ENED's Revenge BattleBot Design

Senior Design Proposal 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

Our team’s problem statement is to design a combat robot that can inflict the maximum amount of damage to its competition while remaining fully functional. The construction must result in a robot that is as durable as possible while remaining at or below the weight constraints as well as remaining financially feasible. There is an existing UC BattleBots Club under Professor Dong, and our group has joined this club and plan to design and build a battle bot to participate in competition. The main goal is to produce a battle bot that can withstand abuse and combat against opponents and document our progress and design process.

Research

Background of the Problem

BattleBots was created after the original live-combat robot franchise called Robot Wars. This was the brainchild of Lucasfilm toy designer Marc Thorpe. Robot Wars attracted builders from across the country as well as internationally to fabricate combat robots and compete in San Francisco warehouses. This has evolved over the years into a publicized television show that brought the sport into the open where BattleBots competed in area matches with money prizes and weight classes to regulate combat (1). BattleBots has fallen out of the limelight of the media, however, it has a strong following of hobbyists, high school, and college teams, such as the University of Cincinnati BattleBots Club. The combat robot design generally is comprised of three main sections: the energy transfer devices systems, armor and defensive systems, and frame and movement systems. Combat robots are made to inflict the maximum amount of damage to their opponent while taking minimal damage with the goal of disabling or damaging their opponents beyond use or disabling their drive systems. Multiple rounds may be held if both

BattleBots remain operational after the initial round making long-term reliability and durability key factors on the outcomes of the fights.

BattleBots is a thrilling event to compete in and watch. Powerful robots fight for victory with immense power and precision; however, defense is a large part as well. The perfect BattleBot is one that can deal immense damage and take little to none from the various attack strategies used against it. Our Team wanted to address how hard it is to design a robot that can both attack and defend against different kinds of robots. It is interesting to see the differences in robot designs when analyzing the last several years of winners starting in 2018. In the years 2018 and 2019 the winner was Biteforce which is a Battle Bot with the primary energy transfer device of a vertical spinner bar. The exterior of Biteforce was made of 6061 Aluminum. In 2020, the winner was End Game which also had a vertical spinner disk as an energy transfer device with an exterior made of aluminum. During the year 2021 the winner was Tantrum which is a robot with a vertical spinner on a puncher. Tantrum was made of 1⁄2 " AR400 Steel which is a high carbon steel. In 2022, the winner was SawBlaze which is a robot with an attack of a hammer saw, a cutting saw, and a flamethrower. SawBlaze possesses an insane attack in addition to an even better defense of AISI 4140 low alloy steel construction. (2). Over the last several years there have been a broad variety of robots with various attack mechanisms and composed of different materials. Although the robot designs are very different, there are similarities, such as a vertical spinner and the main body being composed of a hard material that is not brittle.

Our Team will be implementing the above information into our BattleBots design through our University of Cincinnati senior design project. We will be testing to see if using the background information above to create an optimized BattleBot that can deal large quantities of damage while remaining fully functional. University of Cincinnati's BattleBots Club is a collaboration of UC students from a wide variety of majors such as Aerospace, Electrical, Mechanical, and Mechanical Engineering Technology. Limitations are applied to staying within certain parameters of competition rules and weight limits. Our team will be competing in the twelve-pound bot league and attempting to accomplish our goal. Competitions will be held locally or nationally through RoboGame (3) (4).

Applicable Standards

The robot we design, and build must comply with the rules and regulations of BattleBots that are posted on their website at the time of registration (4). See the appendix for more information. In addition, the robot must have a physical disabling device to restrict the spinner motion when outside the arena at all times. Engineering safety standards must be followed when working in any facilities on the main campus or Victory Parkway campus, including proper personal protective equipment. The technical drawings and 3D models created in the design process must be formatted according to industry standards as well to aid in the manufacturing process. See the appendix for details.

State of the Art

Figure 1: SawBlaze (2)

SawBlaze built and piloted by team SawBlaze is the world champion for multiple seasons in the heavyweight class. SawBlaze has a unique energy transfer device design that allows it to get underneath opponents utilizing wedges and then deal damage from above utilizing an AR600 steel vertical blade on a movable arm, trapping the BattleBot. The energy transfer device also had interchangeable parts that allowed a hammer-saw disc to be mounted for applications where greater impact force is necessary. This BattleBot was maneuvered by controlling two large rear wheels made of vulcanized rubber and rests on forks on the ground in the front of the robot, aiding in stability due to a large contact patch. The frontal wedges also give SawBlaze a larger footprint, making it more difficult to overturn. In addition, once overturned, the main energy transfer device has power and speed to function as a self-righting device which is effective despite the robot's weight. SawBlaze does however have a lack of rear armoring and because of its moveable arm-mounted blade, it lacks structural rigidity that reduces its hit impact. Its rear drive wheels are also unarmored and exposed to attacks which could potentially disable its movement (5) (2).

Figure 2: Tantrum (2)

Tantrum is a differently structured world champion combat robot designed by Seems Reasonable Robotics and competed in the heavyweight class. The energy transfer device system on Tantrum consisted of a pneumatically actuated flipping arm that held a blunt vertical spinner that could be spun up to great tip speeds and then launched into opponents to increase the force behind the blows. This robot has incredible mobility due to its four-wheeled design that utilizes planetary gearing inside custom wheels to maximize torque. Tantrum also possessed extensive armoring made of AR400 steel that shields its vital air tanks, battery, and wiring from damage. Similarly, to SawBlaze, Tantrum also has a self-righting device built onto its body that extends the stylized fists on its exterior to reorient the BattleBot when it is overturned. This BattleBot does possess rear armor but has an energy transfer device that is not mounted rigidly to the chassis which takes away the impact force when the blade contacts another bot. In addition, Tantrum’s blade does not have a deep bite because of its geometry, making it less effective against thick armor plates (6) (2).

Figure 3: End Game (2)

OYES Robotics created the world champion robot End Game which has won many titles and competed in every season since World Championship III. End Game is a simple robot armed with a powerful and heavy vertical spinner with two blunt blade tips. Different blades including a disc, teardrop-shaped energy transfer device, and asymmetric bar energy transfer device have been used in different scenarios depending on what opponent End Game is facing. The drive system of End Game is four-wheel drive and completely enclosed which protects the wheels from bladed attacks. A massive steel wedge makes up the frontal armor and functions to drive opponents up and into the main energy transfer device. Its defensive capabilities include a durable 7050 Aluminum frame and a self-righting device that looks like a pair of shades which can pitch the robot upright if it is overturned. Although heavily armored in the front, the rear lacks substantial protection making this bot susceptible to attacks from behind. Its self-righting mechanism is also located in the rear and vulnerable. The location of the drive wheels also leaves them with minimal protection from blows from above and below the chassis (7) (6).

Figure 4: Bite Force (2)

Heavyweight champion Bite Force designed and driven by Aptyx Designs is a BattleBot that has a 26-1 career record and was extremely effective with a vertical spinner energy transfer device. An arm or jaw mechanism rests below the energy transfer device and grabs other BattleBots enabling it to lift and overturn them although this feature was removed in a later iteration of the design. A fixed brace was mounted in its place on the top of Bite Force which functioned in a shearing action with the main blade. Bite Force is driven by a four-wheel drive setup which has superior traction control and plants the robot solidly to the ground to put power behind its attacks. In addition, its frame was made primarily of 6061 Aluminum with four steel wedges in the front of the robot to absorb the brunt of the damage inflicted by opponents. Weight reduction was a large consideration behind Bite Force’s construction as evident in its aluminum honeycomb design and stripped-down aesthetic. The rear of this BattleBot, however, is only lightly armored and its wheels are protected only from horizontal blows while remaining open on the top and bottom. While attacking an opponent head-on does not expose openings, the trellis frame is also fragile to heavy impact blows from the sides and above (2) (6).

End User

The end user of this document is most likely a male demographic and those with engineering backgrounds including mechanical and electrical disciplines. In addition, educators may utilize the information we have compiled in their work and other hobbyists who are actively building BattleBots could benefit from this document. Finally, other students enrolled in similar programs would be able to use what we have learned as a reference and a starting point for further improvements in the future. Also, individuals who would be getting into BattleBots as a club in high school or college and are interested in past knowledge and performance may find this project insightful. Using our documents these end users can follow and learn from our experience and data and substantially increase their knowledge of BattleBot design and construction (8).

Summary of Research

Overall, BattleBots has become more of a hobby than a limelight shows on tv like it used to be. The Battle bot is comprised of three main sections: energy transfer device systems, armor and defensive systems, and frame and movement systems. BattleBots are made to inflict the most damage while also taking the least amount of damage, and the last bot to remain active or alive will win the match. There are multiple rounds to each fight if both bots remain active after the initial round or subsequent rounds after, however, in between fights each team is given 20 min to make any necessary repairs before the next fight.

BattleBots are about defense as well as power. If the robot cannot take a hit and keep going, then all the power is useless when it comes to a battle. After comparing previous winners throughout the years there was a common aspect utilizing some variation of vertical spinner with the body constructed from a hard and not brittle material. We will be using the above information and implementing it into our battle bot design.

Our team will test to see if we can apply the background information above to create an optimized BattleBot that can deal large quantities of damage while remaining fully functional. University of Cincinnati's BattleBots Club is a collaboration of UC students from a wide variety of majors such as Aerospace, Electrical, Mechanical, and Mechanical Engineering Technology. Certain limitations constrain specific parameters of the design to comply with competition rules and weight limits. Our team will be competing in the twelve-pound bot league and attempting to accomplish our goal.

