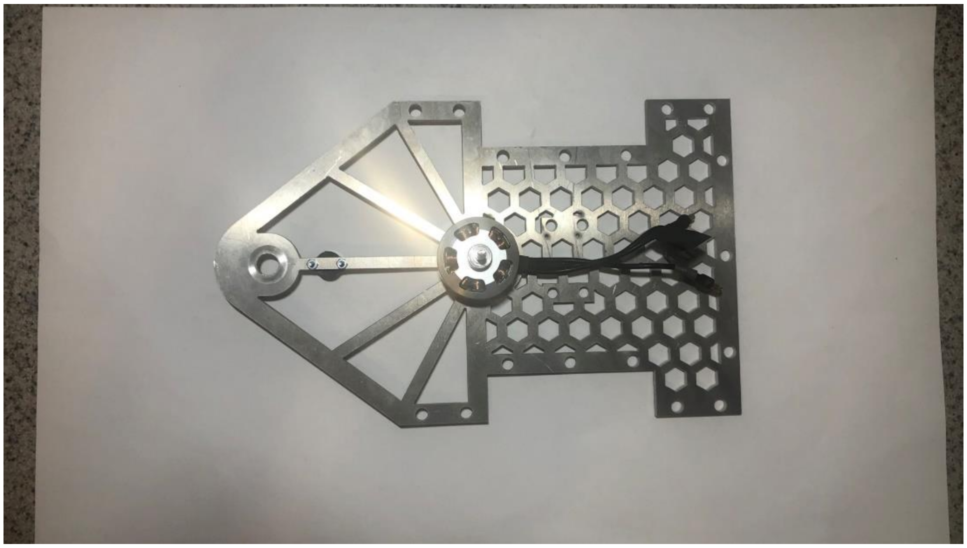


Figure 42: Additions: Turnigy Aerodrive SK3 3530-1150kv Brushless Outrunner Motor

