DUMBOT

A Baccalaureate thesis submitted to the

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requirements for the degrees of

Bachelor of Science

in Mechanical Engineering

& Mechanical Engineering Technology

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ABSTRACT

The University of Cincinnati BattleBots Club regularly designs, build, and competes battlebots in the annual National Havoc Robot League March Event – one of the leading BattleBots competitions in the world, held in Norwalk, CT – in which a series of combat robot fights are held in an enclosed arena. This event requires competitors to abide by the set standards and regulations such as weapon limitations and weight and size requirements. Dumbot was designed over the past year and finally competed in the NHRL event in the 12 lb. weight class on March 2, 2024, with the goal of reining victorious over our opponents by knockout, tap out, or judges' decision. With the knowledge we have obtained in the mechanical, electrical, and design fields at the University of Cincinnati, we were responsible for designing, building, testing, and competing the robot. While completing this project, the team stayed within the budget that has been provided through funding by the University of Cincinnati BattleBots Club. This paper aims to document this project in a comprehensive and informative manner.

PROBLEM STATEMENT

If maintaining a competitive edge over their opponents is desirable, a combat robotics team must be willing to take innovative approaches when implementing technology in their battlebot. For our team to have the best chances of victory, our situation was no different. Therefore, with funding granted to us by the University of Cincinnati BattleBots Club, as well as our knowledge obtained in the mechanical, electrical, and design fields at the University of Cincinnati, we undertook the daunting task of developing a battlebot to compete in the NHRL March Event. The goal of the event is to win, by dealing the most damage possible to opponents while receiving as little damage possible to our robot. More so, our participation in competing and the purpose of this project was to make a name for the University of Cincinnati in the field of combat robotics on the national level as well as further the "meta," or current state of the art, of the sport. Additionally, by participating in NHRL, we hope to inspire young minds to pursue careers in science, technology, engineering, and mathematics. The technologies investigated while completing this project, as well as the many new innovations and advancements to the meta we produced while completing this project have broader implications for use in society and industry, and this project has done the work of honing our problem-solving skills, which are invaluable in tackling complex challenges across various industry domains.

Team member delegations include Zachary Jacob being in charge of the development of the main structural components, such as body and uprights, as well as operate and drive Dumbot in the NHRL March Event; Greg Nemrow assisting with structure design and being chief finite element analysis director; and Dylan Schreder being in charge of the design of the mechanical components such as the weapon and electronic systems.

RESEARCH

Background of the Problem

Being a team comprised of three people with zero experience in designing and building a battlebot prior to undertaking this project, the learning curve was practically Mt. Everest. In order for us to gain a competitive edge on our opponents and create the best battlebot we could, we immersed ourselves in the sport; learning all there is to know about current state of the art, competition rules and regulations set forth by NHRL, which material properties are desirable and which aren't and for what purpose, and so much more. Additionally, we had to efficiently allocate resources, source cost-effective materials, and maximize the utility of every dollar spent such that the budget granted to us did not go wasted. Furthermore, and as mentioned previously, following the NHRL rules (1) is mandatory in order to compete. The competition is governed by a set of rules and regulations set forth by the NHRL designed to ensure fair play and safety. Deviating from these guidelines can lead to disqualification or even endangering our team and spectators. In the 12 lb. weight class, we faced a diverse array of robots, each with their unique strengths and strategies. Some competitors prioritize speed and agility, while others focus on armor and brute force. For this project, we aimed to analyze and adapt to our competitors' designs and tactics. Our battlebot was designed with versatility, robustness, and the ability to counter a wide range of threats in mind.

Scope of the Problem

Throughout the project, we faced many topics regarding mechanical design, electrical components, software development, weaponry, communication amongst the team, strategy, and tactics. Since the project involves starting a new battlebot from scratch rather than an evolution of a previous generation, many considerations had to be made such as chassis and weapon systems, factors such as weight limitation and distribution, and characteristics like durability and maneuverability. Utilizing Autodesk Fusion 360, we successfully implemented a process that involves modeling, selecting appropriate materials, and conducting structural analyses.

Building a BattleBot requires a comprehensive application of engineering principles, from mechanical design to electronics and software development. Throughout this project, we pushed the boundaries of our engineering skills learned from the classroom and industry. This project encouraged us to think creatively and come up with unique solutions to the design, control, and combat challenges we face. Structural limitations are a very real obstacle in the world of combat robotics and trying to create a bot that is fast and heavy hitting, yet strong and resilient to opponent blows all while staying below weight is a challenge to say the least. To overcome this obstacle, advanced materials such as carbon fiber, ultra-high molecular weight polyethylene (UHMW), and titanium were used for their unique material properties. Another limitation that comes with a project like this is time. The project was on a much more expedited timeline when compared with many other baccalaureate capstone projects for the simple reason of needing to compete in NHRL events. Dumbot was finalized and competed on March 2, 2024, which means the project was effectively completed by the end of February. Most often, projects with fast-paced timelines and seemingly impossible expectations bring the most creative solutions out of the engineers.

Standards, Codes, and Specifications

One of the most utilized design standards developed by the University of Cincinnati BattleBots Club – no doubt backed up by the many encounters with hard hitting and damage inducing opponents – is the 10 mm impact theory. The theory states that any impact given or received will take away material from or deflect a component by 10 mm. This theory can be extrapolated to say that, for example, a wall that is 30 mm thick will be able to withstand three direct impacts. By applying this theory to the design, we can promote the safety of the inner components of the robot by ensuring at least 10 mm of material in all wall thicknesses, often times much more.

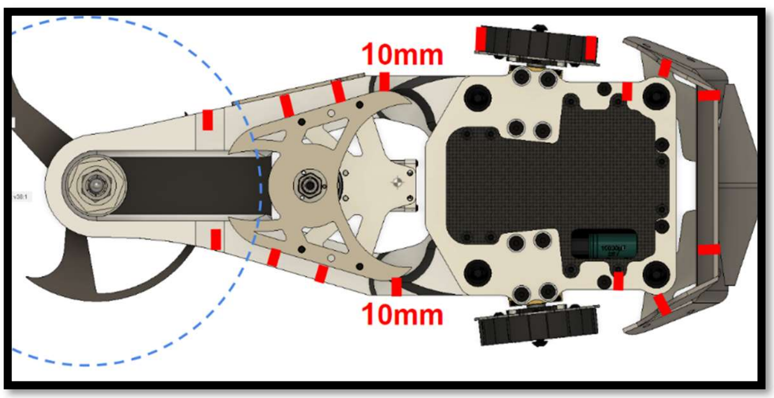


Figure 1: 10mm Impact Theory implemented by the UC BattleBot Club.

Applying this theory in Figure 1, we can see that there is at least 10 mm worth of material on all sides of the robot that are vulnerable to impact. After applying this theory to our battlebot, we can rest assured that our defensive capabilities are maximized.

As with any industry involving the possibility of electronic fire or malfunction, the battlebots community – and more specifically the University of Cincinnati BattleBots Club – does not regard sufficient protection lightly. With the possibility of catastrophic offensive blows, the robot must be designed to properly withstand these occurrences. With proper protection, the sensitive components will remain unscathed and have the ability to continue the fight.

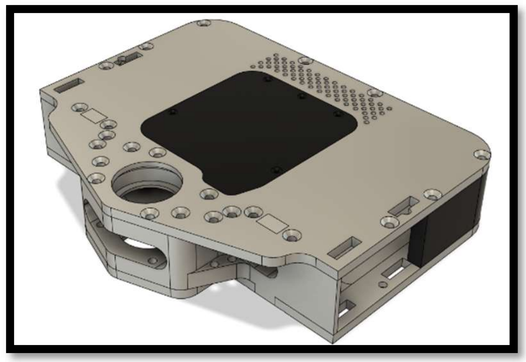


Figure 2: Configuration from previous designs, protecting main components.

As seen in Figure 2, this design provides sufficient protection from the top, bottom, and sides as the armor prevents any exposure to vital components such as batteries, motors, and ESCs.

For the consideration of a weapon for our design, a high-speed, vertical blade was selected to be our choice. Many competitors use horizontal or vertical blades and have great success with them. Horizontal blades cause massive instability in the robot when striking opponents due to the nature of the weapon. Since horizontal blades tend to be very large, when they contact an opponent, the energy transfer is immense and unfortunately it is commonplace for horizontal spinner robots to go flying even when they are the one dealing the blow. Because of this undesirable effect of horizontal spinners, as well as the reliability that comes from a vertical spinner, a vertical spinner was selected for Dumbot’s weapon system.

In order to ensure safety of the team and users of the bot, as well as ensure ease of manufacture with the use of standardized components, standards regarding fastener usage, material selection, and electrical components are considered when designing Dumbot. Below is a table of relevant standards considered when designing this project.

Table 1: Standards Utilized While Designing Dumbot

Standard	Use
ASTM B258-18	Prescribes the standard nominal diameters and cross-sectional areas of American Wire Gage sizes of solid round wire.
ISO 4762	Specifies product grade A hexagon socket head cap screws with metric threads and thread diameters from 1.4 to 100 mm.
ISO 7380	Specifies product grade A hexagon socket button head screws with threads from M3 up to and including M16
ISO 10642	Specifies product grade A hexagon socket countersunk head cap screws with threads from M3 up to and including M20, with property classes 8.8, 10.9, and 12.9
ASME B18.3, ASTM F912	Specifications for hexagon socket head cap screws for lock wire applications
ARPM/RMA IP-3-2	Examines the oil and chemical resistance of power transmission belts
IP-3-3	Examines the static conductive test method for power transmission belts
ASTM B209	Specifications for aluminum and aluminum alloy flat sheet, coiled sheet, and plate

ASTM B265	Specifications for titanium and titanium alloy strip, sheet, and plate
ISO9001, ISO14001	Internationally recognized standard for environmental management systems

Constraints

Economic

The project considers economic limitations. The team is constrained by a budget allotted by The University of Cincinnati BattleBots based on the preliminary budget provided of roughly $1900.00. In order to combat this limitation, considerations were made to limit material and machining cost by choosing less expensive materials and performing postprocess machining ourselves.

Environmental

The project considers environmental limitations. When competing, the battlebot is confined to an arena with predetermined environmental conditions that need to be considered for the development of the BattleBot. For example, the NHRL cage floor is comprised of plywood, so design considerations have to be made such that the BattleBot is capable of performing well when driving on plywood.

Sustainability

The project considers sustainability limitations. When deciding which electronics to purchase for this build, thought was put into what electronics would be able to be reused for years to come. With this in mind, all the motors (drive and weapon), ESCs, batteries, and controllers are able to be reused in the University of Cincinnati BattleBots club for years to come resulting in project funding to be allocated to more projects.

Manufacturability

The project considers manufacturability limitations. The ease of manufacturability of a component is directly related to whether that component is chosen to be used in the BattleBot construction. When designing the BattleBot, we had to account for unidirectional machining processes instead of multidirectional for ease of manufacturing. This led to some unique problem solving and the need for postprocessing of the majority of the components. When determining component materials, we considered material properties and ease of manufacturing of each material. For example, the weapon and wedges are fabricated from AR500 steel – a notoriously strong material – and therefore would be very difficult to postprocess. This means that the CAD models had to be detailed and accurate since once the part was received, no more work could be done to it. This was less of a problem for the CAD models for components such as the 6061 aluminum uprights since these components are more easily modified retroactively.

Ethical

The project does not consider ethical limitations since the team feels there is no one at risk of being directly affected in a negative way by the production of the BattleBot.

Health & Safety

The project does consider health and safety limitations. Since BattleBots and combat robotics as a whole is a notoriously violent sport, the need for strict health and safety regulations is apparent. Throughout the entirety of the project, the health and safety of the team as well as others was the utmost priority. Since the team is dealing with potentially unsafe conditions, directly with the BattleBot itself and indirectly in the 1819 Innovation Hub while performing fabrication and manufacturing, focusing on health and safety is vital. The team has made considerations to ensure the weapon system is as safe as possible with the use of kill switches and other safeguards.

Bot Design Rules 2024 (1):

Weight Classes

NHRL offers 3 different weight classes to compete in: 3lb, 12lb and 30lb. All robots must be at or below the maximum weight listed for their respective weight class at the start of the fight. In any given class, additional weight bonuses and exemptions may be allotted to entrants that meet certain criteria set out in this Bot Design Rules section. Competitors can stack weight bonuses, but the total weight of the bot cannot exceed 1⅔ times the weight limit for bots without bonuses.

Weight bonuses are summarized in this table:

Table 2: NHRL Weight Classes

Weight Class	Non-Traditional Locomotion Bonus	Multibot Bonus	Maximum Bot Weight
3lb	+1.5 lbs	+1 lb	5 lbs
12lb	+6 lbs	+3 lbs	20 lbs
30lb	+15 lbs	+12 lbs	50 lbs

NHRL has sole and final discretion regarding awarding bonuses to competitors.

Non-Traditional Motion Bonus

Any robot that falls outside the definition of a "Traditional Motion System" qualifies for the Non-Traditional Locomotion Bonus. NHRL classifies Traditional Motion Systems as a robot that relies on rotational motion of a component in contact with the ground as its method of locomotion around the arena. This includes all forms of wheels (round, non-circular, spoked, or offset axis) as well as continuous tread, track or belt driven systems. This also includes any robot that uses unpowered rotating objects (wheels, drums, rollers, ball bearings, etc.) as a means of friction reduction with the ground.

Multibot Bonus

Any competitor with multiple independent robot components fighting under a single entrant qualifies for the Multibot Bonus. Each bot component in a Multibot must have independent active control and be capable of influencing the fight. At least 51% of the weight of a multibot must be on bot components with active weapons. Additionally, for a multibot to benefit from the Non-Traditional Locomotion Bonus, only the heaviest component of the bot needs to meet the criterion to qualify for the Non-Traditional Locomotion weight bonus.