Quality Function Deployment

Customer Features

Customer features for this design project were ascertained through a public survey that asked participants to rank characteristics of BattleBots with regard to importance. This survey also collected data on how well the existing BattleBot designs meet these features. Through the responses to the survey, a compiled list of features has been created and implemented in the House of Quality diagram below.

Customer features for an optimized BattleBot include the following:

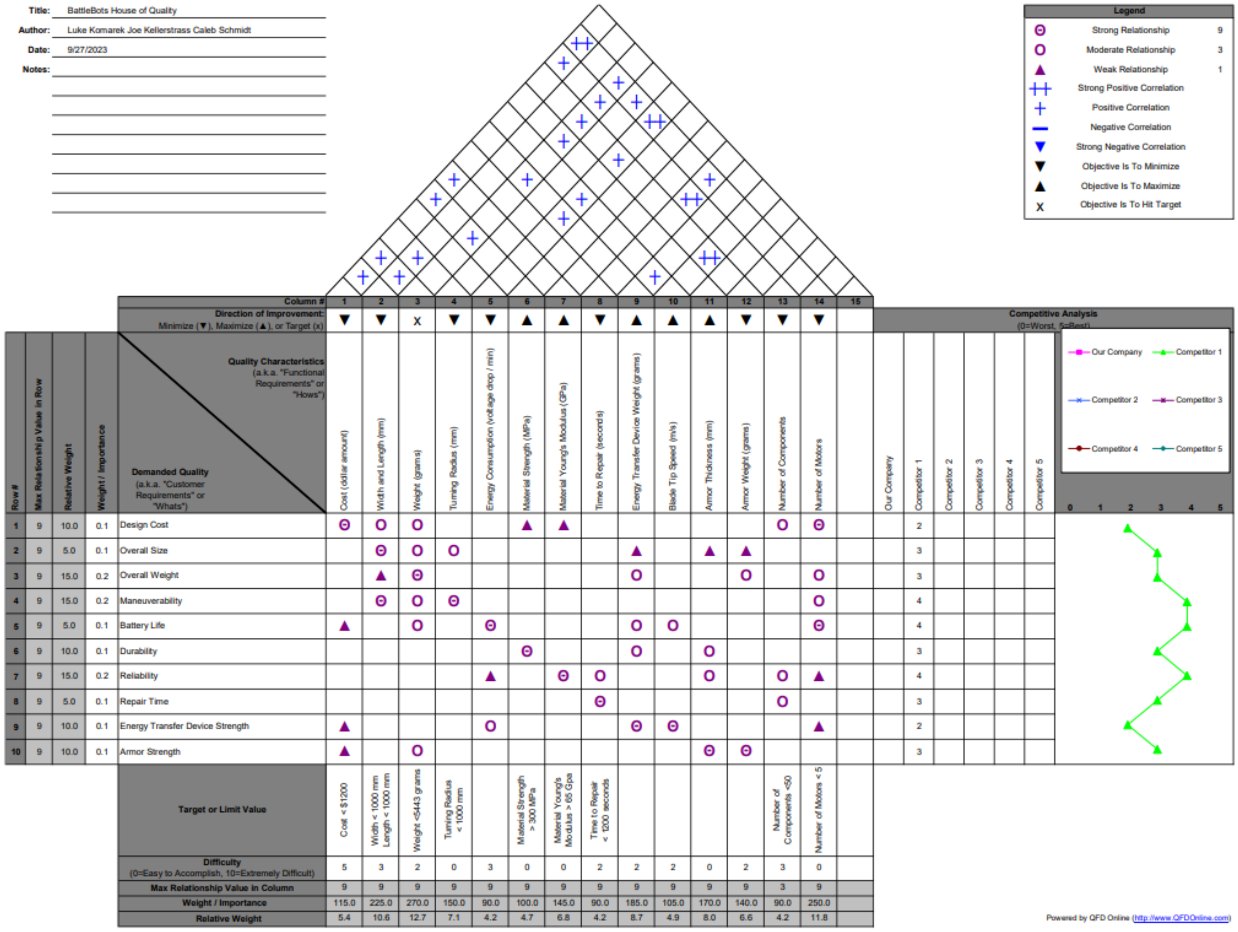
1. Low cost
2. Small overall size
3. Weight that is less than or equal to 12 lbs.
4. Maneuverability
5. Long battery life
6. Superior durability
7. Superior reliability
8. Low repair time
9. High energy transfer device strength
10. High armor strength

Engineering Characteristics

Engineering characteristics for our design include the following:

1. Cost (dollar amount)
2. Width and length (mm)
3. Weight (grams)
4. Turning radius (mm)
5. Energy consumption (voltage drop/min)
6. Material strength (Mpa)
7. Material Young's Modulus (Gpa)
8. Time to repair (seconds)
9. Energy transfer device weight (grams)
10. Blade tip speed (m/s)
11. Armor thickness (mm)
12. Armor weight (grams)
13. Number of components
14. Number of motors

House of Quality



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")	Cost (dollar amount)	Width and Length (mm)	Weight (grams)	Turning Radius (mm)	Energy Consumption (voltage drop / min)	Material Strength (MPa)	Material Young's Modulus (GPa)	Time to Repair (seconds)	Energy Transfer Device Weight (grams)	Blade Tip Speed (m/s)	Armor Thickness (mm)	Armor Weight (grams)	Number of Components	Number of Motors		Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	x	▼	▼	▲	▲	▼	▲	▲	▲	▼	▼	▼							
1	9	10.0	0.1	Design Cost	Θ	O	O			▲	▲						O	Θ			2				
2	9	5.0	0.1	Overall Size		Θ	O	O					▲		▲	▲					3				
3	9	15.0	0.2	Overall Weight		▲	Θ						O			O		O			3				
4	9	15.0	0.2	Maneuverability		Θ	O	Θ										O			4				
5	9	5.0	0.1	Battery Life	▲		O		Θ				O	O				Θ			4				
6	9	10.0	0.1	Durability						Θ			O		O						3				
7	9	15.0	0.2	Reliability					▲		Θ	O			O		O	▲			4				
8	9	5.0	0.1	Repair Time								Θ					O				3				
9	9	10.0	0.1	Energy Transfer Device Strength	▲				O				Θ	Θ				▲			2				
10	9	10.0	0.1	Armor Strength	▲		O								Θ	Θ					3				
				Target or Limit Value	Cost < $1200	Width < 1000 mm Length < 1000 mm	Weight <5443 grams	Turning Radius < 1000 mm		Material Strength > 300 MPa	Material Young's Modulus > 65 Gpa	Time to Repair < 1200 seconds					Number of Components <50	Number of Motors < 5							
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	5	3	2	0	3	0	0	2	2	2	0	2	3	0							
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	3	9							
				Weight / Importance	115.0	225.0	270.0	150.0	90.0	100.0	145.0	90.0	185.0	105.0	170.0	140.0	90.0	250.0							
				Relative Weight	5.4	10.6	12.7	7.1	4.2	4.7	6.8	4.2	8.7	4.9	8.0	6.6	4.2	11.8							

Table 1: House of Quality

Product Objectives

Below are the product objectives with their importance weighting generated from our House of Quality table and the survey results. All product objectives are listed from most important to least important based on the compiled data.

- Weight (12.7)
- Number of motors (11.8)
- Width and Length (10.6)
- Energy transfer device Weight (8.7)
- Armor thickness (8.0)
- Turning Radius (7.1)
- Material Young's Modulus (6.8)
- Armor Weight (6.6)
- Cost (5.4)
- Blade Tip Speed (4.9)
- Material Strength (4.7)
- Energy (4.2)
- Time to Repair (4.2)
- Number of Components (4.2)

Concepts Designs

Concept 01:

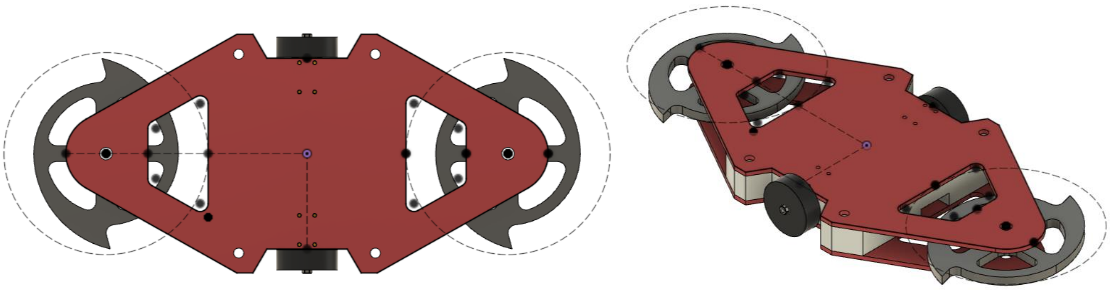


Figure 5: Concept 01

Concept 01 is a variation of the horizontal spinner with a small blade with high tip speed located on each end of the chassis. The drivetrain consists of two motors and gearboxes that are centrally located, and casters are placed underneath each blade to aid in maneuverability. The wheels themselves are inset and protected to reduce the likelihood of mobility being reduced due to damage while competing. The frame and armor of this concept are low profile and allow the BattleBot to function in the inverted orientation without negatively impacting control. The chassis of this design consists of two 2D aluminum plates for ease of manufacturing and an interior 3D printed TPU shell located between the plates to protect internal components. The basis of this design was to eliminate the weak rear armor and lack of rear energy transfer devices on most BattleBots. This is usually done due to weight restrictions, however, the energy transfer devices in this concept are significantly smaller and lighter than typically found which will theoretically keep the weight of the entire unit within specifications. Ultimately the goal of this design is to achieve both defense and offense from the horizontal spinners and sacrifice additional armoring in favor of speed and maneuverability.