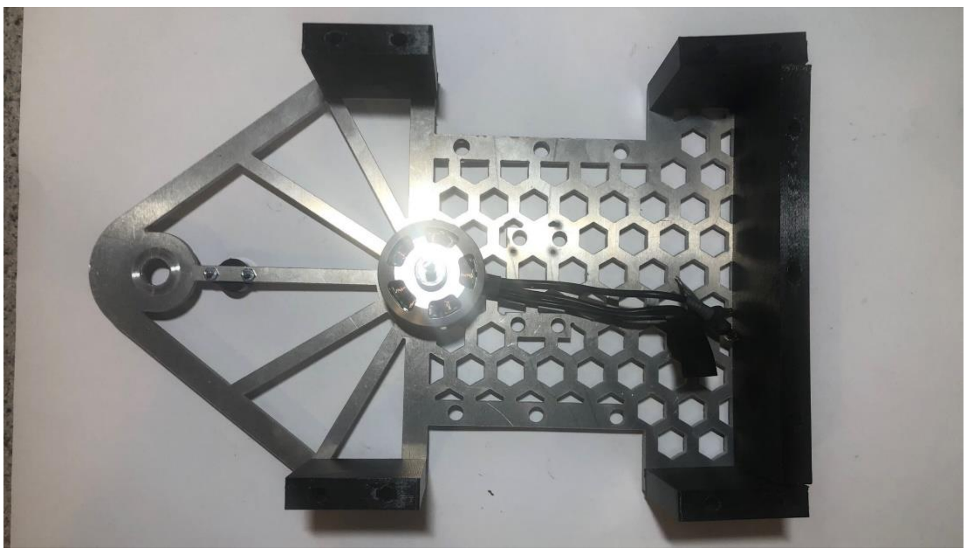


Figure 43: Additions: Nylon 12 Walls

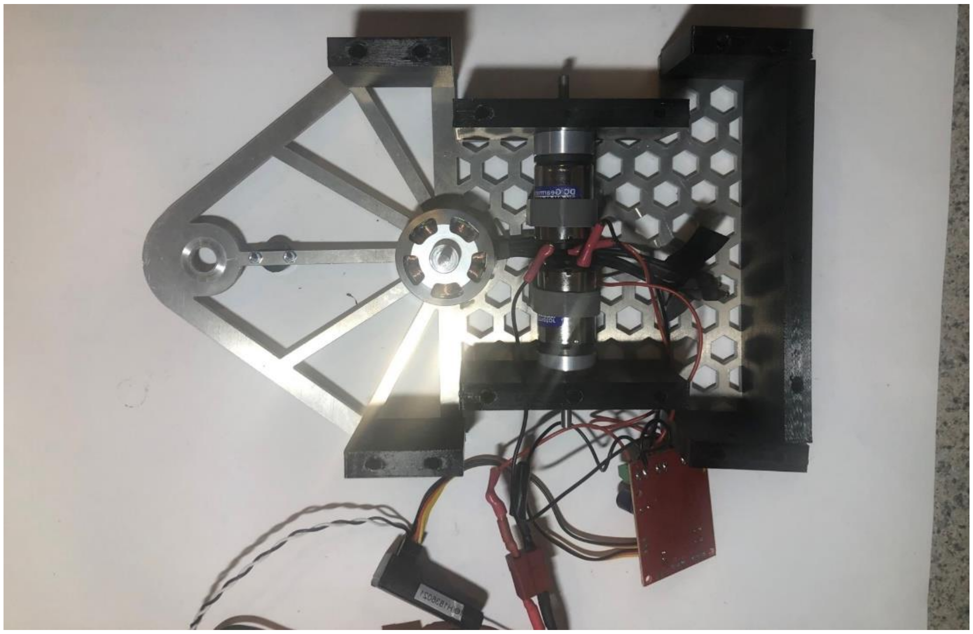


Figure 44: Additions: (2) 22MM DC Gearmotor & Motor Mounts

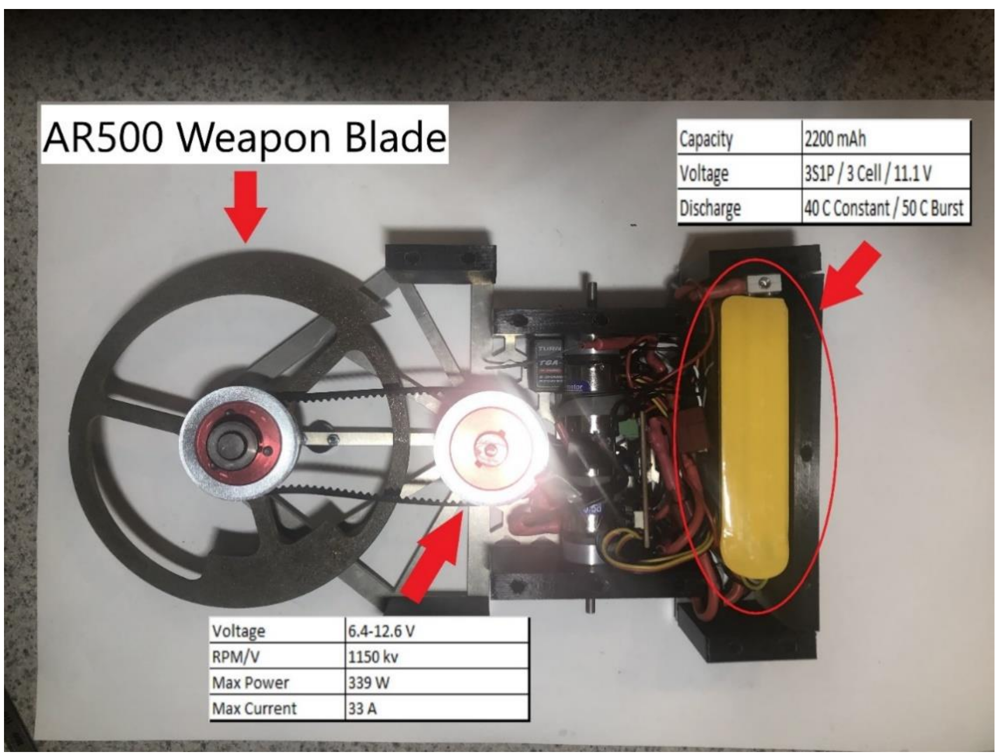


Figure 45: Additions: Wiring harness

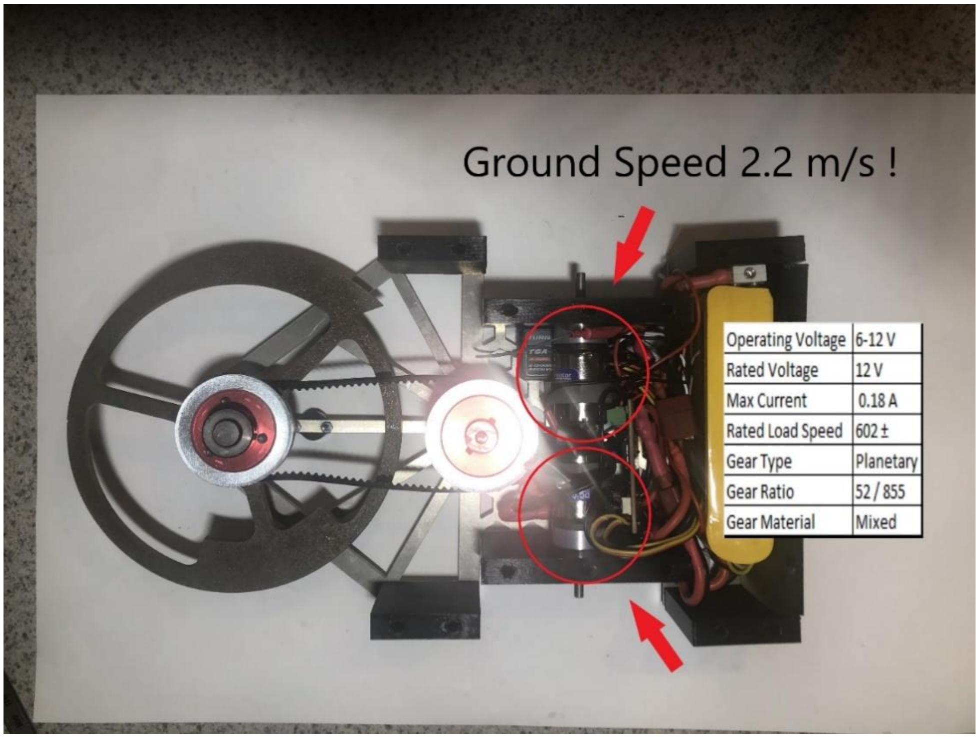


Figure 46: Additions: Weapon System

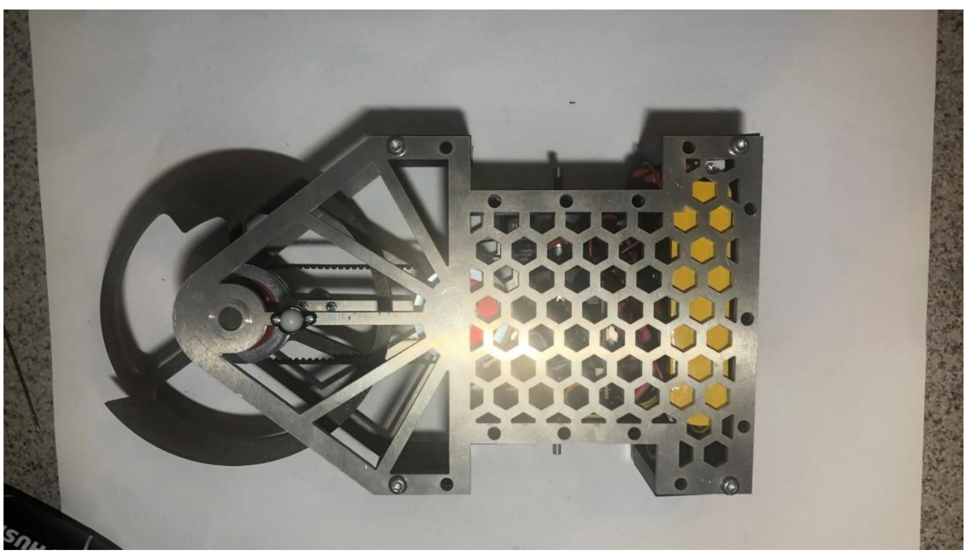


Figure 47: Additions: Top Aluminum Frame, Caster

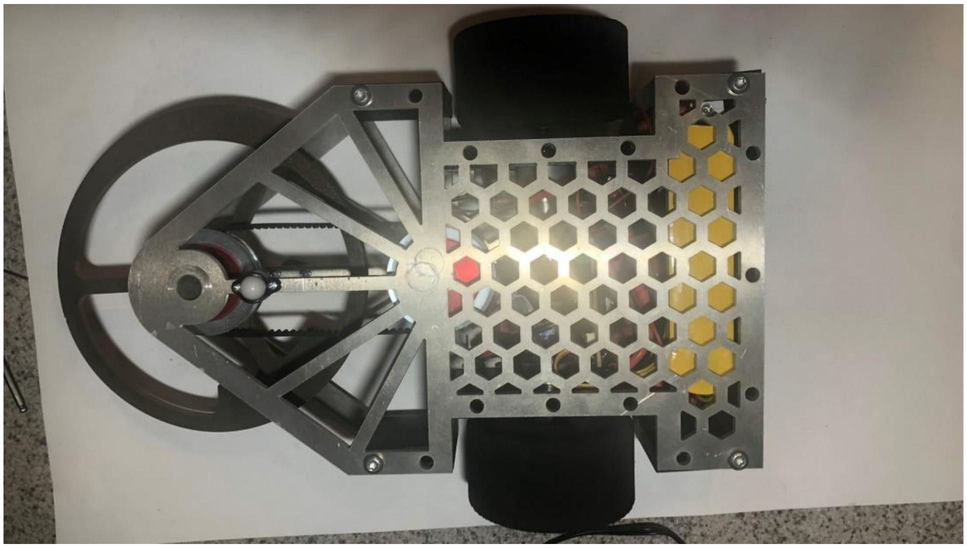


Figure 48: Additions: COMBAT ROBOT WHEELS WITH FOAM TIRES, 2.75"X1.5"

Proposed Testing

One our bot is ready to test the weapon and drive systems we will take it to Victory Parkway Campus to do live bot tests inside the UC BattleBot Club's test cage. This cage was built by a previous senior design team and will provide a safe environment to turn on our weapon motor and drive motors. The test cage is made of a hardened plexiglass and steel floor and will prevent any contact between our bot and us. Fire hazards, mechanical failure, and electrocution will all be preventable using the cage.

Along with these tests, our team will test all electrical components before assembly into our bot. This will prevent any time loss from faulty components.

Actual Testing

Figure 49: DC Motor with Missing Leads

During our initial testing we broke the lead off one of our drive motors. While repairing this the lead became unseated melted down into the motor and continuity was lost in the motor rendering it useless.

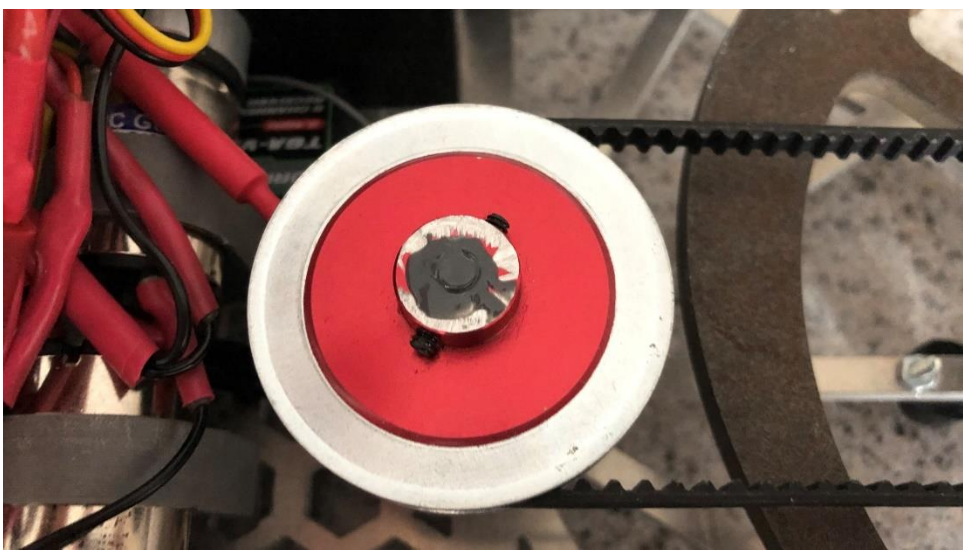


Figure 50: JB Welded Pulley onto AC Motor Shaft

As previously mentioned in the actual fabrication section the pulley wheel hole was unintentionally too large. Because of this it was very difficult to center on the AC motor shaft. Due to it being uncentered there was a lot of vibration in the system when the weapon was tested. The vibration caused the pully wheel set screws to come loose and thus the pully wheel would not be driven. To fix this first we tried to add “flats” to the pully wheel so that the set screws had a larger surface to grip on but that did not work. Next, we added Loctite to the set screws so they wouldn’t come undone, but they still slipped. Finally, we decided to put JB Weld on the bottom of the pully wheel, the AC motor shaft, and the top of the pully wheel. This secured the pully wheel, and we no longer had any slipping problems but the vibration due to it not being centered was still there.

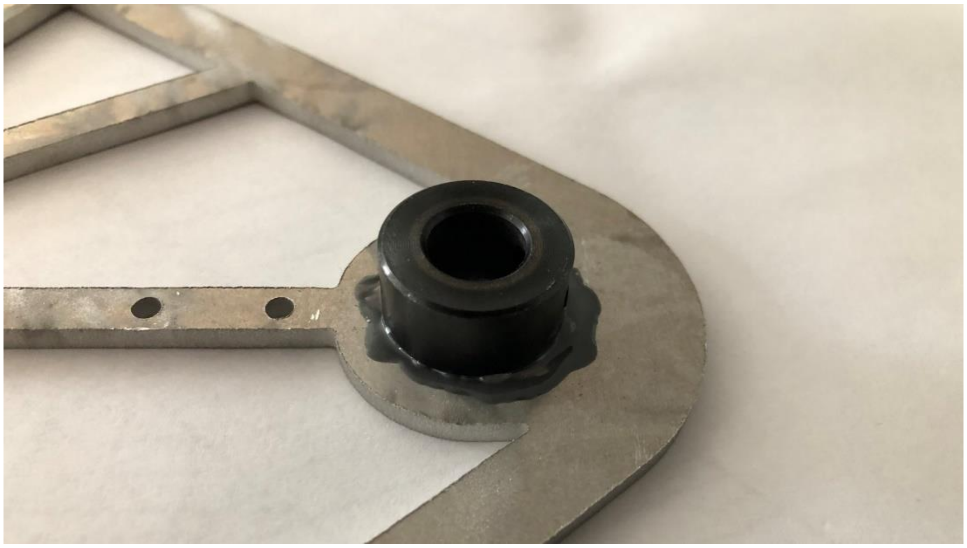


Figure 51: JB Welded Shaft Collars Attached to Frame

We decided to add JB Weld to the collar to secure it to the inside of the top and bottom pieces of the frame so that the shaft wouldn't slip while the weapon was in action. A Secondary reason we decided to do this was so that we would have a mounting point at the end of the frame.

During testing we failed to check the voltage of our battery and ran the battery down too low. This happened because our DC motors were still within their operational voltage range, and it kept draining the battery. The battery was beyond repair and a new battery was purchased.

Proof of Design

Our senior design project will be a success if our complete bot is operational, passes all safety checks, is underweight, and meets all build limitations.

All these will be tested at the internal UC BeetleBot competition that is being held in April of 2021.

Competition Results

The appendix contains videos from all the battles of the competition.

First Battle:

Hash Slinging Slasher vs. Rampway to Hell

This battle ended with a DNF for the Hash Slinging Slasher. Due to a faulty soldering job, our bot was unable to finish the battle resulting in a loss. This issue was quickly remedied by resoldering the wire. Our bot sustained minimal damage, mostly to the underside due to the Rampway to Hell's weapon being a ramp with a vertical spinner. After further inspection the bottom shaft collar broke off from the bottom plate. There's was no way to fix this problem and the weapon was still functional. The only other damage sustained was to the foam wheels.

Figure 52: Underside Frame Damage

Figure 53: Wheel Damage

Figure 54: More Wheel Damage

Second Battle

Hash Slinging Slasher vs. Grogu

This battle was technically the loser's bracket. Grogu was not functional at this stage in the competition and the battery was removed for safety reasons prior to the battle. This battle consisted with one hit with the Hash Slinging Slasher's weapon at full speed. The weapon connected with the steel bearing of Grogu and sparks and shrapnel flew in the cage. The results left the Hash Slinging Slasher's weapon completely broken due to a broken pulley and side wall. The force of the hit dislodged the weapon shaft and as the weapon continued to spin it came into contact with the AC motor, breaking the pulley, and then into the side wall where it shattered it. The resulting damage to Grogu's steel bearing was complete destruction.