The weight of any component of a multibot may not exceed 110% of the 'base weight' for its respective weight class, except in the 3lb class. Base weight is defined as the maximum weight the bot can be within the rules without applying the Multibot Bonus. If the bot also qualifies for the Non-Traditional Locomotion Bonus, the additional weight limit is a part of the base weight.

For example, the heaviest segment of a 12lb multibot may not exceed 13.2 lbs. However, if the robot also qualifies for the Non-Traditional Locomotion Bonus, the maximum weight of the heaviest segment increases to 19.8 lbs (18lbs x 110%).

If a competitor's robot requires the multibot bonus to make weight, but arrives at the cage with a non-functional multibot, the competitor will lose the match by Technical Knockout.

Weight Exemptions

Any bots with flamethrowers, hydraulic-, pneumatic- or ICE-powered weapons systems will be weighed "dry" (without fuel).

Flamethrower bots will be weighed with no fuel in their tanks.

Pneumatic and ICE systems will have their tanks removed for weigh-in. Any tanks used must be commercially available tanks.

Competitors who bring hydraulic systems must declare in advance how much hydraulic fluid is in their system and how much it weighs. The fluid weight will be subtracted from the bot's scale weight. These bots will be subject to random inspections, where the hydraulic fluid will be removed and measured.

Any active cameras or recording equipment on the bot do not count towards the robot's weight but must be approved during bot inspection by a Bot Inspector.

Size Requirements

3 lb. robots must be able to fit into a 30 x 30 x 24-inch box.

12 lb. and 30 lb. robots must be able to fit into a 36 x 36 x 36-inch box.

In the case of a multibot, all segments of the robot must fit within the box size together.

Once the match begins, robots are allowed to expand or contract to any size.

Batteries and Power

Bots must have an easily accessible master power cutoff in the form of a switch or removable link (an easily accessible battery connector is an example of a removable link). The power cutoff must be accessible without disassembling the robot in any way. The power cutoff must be able to be deactivated in no more than 15 seconds.

Nominal battery voltage may not exceed 60 volts for 3 lb. bots, or 75 volts for 12 lb. and 30 lb. bots. It is understood that a fully charged battery pack will have an initial voltage above its nominal Voltage.

Any robot system that produces voltages above the robot's battery voltage limit must be approved by NHRL prior to participating in any competition and may require additional inspection. Email safety@nhrl.io to discuss your design.

Robot Control Systems

Robot controls and communication systems must pass a failsafe test overseen by a Bot Inspector at Bot Inspection in order to compete. In the event of signal loss or transmitter power-down, the bot's drive system must stop within 30 seconds and weapons must come to a complete stop within 60 seconds.

All robots and multibot components must have a dedicated receiver(s).

Autonomously controlled robots are allowed, but they must still retain a radio control module that can remotely activate and deactivate the robot.

Weapons

All robots must have an active weapon. An active weapon is defined as a weapon or mechanism that operates independently from the robot's drivetrain or means of locomotion and is clearly designed to influence the opposing robot. In a multibot, at least 51% of the weight of a multibot must be on bot components with active weapons.

"Meltybrains" (bots that can show controlled movement while spinning at rapid speeds), and "Gyro Walkers" (bots that use spinning masses or weapons to generate inertia to induce translational motion) are exempt from this rule. "Thwackbots," (robots which use momentum created by the robot's drivetrain to 'actuate' an otherwise unpowered weapon) do not qualify as having an active weapon.

NHRL strongly encourages competitors designing a non-conventional active weapon to share their plans with NHRL in advance so confirmation can be given if the weapon is deemed active or not. In the event that a ruling on a weapon is required at a NHRL tournament, the Tournament Stewards will make a ruling once they have been alerted by the Bot Inspector. Here are some examples of criteria the Tournament Stewards will use to make a decision:

- A good-faith explanation of how the weapon is designed to influence an opponent.
- The proportion of bot weight dedicated to the weapon system.

Weapon Locks

All weapon systems must have a lock that stops their actuation, extension, expansion, rotation, ignition, etc. Weapons that move or rotate must have a lock or be constrained such that movement is restricted in all directions. Weapons that shoot a projectile or gas must have physical means to prevent firing AND block the expulsion of a projectile. Additionally, all means of fuel storage must be designed to default to the closed position if damaged or removed from the robot.

Weapon locks that force the competitor's fingers to be in the path of the weapon for an extended period of time will not pass bot inspection. Clamps can only be used as weapon locks if they clamp to themselves and not to the bot or any other object.

Current State of the Art

Tombstone has made a huge impact in the heavyweight class in the battlebot community and has been deemed as one of the most iconic spinning robots in the history of BattleBots (2). With the large, horizontally mounted spinning bar, the weapon can deliver extremely high offensive attacks due to the kinetic energy that is stored in the system. This weapon design is the reason that most of Tombstone's fights result in knockouts. Tombstone is known for its simplicity and brute force, along with the devastating blows it can deliver to the opposition. Success can be accredited to Tombstone's strong and robust frame and effective weapon protection. The single axis drivetrain also allows the robot great maneuverability to quickly spin and face the direction of the opponent.

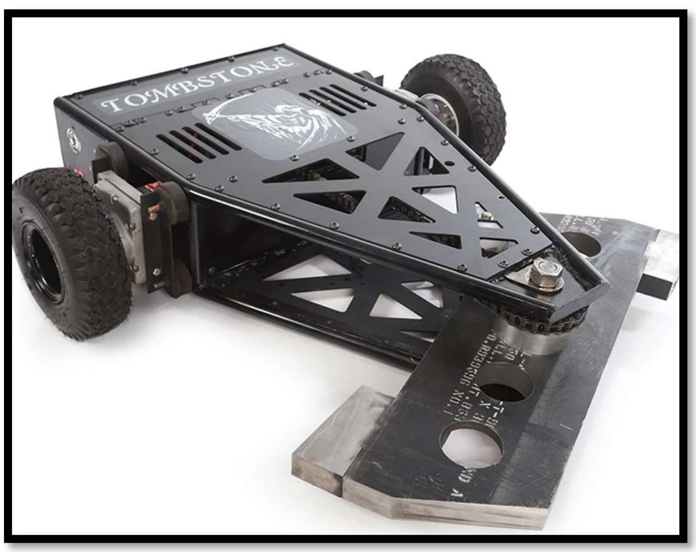


Figure 3: Tombstone's final design, 2022

Whiplash's unique design includes a vertical spinning blade attached to the end of a 180-degree vertical flipper (3). This robot has excellent versatility by being equipped with components that allow for lifting opponents and immobilizing them while also striking them. With this configuration, the team has the ability to strategically choose between aggressive striking or tactical control depending on the opponent's weaknesses. With the 2-axle drive design, the robot is incapable of turning sharp radii quickly and effectively. While possessing increased maneuverability, Whiplash's design falls short due to vulnerability of wheel exposure. With this massive design flaw, Whiplash is prone to quick immobilization.

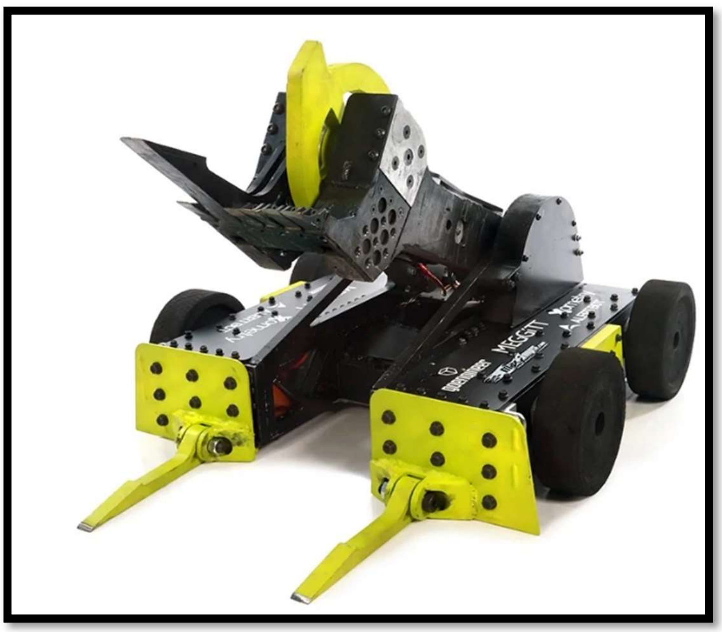


Figure 4: Whiplash's final design, 2021

Minotaur's design is unique due to the fact that it utilizes a spinning drum rather than a disk (4). The main structural housing is fully enclosed and denies any opponent from entering externally. The teeth on the spinning drum act like mini hardened blades, causing large amounts of damage to the opponent. These teeth have the ability to grasp onto the opponent's hull and rip apart anything that is sticking out. Another valuable design choice in Minotaur's arsenal is the ability to operate whether the robot is upside down or right side up. On top of the dual oriented capability, the wheels are also partially protected with an armor bar to help prevent any demobilization.

Figure 5: Minotaur's final design, 2021

Materials Science Research

When determining which material to use in the development of Dumbot, it is important to understand how we want the robot to react under extreme circumstances. For example, when struck by an impact, do we want the uprights to deform or shatter? Obviously, the preferred answer is neither, but since that is simply not possible and some reaction must occur, understanding how materials respond is invaluable. This research proved very useful when determining the material to be used for the uprights. 7075 aluminum has almost twice the tensile strength, twice the fatigue strength, and is twice as hard as 6061 aluminum, but 6061 aluminum was selected for our uprights. Why is that? Well, when impacted, 7075 aluminum shatters completely where as 6061 aluminum smears. This property of 7075 aluminum is extremely undesirable in a structural component such as an upright and so for that specific reason, 6061 was chosen. Similar dives into material properties were made when determining to use AR500 for high impact components, titanium for lightweight support structures, and ultra high molecular weight polyethylene (UHMW) for the body. Every component was carefully researched to ensure that we were getting the best bang for our buck, all while staying under budget.

End User

Our senior design team is the end user. Each member has become intimately familiar with the robot in order to perform any and all maintenance or repairs needed. Since we are the end users, we have decided the robot must be easy to control as well as consistent and durable. These are characteristics of a sure and steady robot. We will stick to a minimalistic approach when it comes to design to ensure manufacturability, assembly, and maintenance are as streamlined as possible.

Conclusions and Summary of Research

To achieve the goal of creating an innovative and boundary pushing robot, the team was committed to harnessing expertise in mechanical, electrical, and design fields gained at the University of Cincinnati. Abiding by standards and codes set forth both by industry and specific to the world of battlebots, the team was able to focus on creativity more effectively. As mentioned above, one significant aspect of our research involved the 10 mm impact theory, which guides the robot's design to protect sensitive components from external impacts. We also emphasized the importance of safeguarding batteries and motors to ensure continuous functionality throughout the competition. Our weapon of choice is a high-speed vertical blade, designed to maximize destruction, mobility, and control. We've also carefully considered the blade's rotation direction to optimize performance. Material property investigations proved valuable in the team's decision for which materials to select for body components when designing the robot.

Adherence to the NHRL rules makes it mandatory to compete safely and fairly. The team understood that deviations from these guidelines could result in disqualification or pose risks to team members and spectators. In the highly competitive 12 lb. weight class, there are countless diverse robot designs, each with unique strengths and strategies, making innovation that much more valuable.

Quality Function Deployment

Customer Features

While considering the importance of each component of our battlebot, we presented a survey to people who have a background in robotics to gain further insight. The majority of the responses were from the University of Cincinnati BattleBots Club, and the remaining respondents were students from class. The survey included multiple choice selections, rated opinions on a scale from 1-10, and short answer responses for the more involved questions. In conducting this survey, we understood what works best in the competitive environment. From the survey, 30 individuals participated, and the data was analyzed to best present the final HOQ template regarding Mechanized Mayhem.

From the data, the customer requirements that we focused on were:

- Damage delivery
- Weapon durability
- Weapon effectiveness
- Maneuverability
- Safety features
- Maintenance repairability
- Visual appearance
- Traction
- Wheel protection

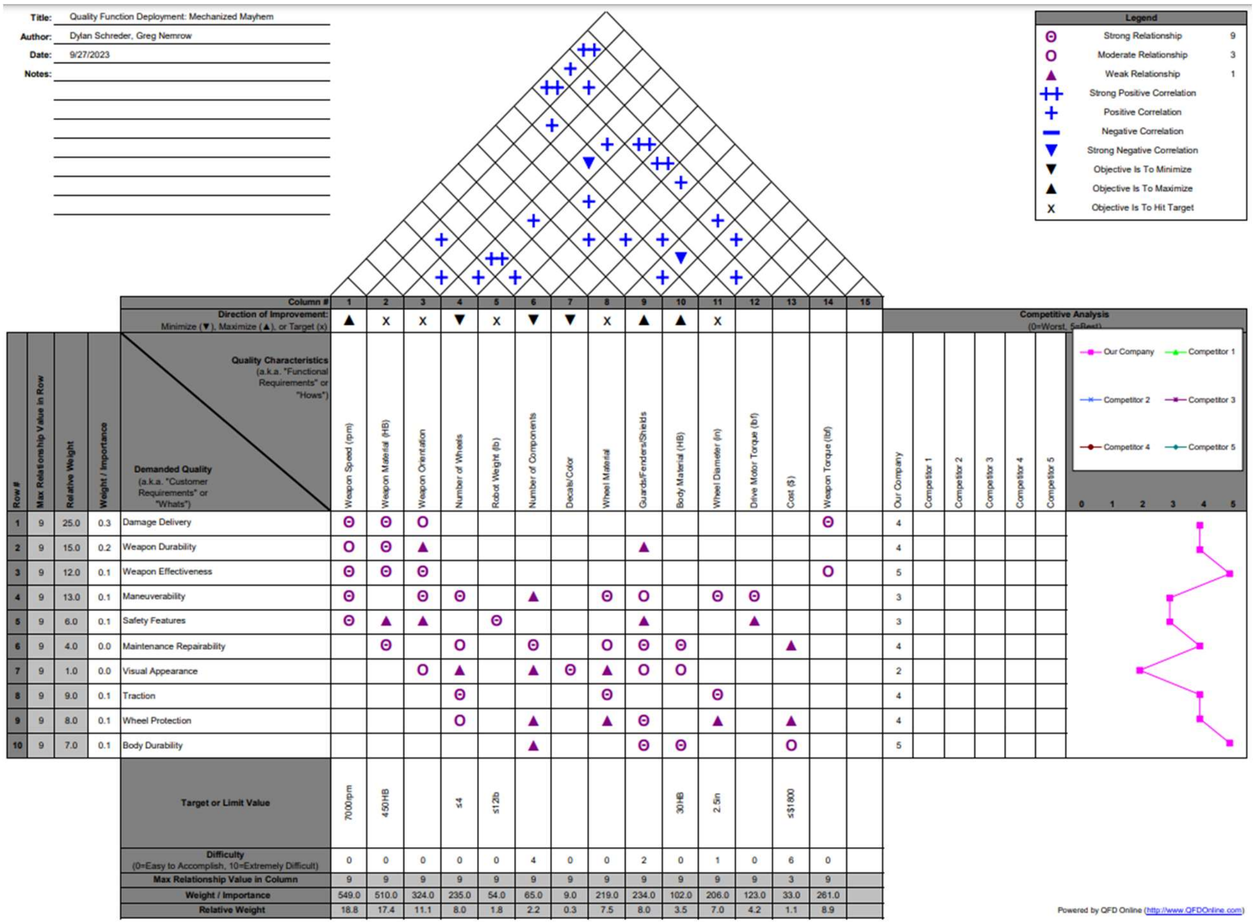
Engineering Characteristics

The following engineering characteristics were created to measure the customer features listed above:

- Weapon speed (rpm)
- Weapon material (HB)
- Weapon orientation
- Number of wheels
- Robot weight (lb)
- Number of components
- Decals/color
- Wheel Material
- Guards/Fenders/Shields
- Body Material (HB)
- Wheel diameter (in)
- Drive motor torque (lbf)
- Cost ($USD)
- Weapon torque (lbf)

House of Quality

Table 3: House of Quality Results, 9/28/2023



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")	Weapon Speed (rpm)	Weapon Material (HB)	Weapon Orientation	Number of Wheels	Robot Weight (lb)	Number of Components	Decals/Color	Wheel Material	Guards/Fenders/Shields	Body Material (HB)	Wheel Diameter (in)	Drive Motor Torque (lbf)	Cost ($)	Weapon Torque (lbf)		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	x	▼	x	▼	▼	x	▲	▲	x										
1	9	25.0	0.3	Damage Delivery	Θ	Θ	O											Θ		4					
2	9	15.0	0.2	Weapon Durability	O	Θ	▲						▲							4					
3	9	12.0	0.1	Weapon Effectiveness	Θ	Θ	Θ											O		5					
4	9	13.0	0.1	Maneuverability	Θ		Θ	Θ		▲		Θ	O		Θ	Θ				3					
5	9	6.0	0.1	Safety Features	Θ	▲	▲		Θ				▲			▲				3					
6	9	4.0	0.0	Maintenance Repairability		Θ		O		Θ		O	Θ	Θ			▲			4					
7	9	1.0	0.0	Visual Appearance			O	▲		▲	Θ	▲	O	O						2					
8	9	9.0	0.1	Traction				Θ				Θ			Θ					4					
9	9	8.0	0.1	Wheel Protection				O		▲		▲	Θ		▲		▲			4					
10	9	7.0	0.1	Body Durability						▲			Θ	Θ			O			5					
				Target or Limit Value	7000rpm	450HB		≤4	≤12lb					30HB	2.5in		≤$1800								
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	0	0	0	0	0	4	0	0	2	0	1	0	6	0							
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	3	9							
				Weight / Importance	549.0	510.0	324.0	235.0	54.0	65.0	9.0	219.0	234.0	102.0	206.0	123.0	33.0	261.0							
				Relative Weight	18.8	17.4	11.1	8.0	1.8	2.2	0.3	7.5	8.0	3.5	7.0	4.2	1.1	8.9							

Product Objectives

Based on the results of the survey and our House of Quality, we have assigned weighted importance ratings to each engineering characteristic. The characteristics and their associated ratings are listed below. We used this data to move the design of the robot forward with justification.

- Weapon Speed (18.9)
    - Weapon speed must be high enough to deliver large amounts of damage.
- Weapon Material (17.6)
    - Weapon must be able to withstand large loads over a long period of time.
- Weapon Orientation (11.2)
    - Weapon must be mounted in a position to reach the opponent.
    - Weapon orientation must not impact the mobility of the robot.
- Number of wheels (8.1)
    - The bot must be able to move with ease when upside down or right side up.
- Robot weight (1.9)
    - The total weight must not exceed 12 lb. to comply with the NHRL rules.
- Number of components (2.2)
    - We must use the least number of components possible to allow for weight saving and simplistic design.
- Decals/color (0.3)
    - The robot must have an attractive appearance.
- Wheel material (7.6)
    - The wheels must be able to grip the surface.
- Guards/fenders/shields (7.2)
    - Enough armor should be used to defend the robot appropriately without impacting the mobility.
- Body material (3.5)
    - The materials used on the body must be rigid enough to hold the body together.

- Wheel diameter (7.1)
  - The wheels must be able to drive over small obstacles.
  - The wheels must be able to reach the ground when upside down or right side up.
- Drive motor torque (4.2)
  - The torque must be high enough to move the robot at a reasonable pace.
- Cost (1.1)
  - Cost must be within the budget allocated by the University of Cininnati BattleBots Club.
- Weapon torque (9.0)
  - Weapon torque must be high enough to get the spinner moving to a reasonable speed.

Team Members and Responsibilities

The project was split into various tasks in order to facilitate workflow. These tasks started from the very beginning stages of the project and extended through the very end. These tasks were as follows: technology and current state of the art research; BattleBot body component brainstorming; materials research; Autodesk Fusion 360 familiarization; prototype CAD design; finite element analysis and component simulation; product CAD redesign and finalization; determination of non-fabricated parts and hardware required; bill of materials creation; budget calculation; ordering of fabricated and manufactured parts; receiving of parts; postprocessing fabricated parts; assembly of weapon system; assembly of electronic drive systems; CAD redesign of incorrect or obsolete parts; complete assembly of BattleBot including any modifications that were previously made; testing of BattleBot and fine-tuning electronics; competing in the NHRL March Event, including driving Dumbot; attending the CEAS expo, and putting together everything related to that; putting together and presenting final presentations; and redesigning of models and assemblies for said presentations. All the while, documenting and report creation are and have been occurring.

Some of these tasks were able to be completed concurrently, such as bill of materials creation and budget calculation, while others required a more consecutive approach. Obviously, a CAD redesign of the parts must follow the receival and post processing of the parts. This required method of task completion caused a massive time constraint as we rapidly approached competition, forcing us to have to partake in the aptly named “dynamic manufacturing” approach of rapid CAD redesigns onsite, quick fabrication turnaround times, and lots and lots of coffee consumption.

For the delegation of assignments for the project, the team by and large adopted the “all hands-on deck” approach for the completion of the majority of tasks. In the beginning stages of the project, all three members of the team were involved in all tasks in at least some way. G. Nemrow and D. Schreder were more involved in the beginning stages, with G. Nemrow taking over the finite element analysis of the initial prototype models and D. Schreder in charge of the more business and financial side of things, with Z. Jacob being heavily involved in the middle and end stages such as component postprocessing, much of the CAD redesign, and BattleBot assembly. Listed below in Table 1 is the full task separation and responsibility delegation for the project.

Table 4: Delegation and Assignment of Tasks

#	Task	Team Member(s) Responsible	Note
1	Technology and current state of the art research	Jacob, Nemrow, Schreder	Entire group responsible.
2	BattleBot body component brainstorming	Jacob, Nemrow, Schreder	Entire group responsible.
3	Materials research	Jacob, Nemrow, Schreder	Entire group responsible.
4	Autodesk Fusion 360 familiarization	Jacob, Nemrow, Schreder	Entire group responsible.
5	Prototype design	Jacob, Nemrow, Schreder	Entire group responsible.
6	Finite element analysis and component simulation	Nemrow	G. Nemrow has the most experience using Fusion 360's FEA functionality. Occurred concurrently with Task 7.
7	Product CAD redesign and finalization	Jacob, Schreder	Z. Jacob and D. Schreder took on the redesign. This task occurred concurrently with Task 6.
8	Determination of non-fabricated parts and hardware required	Jacob, Nemrow, Schreder	Entire group responsible.
9	Bill of materials creation	Schreder	D. Schreder has the most experience with BOM creation.
10	Budget calculation	Schreder	D. Schreder has the most experience with budgeting.

11	Ordering of fabricated and manufactured parts	Schreder	Since direct relation with Tasks 8 and 9, D. Schreder took on this task as well.
12	Receiving of parts	Jacob, Nemrow, Schreder	Entire group responsible.
13	Postprocessing fabricated parts	Jacob	Z. Jacob completed machining and postprocessing of fabricated parts.
14	Assembly of weapon system	Jacob	Occurred during UC BattleBots club joint manufacturing day.
15	Assembly of electronic drive systems	Jacob, Nemrow	Occurred during UC BattleBots club joint manufacturing day.
16	CAD redesign of incorrect or obsolete parts	Jacob	Z. Jacob completed CAD redesign of product parts. Utilized “dynamic manufacturing” skills.
17	Complete assembly of battlebot including any modifications that were previously made	Jacob	Since directly responsible for part CAD redesign, Z. Jacob was most familiar with BattleBot and therefore did complete assembly.
18	Testing of battlebot and fine-tuning electronics	Jacob	Z. Jacob responsible for seeing BattleBot completion to the end.
19	Competing in NHRL March Event	Jacob, Nemrow	D. Schreder unable to attend.
20	Driving Dumbot in NHRL March Event	Jacob	It was determined Z. Jacob would be the driver for the event.
21	Documenting and report creation	Jacob, Nemrow, Schreder	Entire group responsible. This task occurred concurrent with Tasks 1 – 19.
22	CEAS expo	Jacob, Nemrow, Schreder	Preparation and execution of our booth for the CEAS Expo 4/9/24
23	Videos for CEAS expo	Schreder	Cutting and clipping of documented footage.
24	CEAS poster	Jacob	Created for CEAS expo
25	Project presentation	Jacob, Schreder, Nemrow	Entire group responsible.
26	Project testing videos	Schreder	Cutting and clipping of documented footage.
27	Redesign of CAD models and assembly	Jacob	Redesigned CAD models to accurately represent current state of battlebot.
28	Rendering of CAD models and assembly	Jacob	Rendered CAD models to accurately represent current state of battlebot.

29	Project report	Jacob, Nemrow, Schreder	Entire group responsible.
30	Submission of final report to CEAS Library	Schreder	Final Submission by 4/26/24.

Table 5: Team Member Hour Log

Team Member	**Hours Worked**
Zachary Jacob	300
Greg Nemrow	240
Dylan Schreder	280