Concept 02:

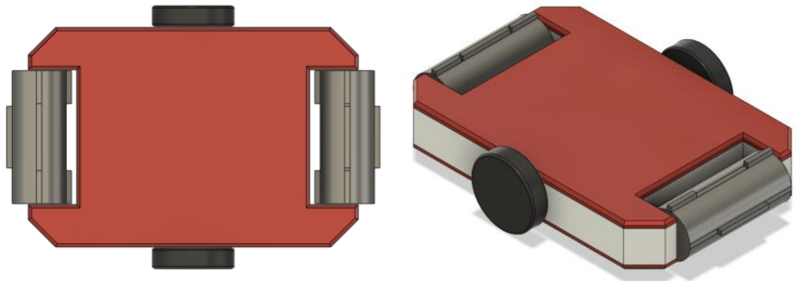


Figure 6: Concept 02

Concept 02 is a horizontal drum-based design with a drum at both the front and rear or the BattleBot. Two separate energy transfer devices prevent the BattleBot from being as susceptible to rear assaults and its low-profile design enables it to function inverted without impacting its effectiveness. The chassis is compact and houses two brushless motors and gearboxes that are located in the middle of the body. This allows the movement of 360 degrees eliminating any turning radius limitations. The chassis is three pieces in concept 02 consisting of a machined block of UHMW because of the simple geometry of the design which houses the electrical components and motors. This block is placed between two 2D machined aluminum plates. Each drum would also be spun in opposing directions which should counteract the forces generated and improve maneuverability. While the energy transfer devices provide offense and defense from the front and rear the wheels would serve to both move the BattleBot and as additional defensive armor for both sides. A variety of different drums and beater bars could be interchanged easily in this design due to the ample clearance given which enables the robot to be armed to be effective in specific situations or change the blade tip speed. The three-part construction also results in ease of maintenance that reduces the required time to access components and therefore repair time.

Concept 03:

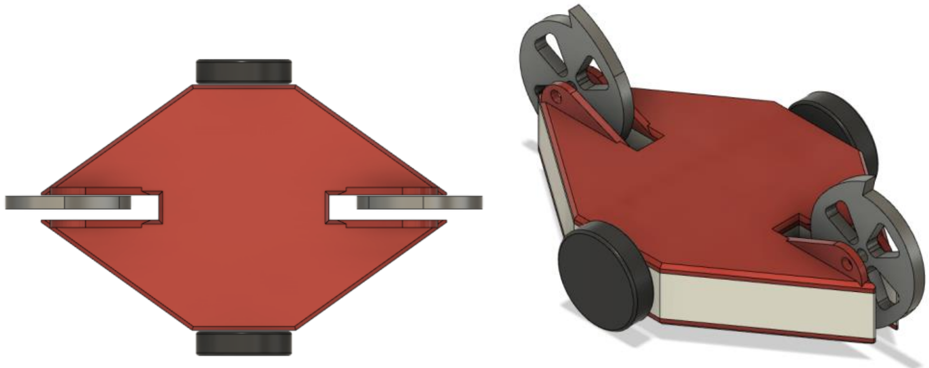


Figure 7: Concept 03

Concept 03 is armed with dual vertical spinners at the front and rear of the chassis and an angled profile that allows greater reach while maintaining interior storage for electrical components. The dual blades and body profile are designed to deflect and let blows glance off the chassis without causing significant damage. This BattleBots drivetrain consists of two motors and gearboxes mounted at the center of the body to aid in weight distribution in addition to reducing the turning radius. Concept 03 has a 3D printed TPU core that houses internal components due to its complex geometry and 2D machined aluminum plates that lend structural rigidity to the chassis. While this design is not low profile its dual vertical spinners function as a self-righting device because of the direction the blades rotate. Multiple aspects of this design are aimed at weight reduction including the chassis profile and materials chosen, enabling it to incorporate relatively large blades despite possessing two energy transfer devices. The maintenance and repair of this concept are done through the bottom due to the vertical spinner brackets mounting to the upper plate. Finally, this design will also spin each spinner in an opposing direction which cancels the forces generated and results in better maneuverability than a single vertical spinner-armed BattleBot.

Concept Design Selection

The final design was selected by utilizing the weighted matrix method to select the optimal design. The three unique concept designs were rated against the ranked product objectives that were generated from survey analysis. This is effective because the objectives that are more important will impact the scores more than minor objectives. The criterion that influenced the scores the most included the overall weight, the number of motors, and the length and width of the chassis. Importance-weights were assigned to their corresponding product objectives and then each concept was rated on a scale of 0 to 4, with 0 ranked as unsatisfactory and increasing to 4 ranked as very good. The first concept design scored the highest overall weighted score, followed by concept design two, and finally concept three. This result justifies our decision to move forward with the first concept as our final design.

		Concept 01		Concept 02		Concept 03	
Criterion	**Importance Weight**	**Rating**	**Weighted Rating**	**Rating**	**Weighted Rating**	**Rating**	**Weighted Rating**
Weight	0.175	4	0.700	4	0.700	4	0.700
Number of Motors	0.100	5	0.500	4	0.400	4	0.400
Width and Length	0.100	4	0.400	3	0.300	3	0.300
Energy Transfer Device Weight	0.100	5	0.500	4	0.400	3	0.300
Armor Thickness	0.100	3	0.300	4	0.400	3	0.300
Turning Radius	0.050	5	0.250	5	0.250	5	0.250
Material Young's Modulus	0.050	4	0.200	4	0.200	4	0.200
Armor Weight	0.050	5	0.250	5	0.250	4	0.200
Cost	0.050	3	0.150	4	0.200	3	0.150
Blade Tip Speed	0.100	5	0.500	3	0.300	5	0.500
Material Strength	0.050	4	0.200	4	0.200	4	0.200
Energy Consumption	0.025	3	0.075	3	0.075	3	0.075
Time to Repair	0.025	4	0.100	5	0.125	4	0.100
Number of Components	0.025	5	0.125	5	0.125	5	0.125
Total	1.000	N/A	4.250	N/A	3.925	N/A	3.800

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

Table 2: Concept Selection Weighted Rating Matrix Method

Development of Design Prototype

As a team we decided for Battle Bots the best defense is a good offense. We then looked into the world of already created Battle Bots for a Bot that has an impenetrable offense. This Battle Bot is Droopy, this is where our idea of the double horizontal spinner came from. The main difference in our concept design is the use of a central drivetrain and wheels instead of relying on the horizontal spinners for movement. In theory our design will be significantly more maneuverable as a result of this change.

Figure 8: Droopy

Moving forward we decided to try to create our own singular Bot with the base concept of a double horizontal spinner. We started with a basic symmetrical shape that could have room for our double horizontal blades. With our robot having two energy transfer devices which is out of the norm, the majority of our design was around creating a robot light enough and stable enough to support it. Our first design was a rough put together without any calculations on weight or specific factors of space in the internals for electronics.

Prototype Design Process

Frame Design:

The frame of our BattleBot consists of three main components, the top plate, bottom plate, and core. The motors chosen are integrated into the frame and provide mounting points for the exterior plates. Finally, covers are used to enclose the sections of the plates used to remove weight to protect the internals and increase rigidity.

Figure 9: E.R. Frame

The top and bottom plates will be machined from 0.25 in UHMW sheets and consist of only 2D features including hole patterns and slots. The structural 0.5 in-through bolts have four machined holes that are present in both plates. Four mounting holes are machined into the plates to secure the gearboxes into place on each side of the plate. In addition, four motor mounting holes and one clearance hole for the motor shaft are machined into each side of the bottom plate. Finally, mounting holes for the top and bottom carbon fiber cover plates are machined on both sides of each plate. The top and bottom plates function both as armor and as the mounting point for the horizontal spinner. These two plates will be fabricated by SendCutSend but the holes requiring thread will be done separately to reduce cost.

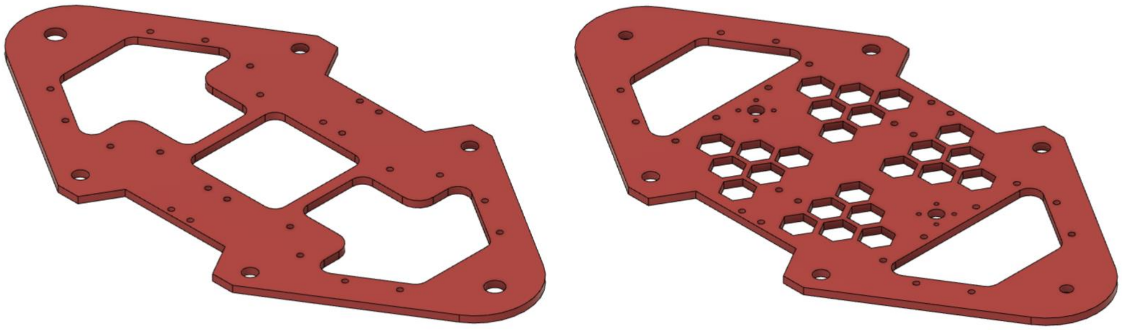


Figure 10: E.R. Top and Bottom Plates

The internal core will be a TPU 3D printed part with approximately 50 percent infill to maintain rigidity while reducing weight. This core is a complex 3D shape that is well suited to 3D printing rather than machining. The core surrounds the internal electronics and motors and acts as a standoff between the top and bottom plates. The core's exterior walls are all 10 mm thick or greater to reduce the chance of damage occurring to the internals. There are four 0.5 in bolt-through holes that correspond to the similar holes on the top and bottom plates to secure the chassis together and ensure rigidity. The core will be fabricated by our group utilizing the University of Cincinnati 3D Printing resources.