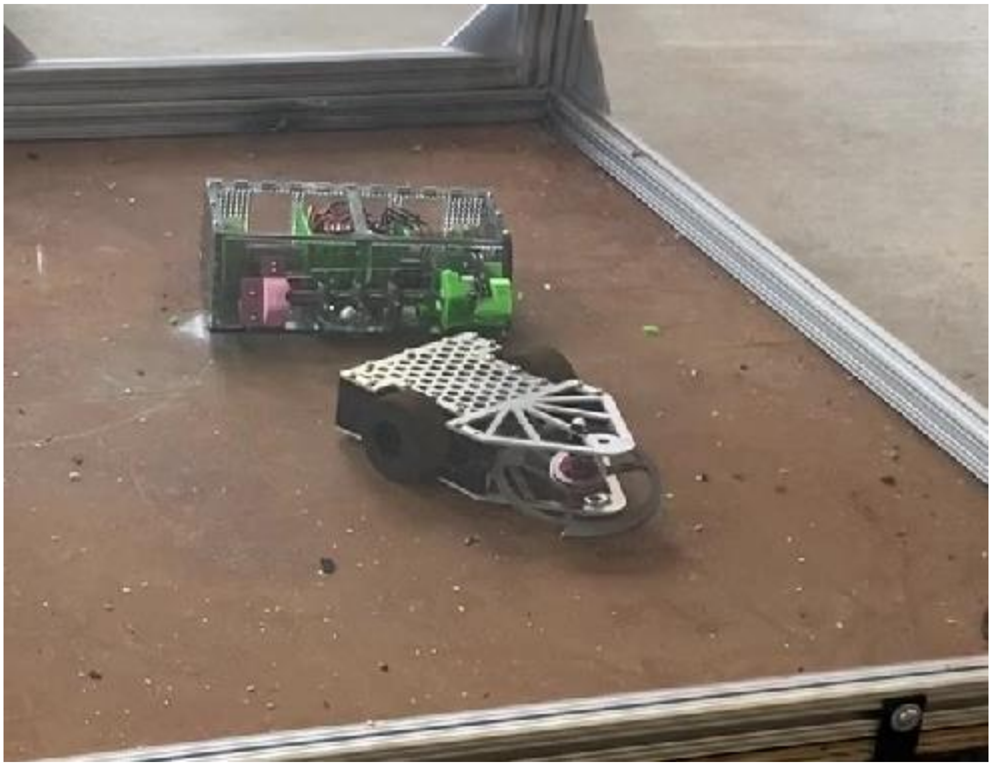


Figure 55: Bot with Slipped Weapon Assembly

Figure 56: Bot with Missing Weapon Assembly

Figure 57: Broken Side Wall

Figure 58: Broken Pulley

Third Battle

Free-for-all Battle Royale

The final battle was a free-for-all with all 4 bots in the cage at once. Our bot was modified by completely removing the weapon assembly and utilizing the drive wheels to ram into other bots. We utilized a quick 360 spin as our main attack method for this battle. Our speed and agility were ultimately what crowned us as the winner per the judge's decision. Our bot also sustained no damage.

Winner: Hash Slinging Slasher

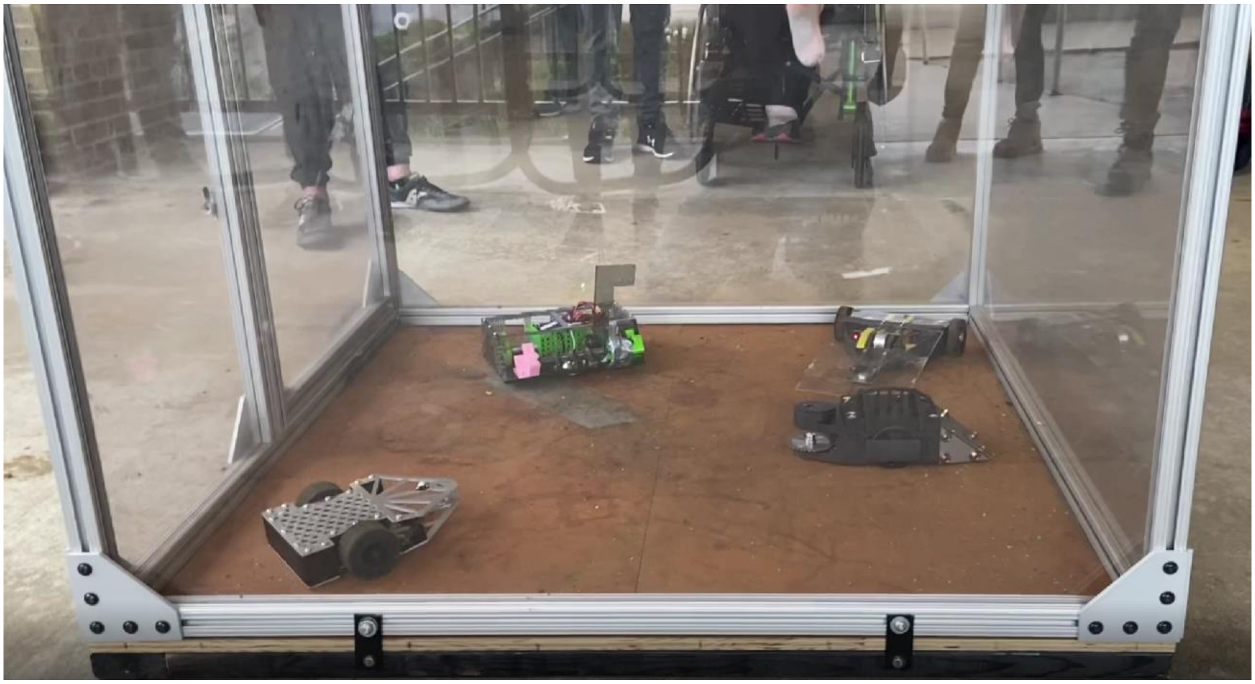


Figure 59: Third Battle

Figure 60: Champion with His Trophy

Project Management

Proposed Budget

Our final budget comes in at $427.81. This build price excludes shipping and fabrication costs and tax. Hardware was sourced through McMaster-Carr and totals approximately $50. We plan on sourcing our hardware elsewhere, as these prices are for bulk amounts of hardware that are not necessary for our build. The UC BattleBot club will provide a $340 sponsorship of our bot.

Use	Item	Cost	Qty	Source	Weight (g)	Cad Design
Weapon motor	Turnigy Aerodrive SK3 3530-1150kv Brushless Outrunner Motor	$ 31.42	1	https://bit.ly/3IVFJKM	71	Y
Drive motor	22MM DC GEARMOTOR WITH ALUMINUM GEARBOX	$ 63.90	2	https://bit.ly/3pVC0PO	146	Y
Communication	Turnigy T6A-V2 AFHDS	$ 30.50	1	https://rb.gy/fividd	13	Y
Drive motor controller	SCORPION MINI ELECTRONIC SPEED CONTROL (ESC)	$ 44.95	1	https://bit.ly/2J5jfIA	17	Y
Weapon motor controller	Turnigy MultiStar 40A BLHeli-S Rev 16 ESC 2~4S V3 (Opto)	$ 11.92	1	https://bit.ly/2KsZThr	9.6	Y
Wheels	COMBAT ROBOT WHEELS WITH FOAM TIRES, 2.75"X1.5" (PAIR)	$ 23.95	1	https://bit.ly/2J7KjXD	48	Y
Wheel hubs	AXLE ADAPTER KIT - D2, ANT1	$ 11.90	2	https://bit.ly/35Yf6iL	20	N/A
Armor materials	Slippery UHMW Polyethylene Bar (3' x 1-3/4" x 3/8") (p/n 8702K732)	$ 9.90	1	https://bit.ly/3kLxmjB	172.2	Y
Frame materials	6061-T6 aluminum sheet (1' x 1' x 1/8") (p/n 89015K18)	$ 27.71	1	https://bit.ly/3obDi7s	292.72	Y
Batteries	ZIPPY Compact 2200mAh 3s 40c Lipo Pack	$ 18.05	1	https://bit.ly/3q0QttU	196	Y
Belt	FingerTech S3M Timing Belt (107T)	$ 2.93	1	https://bit.ly/3nCeiGi	3	Y
Pully	FingerTech S3M Timing Pulley (42T)	$ 13.80	2	https://bit.ly/3feElQK	52.6	Y
Battery charger conector	Venom UNI 2.0 XT60 Male to Deans Battery Adapter - 1 piece	$ 6.00	1	https://amzn.to/2KuPQZ3	N/A	N/A
Wires					N/A	N/A
AC motor hardware	316 Stainless Steel Pan Head Phillips Screws M2.5 x 0.45 mm Thread, 6mm Long (p/n 90116A110)	$ 5.76	4	https://bit.ly/33fp0Lk	1.56	Y
Weapon to pulley hardware	Black-Oxide Alloy Steel Socket Head Screw M4 x 0.7 mm Thread, 14 mm Long (p/n 91290A150)	$ 10.69	3	https://bit.ly/39ffZpc	6.33	Y
Cable to splice in power switch	Youme 2pcs Deans T Plug Connector Series Leads with 12awg Silicone Wire 1 Female to 2 Male Connectors	$ 7.09	1	https://amzn.to/2URtAdU	N/A	N/A
Power splitter connector	Onkuey T Plug Male to 2 T Plug Female Parallel Battery Connector Cable	$ 7.98	1	https://amzn.to/3nQjLJD	N/A	N/A
Weapon ESC to motor connectors	3.5MM FEMALE BULLET CONNECTORS (9)	$ 3.49	1	https://bit.ly/364p56I	0.75	N/A
Weapon material	AR500 Carbon Steel 6" x 6" x 3/16"	$ 32.28	1	https://bit.ly/36OY2Ln	230	Y
Power switch	FingerTech Mini Power Switch	$ 7.50	1	https://bit.ly/3kJXzir	2	Y
Power switch mounting hardware	Thread-Forming Screws for Thin Plastic Zinc-Plated Steel, M2.5 Size, 12 mm Long (p/n 96817A274)	$ 6.93	2	https://bit.ly/39dEoeK	4	Y
Shaft	1566 Carbon Steel 3/8" 3" long (p/n 6061K418)	$ 4.76	1	https://bit.ly/2IZsvxP	28.2	Y
Bearing	3/8" Needle-roller bearing (p/n 5905K22)	$ 5.57	1	https://bit.ly/3fjy4Dt	5.1	Y
LED	LED POWER INDICATOR LIGHT	$ 4.00	1	https://bit.ly/36WMyWg	4	
Ball caster	Pololu Ball Caster with 3/8" Plastic Ball	$ 3.98	2	https://bit.ly/3kZzxQF	1.6	Y
Shaft bushing top	Oil-Embedded Flanged Sleeve Bearing for 3/8" Shaft Dia 1/4" Long (p/n 6338K414)	$ 0.88	1	https://bit.ly/3pVPURS	2	Y
Shaft bushing bottom	Oil-Embedded Flanged Sleeve Bearing for 3/8" Shaft Dia 1/2" Long (p/n 6338K312)	$ 1.12	1	https://bit.ly/3kYh7jo	4.5	Y
Body screws	Torx Rounded Head Thread-Forming Screws for Plastic, Zinc-Plated Steel, M4.55 Size, 12 mm Long (p/n 99397A731)	$ 12.31	38	https://bit.ly/3IYScxr	70.6	Y
Ball caster mounting bolts	Black-Oxide Alloy Steel Socket Head Screw 2-64 Thread Size, 5/16" Long (p/n 91251A097)	$ 12.13	4	https://bit.ly/3nTw2wX	1.2	Y
Ball caster mounting nuts	Low-Strength Steel Hex Nut Zinc-Plated, 2-64 Thread Size (p/n 90480A135)	$ 1.55	4	https://bit.ly/2J7t6Oc	0.8	Y
Drive motor mounts	Custom 3D printed		2		8	Y
Shaft collars	for 3/8" Shaft Diameter and 1/2" Housing ID, 1/4" Long (p/n 9414T8)	$ 2.86	2	https://bit.ly/3IM2yAu	31.3	Y
Budget:		$340	`	Max Weight	1500	
Total Cost:	does not include shipping or tax	$427.81		Total Weight	1443.06	

Table 6: Project Budget Limit

Actual Budget

After purchasing all the required materials, paying for everything to be fabricated at 1819, and any extra assembly materials, our final budget came out to $743.08. With the $340 allotted to our bot from the UC BattleBot club, that leaves each member paying $134.36 to complete the build. The only materials we did not use is the polyethylene bar, as we chose to use 3D printed Nylon 12 as our side walls instead.