Concept Drawings

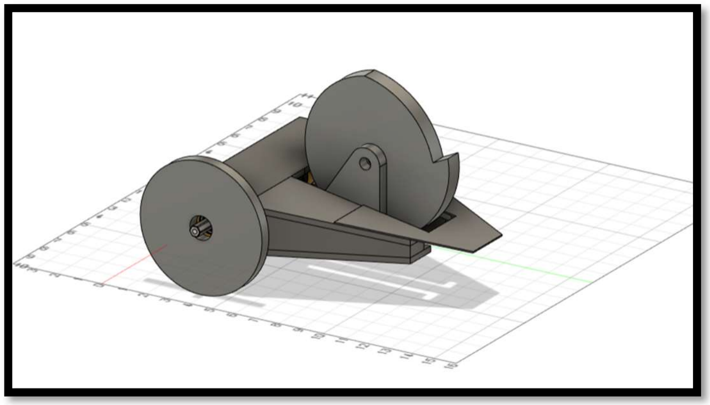


Figure 6: Original concept idea, large weapon and wheels

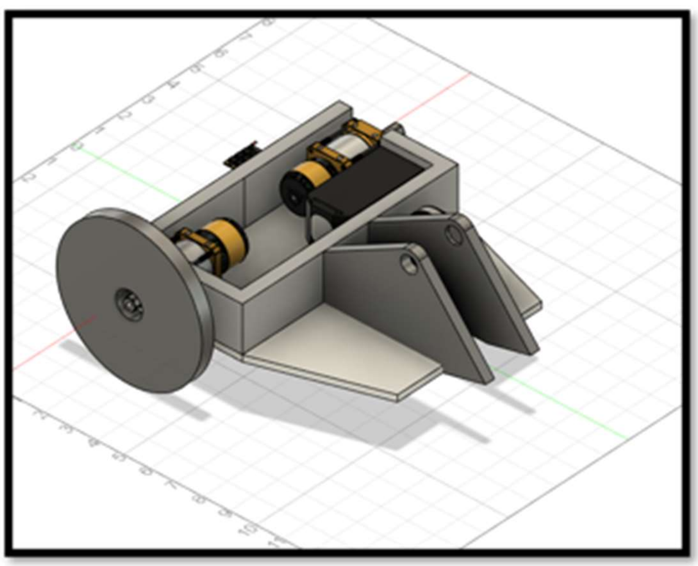


Figure 7: Improvement in component box

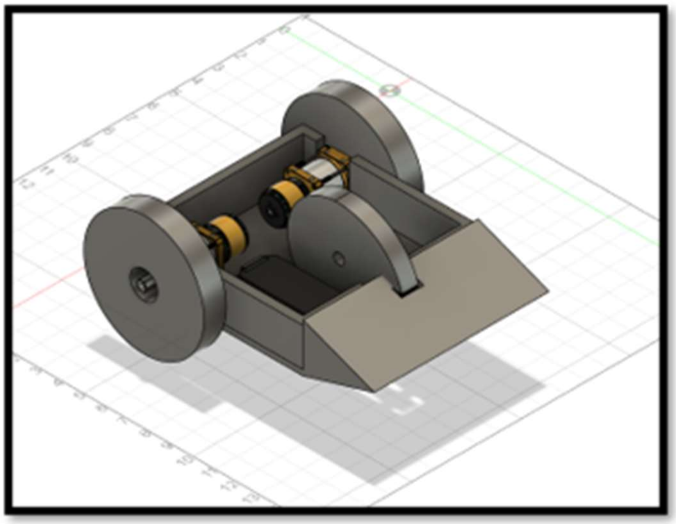


Figure 8: Improvement in component box space and wedge use

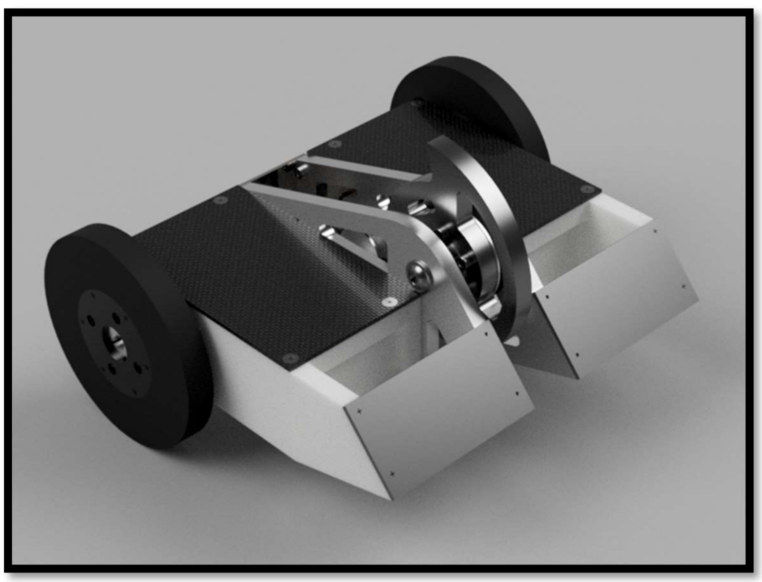


Figure 9: Very solid iteration of the product prior to final changes

Design

Design Alternatives and Selection

During the beginning of the design process, we failed to consider manufacturability when designing prototypes. In part due to being wet behind the ears when it comes to designing a combat robot and in part due to sheer excitement in designing a cool robot. Unfortunately, this way of designing caused many "start from scratch" moments when we realized it just was not possible to continue down the path we were traveling. Due to this, it is notably difficult to list specific design alternatives because the vast majority of the battlebot is alternative in one way or another to the original prototype designs. Fortunately, before long, we came to the realization that designing in a way that was built on a proper foundation and was stable from the beginning meant there was much less room for error down the line. So, we started from scratch one more time and started down the path that led to our end result. Obviously, this path had design changes and reworks of its own. Some of these included the decision to use a split-body design that is mirrored and mounted together with the uprights, rather than one solid body; the change of a 0.52:1 weapon gear ratio to a 1:2; and the inclusion of one AR500 steel wedge at the bow of the battlebot for better opponent contact as opposed to one on each half.

The team created the "final" design of Dumbot by the middle of February. Since then, there have been small changes made in order to get to the true final design and the configuration in which Dumbot sits today. These changes include upright redesign to facilitate the use of nutstrips, as well as the change from two twin wedges to one solid wedge, as mentioned above. The design of the robot prior to these changes is shown above, in Figure 9, and the true final design of the robot is shown in the following section.

The final design of Dumbot consists of two UHMW electronics boxes mirrored around two aluminum uprights. The battlebot features two oversized wheels to promote the aesthetic theme and a slanted angle of attack. The battlebot rests on one AR 500 wedge at the bow of the vehicle that extends the width of the robot and allows Dumbot to get underneath its opponent effectively. Titanium top, back, and bottom plating provide armor as well as acting as structural connections between the two halves. Carbon fiber is utilized for the component box covers to promote any weight restrictions are met. The components are housed within the component boxes, which act as the main body of the design. Looking above to the first concepts assembled in CAD, the figures show insight into our early design ideas. We had started to figure out the dimensions required to fit our electronics and based off that we could conceptualize our movement and combat geometry. Key features of Figure 6 include large wheels, a wedge, and a large circular weapon. Figure 6 is an early model in which we were at the extremes of the robot's geometry. Going to extremes can be helpful to find limits, but it also shows the inexperience the team originally had. This design phase is very far from the final product, but it was a necessary step in order to get to the final design. Figure 7 was our next significant concept iteration. In this stage we figured out how we can incorporate uprights into the design which led us to our breakthrough of splitting the structure into four main components with the uprights becoming more structural. In this design the wheels are still very large, and we started to figure exactly how much space our electronics needed. In Figure 8, we figured out the last decisions needed to create our final concept. We experimented with different wheel and weapon sizes as well as electronics orientation and the final overall size. Our final product is a culmination of keeping our early concept ideas in mind while starting over and modeling on a firm foundation.

Product Model and Illustrations

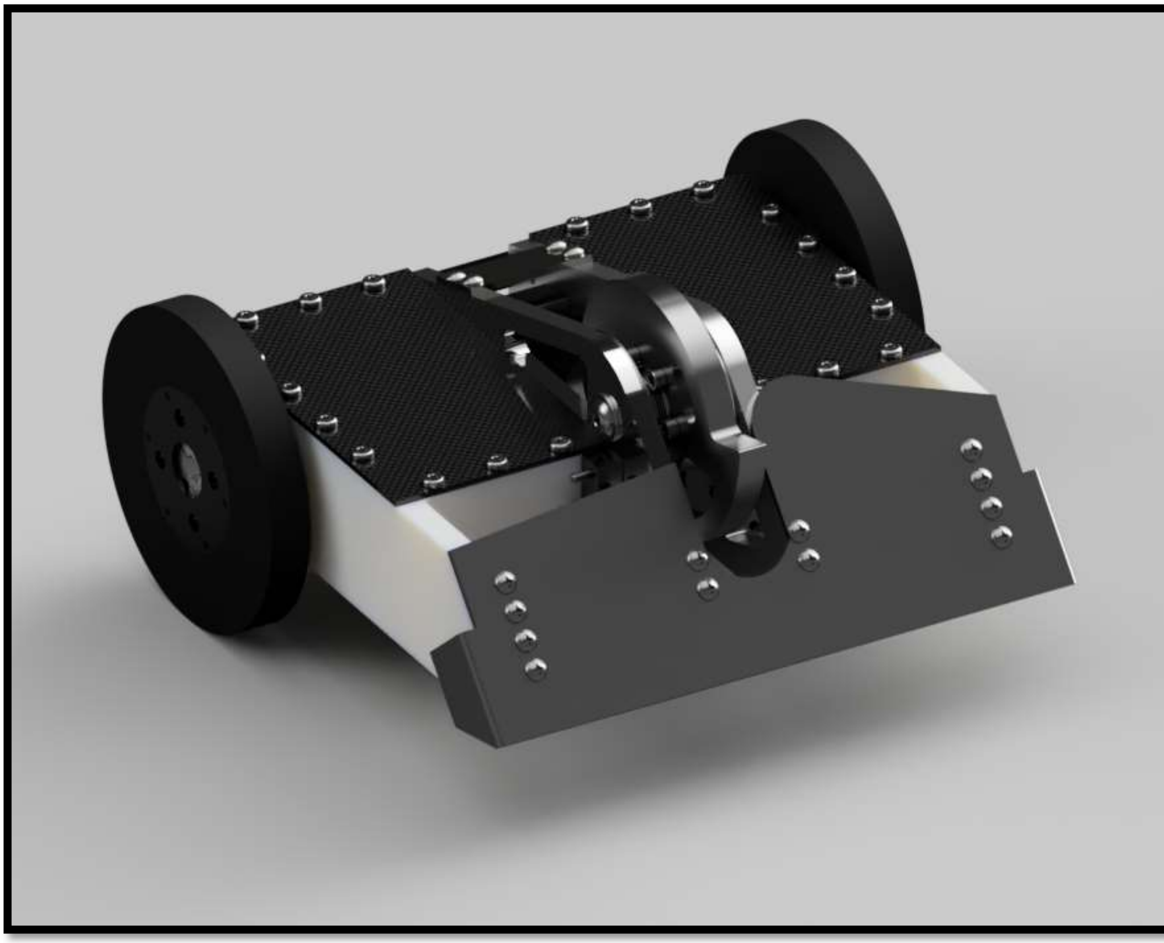


Figure 10: Dumbot

As a result of multiple iterations and many design changes, we came up with a design that we are thrilled with. The final design has two UHMW component boxes that sandwich two aluminum uprights. The split design denies the travel of energy from opponent impacts throughout the system, rendering vibrations down rather than transferring them through one solid body. Impacts are mitigated throughout the standoffs and connection points, acting as a mechanical damper for the vibrations. Throughout the design, we have stayed true to the original aesthetic design that we wanted our robot to have, most notably the large wheels and weapon. This design is approximately 11.93lb in Fusion 360 and about 11.22lb in reality. The simplicity of a design like this truly is revolutionary in combat robotics. The ease of performing maintenance, swapping out armor packages, and replacing damaged parts was appreciated greatly in the pits at NHRL.

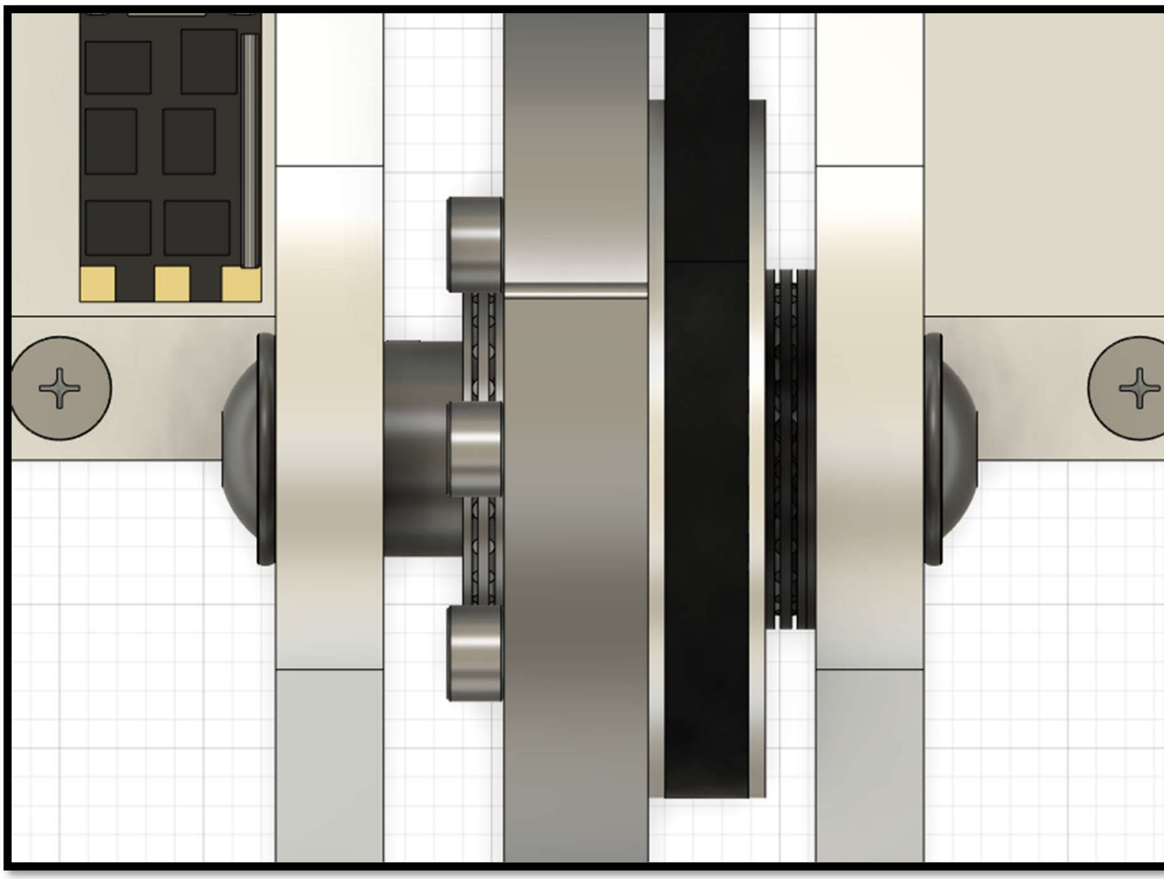


Figure 11: Bearing & washer stack up for weapon shaft

The battlebot is designed such that there is a little play in the weapon washer stack up. This is to ensure binding does not occur when the weapon gets up to operating speed. To establish proper belt alignment with the driving and driven pullies, we used both needle roller thrust bearings and washers.