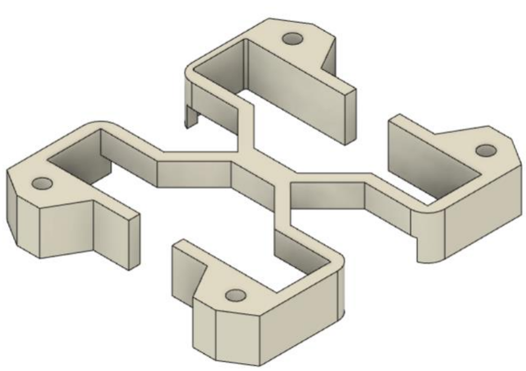


Figure 11: E.R. Internal Core

The top plate, core, and bottom plate are secured together by four 0.5 in bolts that pass through them, as well as the two ⅝ in horizontal spinner shafts on both ends of the chassis. In addition, the motors are integrated into the core and are secured both through the top plate and bottom plate with M3.5 bolts to ensure the frame is secure.

Cover Design:

The covers for this design will be fabricated out of 4 mm carbon fiber sheet due to its superior strength and low density. There will be four covers made and the top and bottom covers are interchangeable respectively. All covers are designed to have only 2D features to aid in fabrication. The top covers include clearance holes for the driving pulley as well as M 3.5 mounting holes and slots. The bottom covers have M 3.5 mounting holes and slots; however, they have a different portion removed to access the motor mounting bolts for ease of maintenance.

Figure12: E.R. Carbon Fiber Covers

Energy Transfer Device Design:

The horizontal spinner or energy transfer device of our BattleBot consists of multiple purchased and fabricated components. The stack-up includes the following: a washer, needle thrust bearing, washer, energy transfer device plate, driven pulley, and internal needle bearing. This stack-up is mirrored on the other side of the driven pulley and a ⅝ in shoulder bolt acts as the shaft to secure the energy transfer device to the chassis. In addition, the horizontal spinners are offset 90 degrees to increase their bite effectiveness.

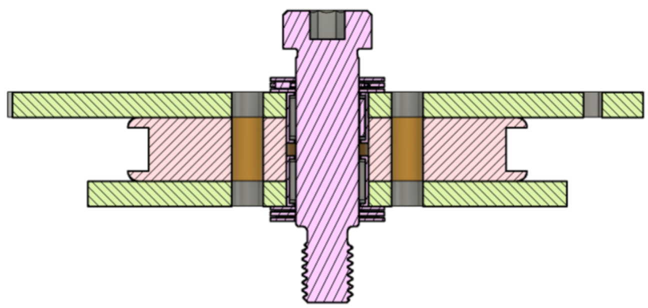


Figure 13: E.R. Energy Transfer Device Cross Section

The energy transfer devices will be machined out of a 0.25 in plate Hardox steel because of its high hardness and impact resistance. These plates are 2D and include two contact points per plate. Material has been removed from the center of the device for weight reduction while the outer perimeter has additional mass to increase the kinetic energy. Four mounting holes are machined into the plate which key it to the driven sprocket. There is a center hole for the ⅝ in needle bearing as well, which will be machined to a press fit tolerance. These four plates will be fabricated by SendCutSend.

Figure 14: E.R. Energy Transfer Device Plates

The driven sprocket is a 55-tooth design that will be 3D printed out of TPU. This is a relatively large sprocket, and the material was chosen to reduce the weight and spin-up time of the energy transfer device. The tooth profile and pitch of this part fit an XL timing belt which will connect the driven pulley to the driving pulley. The driven sprocket has a matching ⅝ in needle bearing center hole and four holes to secure the energy transfer devices. Complex geometry and features make this part an ideal candidate for 3D printing. The driven pulley will be fabricated by our group utilizing the University of Cincinnati 3D Printing resources.

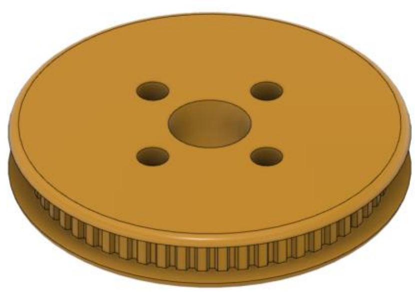


Figure15: E.R. TPU Driven Sprocket

The driving sprocket is a 32-tooth design that will be 3D printed out of TPU. This is a hub sprocket and fits over the exterior of the motor drum and is attached to the motor through the use of three M2.5 bolts. The tooth profile and pitch of this part fit an XL timing belt which will connect this sprocket to the driven sprocket. The driving sprocket has complex geometry making it an ideal candidate for 3D printing. The driven pulley will be fabricated by our group utilizing the University of Cincinnati 3D Printing resources.

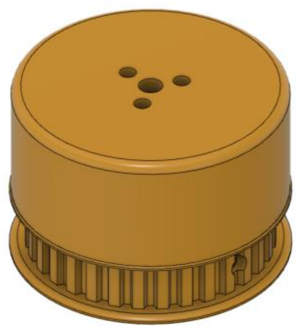


Figure 16: E.R. TPU Driving Sprocket

The energy transfer device drivetrain consists of two BA 3520 970 KV motors running on a 6s Lithium polymer battery which provides 22.2 volts. The driven sprockets have 55 teeth, and the driving sprockets have 32 teeth, resulting in a 1.72:1 reduction ratio. The energy transfer devices have a maximum diameter of 152.4 mm, which results in a tip speed of 99.975 m/s from our analysis. The energy transfer electronic speed controller chosen is the castle sidewinder 8th because it is reliable and used by the BattleBots club for 12-pound builds. The ESC is capable of handling up to 2400 KV motors and has an 8-amp peak BEC. In addition, the ESC only weighs 100 g which is suitable for our design because two are required. The castle sidewinder is also compatible with 6 cell LiPos which simplifies the necessary wiring.

Drivetrain Design:

The BattleBots movement drivetrain consists of two Tempest 2814 850 KV motors running on a 6s Lithium polymer battery which provides 22.2 volts. These motors are mated to the “beef-box” with a gear reduction of 20:1. The motors can rotate a maximum of 18000 RPM with the supplied voltage and the wheels have an outer diameter of 88.9 mm, which enables our BattleBot to reach a xx m/s top speed. The drivetrain electronic speed controller chosen is the Flycolor Francy 2 BLHeli_32 3-6S Dshot which is also a standard BattleBot Club component for 12-pound builds. The ESC is reliable, high performance, and tested in previous designs. The ESC is capable of up to 50 amps and is compatible with 6 cell LiPo batteries as well. In addition, the Flycolor Francy weighs only 16.5 g and has a low-profile design that is space efficient.

The turning radius of this design is 600mm because that is the length of the BattleBot including the spinners and it relies only on two wheels for motion which can be controlled independently. The chassis rests on the front or back of the bottom plate while moving depending on its direction of travel and because three points constitute a plane, this is a fundamentally stable design. If the BattleBot becomes inverted there is ample clearance for the wheels to function properly however the steering becomes reversed.

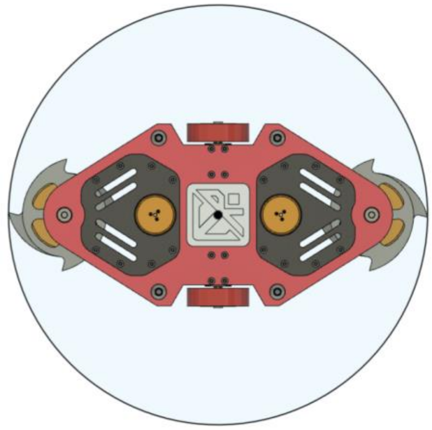


Figure 17: E.R. Turning Radius

Wheel Design:

The wheels of our BattleBot consist of three parts: a 3D printed TPU inner hub, an aluminum adapter, and a cast outer shell. The inner hub has mounting holes and is keyed to the aluminum adapter which allows it to be fixed to the shaft from the beefbox. The outer perimeter has teeth and a central ridge that engage with the casting and prevent it from shifting when under load. The inner hub has very complex geometry which makes 3D printing the most efficient fabrication method. A mold with an outer diameter of 88.9 mm will be used to cast the shell around the inner hub. The wheel assembly will act as protection from blows from the sides and does not require additional protection which is beneficial to weight reduction.

Figure 18: E.R. TPU Wheel Assembly

Materials Selection:

The upper and lower frame plates will be machined out of UHMW because of its low density and high mechanical properties. These components have a simple 2D profile that is suitable for machining. UHMW has a yield strength of 21.4 MPa, an ultimate strength of 38.6 MPa, and a modulus of elasticity of 894 MPa. The resulting components will be lightweight and flexible, allowing them to deform with blows and absorb the energy before returning to their original shape.