1	Use	Item	Cost	Qty	Source	Weight (g)		Reinbursment
2	Weapon motor	Turnigy Aerodrive SK3 3530-1150kv Brushless Outrunner Motor	$ 31.42	1	https://bit.ly/3lVFJKM	76		$ 121.17
3	Drive motor	22MM DC GEARMOTOR WITH ALUMINUM GEARBOX	$ 95.85	2	https://bit.ly/3pVC0PO	146		
4	Communication	Turnigy T6A-V2 AFHDS	$ 30.59	1	https://rb.gy/fividd	8		
5	Drive motor controller	SCORPION MINI ELECTRONIC SPEED CONTROL (ESC)	$ 44.95	1	https://bit.ly/2J5jfIA	16		
6	Weapon motor controller	Turnigy MultiStar 40A BLHeli-S Rev 16 ESC 2~4S V3 (Opto)	$ 11.92	1	https://bit.ly/2KsZThr	10		
7	Wheels	COMBAT ROBOT WHEELS WITH FOAM TIRES, 2.75"X1.5" (PAIR)	$ 23.95	1	https://bit.ly/2J7KjXD	54		
8	Wheel hubs	AXLE ADAPTER KIT - D2, ANT1	$ 11.90	2	https://bit.ly/35Yf6iL	18		
9	Armor materials	Custom 3D printed (Nylon 12)	N/A	1	1819	200		
10	Frame materials	6061-T6 aluminum sheet (1' x 1' x 1/8") (p/n 89015K18)	$ 29.37	1	https://bit.ly/3obDi7s	258		
11	Batteries	ZIPPY Compact 2200mAh 3s 40c Lipo Pack	$ 37.04	1	https://bit.ly/3q0QttU	185		
12	Belt	FingerTech S3M Timing Belt (107T)	$ 3.15	1	https://bit.ly/3nCeiGi	2		
13	Pully	FingerTech S3M Timing Pulley (42T)	$ 14.83	2	https://bit.ly/3feElQK	57		
14	Battery charger conector	Venom UNI 2.0 XT60 Male to Deans Battery Adapter - 1 piece	$ 5.99	1	https://amzn.to/2KuPQZ3	N/A		
15	AC motor bolts	18-8 Stainless Steel Socket Head Screw M2.5 x 0.45 mm Thread, 10 mm Long	$ 5.42	100	https://bit.ly/2N3vjMs	1		
16	AC motor lock washers	l Belleville Spring Lock Washer for M2.5 Socket Head Screws, 0.106" ID, 0.189"	$ 6.86	100	https://bit.ly/3pWn5nT	1		
17	AC motor flat washers	18-8 Stainless Steel Washer for M2.5 Screw Size, 2.7 mm ID, 6 mm OD	$ 1.58	100	https://bit.ly/3tAcOjK	1		
18	Weapon to pulley hardware	Socket Cap Screws M4-0.7 x 14mm	$ 2.11	3	Home Depot	5		
19	Cable to splice in power switch	nector 1 Female to 2 Male T Plug in Series Power Connector Adapter with 12cm	$ 7.99	1	https://amzn.to/2MwyZ9i	15		
20	Power splitter connector	Onkuey T Plug Male to 2 T Plug Female Parallel Battery Connector Cable	$ 7.98	1	https://amzn.to/3nQjLJD	18		
21	Weapon ESC to motor connectors	3.5MM FEMALE BULLET CONNECTORS (9)	$ 3.49	1	https://bit.ly/364p56l	1		
22	Weapon material	AR500 Carbon Steel 6" x 6" x 3/16"	$ 32.28	1	https://bit.ly/36OY2Ln	220		
23	Power switch	FingerTech Mini Power Switch	$ 7.97	1	https://bit.ly/3kJXzir	1		
24	Power switch mounting hardware	Thread-Forming Screws for Thin Plastic Zinc-Plated Steel, M2.5 Size, 12 mm Long (	$ 6.93	2	https://bit.ly/39dEoeK	1		
25	Shaft	1566 Carbon Steel 3/8" 3" long (p/n 6061K418)	$ 4.88	1	https://bit.ly/2IZsvxP	26.67		
26	Bearing	3/8" Needle-roller bearing (p/n 5905K22)	$ 5.57	1	https://bit.ly/3fjy4Dt	4		
27	LED	LED POWER INDICATOR LIGHT	$ 4.00	1	https://bit.ly/36WMyWg	3		
28	Ball caster	Pololu Ball Caster with 3/8″ Plastic Ball	$ 3.98	2	https://bit.ly/3kZzxQF	4		
29	Shaft bushing top	il-Embedded Flanged Sleeve Bearing for 3/8" Shaft Dia 1/4" Long (p/n 6338K414	$ 0.88	1	https://bit.ly/3pVPURS	1		
30	Shaft bushing bottom	il-Embedded Flanged Sleeve Bearing for 3/8" Shaft Dia 1/2" Long (p/n 6338K31	$ 1.12	1	https://bit.ly/3kYh7jo	4		
31	Body screws	d Thread-Forming Screws for Plastic, Zinc-Plated Steel, M4.55 Size, 12 mm Long	$ 12.31	38	https://bit.ly/3lYScxr	64		
32	Shaft collars	for 3/8" Shaft Diameter and 1/2" Housing ID, 1/4" Long (p/n 9414T8)	$ 2.86	2	https://bit.ly/3lM2yAu	26		
33	Drive motor mounts	Custom 3D printed (PLA)	N/A	2	1819	5		
34	Armor materials	Slippery UHMW Polyethylene Bar (3' x 1-3/4" x 3/8") (p/n 8702K732)	$ 9.90	1	https://bit.ly/2I6gGWC	N/A		
35	Hobbyking Tax/Shipping		$ 38.35					
36	Fingertech Tax/Shipping		$ 8.24					
37	Pololu Tax/Shipping		$ 4.57					
38	TeamTrinity Tax/Shipping		$ 3.41					
39	McMaster-Carr Tax/Shipping		$ 35.93					
40	Botkits Tax/Shipping		$ 3.85					
41	1819 Machining	Pulley wheels, shaft, bushings	$ 48.00		2 hours			
42	1819 Waterjet	Aluminum top & bottom, AR500 weapon	$ 24.00		1 hour			
43	1819 3D Printing	Nylon 12 Side walls, PLA motor mounts	$ 80.00		7 hours			
44	Controller Batteries	AA & AAA	$ 14.28		Kroger			
45	Electrical Tape		$ 0.94		Home Depot			
46	Super Glue		$ 5.97		Home Depot			
47	Threadlock		$ 6.47		Home Depot			
48								
49	Budget:		$340	`	Max Weight	1500		
50	Total Cost:		$ 743.08		Total Weight	1431.67		

Table 7: Actual Budget

Key Milestones

Proposed Timeline

		Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21
Senior Design 1	Problem Statement	24-Aug								
	Research		18-Sep							
	QFD			2-Oct						
	Concept Drawings			9-Oct						
Senior Design 2	Budget				22-Nov					
	Timeline				22-Nov					
	Senior Design 2 Presentation					2-Dec				
Senior Design 3	Order Parts						2-Jan			
	Fabrication							2-Feb		
	Assembly								2-Mar	
	Testing									1-Apr
	Tech Expo									1-Apr
	Competition									April

Table 8: Proposed Timeline

Actual Timeline

		Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21
Senior Design 1	Problem Statement	24-Aug								
	Research		18-Sep							
	QFD			2-Oct						
	Concept Drawings			9-Oct						
Senior Design 2	Budget				22-Nov					
	Timeline				22-Nov					
	Senior Design 2 Presentation					2-Dec				
Proposed Senior Design 3	Order Parts						2-Jan			
	Fabrication							2-Feb		
	Assembly								2-Mar	
	Testing									1-Apr
	Tech Expo									1-Apr
	Competition									April
Actual Senior Design 3	Order Parts						13-Jan			
	Fabrication							22-Feb		
	Assembly								26-Feb	
	Testing									28-Mar
	Tech Expo									15-Apr
	Competition									17-Apr

Table 9: Actual Timeline

Conclusion

Recommendations

In hindsight, there are a few alterations that we would make to our bot. The main change we would make is with our weapon system. The AR500 horizontal blade was too much to handle for our bot. The bot effectively became a glass cannon, meaning that while it was able to output a lot of damage to the opposing bot, it also inflicted damage upon itself. To be able to stick with our initial weapon design of a horizontal spinner there would need to be a few changes such as making the weapon lighter. The AR500 blade was 220 grams, and the entirety of the weapon system was 300 grams which is over a fifth of our total weight. Another change we would make is designing a better way for our weapon shaft collars to become a part of the frame. The temporary change we made was to JB Weld the collars to our frame, but after two battles the welds failed, causing catastrophic failure. A solution to this would be to weld the collars to the frames, locking them in place so the shaft has no opportunity to slip. There are also some general changes that we would have made to the bot and our overall fabrication process. Firstly, covering the soft foam wheels would eliminate a lot of damage to the weakest part of the bot. For fabrication, we would not use the 1819 Innovation Hub as our method of machining our parts because of our budget complications.

Conclusion

Considering our problem statement, our team was successful in creating a 1.5kg Battlebot that was able to compete, and ultimately win the UC Beetle Bot competition. As a team, we were able to follow our proposed timeline and design a bot that met all technical and physical requirements in order to be ready for the competition date. Although our bot won, there was a key flaw that was presented after battling, the weapon system was not as durable as intended which rendered it useless after two battles. However, there were many aspects of our bot that were successful. The drive train design made our bot quick and nimble, allowing us to repurpose a backup weapon system using the front of the frame. Another successful part of the bot was the armor. No bot was able to penetrate the aluminum frame, or the 3D printed Nylon walls. Overall, the bot performed to our expectations and our group was able to prove ourselves after countless hours of work. Senior design allowed us to experience the teachings from classes five years in the making. Utilizing project management, material selection, design and machining it gave us the opportunity to show what we learned and put it into practice.

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Appendices

Appendix A: Rules and Regulations

1. General

1.1 Participation

All participants build and operate Robots at their own risk. Fighting Robots is inherently dangerous. There is no amount of regulation that can encompass all of the dangers involved. Please take care to not hurt yourself or others when building, testing, and competing. Compliance with all event rules and competition regulations is mandatory. It is expected that competitors stay within the rules and procedures of their own accord and do not require constant policing.

1.2 Loopholes

If you have a robot or weapon design that does not fit within the categories set forth in these rules or is in some way ambiguous or borderline, please contact the Fighting Robots Association. Safe innovation is always encouraged, but surprising the event staff with your brilliant exploitation of a loophole may cause your robot to be disqualified before it ever competes.

1.3 Safety Inspections

Each event has safety inspections known as Tech checks. It is at the inspector's sole discretion that your Robot is allowed to compete. As a builder you are obligated to disclose all operating principles and potential dangers to the inspection staff.