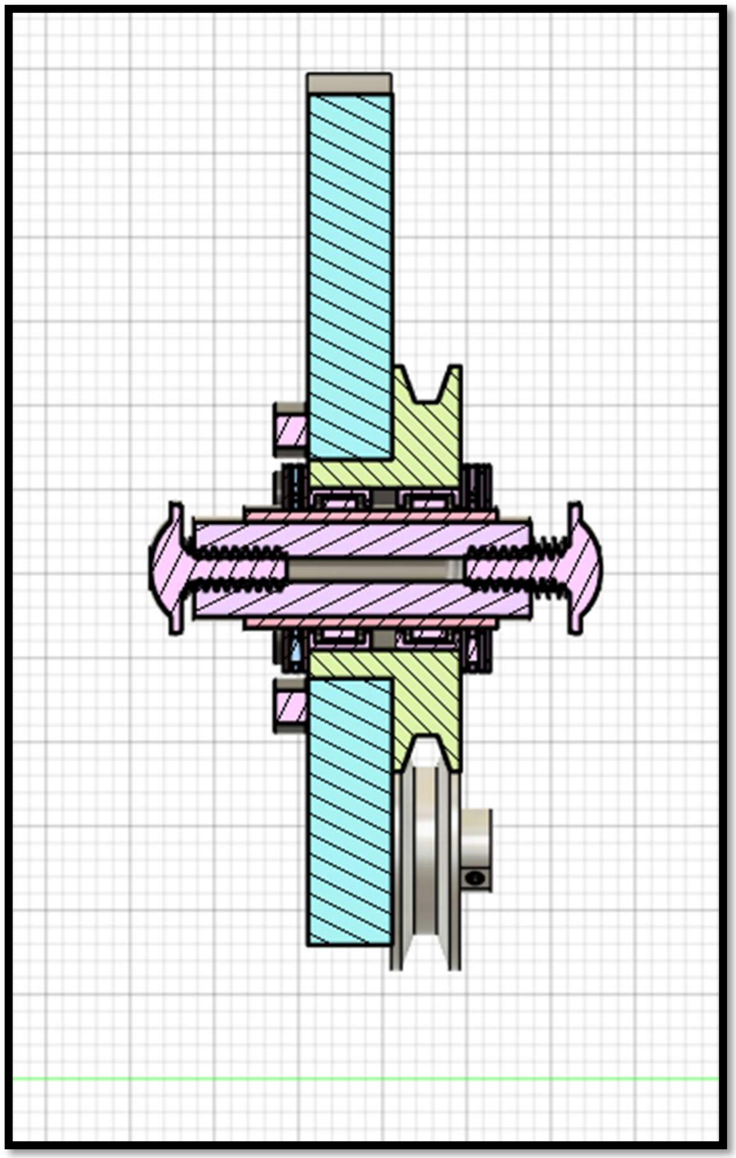


Figure 12: Weapon shaft cross section

The weapon system is one of the design characteristics of the robot we are most proud of. Many battlebots currently utilize a dead axle for their weapon system. This means that their weapon spins freely overtop a fixed shaft. Simple enough. Dumbot's weapon system acts as not only a shaft for the weapon to spin on, but also as a key structural support. As shown above in Figure 12, the cross section shows the following components:

- Blue – Weapon disk
- Green – Driven pulley
- Purple – Titanium shaft with tapped ends
- Pink – Shaft hex bolts
- Salmon – Steel shaft sleeve

The titanium shaft sits flush inside the axle holes in either upright. The steel sleeve sits overtop of the titanium shaft and between the two uprights, with the weapon disk resting on the sleeve. The sleeve is designed to be shorter than the distance between the two uprights such that when the two shaft hex bolts on either side of the titanium shaft are tightened, the uprights are drawn in together and squeeze the steel sleeve. This design provides an excellent point of structural support between the two halves of the robot, while still acting as a simple weapon axle. Implementing structural integrity into the weapon axle is an innovation that we are sure we will see more of in the field in years to come.

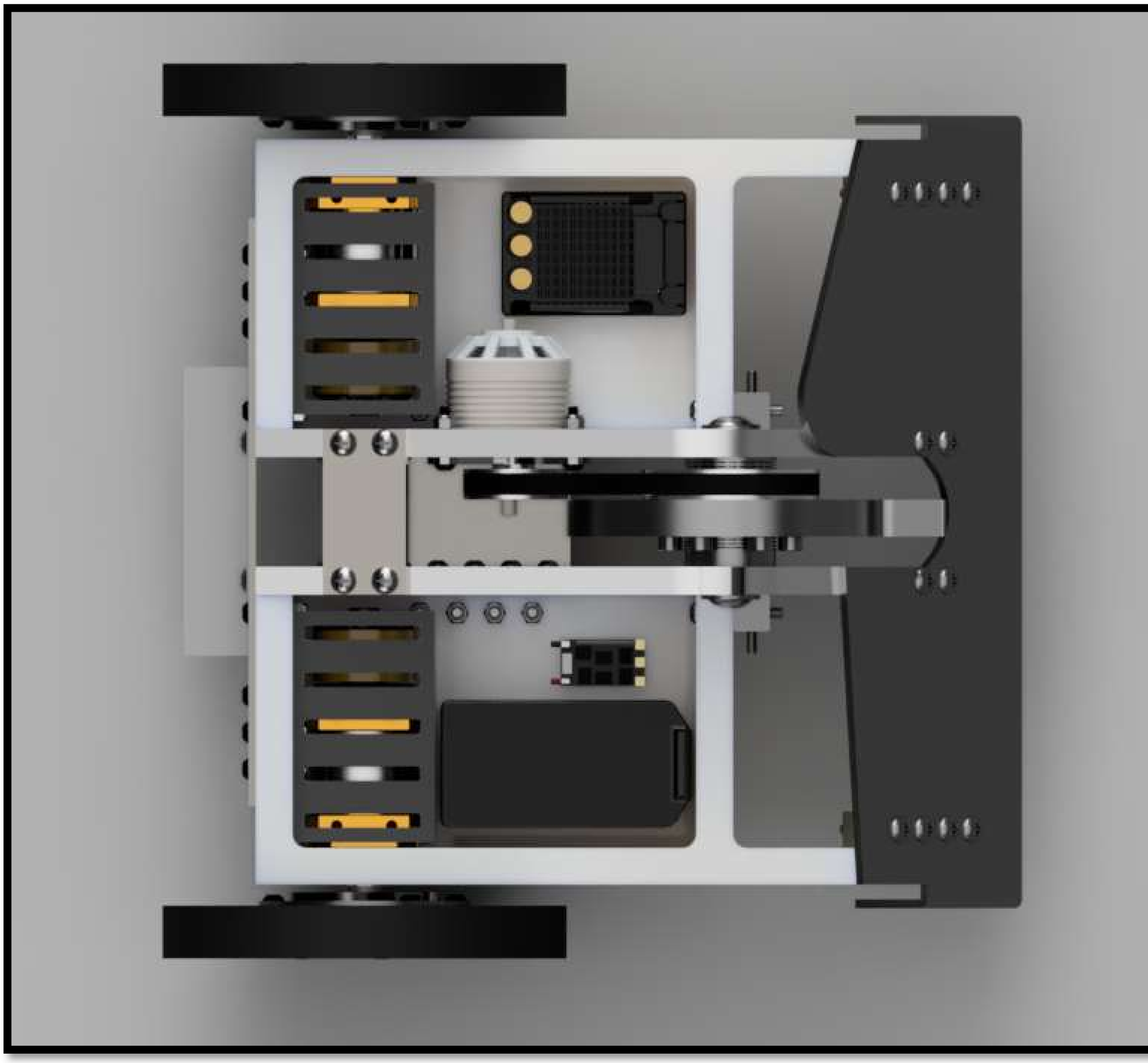


Figure 13: Top view of Dumbot showing the placement of components

Shown above in Figure 13, the internal components of the robot can be seen. Inside the right component box will be the right-side drive motor, the drivetrain ESC, and the battery to power the entire system. In the left component box will be the left-side drive motor, weapon motor ESC, and weapon motor mounted to the titanium motor mount mounted to the outside of the left upright. Also shown in this figure are two 3D printed motor cages specifically designed to slot into the boxes and overtop of the drive motors to prevent unwanted wear on the wires. These cages were a part of the "dynamic manufacturing" portion of the design listed above. Wiring between the two halves was ran through another designed and 3D printed component that acts as a wiring tunnel and slots into two of the weight optimization cutouts in the uprights. The wiring tunnel protects the wires from any impacts or sharp corners that might pose a threat to their integrity.