The inner core, driving and driven sprockets, and the wheels will be 3D printed from TPU because these components have complex geometry that would make machining them impossible or extremely expensive. TPU is low density and has a yield strength of 21 MPa, an ultimate strength of 30 MPa, and a modulus of elasticity of 110 MPa. This is used for the inner core because of its larger volume and for the sprockets due to their difficult to machine features. These components can also be printed at less than 100% infill which results in further weight reduction without a significant decrease in the components strength.

The frame, drivetrain, and energy transfer device hardware will be comprised of steel alloy which is high density and possesses the high strength necessary in these applications. The structural bolts that pass through the frame as well as the drivetrain and energy transfer device hardware are all subjected to high forces and shock which requires the material to be able to withstand the applied stress without failing. Alloy steel has a yield strength of 950 MPa, an ultimate strength of 1150 MPa, and a modulus of elasticity of 190000 MPa. The hardware components necessary will be purchased from McMaster Carr and will provide rigidity and strength to the frame, drivetrain, and energy transfer device.

The cover plates will be machined from carbon fiber stock which is more rigid than the UHMW plates. This allows UHMW to be used rather than aluminum and aids in weight reduction. Carbon fiber is low density and high strength but only in a single plane. Carbon fiber has a yield strength of 2500 MPa, an ultimate strength of 4000 MPa, and a modulus of elasticity of 500000 MPa. The high mechanical properties come at a very high cost and therefore only simple 2D profile components such as the covers are feasible due to the budget limitations of our design.

The energy transfer device plates will be machined from Hardox 450 because they require substantial hardness and durability to remain unharmed while experiencing repeated blunt impacts. Hardox 450 has a high surface hardness however the components are 2D profiles which enables them to be fabricated. The steel has a yield strength of 1250 MPa, an ultimate strength of 1400 MPa, and a modulus of elasticity of 200000 MPa. The energy transfer device plates are wear-components and therefore they must be as wear resistant as possible, which justifies our material selection. In addition, Hardox is a high-density material which is preferred because its mass enables the device to transfer more energy when it impacts than otherwise possible.

Standards and Codes

Component	Standards on Codes	
Needle Bearing	Specifications Met	DIN 281, ISO 76
	RoHS	RoHS 3 (2015/863/EU) Compliant
	REACH	REACH (EC 1907/2006) (07/08/2021, 219 SVHC) Compliant
Thrust Needle Bearing	DFARS	Specialty Metals COTS-Exempt
Shaft	Specifications Met	ASME B18.3, ASTM A574
	Specifications Met	ASME B18.3, ASTM F879
	RoHS	RoHS 3 (2015/863/EU) Compliant
	REACH	REACH (EC 1907/2006) (06/14/2023, 235 SVHC) Compliant
Frame Bolts	DFARS	Not Specialty Metals Compliant
	Specifications Met	ISO 7380
	RoHS	RoHS 3 (2015/863/EU) Compliant
	REACH	REACH (EC 1907/2006) (06/14/2023, 235 SVHC) Compliant
Bolts	DFARS	Not Specialty Metals Compliant

Table 3: Applicable Standards and Codes

Design Analysis and Calculations

Energy Transfer Device Tip Speed and Energy Calculations:

$Motor\ KV = 970\ KV$

$Battery\ Voltage = 22.2\ Volts$

$Driving\ Sprocket\ Teeth = 32\ Teeth$

$Driven\ Sprocket\ Teeth = 55\ Teeth$

$Energy\ Transfer\ Device\ Diameter = 88.9\ mm$

$MOI\ Energy\ Transfer\ Device\ \ kg/m^2 = 0.002028\ \ kg/m^2$

$$Tip\ Speed\ (m/second) = (ETD\ Plate\ Diameter, mm\ )\ x\ (\pi)\ x\ (RPM)\ x\ \left(\frac{1\ m}{1000\ mm}\right) x\ \left(\frac{1\ minute}{60\ seconds}\right)$$

$$Tip\ Speed\ (m/second) = (152.4\ mm\ )\ x\ (\pi)\ x\ (12529)\ x\ \left(\frac{1\ m}{1000\ mm}\right) x\ \left(\frac{1\ minute}{60\ seconds}\right) = 99.98\ m/sec$$

$$RPM = ((Motor\ KV)\ x\ (Battery\ Voltage)) * \left(\frac{Driving\ Sprocket\ Teeth}{Driven\ Sprocket\ Teeth}\right)$$

$$RPM = \big((970\ KV)\ x\ (22.2\ Volts)\big) * \left(\frac{32\ Teeth}{55\ Teeth}\right) = 12529\ RPM$$

$$Deg/s = (RPM)\ x\ (6)$$

$$Deg/s = (12529\ RPM)\ x\ (6) = 75173\ \ Deg/s$$

$$Rad/s = (Deg/s)\ x\ \left(\frac{\pi}{180}\right)$$

$$Rad/s = (75173)\ x\ \left(\frac{\pi}{180}\right) = 1312\ \ rad/s$$

$$Energy\ Transfer\ Device\ Energy = (0.5) x\ (MOI, kg/m^2) x\ (rad/sec)^2$$

$$Energy\ Transfer\ Device\ Energy = (0.5) x\ (0.002028\ kg/m^2) x\ (1312\ rad/sec)^2 = 1745.5\ J$$

$$Energy\ Transfer\ Device\ Energy = (1745.5\ J)\ x\ \left(\frac{1\ KJ}{1000\ J}\right) = 1.75\ KJ$$

XL Belt Length Calculations:

$$Xl\ Belt\ Pitch = 0.2\ \ in/tooth$$

$$Driving\ Sprocket\ Teeth = 32\ Teeth$$

$$Driven\ Sprocket\ Teeth = 55\ Teeth$$

$$Center\ to\ Center\ Distance = 130\ mm$$

$$Center\ to\ Center\ Distance = (130\ mm)\ x\ \left(\frac{1\ in}{25.4\ mm}\right) = 5.12\ in$$

$$Pitch\ Diameter = \frac{(Pitch)\ x\ (Number\ of\ Teeth)}{(\pi)}$$

$$Driving\ Sprocket\ Pitch\ Diameter = \frac{(0.2\ \ in/tooth)\ x\ (32\ Teeth)}{(\pi)} = 2.04\ in$$

$$Driven\ Sprocket\ Pitch\ Diameter = \frac{(0.2\ \ in/tooth)\ x\ (55\ Teeth)}{(\pi)} = 3.5\ in$$

$$\begin{aligned} XL\ Belt\ Length & \\ &= (2)x(Center\ to\ Center\ Distance) \\ &+ \left(\frac{\pi}{2}\right)x(Driven\ Sprocket\ Pitch\ Diameter + Driving\ Sprocket\ Pitch\ Diameter) \\ &+ \frac{(Driven\ Sprocket\ Pitch\ Diameter - Driving\ Sprocket\ Pitch\ Diameter)^2}{(4)x(Center\ to\ Center\ Distance)} \end{aligned}$$

$$XL\ Belt\ Length = (2)x(5.12\ in) + \left(\frac{\pi}{2}\right)x((3.5\ in) + (2.04\ in)) + \frac{\left((3.5\ in) - (2.04\ in)\right)^2}{(4)x(5.12\ in)} = 19.04\ in$$

Maximum Speed Calculation:

$$Gearbox\ Reduction\ Ratio = \frac{1}{20}$$

$$Wheel\ Diameter = 88.9\ mm$$

$$Wheel\ Circumference = \ \pi\ x\ Wheel\ Diameter$$

$$Wheel\ Circumference = \ \pi\ x\ (88.9\ mm) = 279.29\ mm$$

$$Actual\ Wheel\ RPM = \big((Motor\ KV)\ x\ (Battery\ Voltage)\big) * (Gearbox\ Reduction\ Ratio)$$

$$Actual\ Wheel\ RPM = \big((850\ KV)\ x\ (22.2\ Volts)\big) * \left(\frac{1}{20}\right) = 943.5\ RPM$$

$$Actual\ Linear\ Speed = Actual\ Wheel\ RPM\ x\ Wheel\ Circumference\ x \left(\frac{1\ min}{60\ s}\right) x\ \left(\frac{1\ m}{1000\ mm}\right)$$

$$Actual\ Linear\ Speed = (943.5\ RPM\ )x\ (279.29\ mm)\ x\ \left(\frac{1\ min}{60\ s}\right) x\ \left(\frac{1\ m}{1000\ mm}\right) = 4.39\ \ m/s$$

Finite Element Analysis

Energy Transfer Device FEA Calculations:

$$Mass = (12\ lbs)x\frac{(0.4526\ kg)}{(1\ lb)} = 5.44\ kg$$

$$Height = (10\ ft)\ x\ \left(\frac{0.305}{1ft}\right) = 3.05\ m$$

$$Force = Mass\ x\ Acceleration$$

$$Force = (5.44\ kg)x\ (9.81\ m/s^2) = 53.37\ N$$

$$Work = Force\ x\ Distance$$

$$Work = (53.37\ N)x\ (3.05\ m) = 162.78\ J$$

$$W = I\ x\ \omega^2$$

$$\omega = \sqrt{\frac{W}{I}}$$

$$\omega = \sqrt{\frac{(162.78\ J)}{(0.002028\ \ kg/m^2)}} = 283.31\ radians/s$$

$$\Delta L = I\ x\ \Delta\omega$$

$$\Delta L = (0.002028\ \ kg/m^2)x\ (283.31\ radians/s) = 0.575\ Ns$$

$$Time = \left(\frac{Steps\ in\ Contact}{Total\ Steps}\right)x(Step\ Duration)$$

$$Time = \left(\frac{74\ steps}{200\ steps}\right)x(0.0005\ s) = 0.000185\ s$$

$$Force = \frac{Impulse}{Time}$$

$$Force = \frac{(0.575\ Ns)}{(0.000185\ s)} = 3108.11\ N$$

Energy Transfer Device FEA:

Our dynamic finite element analysis for the energy transfer device was calculated by attaching a pivot joint to our energy transfer device plate and assigning an initial angular velocity equal to our motor rpm. The plate was assigned Hardox material properties, and the test component was assigned aluminum to simulate the chassis of another BattleBot. A 12 lb. mass and the height of the arena were used to calculate work which was then equated to the impulse and angular velocity. Next the duration of contact was determined from the simulation and used to calculate the force transferred. This resulted in a 3100 N force on each impact and a safety factor of 6 for the energy transfer device plate. This is an acceptable safety factor, and the strength of the chosen material is sufficient to handle the forces that will result from impact.