1.4 Activation

Robots must only be activated in the arena, testing areas, or with expressed consent of the event organizer and the safety officials. All activation and de-activation of robots must be completed from outside the arena barrier or within specially designated areas. You must never enter the arena with live robots without the express permission and supervision of the event organizer.

1.5 Safety Covers

All Robots not in an arena or official testing area must have secure safety covers over any sharp edges and pinch hazards. Safety covers must be designed in such a way that they cannot be dislodged unintentionally.

1.6 Locking Bars

All weapons must be secured using a locking bar. The locking bar must be designed in such a way that it can quickly and easily be installed or removed without touching the weapon. The design must ensure that the weapon cannot be fired during the activation process.

1.7 Tethers

All high-speed weaponry with a single linkage, such as axes and flippers, must carry a suitable tether to ensure moving parts cannot break free from the chassis during operation.

1.8 Carrying Cradles

All robots not in an arena or official testing area must be raised on their carrying cradles in a manner so that their motive power cannot cause movement if the robot were turned on, or cannot roll or fall off a pit table. Runaway robots are VERY dangerous.

1.9 Restrictions

In some situations, the safety inspection team may deem it necessary to place restrictions on your robots operation for safety purposes. It is entirely your responsibility that these restrictions are adhered to at all times.

1.10 Power Tools

It is expected that builders will follow all basic safety practices such as gloves and goggles when operating any machinery. The use of welders, grinders and other equipment that may produce smoke, debris or other harmful substances is only permitted in dedicated workshop areas. Please take care of yourself and others around you.

2. Weight Classes

2.1 Weight Classification

- Antweight: Maximum 150g
- Beetleweight: Maximum 1.5kgs
- Featherweight: Maximum 13.6kgs
- Lightweight: Maximum 30kgs
- Middleweight: Maximum 55kgs
- Heavyweight: Maximum 110kgs

2.2 Legged Robots

Legged Robots or “Walkers” can weigh up to twice the specified weight in all classes. A walker must employ moveable legs to support its weight. Each leg must have at least 2 degrees of freedom. Robots with rolling or sliding mechanisms will not be classified as walkers.

2.3 Consumables

Maximum weight includes all consumables.

2.4 Safety Equipment

Maximum weight does not include safety covers or locking bars that are removed when the robot is activated.

2.5 Interchangeable Panels

If interchangeable panels or weapons are used, the weight is measured with the heaviest set-up in place.

3. Mobility

3.1 Methods

All Robots must have (easily visible mobility) in order to compete. Methods of mobility include:

3.1.1 Rolling

Rolling on wheels or the whole robot rolling.

3.1.2 Walking

Walking such as linear actuator operated legs.

3.1.3 Shuffling

Shuffling mechanisms such as rotational cam operated legs.

3.1.4 Ground Effect

Ground effect air cushions such as a hovercraft

3.1.5 Jumping

Jumping and hopping (although the height may be limited by each event due to arena safety constraints)

3.1.6 Flying

Flying (helium balloons, multirotors, etc.) (Currently flying robots are not allowed unless prior approval by the event has been granted.)

3.2 Restrictions

Event organizers may impose additional restrictions on robots for the safety of the event.

4. Radio control requirements

4.1 Frequencies

4.1.1 Permission

Transmitters must not be turned on at, or near events for any purpose without obtaining explicit permission from the event organizer.

4.1.2 Regulation

Radio systems used at events MUST comply with restrictions put in place by local regulatory bodies and applicable laws. For the UK this is OFCOM. Where a special license is required for operation of radio equipment the event organizer must be informed and the license must be available for viewing at the event.

4.1.3 Interference

Radio systems MUST NOT cause interference to other frequency users.

4.1.4 Digital Spread Spectrum

Commercial Digital Spread Spectrum 2.4GHz is recommended for combat robotics in all weight classes.

4.1.5 Allowed Frequencies

For use in robots, the following frequencies are allowed:

	AW	BW	FW	LW	MW	HW
IR	□	□	X	X	X	X
27/40MHz AM/FM	□	□	X	X	X	X

40MHz FM Digital	□	□	□	□	□	X
2.4GHz DSS	□	□	□	□	□	□
459MHz Digital	□	□	□	□	□	□

Please note that events may have additional restrictions on allowable frequencies.

Symbols:

□ = Allowed Frequency X = Disallowed frequency

AW = Antweight BW = Beetleweight FW = Featherweight LW = Lightweight

MW = Middleweight HW = Heavyweight

IR = Infra-Red remote control systems – For use with Antweights Only

27/ 40MHz AM/FM = PPM radio systems e.g. Futaba Skysports 4 40MHz FM Digital = 40MHzPCM radio systems e.g. Futaba Fieldforce 6

2.4GHz DSS = Digital Spread Spectrum radio systems e.g. Spektrum DX6 459MHz Digital = Radio systems using 459MHz Modules

4.1.6 Special Exceptions

Use of disallowed frequencies may be permitted in limited circumstances for example if running an armored radio control car or for older machines providing safe control can be demonstrated. This will be limited to non-competition fights.

4.2 Failsafes

4.2.1 Dangerous Systems

All systems that are deemed to be 'dangerous' (normally the drive and weapons) must have a 'failsafe' device. This MUST bring the systems to a pre-set 'off' or 'zero' position if the transmitter signal experiences interference or is lost. These devices must failsafe when the receiver battery is low or if power is completely lost.

4.2.2 Types of Devices

The failsafe(s) may take the form of plug-in commercial devices; electronic circuitry incorporated into receivers, or other devices. It may also consist of digital switches, which return to pre-set off position on loss of power. Care must be taken in the selection of devices to ensure they meet the requirements specified above.

4.2.3 Built-in Devices

Some receiver failsafes such as PCM do not store the pre-set positions and will take a few seconds from first turning on to receive these settings from the transmitter. This type of failsafe MUST be set correctly to ensure the safe operation of the robot and are strongly discouraged.

4.2.4 Setting Failsafes

Care must be taken to ensure that the failsafe(s) are set correctly.

Particular attention must be taken with programmable failsafe(s) that may be overlooked when transferring receivers between robots or when altering the trim (zero position) on sticks that may affect the ‘off’ or ‘zero’ position. With newer receivers it may be necessary to ‘bind’ your receiver to program the pre-set failsafe positions.

4.2.5 Servo Control

Care must be taken when using servo/ pot/ micro-switch interfaces, as these will remain in their last position with loss of power leaving the weapon active. Additional precautions must be taken when these interfaces are in use.

4.3 Failsafe Light (Advisory)

In addition to the main power light a separate light may also indicate if the robot is in “failsafe”, “off” or “zero”

position.

4.4 Remote Kill (Advisory)

Robots may incorporate a “remote kill” that brings the robot’s failsafe device(s) to the pre-set ‘off’ or ‘zero’ position via a switch on the transmitter. This is to allow for de-activation of robots from outside a fully enclosed arena and prevent accidental operation of controls.

4.5 Operation

All device(s) MUST operate to the tech checker’s satisfaction before the robot will be allowed to compete.

4.6 Crystals

Where used, spare crystal pairs must be available for each Radio Control set involved in running the robot.

4.7 Changeable Frequencies

Frequencies must be easily changeable e.g. where crystals are used, they must be accessible, particularly on the receiver, so that a change of frequency can easily take place.

4.8 Output Power

Transmitter output power must not exceed that specified by the local regulatory body or any applicable laws.

4.9 Home Built

If you are using a home built remote control system, you must first clear it with the event organizer and declare it during 'Tech Check'. Home built remote control systems are not recommended.

4.10 Power Switch

Radio equipment may be operated independently of the removable link, providing that no dangerous systems can be operated with the link removed.

4.11 Reserved Frequencies

The event may have reserved frequencies for testing, safety, and arena effects that you may not use.

4.12 Telemetry

Radio telemetry is permitted on 433MHz and 2.4GHz. Please check with the event organizer if you are using radio telemetry.

5. Autonomous/ Semi-Autonomous Robots

Robots that do not require human input for one or more of their functions.

If you are bringing an autonomous robot or a robot with significant autonomous functions, please contact your event organizer in advance.

5.1 Remote Operation

Any autonomous function of a robot, including drive and weapons, must have the capability of being remotely armed and disarmed.

5.2 Disarming

While disarmed, the robot is not allowed to function in an autonomous fashion.

5.3 Light

In addition to the required main power light, robots with autonomous functions must have an additional clearly visible light, which indicates whether or not it is in autonomous mode.

5.4 Deactivation

When deactivated the robot must have no autonomous functions enabled, and all autonomous functions must failsafe to off if there is loss of power or radio signal.

5.5 Timeout

In case of damage to components that remotely disarm the robot, the robot will automatically deactivate 4 minutes after being activated.

6. Electrical Power

6.1 Deactivation

Robots must incorporate a way of removing all power to weapons and drive systems (systems that could cause potential human bodily injury) that can be operated easily without endangering the person turning it off.

6.1.1 Removable Link

The main power cut-off MUST be an insulated, removable link, which must NOT be in place unless the robot is in the arena or under the supervision of a technician. The link must be removable without the use of tools. A key or switch is not allowed.

6.1.2 Accessibility

The link must be positioned in a visible part of the robot's bodywork, fitted away from any operating weaponry or drive, and this position must be clearly marked.

6.1.3 Covers

The link may be fitted under a cover, but the cover must be able to be opened without the use of tools.

6.1.4 Kill Switch

If the robot uses an internal combustion engine(s), the "Power" cut-off must take the form of a clearly labelled "Kill" switch. See Section 7 for further details on engines.

6.1.5 Inverted Link

Robots in the heavyweight class that are capable of being driven inverted, having a removable link fitted that is only accessible when the robot is the right way up, must have a duplicate link fitted in the opposing panel, so as to allow the robot to be disarmed when inverted.

6.2 Cabling

Cabling must be of sufficient grade and suitably insulated for maximum operational voltage and current.

6.3 Exposed Components

Current must not be carried through exposed components.

6.4 Power Light

Robots must have at least one surface mounted non-filament power light that is illuminated when the main link is fitted. The power light may be any color but must be non-flashing and in contrast with the surroundings.

6.5 Activation

The robot must be capable of being activated and de-activated by way of the removable link from outside an arena. (e.g. in a “bullpen” over a low wall).

6.6 Voltages

Voltage must not exceed 75V for direct current or 50V for alternating current except where prior approval from the event organizers has been confirmed. Note that batteries may have a higher voltage during charging and care must be taken not to exceed these limits.

7. Batteries

For assistance in selecting batteries please contact the Fighting Robots Association.

7.1 Protection

Batteries must be adequately protected within the body shell and securely fixed to minimize the chance of being punctured or coming loose during combat. In addition, packing such as high-density foam is recommended to reduce the shock of impacts.

7.2 Terminals

Battery terminals must be protected to prevent short circuits.

7.3 Permitted Types

The only permitted batteries are ones that cannot spill or spray any of their contents when inverted. Standard car and motorcycle wet cell batteries are prohibited.