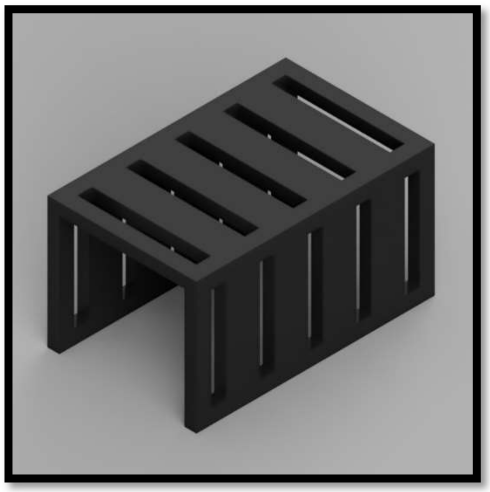


Figure 14: Drive motor cage for wires

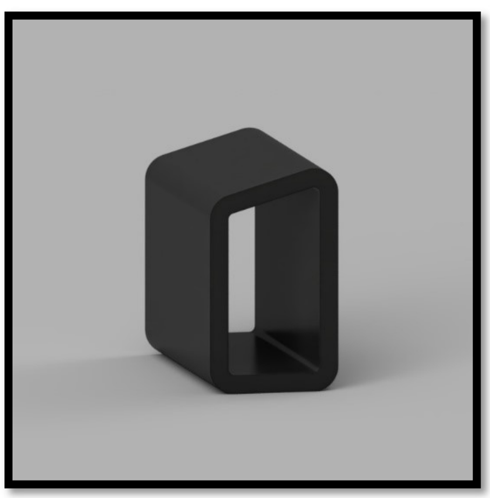


Figure 15: Wiring tunnel

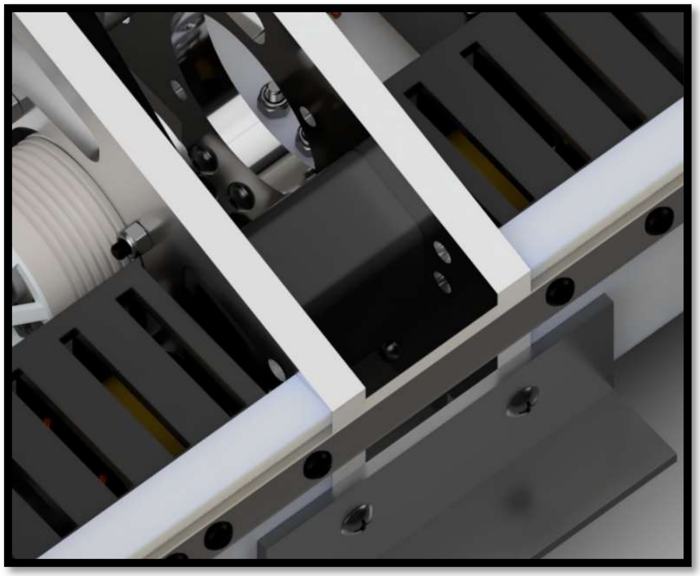


Figure 16: Wiring tunnel pathway between the component boxes

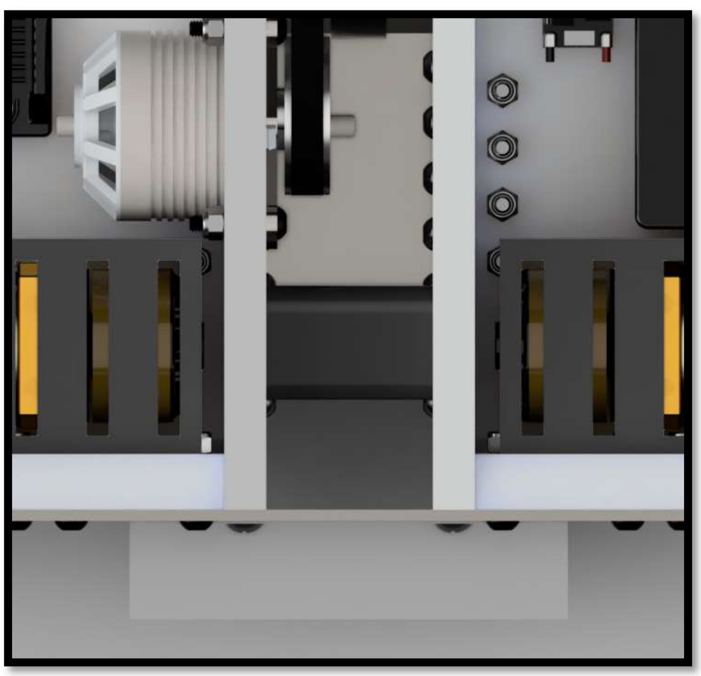


Figure 17: Wiring tunnel from above

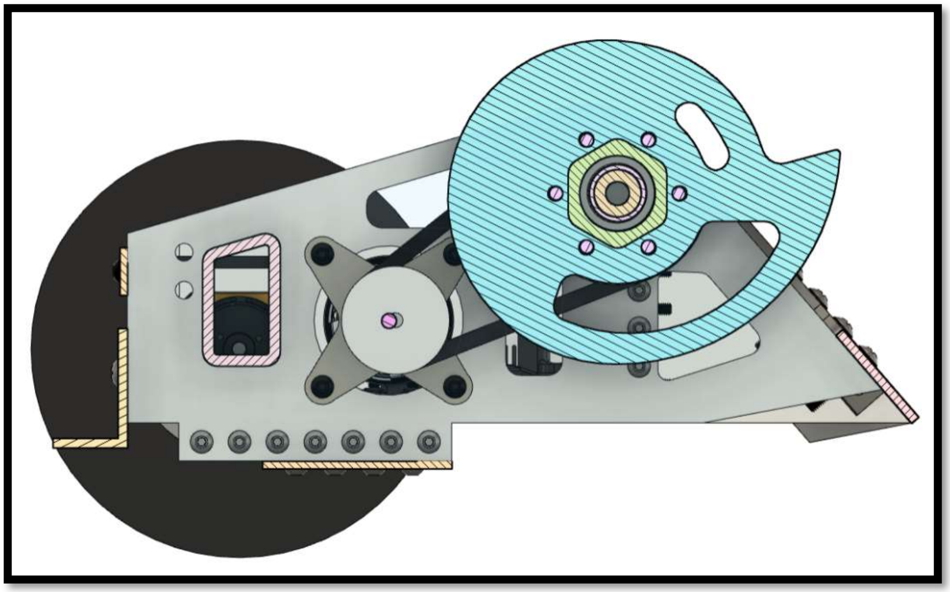


Figure 18: Section view of Dumbot

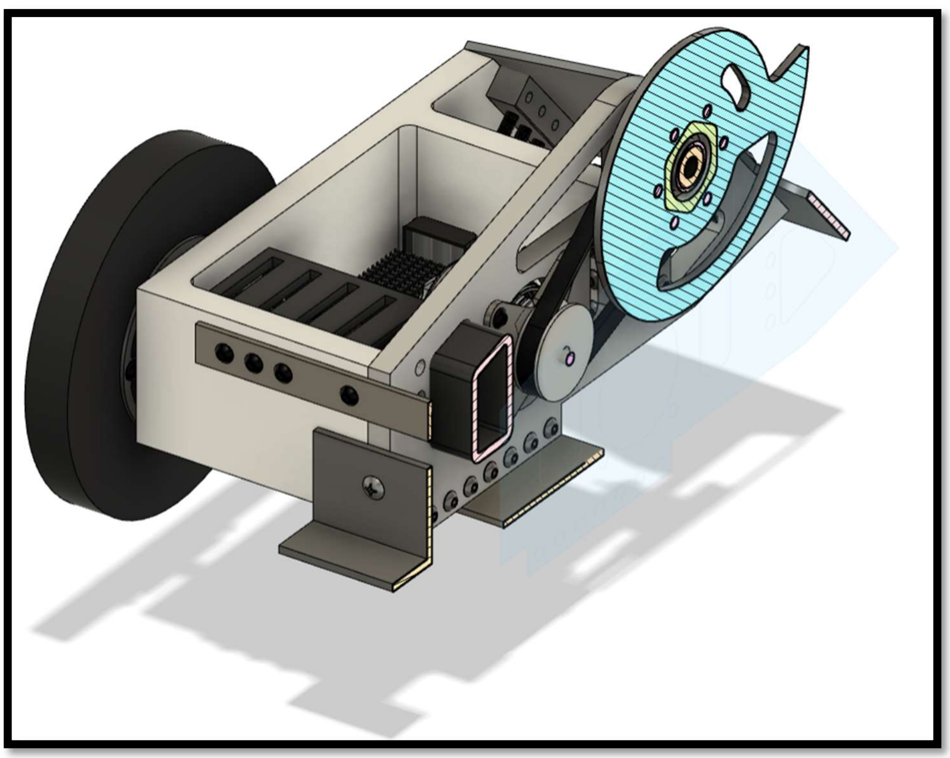


Figure 19: Section view of Dumbot

Figure 18 and Figure 19 show cross section views of the robot and weapon system. The pulley (green) is machined to fit inside a hexagonally keyed hole to reduce the stress of the bolts (pink) holding both the driven pulley and the weapon together. This design ensures that the weapon will not disconnect from the driven pulley while moving at high speeds and experiencing high impact forces while operating.