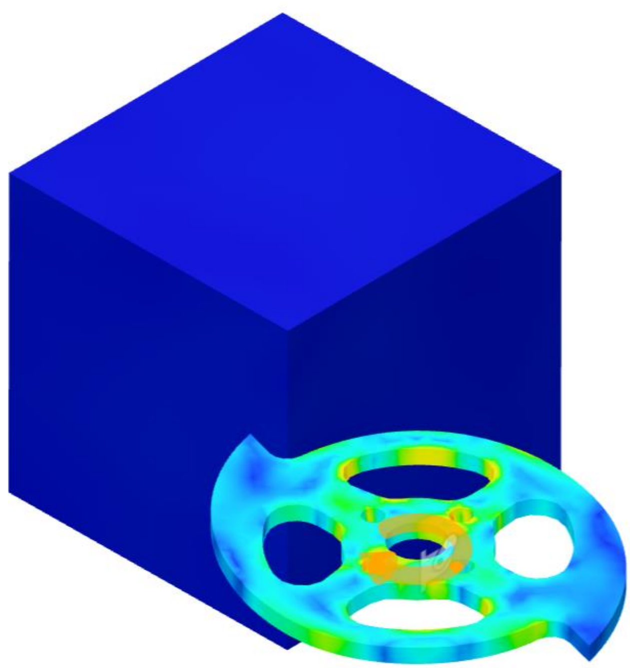


Figure 19: Energy Transfer Device FEA:

Chassis FEA:

The static finite element analysis for the chassis was calculated by applying a force equal to half of the force calculated for the energy transfer device because the force will be transmitted through both the upper and lower chassis plates. The four frame structural bolt holes were assigned rigid constraints to simulate the plate being mounted to the robot. UHMW was assigned to the frame plate to simulate the material properties of the actual BattleBot chassis. The simulation resulted in a safety factor of 8 for the chassis plate which is an acceptable value for this application. Although this simulation is realistic the actual force will have even less effect on the frame because the BattleBot is not rigid and will move upon impact, absorbing a portion of the force.

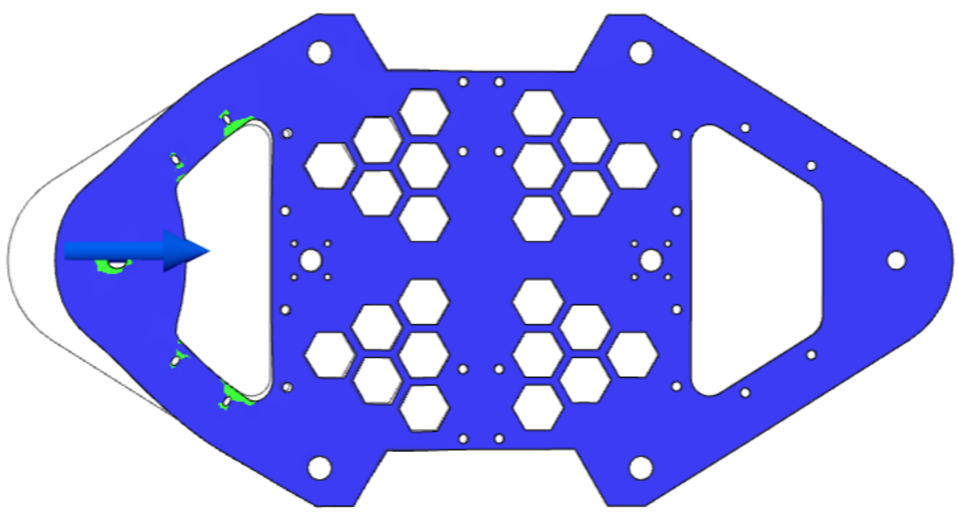


Figure 20: Chassis FEA:

Project Management

Preliminary Budget:

Preliminary Budget	
Subsystem:	**Cost:**
Frame	$160
Armor	$40
Energy Transfer Device	$80
Drivetrain	$300
Electronics	$270
Manufacturing	$150
Total:	**$1000**

Table 4: E.R. Preliminary Budget

Updated Budget:

Component	Manufacturer	Description	Part	Cost Each	Number of Parts	Number of Parts in Package	Total Cost
Frame	amazon	Middle Chassis	TPU	$30.00	2	N / A	$60.00
Frame	Sendcutsend	Top Plate	UHMW	$137.64	1	N / A	$137.64
Frame	Sendcutsend	Bottom Plate	UHMW	$165.20	1	N / A	$165.20
Frame	Sendcutsend	CFRP Top Cover	CFRP	$182.30	1	N / A	$182.30
Frame	Sendcutsend	CFRP Bottom Cover	CFRP	$150.26	1	N / A	$150.26
Energy Transfer Device	Sendcutsend	Energy Transfer Device Blank	Hardox	$50.52	1	N / A	$50.52
Belt	McMaster Carr	19 in XL Belt	190XL025	$7.00	3	N / A	$21.00
Wheel	gobilda	Adapter	1314 Series Steel Set-Screw Hub (5mm Bore)	$5.99	2	N / A	$11.98
Energy Transfer Device Hardware	McMaster Carr	Alloy Steel Shoulder Bolt	91259A800	$6.10	2	N / A	$12.20
Energy Transfer Device Hardware	McMaster Carr	Button Head Hex Drive Screw	92095A459	N / A	6	25	$7.14
Energy Transfer Device Hardware	McMaster Carr	Needle-Roller Bearing	5905K506	$6.83	4	N / A	$27.32
Energy Transfer Device Hardware	McMaster Carr	Needle-Roller Thrust Bearing	5909K32	$3.91	4	N / A	$15.64
Energy Transfer Device Hardware	McMaster Carr	0.032 Thick Washer for 5-8 Shaft	5909K45	$1.30	8	N / A	$10.40
Frame Hardware	McMaster Carr	18-8 Button Head Hex Drive Screw	92949A884	$3.11	4	N / A	$12.44
Frame Hardware	McMaster Carr	Button Head Hex Drive Screw	92095A127	N / A	16	100	$16.88
Frame Hardware	McMaster Carr	Button Head Hex Drive Screw	92095A161	N / A	8	100	$5.52
Frame Hardware	McMaster Carr	Button Head Hex Drive Screw	92095A208	N / A	32	100	$16.33
Electronics	amazon	Battery	Battery (1550 mah 6s)	$40.00	1	N / A	$40.00
Electronics	innov8tivedesigns	Energy Transfer Device Motor	Badass 2305 Motors	$75.00	2	N / A	$150.00
Electronics	innov8tivedesigns	Drive Motor	Tempest 2814	$37.00	2	N / A	$74.00
Electronics		Dive Gearbox	Drive Gearbox	$120.00	2	N / A	$240.00
Electronics	getfpv	Speed Controller	Drive ESC (Flycolor Francy 2 BLHeli_32 3-6S Dshot)	$25.00	2	N / A	$50.00
Electronics	castlecreations	Speed Controller	Energy Transfer Device ESC (castle sidewinder 8th)	$130.00	2	N / A	$260.00
Electronics	amazon	Reciever	ar410	$35.00	1	N / A	$35.00
						Total:	$1,751.77

Table 5: E.R. Updated Budget

From our original budget to our final budget some changes occurred. There are various reasons for the increase of $751.77. These reasons are for material and fabrication changes. With the new budget we are ordering UHMW from SendCutSend. In addition, we are ordering carbon fiber plates and four Hardox plates. These changes are the cause of the increased budget however, they are vital to the creation of ENED's Revenge.

Key Milestones

	Preliminary Schedule Gantt Chart										
	Item	**Due Date**	**July**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**
Senior Design I	*Project Approved*	08-28-2023									
	Background Research	09-15-2023									
	Survey Completion	09-22-2023									
	Quality Function Deployment	09-29-2023									
	Final Proposal	10-10-2023									
Senior Design II	*Final Design*	11-22-2023									
	Parts List	12-06-2023									
	Bill of Materials	12-20-2023									
Senior Design III	*Fabrication*	02-07-2024									
	Testing	02-21-2024									
	Competition	03-XX-2024									
	Tech Expo	04-11-2024									

Table 6: Schedule Gantt Chart

There have been no changes to our Preliminary Schedule Gantt Chart. We have stayed on track as a team therefore there is no updated schedule. The design work and documentation has progressed according to plan without encountering any unforeseen roadblocks. We have completed the final design and are finalizing our parts list and bill of materials which will be used in the remainder of the design process and in fabrication.