7.4 Approved Battery Chemistry

	AW	BW	FW	LW	MW	HW
NiCd (Nickel-cadmium)	☐	☐	☐	☐	☐	☐
NiMH (Nickel-metal Hydride)	☐	☐	☐	☐	☐	☐
Pb (Sealed Lead Acid)	☐	☐	☐	☐	☐	☐
LiFePo4 (Lithium Iron Phosphate)	☐	☐	☐	☐	☐	☐
LiPo (Lithium Polymer)	☐	☐	☐	☐	☐	☐

7.5 Maximum Cell Count (series) and voltage

	Number of Cells (series)	Vnom	Vmin	Vmax	Vtotal
NiCd (Nickel-cadmium)	30	1.2v	0.9v	1.9v	36v
NiMH (Nickel-metal Hydride)	30	1.2v	0.9v	1.9v	36v
Pb (Sealed Lead Acid)	18	2.0v	1.5v	2.4v	36v
LiFePo4 (Lithium Iron Phosphate)	12	3.3v	2.8v	3.6v	39.6v
LiPo (Lithium Polymer)	12	3.7v	3.0v	4.2v	44.4v

Vnom – Nominal cell voltage during discharge Vmin – Minimum cell voltage

Vmax – Peek cell voltage during charging Vtotal – Nominal pack voltage during discharge

These values are taken as an approximation. Always check the manufacturers specification.

7.6 Parallel Cells

Batteries cells may be connected in parallel to increase capacity and discharge current. Caution must be taken with NiCd and NiMH as these cells may only be connected in parallel during discharge.

7.7 Charging

Improper charging may result in fire and/ or explosion.

7.7.1 Design

Only chargers specifically designed for the battery chemistry may be used. Chargers will be inspected during the Tech Check to ensure correct operation.

7.7.2 Rate of Charge

The rate of charge must not exceed the manufacturer's specification. Note that high charge rates will decrease battery life and performance.

7.8 Pb (SLA), NiCd, NiMH and LiFePo4

The following battery types can be used without any specific precautions although care must be taken when any battery particularly during charging:

- Pb (Sealed Lead Acid, SLA), non-spillable gel type.
- NiCd and NiMH
- LiFePo4 (Lithium Iron Phosphate)

7.8 LiPo

Lithium Polymer batteries have specific limitations and extra precautions which must be adhered to.

7.8.1 Charging

LiPo batteries MUST be balance charged to prevent damage occurring to the cells. Chargers that do not incorporate an integrated balancing circuitry are not permitted.

7.8.2 Voltage Cut-out (Advisory)

The robot may be fitted with an under-voltage cut-out or alarm set at or higher than the battery

manufacturer's recommendation to prevent the batteries from becoming damaged by over-discharge.

7.8.3 Fusing

A fuse rated below the maximum burst discharge of the battery MUST be fitted. The maximum burst discharge current is calculated by multiplying the C rating by the capacity. E.g. 25C 2200mAh = 55 Amp

7.8.4 Extra Equipment

Roboteers using LiPo batteries must provide a LiPo sack.

7.8.5 Inspection

LiPo batteries must be removed from the robot, inspected, and placed into a LiPo sack prior to and during the charging process.

7.8.6 Charging

Lithium batteries must not be left unattended at any time during the charging process. Leaving batteries unattended while charging will be considered a serious breach of pit safety and may result in you and your robot being removed from the event. Event organizers may provide a dedicated area for charging.

7.8.7 Damage

LiPo batteries showing any evidence of damage or swelling must immediately be placed a LiPo sack and removed to a safe, well-ventilated area such as outdoors. Note that LiPo fires occur rapidly and there is a serious risk of personal injury. Use extreme care when handling any battery that shows signs of damage.

8. Internal Combustion Engines

Note: Please check that your event allows internal combustion engines.

8.1 Fuel Capacity

Fuel capacity is limited to 500ml (17floz).

8.2 Fuel Tanks

8.2.1 Plastic

Fuel tanks separate to the engine must be made of an acceptable type of plastic (e.g. nylon).

8.2.2 Metal

If the tank is integral to the engine assembly and is metal, the cap must be plastic or a plastic "pop off" seal fitted.

8.2.3 Protection

The tank must be adequately protected from puncture.

8.3 Fuel Lines

All fuel lines must be of the correct type and held with the correct type of fittings. They must be routed to minimize the chances of being cut.

8.4 Return Spring

A return spring must be fitted to the throttle of all internal combustion engines to return the throttle to "idle" or "off" in the case of servo breakage or failure. This is in conjunction to any failsafe device.

8.5 Clutch

The output of any engines connected to weapons or drive systems must be coupled through a clutch which will de-couple the motor when it is at idle. This does not include motors used for generators and hydraulic pumps.

8.6 Remote Shut-off

All engines must have a method of remotely shutting off.

8.7 Leaks

Any robot with liquid fuel and oil must be designed not to leak when inverted. Minor leakage may be tolerated, however if it affects other robots or becomes a large clean-up issue you will be banned.

8.8 Non-standard Types

Use of internal combustion engines other than standard piston type (e.g. turbines etc.) must be pre-approved by the Fighting Robot Association.

9. Pneumatics

9.1 Allowed Gases

Pneumatic systems must use Carbon Dioxide [CO2] or Air.

9.2 Maximum Pressure

The maximum pressure at any point within a pneumatics system must not exceed 1000psi (68bar).

9.3 Cylinders

The compressed gas must be stored in a commercially manufactured gas cylinder of appropriate design, specification, and certification. Except where the maximum storage pressure is less than 50psi (3.4bar).

9.4 Burst Disc

The gas cylinder must incorporate a burst disc rated below the maximum test pressure of the bottle. Except where the storage pressure is less than 50psi (3.4bar).

9.5 Manual Isolation Valve

Gas cylinders charged to pressures of greater than 50psi must incorporate a manual isolation valve that can be operated from outside of the robot.

9.6 Remote Isolation Valve

Where the manual isolation valve is not integral to the gas cylinder (for example: the gas is normally released as soon as the cylinder is screwed into the mating pneumatic connection) must have an additional remote isolation valve accessible from outside of the robot.

9.6.1 Position

Any remote isolation valve must be positioned to minimize the pipe length between it and the cylinder. This pipe length must fully vent before the cylinder is fully unscrewed from the pneumatic connection.

9.7 Rating

All pneumatic components used with pressures greater than 50psi (3.4bar) must be rated or tested to at least the maximum pressure available in that part of the system. You may be required to provide documentation or certification to support this.

9.7.1 Custom Components

Custom made components, or parts operating above the suppliers maximum working pressure, must be independently tested and certified at 120% of the maximum system pressure available at that point.

9.7.2 Hydraulic Components

Components originally designed for hydraulics use will be de-rated by 50% for pneumatics use.

9.8 Pressure Relief Device

A pressure relief device must be installed in each part of the pneumatics system where a different operating pressure is used.

9.8.1 Rating

Pressure relief devices must have a rating of 1000psi (68bar) or 110% of the pneumatic component with the lowest ‘maximum working pressure’ rating protected by that particular pressure relief device, whichever is the lower.

9.8.2 Low Pressure Systems

Pneumatic systems employing pressures less than 50psi or systems employing air compressors that have a maximum output pressure lower than the pneumatic component with the lowest ‘maximum working pressure’ do not require a pressure relief device.

The pressure relief device(s) dictate the maximum pressure available in that part of the pneumatics system. The pressure relief device(s) must have a flow rate capacity that exceeds the maximum flow rate that can be expected under ‘over pressure’ conditions. Any attempt to falsify the pressure settings of pressure relief device(s) will be considered as gross misconduct by the FRA and may result in expulsion.

9.8.3 Full Pressure Systems

Non-regulated pneumatic systems or pneumatic systems where the regulator is not directly attached to the gas cylinder require that a 1000psi pressure relief device is fitted.

9.8.4 Regulated Systems

Regulated pneumatic systems that operate at less than 235psi (16bar) and where the regulator is directly attached to the gas cylinder do not require a 1000psi pressure relief device before the regulator. The regulator must be rated to 120% of the gas bottle burst disc pressure. A pressure relief device is required down-stream of the regulator rated at 110% of the component with the lowest 'maximum working pressure' rating.

9.9 Pressure Relief Devices

Pressure relief devices must be readily accessible and must be removable for testing purposes.

9.10 Mounting

All pneumatic components must be securely mounted and adequately protected within the body shell. Any component storing gas (i.e. gas cylinders, buffer tanks etc.) must be secured in such a way as it cannot escape the robot even if suffering a rupture.

9.11 Gauges (Advisory)

Pneumatic pressure gauges and pressure test points are not a requirement but may be requested by some event organizers.

9.12 Dump Valve

All pneumatic systems must incorporate a pressure dump valve accessible from outside of the robot. This dump valve will quickly and reliably exhaust all gas downstream of the gas cylinder isolation (or remote isolation) valve including systems with a maximum operating pressure of less than 50psi (3.4bar).

9.12.1 Normally Open

The dump valve must be left open at all times when the robot is not in the arena or testing areas. Where non-return or quick exhaust valves are used, pay particular attention to ensure no part of the system is left pressurized.

9.13 Removable Cylinders

Gas cylinders must be readily removable for inspection and refilling. You must ensure that your gas cylinder connection is compatible with the event organizer's filling stations, or that you have suitable adapters available.

9.14 Heaters and Boosters

Pneumatic systems using heaters or pressure boosters are not permitted.

9.15 Pressure Equipment Directive

Pneumatic components manufactured from 1 June 2002 must carry a CE mark. Pneumatic components 'custom made' since 30 May 2002 must carry a label indicating their non-conformity with the 'Pressure Equipment Directive' and their non-availability for sale. Components manufactured prior to 30 May 2002 are not necessarily required to carry a CE mark.

10. Hydraulics

10.1 Pressure

Hydraulic system pressure (In the actuator or cylinder) must be limited to 10,000psi by way of a maximum pressure relief valve.

10.2 Test Point

A hydraulic test point is a mandatory fitment to allow verification of a robot's maximum system pressure. A team will need its own test gauge and hose.

10.3 Storage Tanks

Hydraulic fluid storage tanks must be of a suitable material and adequately guarded against rupture.

10.4 Standards

Hydraulic fluid lines and fittings must be to British Standard (BS) and/ or to European DIN specifications.

10.5 Ratings

Hydraulic fluid lines and fittings must be capable of withstanding the maximum working pressures used within the robot.

10.6 Protection

Hydraulic fluid lines must be routed to minimize the chances of being cut or damaged.

10.7 Accumulators

Hydraulic accumulators (pressurized oil storage devices) are banned in whatever form they may take.

10.8 Bleeding (Advisory only)

Care needs to be taken when building a hydraulic system that consideration is given to bleeding the system of air. Trapped air in the hydraulic system will degrade the performance of the system and may make a robot run afoul of rule 10.7.

10.9 Power Sources

For power sources (other than electric motors/ petrol engines) please consult the Fighting Robots Association for advice as to suitability.

11. Rotational weapons or full body spinning robots

Full body spinning robots with an eccentric mass, are excluded from this section unless they spin over 500 revolutions per minute.

11.1 Stopping Time

The spinning element of any rotational weapon must spin down to a full stop in under 60 seconds.

11.2 Limits

Rotational weapons exceeding any TWO of the three limits below must be submitted for review and be pre-approved by the event organizer.