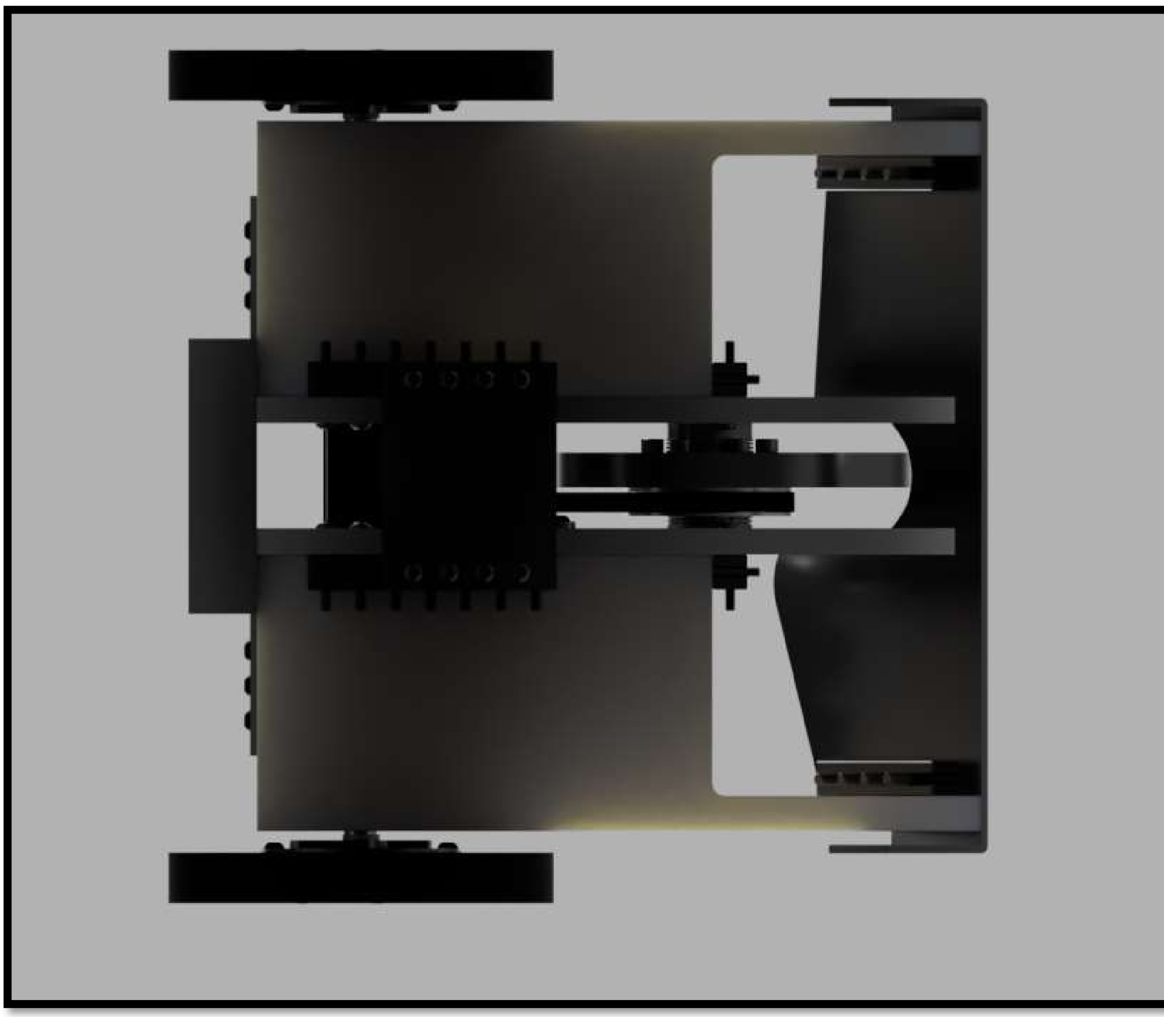


Figure 20: Bottom side of Dumbot

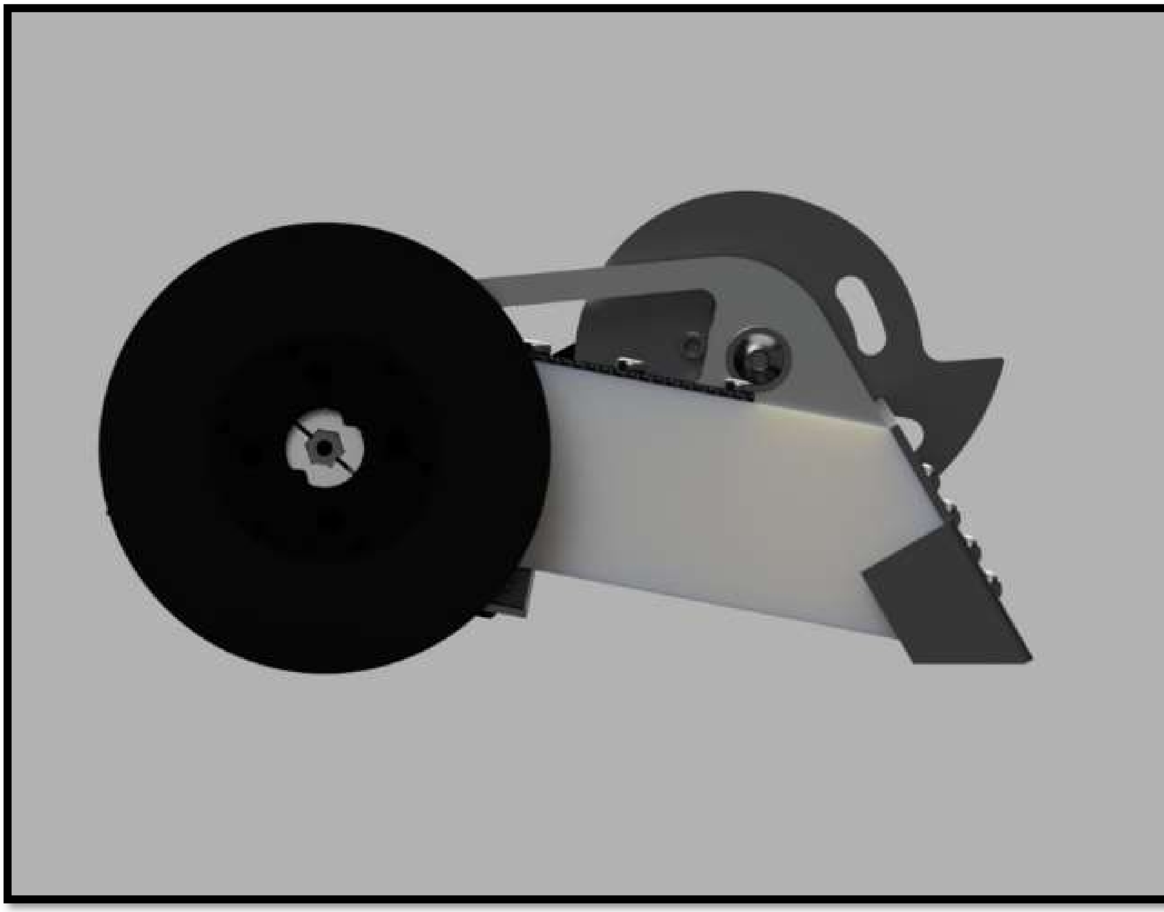


Figure 21: Side view of Dumbot

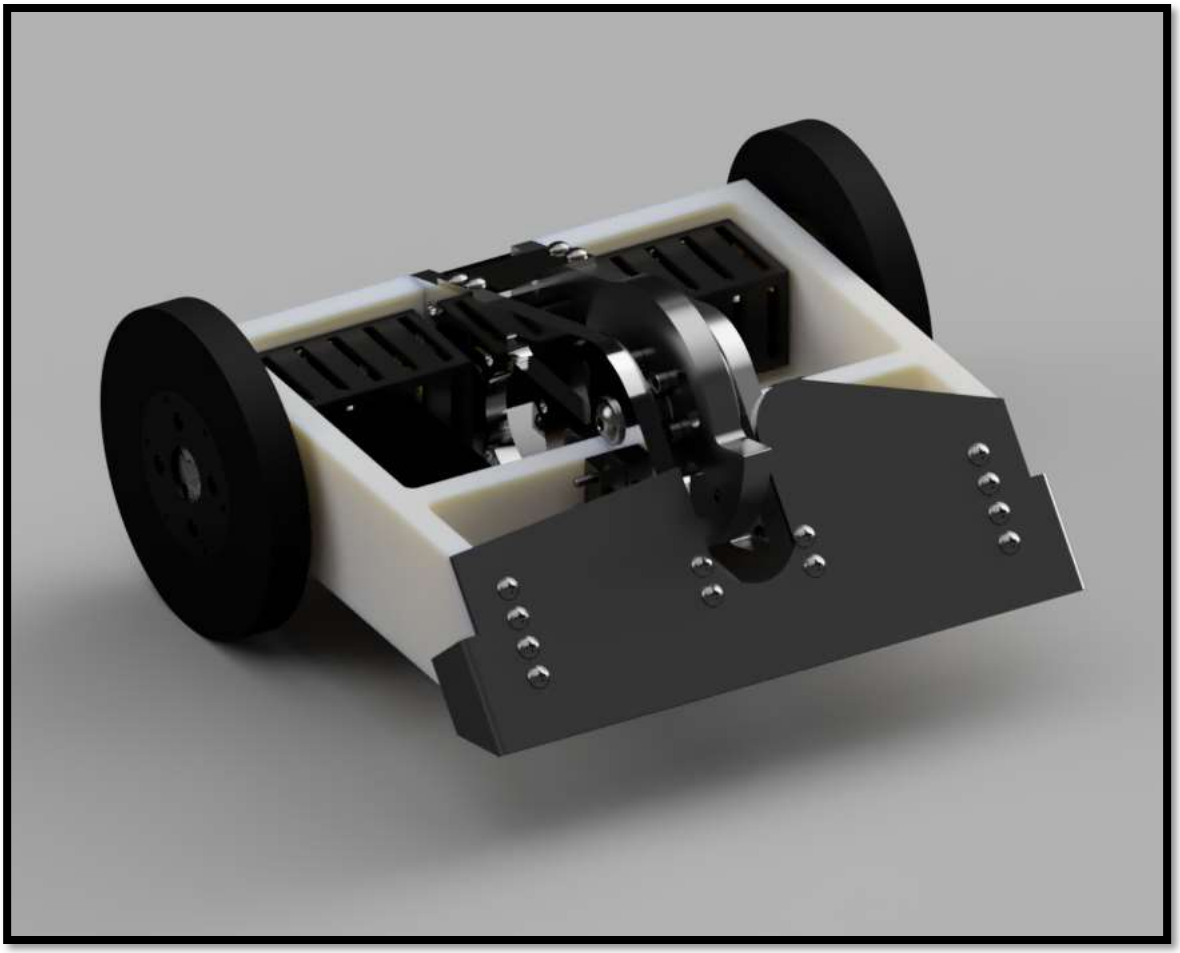


Figure 22: Isometric view of Dumbot with top plates removed

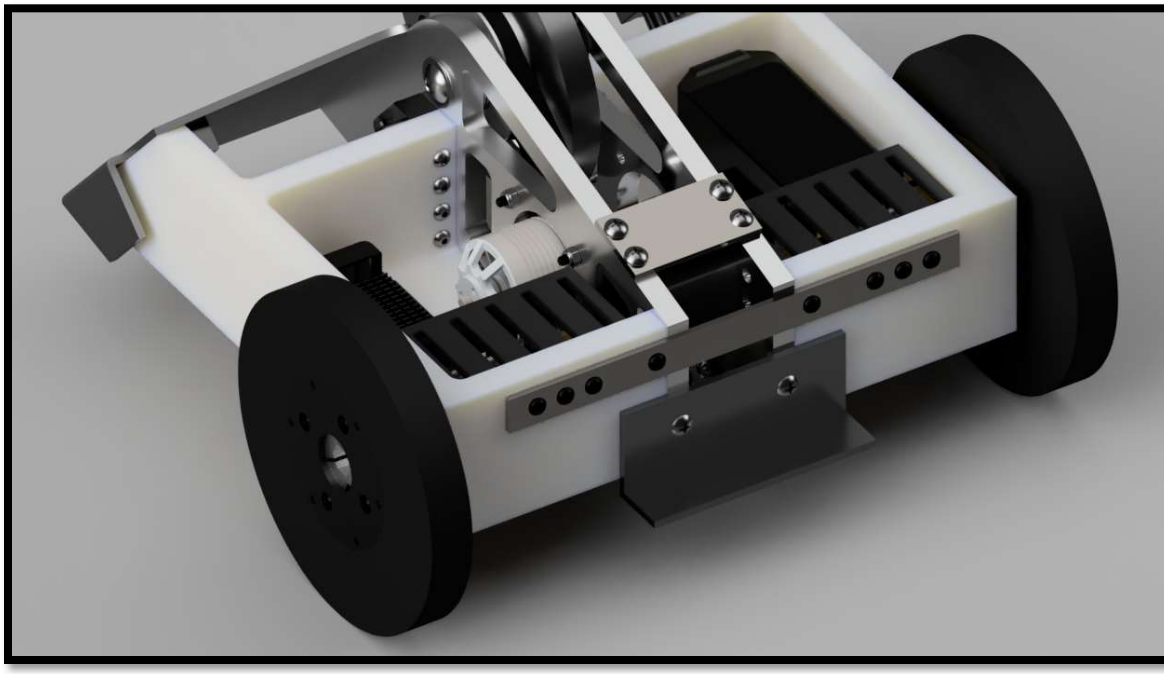


Figure 23: Rear isometric view of Dumbot with top plates removed

Component Selection and Justification

Component Boxes

Fabricated out of ultra high molecular weight polyethylene, this component acts as the main body and chassis structure for Dumbot. UHMW is an extremely tough plastic with high abrasion and wear resistance, making it an ideal material choice for a combat robot. Although the dense component boxes make up a substantial amount of the overall weight of the robot, their large size allows for the electronics and control systems to be safely housed away from external threats. The component boxes also facilitate the mounting of the front wedge.

Component Box Cover

Fabricated out of carbon fiber, the component box covers are extremely lightweight, while maintaining adequate protection for the internal electronics and control systems.

Uprights

Fabricated out of durable 6061 aluminum, the uprights provide mounting points for many of the armor components, as well as act as structure for Dumbot. The uprights are sandwiched between the component boxes and held in place by the many pieces of armor plating. The uprights also provide structure for the weapon shaft system and weapon motor mount. Being made out of 6061 aluminum as opposed to 7075 aluminum, when impacted, the uprights will smear instead of shatter away, meaning that they will maintain their structural integrity, albeit in a deformed state. Finite element analysis testing was performed on the uprights and they were found to have a factor of safety between 10 and 15, meaning that they are more than capable of sustaining the impacts expected when competing as a combat robot.

Wedge

Fabricated out of AR500 hardened steel plating, the front wedge is the main source of protection for Dumbot. Welded together smaller plates and bent into shape, the wedge is specifically designed with protection against horizontal spinners in mind. The wedge extends along the full width of the robot, preventing any possibility of a horizontal spinner catching on the uprights and flinging the robot. The wedge is mounted both via nutstrips mounted on the inside walls of the component boxes as well as directly into the uprights, providing a solid and very formidable structural component to the robot.

Weapon

Fabricated out of the same AR500 hardened steel as the wedge, the weapon disk is an imposing force. Spinning at speeds of 216 mph, the vertical spinner is capable of delivering massive damage to opponents. Mentioned previously and more in depth, the weapon shaft is comprised of a titanium bolt with tapped ends, a stainless steel sleeve, and many needle roller thrust bearings and washers for mobility. The use of titanium aids in keeping weight down to counteract the higher weight caused by using stainless steel for the sleeve for a very strong weapon axle. When assembled, the weapon system provides a rigid and uncompromising point of structure between the two halves of Dumbot.

Armor Plating

Fabricated out of titanium and steel, the armor plating on Dumbot offers high levels of protection from external impacts. On the top, back, and bottom of Dumbot, titanium plating is used to tie together the two halves in a standoff fashion. These plates are strong and extremely lightweight and not to mention very shiny. Also on the backside of Dumbot is a steel plate with a flange that juts out behind the robot. This specialty plate is designed specifically to counteract flipping. Design and fabricated at Norwalk and in between the two fights Dumbot fought in, this plate acts as a sort of wheelie bar for the robot.

Weapon Motor

The motor selected as the dedicated weapon motor for the robot is the BadAss 3520-650Kv Brushless Motor from BadAss Power Systems. This premium grade R/C model aircraft motor provides excellent power output at a reasonably affordable cost and weight. This motor is also standardized throughout the University of Cincinnati BattleBots Club, meaning that if the motor experiences malfunction or becomes inoperative in any way, we can quickly and easily swap it out for a replacement.

Drive System

The drive system for Dumbot consists of dedicated drive motors mounted to gear boxes. The motors selected as the dedicated drive motors are the Tempest 2814 from Innov8tive Designs. The gearboxes used are the UCCR Goldibox 2324. Together, this drive system is a very dependable and easily controllable system that grants Dumbot excellent maneuverability. Again, with cost and weight restrictions in mind, these are solid choices for the drive system. Similar to the weapon motor, these components are standardized throughout the club, allowing for quick replacements and easy maintenance should it be required.

Weapon ESC

The weapon ESC selected for the robot is the Castle Sidewinder 8th from Castle Creations. This ESC is a 1/8 scale sport ESC that provides powerful sensorless motor operation at an affordable price. The Sidewinder allows for smooth sensorless startup, as well as convenient transmitter programming allowing for the ESC to perform exactly as desired. This ESC is a standard component for the University of Cincinnati BattleBots Club aiding in the overall push for part standardization.

Drive ESC

The drive ESCs selected for the robot are the Flycolor Francy 3-6S 50A. These ESCs are very inexpensive and capable of controlling the robot as desired. These components are standardized across the University of Cincinnati BattleBots Club to aid in ease of use and part replacement.

Controller

The controller selected for the robot is the FlySky FS-i6X controller and receiver. This R/C airplane controller has all the functionality needed to properly operate a combat robot, including kill switch capabilities, dedicated motor channels, customizable stick control, and more.

Loading Conditions

Based on information provided via University of Cincinnati BattleBots Club leaders, it was determined that the maximum load force experienced by any component would be the uprights. Intuitively, this makes sense. When the weapon impacts an opponent, the reaction force will be experienced mounting point of the weapon, ie. the uprights. Since determined that the weapon and the uprights would be experiencing the vast majority of all internal forces and therefore stresses, finite element analyses were performed during the design process to ensure proper factor of safety was obtained. Using the simulation function in Fusion 360, the length of time the weapon would stay in contact with a target was found. Using this measurement, we solved for the average force of the impact to be 3217 N.

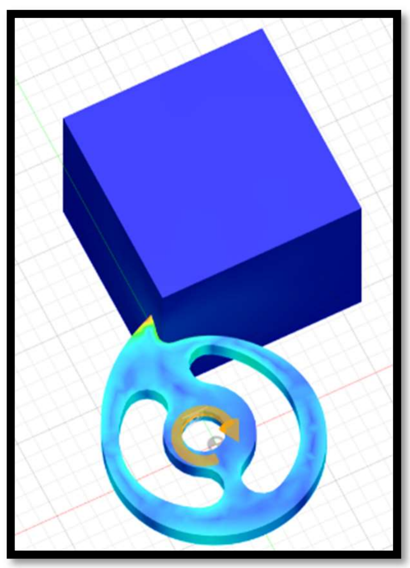


Figure 24: Weapon FEA impact

Using this calculated force, testing was then performed on the upright model using the simulation software. After applying the reactionary force to the upright model, the maximum internal stress obtained measured 26.134 MPa at a point concentration in one of the keyway cutouts. This stress concentration was alleviated by simply removing the use of keyways, which in turn simplified the manufacturing process of the component boxes as well with the removal of the need for the key tab.

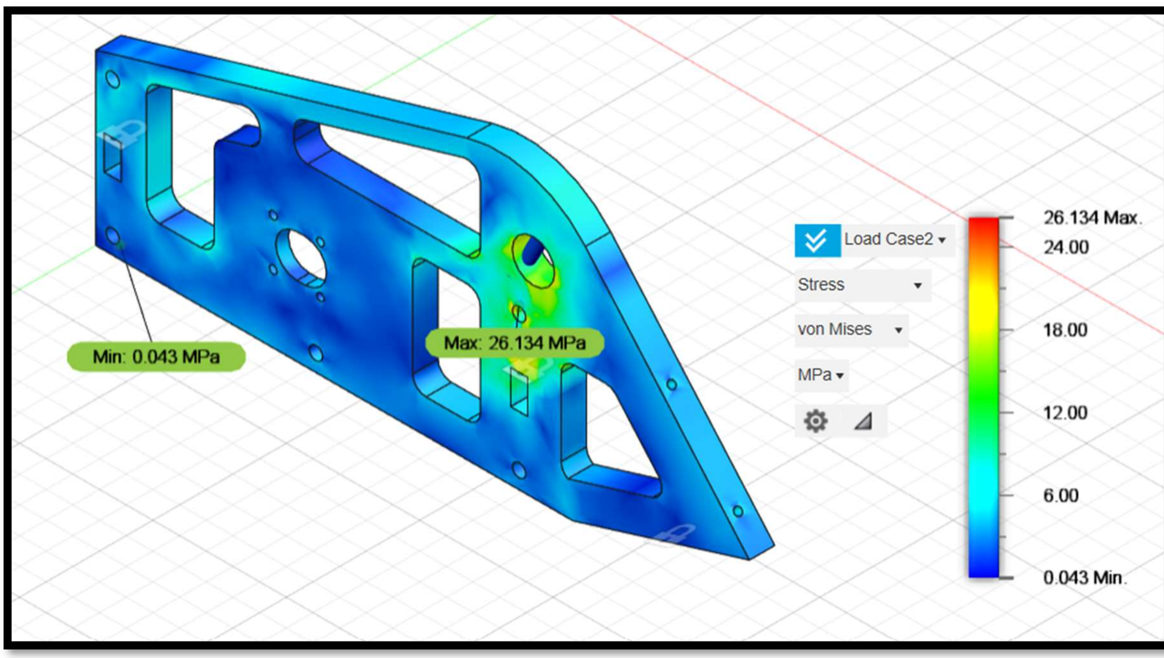


Figure 25: FEA simulation

After obtaining a safety factor well within acceptable range, the uprights were accepted and the design process progressed. There have since been minor tweaks and weight optimizations made to the uprights, but as the stresses in the majority of the upright shape are so minor, these changes were deemed insignificant to the stresses of the upright.

Project management

Budget, Proposed/Actual

This battlebot project aimed to create a formidable and cost-effective robot capable of competing in the NHRL March Event. To keep unwanted costs to a minimum and ensure compatibility from team to team, we planned to utilize a selection of standardized components generously provided to us by the University of Cincinnati BattleBots Club. This approach not only helped us manage expenses, but also enabled us to exchange parts seamlessly for maintenance and upgrades.

For the electronics setup, we carefully chose components that seamlessly walk the line between balancing performance and affordability. These components are as follows:

- (1) BA-3520 motor for the weapon assembly. Known for its power and reliability, this motor will be the driving force behind the offensive capabilities of the robot.
- (2) Tempest 2814 motors. These motors power the drive system, providing agility and maneuverability in the arena.
- (2) UCCR Goldibox 2324 gearboxes. These gearboxes allow for control of the drive motors.
- (1) Castle Sidewinder 1/8 weapon ESC. To efficiently manage the weapon motor, the ESC has been selected for its robustness and precision control.
- (1) Flycolor Francy 3-6S 50A ESC. This ESC will ensure the drive system operates smoothly and responsively.
- (1) 6s, 1300mAh R-Line Battery: A high-capacity battery to provide the necessary power for the robot's demanding tasks.

- (1) Spektrum Remote Controller: A reliable controller to ensure accurate and responsive command input.
- Urethane Wheels: Urethane wheels have been chosen for the drive system to reduce cost while maintaining excellent traction and maneuverability. This decision allows for customizable wheel sizes if needed.
- Frame: The frame will be constructed using a combination of sturdy aluminum alloys, including 6061 and 7075. These materials strike a balance between strength and weight, providing a robust chassis to withstand battle conditions.
- Armor: To protect the robot from opponents' attacks, armor made of UHMW will be utilized. These polymers offer outstanding impact resistance and flexibility.
- Weapon: The offensive weapon will be crafted from AR500 steel, known for its durability and ability to deliver devastating blows to opponents.