Planned Prototype Fabrication

The plan to make our prototype is to focus on having all pieces manufactured here at UC and avoid outsourcing as much as possible. The design of our robot is very simple so manufacturing the parts should not be a big ordeal as long as things go to plan. The hardest part is figuring out the time it will take to manufacture all these parts and make sure they are manufactured correctly. We will start with manufacturing the metal components we will need on our robot because this will take the most time and have the highest chance of a problem or delay occurring. Once we finish manufacturing the metal components that go on our robot, we will make sure all the pieces are the correct dimensions and weight.

After the metal component manufacturing phase is complete, we will move on to the 3D-printing components phase, this phase should take the least amount of time as we already have the pieces modeled and ready to print. This process should be straightforward as long as our dimensions are correct, and we have a good tolerance between the components. We will also be 3D-printing our sprockets, which is not typically done on these robots. All 3D-printed components will utilize TPU filament and only partial infill to reduce weight on our robot.

Overall, the plan to fabricate our prototype is simple, we do know there may be a few inconveniences or delays along the way which we are planning for in our project schedule, to make sure we have time to complete fabrication according to schedule.

Planned Prototype Testing

The testing plan for our robot is to put it through a “simulation” battle. The most important data we need to collect is on our energy transfer device system. This entails making sure it is not drawing too much power or draining the battery too quickly. We will use a stationary hard object and have the energy transfer device make contact to see if the energy transfer system is operational and functional. In addition to the energy transfer system, we also want to collect data on the spin up time for both energy transfer devices. The second most important data we need to collect would be on the armor, because we can use this information to determine how much impact it can withstand. This portion we would focus on how well the armor protects the internals, and how well it holds up against repeated impact. The third most important data we want to collect is on the ability for our robot to drive inverted. A large part of our design was to be able to drive inverted, so if we get flipped by the opponent's bot we can still drive and stay in the fight. The way we would test this would be to have the robot perform its basic functions while inverted to make sure everything still functions regardless of the robot's orientation.

Actual Prototype Fabrication:

The actual fabrication of our prototype was not complex due to the design of our robot. We enabled it to be taken apart and rebuilt in a short amount of time for repairs and maintenance during the competition in Norwalk for NHRL. During the fabrication process we used many different machines to help construct our prototype. The hydraulic press was invaluable because it was used to press our dowel pins into place securely. The dowel pins held our energy transfer device together during assembly, testing, and battles. The belt grinder was the next machine that we used as our dowel pins were longer than expected. We needed to grind the dowel pins down to be flush with the top surface of the energy transfer device. They were press-fit into place to ensure the stack-up would fit perfectly and not cause any interference. We had to solder together various connectors to the energy transfer device ESCs, the drive motor ESCs, and the receiver. After all these things were done the rest of the fabrication process was threading and assembling the bolts into our UHMW chassis and tightening everything down with Loctite to prevent loosening with impact and vibration.

Actual Prototype Testing:

NHRL Norwalk Competition:

The Norwalk NHRL competition is a competition where anyone who has a BattleBot that meets specifications can compete. There are three weight classes that NHRL supports and that's the 3lb, 12lb and 30lb weight classes. People from all over the world can compete in this competition if they are willing to travel to it.

The NHRL Competition consists of two different brackets, the Prelim Brackets where everyone starts and fights against each other's bots to determine who will make it to the Official Bracket where the best bots of the competition compete. Both types of brackets exist for each weight class, so the 3lb has its own, 12lb has its own and the 30lb have their own brackets as well. To move on to the Official Bracket the NHRL competition has a rule where you need to win two of your three fights, so if you lose your first fight you still have a chance to make it to the official bracket.

Austin McChord founded NHRL in 2018. A total of eighteen competitors participated in the first event later that year. In 2021, McChord moved the organization to its current headquarters in Southern Norwalk, where we traveled to compete on March 1st. The next section will break down the opponents we faced, our matches and outcomes, and what we have learned from each fight.

Battle 01: RoboCat

The first fight of ENED's Revenge was against RoboCat. RoboCat is a four-wheeled vertical spinner that has a lot of grip due to the teeth on the front wheels, so they were very fast and accurate with their movement. The shield on the front has a cutout in it to allow the energy transfer device to spin up without hitting. The front shield also has a slope to it to allow the bot to lift its competitor into the energy transfer device.

The outcome of this battle unfortunately ended in our defeat; the battle was not long in length as it only took around 26 seconds to defeat us with a very powerful blow. We received a lot of damage in this fight as one of our energy transfer devices was completely destroyed, and we needed to cut the end off to stay ready for the next fight. We were able to deal some damage to RoboCat on the front shield of the robot, not enough to take them out of the fight, and we also had good damage to their energy transfer device.

A good take away from this fight was that vertical spinners are the worst kind of opponent we could face; the design of our bot needs to be changed to accommodate vertical spinners and the damage they can apply to your bot. A good pro from this fight would be that we learned a lot about our own bot and some of the changes we can make to make it an even better bot next time we compete, for example having better armor around the arms of the energy transfer device would prevent us from losing the energy transfer device as a whole during the next battle. The biggest con of this battle was we had to cut our bot in half to stay in the fight for the next few rounds, and instead of having a second energy transfer device we had to add an armor plate to take its spot. Unfortunately, we had to duct tape this armor to the bot instead of having it bolted, as we didn't design the bot to have bolt holes for armor in this location.

Battle 02: Ratchet

The second fight of ENED’s Revenge was against Ratchet. Ratchet was a battle bot that had a second robot or a mini bot fighting alongside it. The main bot was a 4-wheeled robot that used an overhead saw as its energy transfer device, and the mini-bot also had the same energy transfer device as well. The main bot had a few problems with its driving mechanism to where it wasn’t able to move the best throughout the fight.

The outcome of this battle ended in our victory as we were able to deal critical damage to the mini-bot and knock it out of the fight for good. The main opponent’s drive system as mentioned above was not complete before the beginning of our fight and led to a knockout and ENED’s Revenge taking the victory. ENED’s Revenge did not take any damage during this fight, because we moved quickly in the ring and avoided all damage, and luckily for us the opponent’s robot was not able to move. Overall, we dealt a lot of damage to the opponent, and their mini-bot was completely destroyed beyond repair and allowed us to move on to the next fight.

The biggest takeaway from this fight was that despite the damage suffered, with creativity and ingenuity one can come back with a fully functional robot.

The biggest pro of this outcome was definitely moral as a team. Our morale after this second fight skyrocketed because we realized even if we suffer defeat if we stay levelheaded and think as an engineer we can problem solve and still come out on top. On the other hand, the biggest con that we discovered is that our energy transfer system was not working as intended, and that we need to figure out why and how to fix it.

Battle 03: Doppelgator

The third fight that ENED's Revenge faced at Norwalk was Doppelgator. Doppelgator has a dual Beater Bar energy transfer device. Also, Doppelgator consists of a wedge on the front of the robot with four-wheel drive. It is a smaller robot with an immense armor package guarding every inch of the bot. In addition to its incredible armor package, Doppelgator has two pivot points near the energy transfer device. These pivot points are used when the robot is flipped upside down. Doppelgator also had a mini-bot. The mini-bot was a simple lightweight wedge bot. This is very common to see when a team is using the multi-bot rule.

In the beginning of the fight between ENED's Revenge and Doppelgator, ENED's Revenge took damage quickly. A clash of energy transfer devices caused our belt to snap. With this belt snapped our energy transfer device lost all its power. Shortly after that our armor package that was duct taped onto the back got directly hit and flew off. Fortunately, during this short explosion of contact we got a solid hit in and stuck one of the wheels of Doppelgator. This caused Doppelgator to have driving issues. With Doppelgator experiencing driving issues the bot was not able to move around which allowed ENED's Revenge to control the rest of the fight. In addition, their mini-bot was immobile from the beginning and did not move at all. Once the fight came to an end there was not a clear winner; however, due to a judge's decision ENED's Revenge was able to win the fight. This was due to our bot being completely functional despite the energy transfer device. As well, we maintained control over the fight even with the armor package being gone.

Reflecting on the fight, the biggest takeaway was that we did design a robot that is capable of taking hits and remaining functional. Our drive system was perfectly intact at the end of the fight. The biggest con is due to design flaws and choice of materials we were not able to maintain a functional energy transfer device. However, as a team we are confident we would be capable of fixing this issue in the future.

Battle 04: Steggy

In ENED's Revenge's final battle we faced against Steggy which was a horizontal spinner with a lot of defenses around the whole bot. Steggy had a very low horizontal spinner that had a high rate of speed, which would deal a lot of damage to ENED's Revenge. Steggy had a large, slanted armor plate on the front which acted as its main defense against opponents. Steggy was very fast with good defense and offense which made the fight very difficult to win.

The outcome of this battle was determined to be a loss as the battle went to judge's decision as both bots were not able to deal a critical blow to knockout their opponent. Steggy had a lot of aggression against ENED's Revenge and took the lead in dealing damage, because our energy transfer device was not operational during this battle. Most of the damage received was against our armor plate duct taped to the back end of ENED's Revenge, but we did take some damage to wheels which made the robot a little bit more difficult to maneuver. ENED's Revenge unfortunately was not able to deal a lot of damage to Steggy because our energy transfer device was not operational during this fight.

The biggest takeaway from this fight would definitely be to never give up no matter the challenges or disadvantages. This is demonstrated by using the armor on the back of ENED's Revenge that we engineered on the spot did wonders in protecting the critical components of the robot and kept ENED's Revenge in the fight. The biggest pro that we learned from this fight would be that adding better armor would keep ENED's Revenge in the fight longer with a better possibility of success. The biggest con we learned was that our wheels were very exposed during this fight and could be a critical factor in future fights that could take our robot out of the fight, and eventually cause us to lose the battle.