11.2.1 Weight

The spinning element is more than 20% of the robots’ total weight. (This includes any directly coupled motor components rotating on the same axis).

11.2.2 Speed

The spinning element spins above 500 RPM.

11.2.3 Size

The spinning element is greater than 500mm in diameter.

12. Springs and flywheels

12.1 Springs

Any large springs used for drive or weapon power must have a way of loading and actuating the spring remotely under the robot's power.

12.1.1 Deactivation

Under no circumstances must a large spring be loaded when the robot is out of the arena or testing area. These devices must be made safe before removing the robot from the arena or testing area.

12.1.2 Small springs

Small springs like those used within switches or other small internal operations are excluded from this rule. In addition, springs used in robots less than 5 kilos may be excepted from this rule. Please contact the Fighting Robot Association for clarification.

12.2 Flywheels

Flywheels or similar kinetic energy storing devices must not be spinning or storing energy in any way, unless inside the arena or testing area. These devices must be made safe before removing the robot from the arena or testing area.

12.2.1 Remote Deactivation

There must be a way of generating and dissipating the energy from the device remotely under the

robot's power to allow safe activation and deactivation of the robot.

12.3 Failsafe

All springs, flywheels, and similar kinetic energy storing devices must fail to a safe position on loss of radio contact or power.

12. Weapon Restrictions

The following weapons and materials are forbidden from use: Note: Some of the listed items may be allowed for effects but not as weapons. If you have an application of these items which you feel may be allowed, please contact the Fighting Robot Association.

12.1 Invisible Damage

Weapons designed to cause invisible damage to the other robot. This includes but is not limited to:

12.1.1 Electricity

Electricity as a weapon such as Tesla coils, Van-der-Graaf generators, stun guns, or cattle prods.

12.1.2 Radio Frequency

Radio Frequency jamming equipment or similar devices.

12.1.3 Radio Frequency Noise

Radio Frequency noise generated by an IC engine. Use shielding around sparking components.

12.1.4 Electromagnetic Fields

Electromagnetic fields from permanent or electromagnets, which affect other robots' electronics.

12.2 Stopping Combat

Weapons or defenses, which tend to stop combat completely, of both (or more) robots. This includes, but is not limited to the following:

12.2.1 Entanglement

Entanglement devices such as nets, fishing line, cables, string, glues, or tapes, which require the match to be stopped and the robots separated. (If this occurs the 'entangler' forfeits the match)

12.3 Rotating Weapons

The speed of any rotating weapons - e.g. circular saws, carbon, or steel cutting discs - must not exceed the manufacturer's specification. The manufacturer's specification must be available for inspection.

12.4 Hardened Blades

Commercially manufactured, hardened steel blades that may shatter are not allowed.

12.5 Blade Length

Commercial blades - e.g. bayonets - must not exceed 20cm in length.

12.6 Untethered Projectiles

Projectiles must have a tether capable of stopping the projectile at full speed and be no longer than 2.5m.

12.7 Heat and Fire

Heat and fire are forbidden as weapons, (however some events may allow limited fire effects). This includes, but is not limited to the following:

12.7.1 Generated

Heat specifically generated to damage an opponent

12.7.2 Flammables Flammable liquids or gases

12.7.3 Explosives

Explosives or flammable solids such as DOT Class C devices, Gunpowder, Cartridge Primers or Military Explosives, etc.

12.8 Smoke and Light

Smoke and light-based weapons, which impair the viewing of robots by an Entrant, Judge, Official or Viewer. (You are allowed to physically engulf your opponent with your robot however.) This includes, but is not limited to the following:

12.6.1 Smoke or Dust

Large quantities of smoke or dust. Limited smoke effects may be allowed by some events.

12.6.2 Lights

Lights such as external lasers above Class 2 (1mw) output and bright strobe lights, which may blind the opponent.

12.9 Hazardous Materials

Hazardous or dangerous materials are forbidden from use anywhere on a robot where they may contact humans, or by way of the robot being damaged (within reason) contact humans. If unsure, please contact the Fighting Robot Association.

Appendix B: Blank Survey:

UC MET Battlebot Senior Design 2021

How important is each description to you in a Beetle Bot? (1 being low importance and 5 being high importance)

Overall cost of build *

	1	2	3	4	5	
low	○	○	○	○	○	high

Bot Safety *

	1	2	3	4	5	
low	○	○	○	○	○	high

Bot Maneuverability *

	1	2	3	4	5	
low	○	○	○	○	○	high

Damage Output *

	1	2	3	4	5	
low	○	○	○	○	○	high

Armor Durability *

	1	2	3	4	5	
low	○	○	○	○	○	high

Drivechain Efficiency *

	1	2	3	4	5	
low	○	○	○	○	○	high

Frame Durability *

	1	2	3	4	5	
low	○	○	○	○	○	high

Have you ever built a battle bot? *

- ○ Yes
- ○ No

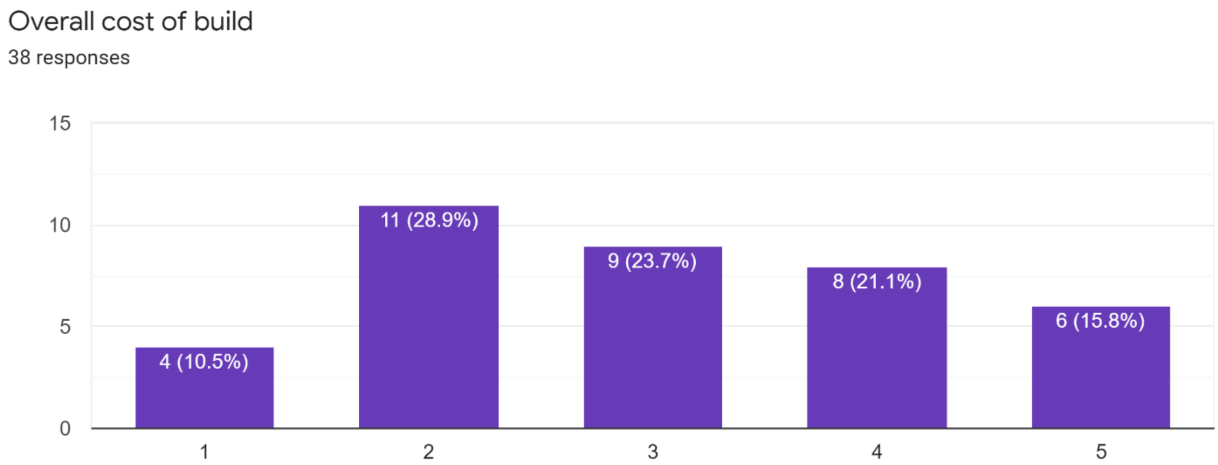
If yes, what size was your bot, and what weapon type?

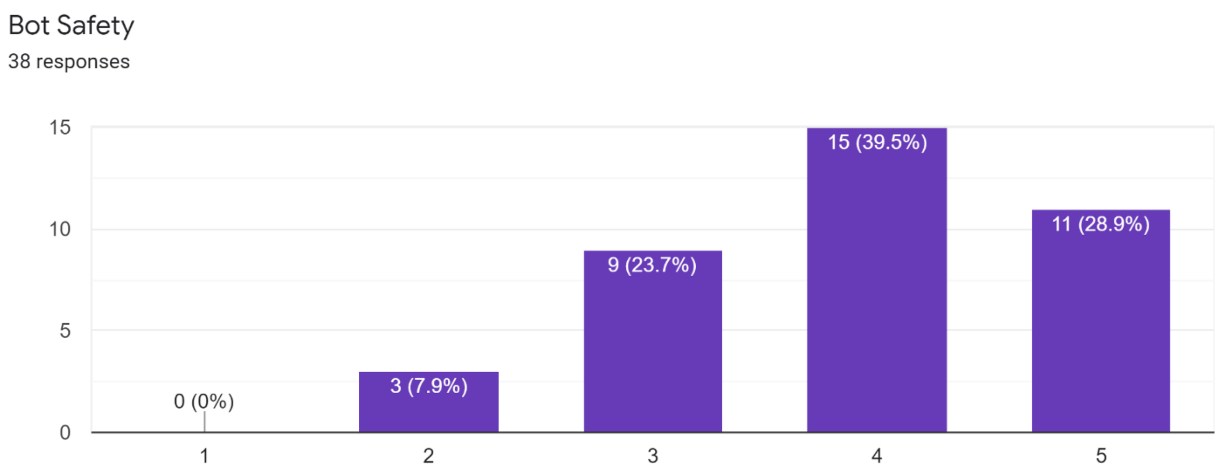
Short answer text

If yes, please list any changes you would make to your bot in retrospect.

Long answer text

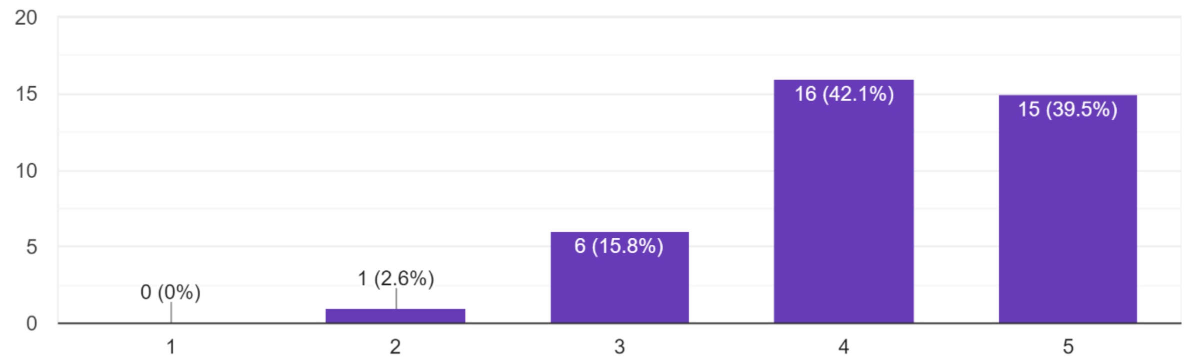
Appendix C: Survey Response Distribution:





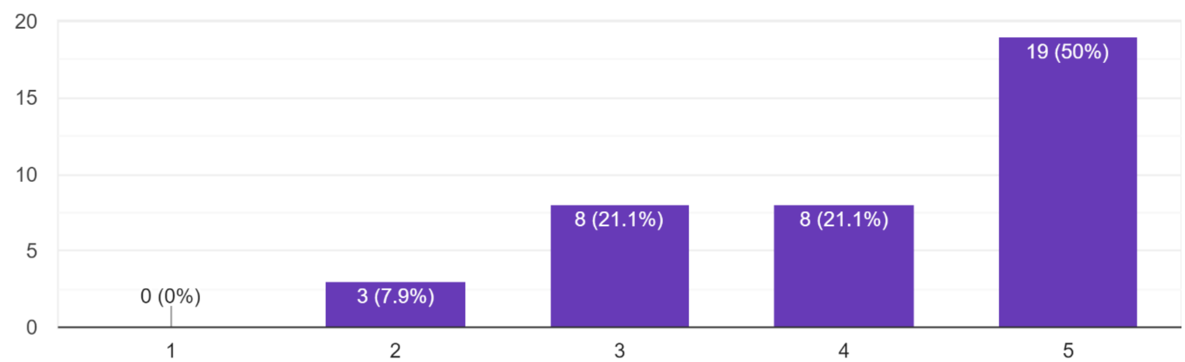
Bot Maneuverability

38 responses



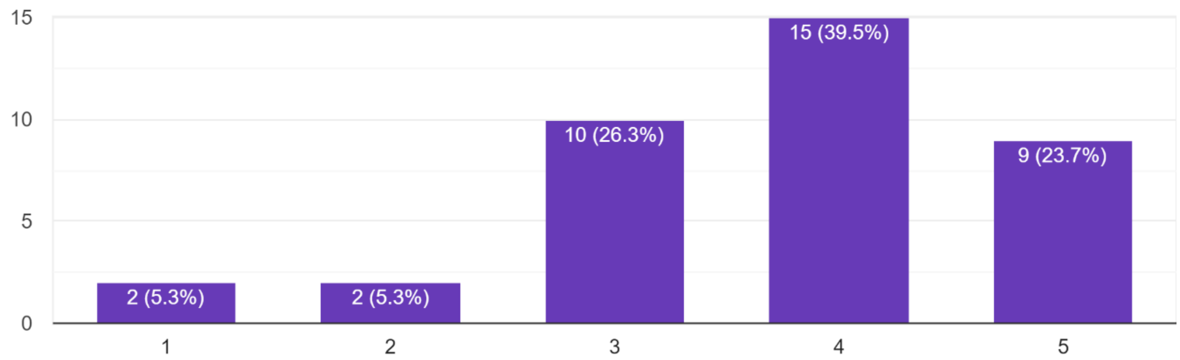
Damage Output

38 responses



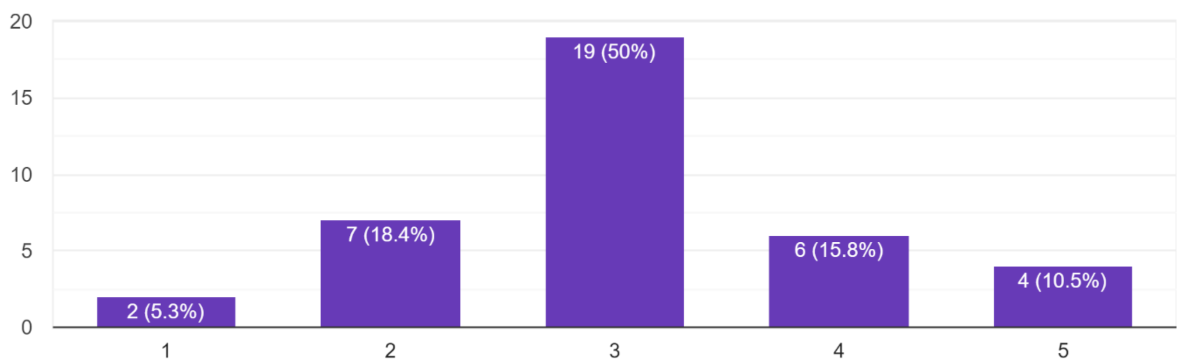
Armor Durability

38 responses



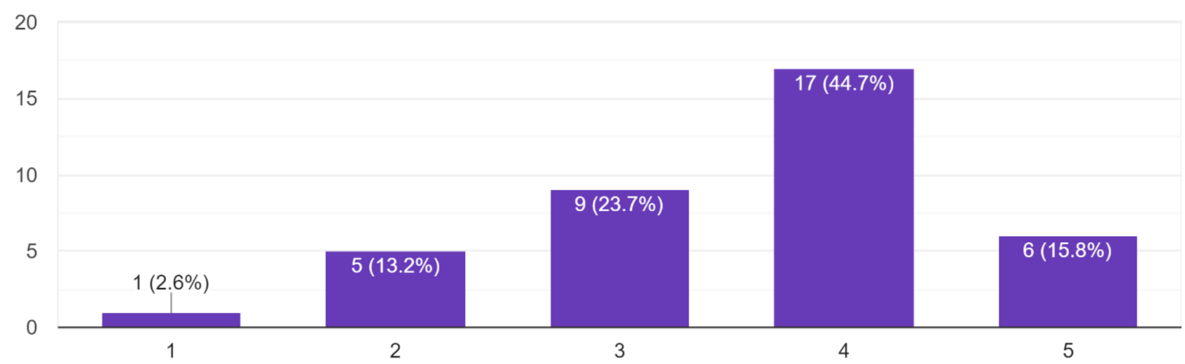
Drivechain Efficiency

38 responses



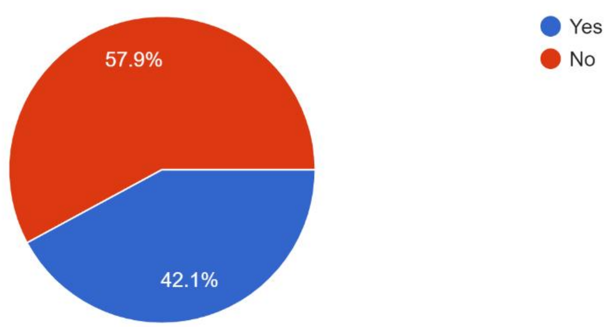
Frame Durability

38 responses



Have you ever built a battle bot?

38 responses



Appendix D: Survey Raw Data:

Timestamp	Overall cost of build	Bot Safety	Bot Maneuverability	Damage Output	Armor Durability	Drivechain Efficiency	Frame Durability	Have you ever built a battle bot?
9/25/2020 17:46	5	3	3	5	4	3	5	No
9/25/2020 18:19	2	5	5	2	4	3	4	Yes
9/25/2020 19:11	5	5	5	5	5	5	5	No
9/25/2020 19:40	1	3	4	3	1	3	2	Yes

9/26/2020 7:15	3	3	3	3	3	3	3	Yes
9/26/2020 10:47	1	5	5	5	4	3	3	Yes
9/30/2020 14:36	3	5	4	4	3	3	4	Yes
9/30/2020 15:36	2	4	4	4	5	2	3	Yes
9/30/2020 16:05	2	5	5	3	4	4	5	Yes
9/30/2020 16:31	1	4	5	5	3	5	4	Yes
9/30/2020 17:11	5	3	4	5	4	3	4	Yes
9/30/2020 20:56	1	4	4	4	5	4	3	Yes
10/1/2020 21:02	3	5	4	4	4	4	4	No
10/1/2020 22:42	3	4	4	5	4	4	4	No
10/2/2020 1:07	4	4	4	4	4	2	4	No
10/2/2020 10:48	3	4	5	5	4	4	3	No
10/2/2020 13:39	4	2	3	3	2	3	4	Yes
10/2/2020 14:18	2	4	5	3	3	4	5	No
10/2/2020 14:33	5	3	2	4	2	2	2	No
10/2/2020 14:49	4	5	5	2	3	2	4	Yes
10/2/2020 15:07	5	5	5	5	5	5	1	Yes
10/2/2020 15:52	3	3	5	5	5	3	5	Yes
10/2/2020 16:29	3	3	3	3	3	3	3	Yes
10/2/2020 21:39	4	4	3	5	5	2	3	No
10/2/2020 21:40	2	3	3	5	4	2	4	No
10/2/2020 21:59	2	4	5	5	4	3	2	No
10/2/2020 21:59	5	4	4	5	4	5	4	No
10/2/2020 22:28	4	5	5	5	5	3	5	No
10/2/2020 22:38	3	4	5	2	3	1	4	No
10/2/2020 22:53	2	4	4	3	3	3	4	No
10/3/2020 1:22	4	2	4	5	5	3	4	No

10/3/2020 10:27	2	4	4	3	3	3	4	No
10/3/2020 16:09	4	5	4	5	1	2	4	No
10/4/2020 0:37	4	5	4	4	5	3	3	No
10/4/2020 2:33	3	2	4	4	3	1	3	Yes
10/5/2020 15:36	2	3	4	5	4	3	4	No
10/6/2020 20:00	2	4	5	5	4	3	2	No
10/22/2020 8:32	2	4	5	5	4	3	2	No
	1.61	1.78	1.84	1.83	1.74	1.62	1.72	

Appendix E: Parts and Sources:

Frame/ Armor

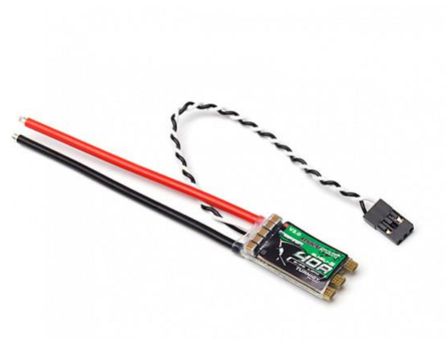
Pololu Ball Caster with 3/8″ Plastic Ball

https://bit.ly/3kZzxQF

Weapon

Turnigy Aerodrive SK3 3530-1150kv Brushless Outrunner Motor

https://bit.ly/3lVFJKM



Turnigy MultiStar 40A BLHeli-S Rev 16 ESC 2~4S V3 (Opto)

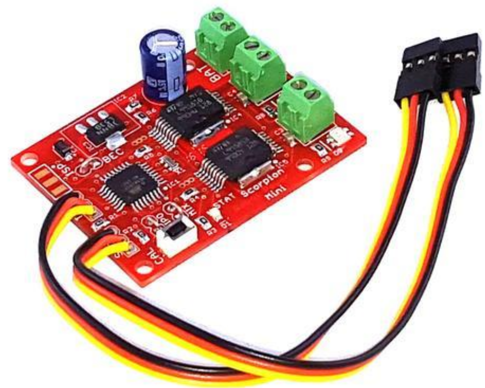
https://bit.ly/2KsZThr

FingerTech S3M Timing Pulley (42T)

https://bit.ly/3feElQK

FingerTech S3M Timing Belt (107T)
https://bit.ly/3nCeiGi

Drivetrain



SCORPION MINI ELECTRONIC SPEED CONTROL (ESC)

https://bit.ly/2J5jfIA

22MM DC GEARMOTOR WITH ALUMINUM GEARBOX

https://bit.ly/3pVC0PO

COMBAT ROBOT WHEELS WITH FOAM TIRES, 2.75"X1.5" (PAIR)

https://bit.ly/2J7KjXD

Electronics

Turnigy T6A-V2 AFHDS Mode 2 2.4GHz 6Ch Transmitter

https://rb.gy/fividd

HobbyKing 2.4Ghz Receiver 6Ch V2

https://rb.gy/fividd

ZIPPY Compact 2200mAh 3s 40c Lipo Pack

https://bit.ly/3q0QttU

FingerTech Mini Power Switch

https://bit.ly/3kJXzir

LED POWER INDICATOR LIGHT

https://bit.ly/36WMyWg

Appendix F: Videos:

Tech Expo Video

https://youtu.be/x8Uvm47ugfM

Battle 1

https://youtu.be/ocCATiampak

Battle 2

https://youtu.be/NrTyDfyLp60

Battle 2 aftermath

https://youtu.be/-hOKOrHZNuA

Battle 3

https://youtu.be/Lu4A2gCNetI