Conclusion:

Design Conclusion and Revisions:

While the current design was successful for a prototype some major changes need to be made that address the issues in performance. The driving sprockets which were 3D printed out of TPU have a modulus of elasticity that is too high and when the motors spin up to full speed the centripetal force causes the sprockets to expand and touch the sides of the frame causing both a reduction in speed and heat caused by friction. In order to sustain high RPMs, the driving sprockets should be printed in a material with a lower modulus of elasticity such as Nylon, PLA+, PEAK, or machined out of an aluminum alloy. In addition, switching over to V–belts would put far less stress on the sprocket teeth and reduce the shock of impacts and spin up. Another unforeseen outcome of mounting the spinner motors to the bottom plate is that the centripetal force and tension on the XL belt caused the motors to cantilever inward which resulted in the XL belts riding up the surface of the sprockets and slipping off the top during high RPMs. This could be combated through either mounting the motors to the top plate in addition to the bottom plate to eliminate the cantilever effect or by changing the geometry of the bottom plate to increase its rigidity. A programming change that would also be beneficial would be to have a gradual spin up of the energy transfer device motors rather than going straight from zero percent power to fifty percent, to one hundred percent.

One major concern we had was passing the safety check at the NHRL event and due to rule changes, we had to add a removable link to the power source instead of simply plugging in and unplugging the battery. The design should be revised to include an opening and easy access to the removable link. On a similar note, we designed the robot with access to the battery through a top cover but in between fights there was not enough time to charge the battery so we had to swap packs instead. This required a partial disassembly of our robot and would have been a major inconvenience if we had not needed to disassemble the robot anyway to replace the sprockets and belts. The battery should either be relocated to the center of the chassis where it can be removed via the access panel, or the panel should be enlarged or redesigned to allow battery removal. Meeting the 12 lb. weight limit was also a challenge and the top and bottom carbon fiber plates and hardware had to be removed during the event to meet weight. Their removal significantly reduced the rigidity of the chassis and allowed more deformation than optimal when dealing damage or receiving impacts. An alternative to prevent this from occurring in later iteration is to scale down the overall size of the robot and then switch to an aluminum alloy for the top and bottom frame plates to increase the rigidity and prevent the severe deformation that was experienced during testing.

Finally, one aspect of this design that should have been under higher scrutiny is the controller, receiver, and setup. At the event there were numerous issues with synchronizing the controller and the receiver and while we were able to find a solution, the controls were not optimized for the robot and the energy transfer device control was inconsistent. These issues could be remedied through the use of a designated controller and receiver as well as with more driving and testing time before the event. There are no test cages at the University of Cincinnati or Victory Parkway campus which made driving and spinning up the robot impossible before the Norwalk Event. Ideally there would be access to a cage to test and troubleshoot out robot's functions and performance prior to competition to diagnose any problems and make necessary modifications as well as to practice driving and other controls.

NHRL Norwalk Competition Conclusion:

The performance of ENED’s Revenge at the NHRL Norwalk Competition was overall very good for a prototype design. While we had some problems with the energy transfer devices, the chassis proved to be highly maneuverable and withstood significant damage while remaining functional. During our first match we received severe damage to our chassis and had to remove a portion of the frame and one spinner motor to remain operational. However, despite these difficulties ENED’s Revenge went on to win the next two matches via knockout and judge’s decision, respectively, to pass the preliminary bracket and more on into the actual competition without any significant damage. Finally, during the competition match ENED’s Revenge survived the fight unscathed although the match was a loss due to judge’s decision because our energy transfer device was not operational. Although we had a 2-2 win-loss record ENED’s Revenge remains the only bot from the University of Cincinnati’s BattleBots Club to make it to the competition bracket. After the first match we competed without energy transfer devices and were able to remain competitive due to the chassis durability and maneuverability. With a functional energy transfer device this concept would be substantially more effective. These results are promising for this design concept and our team hopes to revise and refine this design in the future to continue competing.

References:

1. Berry, Morgan. The history of robot combat: Battlebots. *Servo Magazine.* [Online] 2012. https://www.servomagazine.com/magazine/article/the_history_of_robot_combat_battlebots
2. Battlebots Wiki. *Fandom* [Online] 2023. https://battlebots.fandom.com/wiki/BattleBots_Wiki-Main_Page
3. Dong, Janet and DAVE, Janak. Design–Build–Test-Compete A BattleBot. s.l.: American Society for Engineering Education, 2009
4. NHRL. [Online] 2023. https://wiki.nhrl.io/wiki/index.php/NHRL
5. Awner, Kyle. Combat Robotics: Weapons & Armor. [Online] 2023. https://www.onlinemetals.com/en/combat-robotics-weapons-and-armor
6. BattleBots. [Online] 2023. https://battlebots.com/
7. Garnache, Peter. Know your combat robots! A field guide to competition weight classes and weapons. *Make* [online]. 12 November 2022.
8. Battlebot. *Research Centers & Labs* [Online] 2023.

Appendix A

1. General

1.1. All [MC1] participants build and operate robots at their own risk. Combat robotics is inherently dangerous. There is no amount of regulation that can encompass all the dangers involved. Please take care to not hurt yourself or others when building, testing and competing.

1.2. 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 info@xtremebots.org. 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. Compliance with all event rules is mandatory. It is expected that competitors stay within the rules and procedures of their own accord and do not require constant policing.

1.4. Each event has safety inspections. It is at their 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.

1.5. Cardinal Safety Rules: Failure to comply with any of the following rules could result in expulsion or worse, injury and death.

1.5.1. Proper activation and deactivation of robots is critical. Robots must only be activated in the arena, testing areas, or with expressed consent of the event personnel or its safety officials.

1.5.2. All robots must be able to be FULLY deactivated, which includes power to the drive and the weaponry, within 60 seconds by a manual disconnect. (Removable link or Main Power Switch)

1.5.3. All robots not in an arena or official testing area must be raised or blocked up in a manner so that their wheels or legs cannot cause movement if the robot were turned on. Runaway bots are VERY dangerous. (We strongly suggest a custom designed block that ensures the robot will not be inadvertently dislodged from the block)

1.5.4. Locking devices: Moving weapons that can cause damage or injury must have a clearly visible locking device in place at all times when not in the arena. Locking devices must be painted in neon orange or another high-visibility color. Locking devices must be clearly capable of stopping, arresting or otherwise preventing harmful motion of the weapon. C- Clamps and locking pliers are not allowed.

1.5.5. Weapon locking pins must be in place when a robot is placed in the arena. However, the locking pin may be removed before weapon power is applied during a robot's power-on procedure. This includes all powered weapons regardless of the power source.

1.5.6. It is expected that all builders will follow basic safety practices during work on the robot at your pit station. Please be alert and aware of your pit neighbors and people passing by. A special area in or near the pits will be provided for repeated drilling and or grinding. These operations should not be performed at your pit table if a special area is designated. Continued failure to follow safety directions could result in an individual or the entire team disqualification for the event. (This includes and is not limited to wearing SAFETY GLASSES at ALL times while in the pit area.)

1.5.7. Any sharp-edged weapon must have the edge effectively covered until the bot is in the ring.

2. Weight Classes. These events offer the 15 pound weight class only.

Forbidden Weapons and Materials.

The following weapons and materials are absolutely forbidden from use:

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

12.1.1. Electrical weapons

12.1.2. RF jamming equipment, etc.

12.1.3. RF noise generated by an IC engine. (Please use shielding around sparking components)

12.1.4. EMF fields from permanent or electro-magnets that affect another robot's electronics.

12.1.5. Weapons or defenses that stop combat completely of both (or more) robots. This includes nets, tapes, strings, and other entanglement devices.

12.2. Weapons that require significant cleanup, or in some way damages the arena to require repair for further matches. This includes but is not limited to:

12.2.1. Liquid weapons. Additionally a bot may not have liquid that can spill out when the robot is superficially damaged.

12.2.2. Foams and liquefied gasses

12.2.3. Powders, sand, ball bearings and other dry chaff weapons

12.3. Un-tethered Projectiles (see tethered projectile description in Special Weapons section 13.1)

12.4. Heat and fire are forbidden as weapons. This includes, but is not limited to the following:

12.4.1. Heat or fire weapons not specifically allowed in the Special Weapons section (13.1.1)

12.4.2. Flammable liquids or gases

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

12.5. Light and smoke based weapons that 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:

12.5.1. Smoke weapons not specifically allowed in the Special Weapons section (13.1.1)

12.5.2. Lights such as external lasers above 'class I' and bright strobe lights which may blind the opponent.

12.6. 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.

Appendix B

Survey Questions

How important is each feature to you in a combat robot design? Rate 1-5

(low importance = 1, high importance = 5)

- Design Cost (1-5)
- Overall size (1-5)
- Overall weight (1-5)
- Maneuverability (1-5)
- Battery Life (1-5)
- Durability (1-5)
- Reliability (1-5)
- Repair Time (1-5)
- Energy Transfer Device Strength (1-5)
- Armor Strength (1-5)

Survey Results

- Reliability (33)
- Overall Weight (29)
- Maneuverability (28)
- Durability (27)
- Design Cost (25)
- Armor Strength (23)
- Energy Transfer Device Strength (22)
- Repair Time (21)
- Battery Life (18)
- Overall Size (15)