After calculating estimated costs, we have allocated a budget of $1,850 for the final design. With this budget, we are confident that we can create a battlebot that not only meets our performance expectations, but exceeds them. By utilizing standard parts, carefully selected components, and a thoughtful choice of materials, we believe our robot will be well-prepared to compete effectively in the NHRL March Event.

Design I:

At the beginning of the project, we planned on using standard parts that the University of Cincinnati BattleBots Club provided, in order to keep costs down and make standard components interchangeable. With that in mind, our electronics were to include one BA-3520 Motor for the weapon assembly, two Tempest 2814 Motor, two UCCR Goldibox 2324 gearboxes, one Castle Sidewinder 1/8 ESC for the weapon motor, two Flycolor Francy 50as for the drive ESCs, one 6s, 1300mAh R-line battery, and a Spektrum Remote Controller. For the drive system, we planned to use urethane wheels to reduce cost as well as for the ability to mold our own size wheel. For the uprights we decided to utilize 6061 aluminum. For the armor, UHMW was the selected material; and for the weapon, AR500 steel.

Table 6: Initial Bill of Material

		part	cost	# of part	total part cost		
		BA-3520 MOTOR	$ 74.99	1	$74.99		
		CASTLE SIDEWINDER 8TH ESC	$158.95	1	$158.95		
electronics		DEFAULT BATTERY	$ 40.00	3	$120.00		
		TEMPEST 2814 MOTOR	$ 34.99	2	$69.98		
		SPEKTRUM REMOTE CONTROLLER	$250.00	1	$250.00		
		MATERIAL	cost	weight	cost/hour macl	# of part	total cost
materials/components		TPU (per roll)	$ 25.00			3	$75
		ALUMINUM (per lb)	$ 1.02	12	$80	8	$737.92
		UHMW (armor)	$ 55.00			2	$110.00
		Urethane (per gal)	$ 45.00			1	$ 45.00
		Gears/ timing belt pullies	$ 50.00			3	$150.00
		Belts	$ 20.00			2	$ 40.00
				grand estimation:	$1,850.00		

A budget of $1,850 was determined to be adequate to manufacture this design.

Design II:

The budget listed above does a good job of roughing out the estimated cost of building the robot, but neglects to take into account brass tacks. Items such as hardware, pulleys, belts, component box covers, and additional armor plating are omitted from the budget as these items were simply overlooked when creating it. Additionally, the battlebot underwent some considerable design changes that ultimately affected the budget as well. These changes to the robot included consisting of two UHMW component boxes, two aluminum uprights, two custom wheels molded using urethane, two titanium plates, two AR500 wedges, one AR500 weapon, two different aluminum pulleys, two carbon fiber top plates, and standard electronic components. The controller was also switched from the Spektrum controller to the considerably more cost friendly FlySky. The figure below shows the bill of materials, detailing the cost and price to machine for each component.

Table 7: Final Bill of Material

	LINE #	material	part number	part description	quantity	price	total	qty/pack
CUSTOM	1	variety		wheels	2	$ 35.00	$ 70.00	
CUSTOM	2	UHMW		bodies	2	$150.00	$ 300.00	
CUSTOM	3	aluminum		uprights	2	$185.00	$ 370.00	
CUSTOM	4	titanium		plates	2	$ 55.00	$ 110.00	
CUSTOM	5	steel		weapon bar	1	$ 25.00	$ 25.00	
CUSTOM	6	titanium		weapon bar	1	$ 35.00	$ 35.00	
CUSTOM	7	aluminum		weapon pulley	1	$ 45.00	$ 45.00	
CUSTOM	8	aluminum		motor pulley	1	$ 45.00	$ 45.00	
CUSTOM	9	steel	REV-41-1732	nut strip	2	$ 18.00	$ 18.00	
CUSTOM	10	steel		wedge	2	$ 75.00	$ 150.00	
CUSTOM	11	steel		weapon	1	$215.00	$ 215.00	
https://www.mcmaster	12	rubber	7881K11	2l v belt	1	$ 9.02	$ 9.02	
CUSTOM	13	carbon fiber		top plate	2	$ 20.00	$ 40.00	
https://www.mcmaster	14		5909K33	needle roller thrust bearing	2	$ 3.92	$ 7.84	
https://www.mcmaster	15		5909K46_.032	thick washer	5	$ 1.35	$ 6.75	
		SCREWS						
https://www.mcmaster	16		90485A330	wedge, top plate plastites	12		$ 12.82	25
https://www.mcmaster	17		91290A248	weapon pulley assy	6		$ 11.62	50
https://www.mcmaster	18		91355A191	weapon mount	2		$ 13.69	10
	19		90991A128	plates, wedge	12		$ 7.55	25
https://www.mcmaster	20		91294A133	drive motor mount	14		$ 8.28	100
https://www.mcmaster	21		94105A120	set screw	1		$ 6.43	50
https://www.mcmaster	22		96001A408	Uprights	10			
https://www.mcmaster	23		91290A117	weapon motor screws	4		$ 10.85	100
		COMPONENTS						
	24			battery	1	$ 50.00	$ 50.00	
	25			UCCR goldibox 2324	2	$ 75.00	$ 75.00	
				BA-3520 motor	1	$75.00	$75.00	
	26			default ESC	1	$ 25.00	$ 25.00	
	27			castle sidewinder 8th	1	$ 40.00	$ 40.00	
	28			controller	1	$ 80.00	$ 80.00	
						GRAND TOTAL:	$ 1,862.85	

Design III:

By the competition date – and with a couple more postprocessing items that were performed in–house and at the expense of nothing other than our sweet time – the estimated budget of roughly $1,850 was adhered to, with a grand total of $1,862.85. With this budget, the ability to order or fabricate each of Dumbot's components in time for competition was possible. As mentioned previously, after obtaining specific information about event opponents, changes were made to the robot using scrap steel and spare hardware, assisting in our desire to not exceed the allotted budget. These changes include the addition of the rear wheelie bar steel plate, as well as the change from two AR500 steel wedges to one massive AR500 steel wedge documented further above.

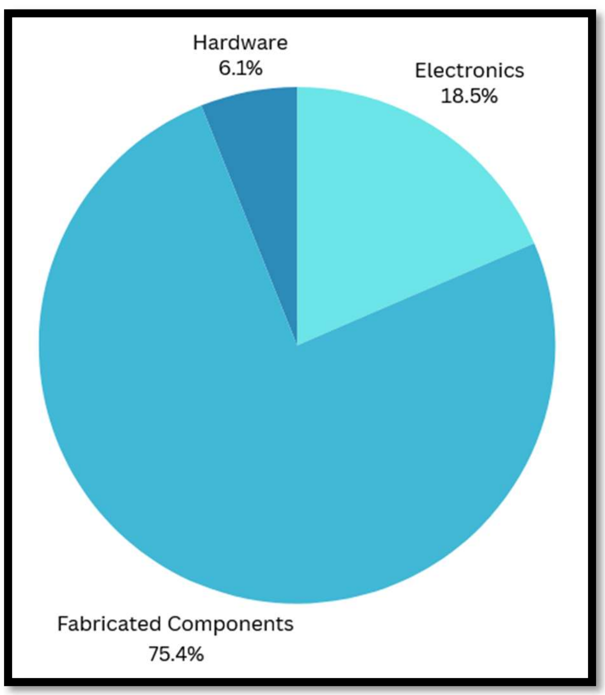


Figure 26: Budget pie chart

Schedule, Proposed/Actual

Design I:

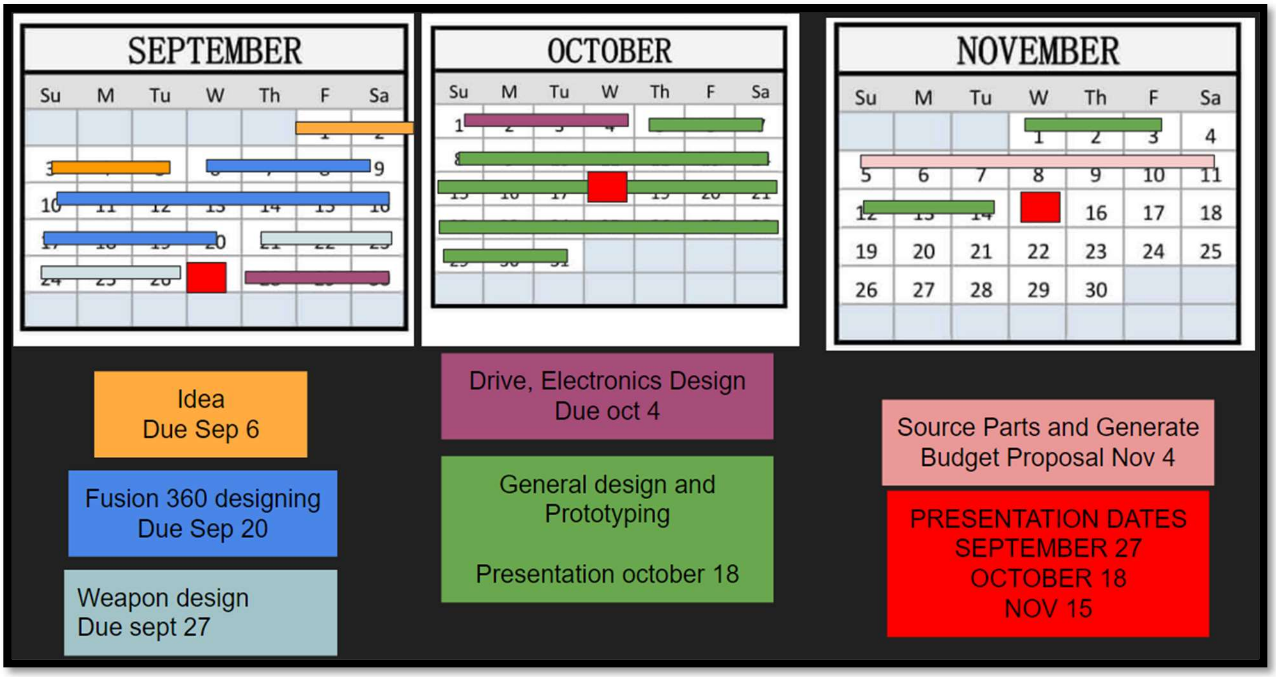


Figure 27: Planned project schedule

Following this schedule provided by the University of Cincinnati BattleBots Club, we were able to stay on the track to success to be able to compete at the NHRL event by March.

Design II:

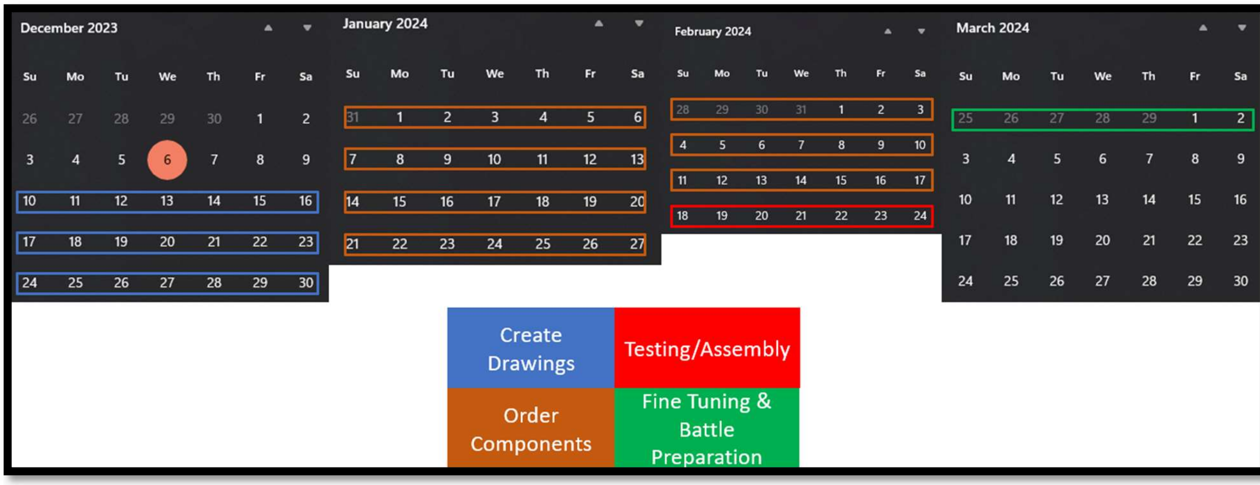


Figure 28: Updated project schedule

The “break” weeks between the 2023 Fall semester and the 2024 Spring semester were spent creating drawings for the manufacturers that were receiving parts. At the beginning of the new year, we couldn’t do much but wait on the manufacturers that we have sent the part prints to. The long, seven week planned schedule for the ordering of components was enough time for the manufacturers to produce the parts that we requested and return them to us. After receiving the parts back from the manufacturers, assembly of the battlebot began. Up until this point, the propsed schdeule was adhered to to a T. Unfortunately, due to unforseen hicups during the assembly process, the assembly of the robot was delayed while new parts had to fabricated. After assembly, we planned on testing the robot in order to get familiar with its tendencies and learn how to efficiently operate. This did not occur as anticpated. Due to the lack of adequate testing facilities at the University of Cincinnati, the weapon system was unable to be tested until in Norwalk. The drive system and other electronics were able to be tested in a very limited capactiy involving seeing if the wheels turned in the correct direction. Finally, the week decidated to fine tuning the robot was spent assembling the components, scrambling to wire the electronics system correctly, and making the 12 hour drive to Connecticut. By and large, the propsed schedule was able to be adhered to until the last leg of the project, in which any and all plans went out the window.

Design III:

Problems that arose

Some of the difficulties the team has experienced when completing the tasks at hand for the project are most notably the time constraint, as well as getting over the Autodesk Fusion 360 learning curve and intrateam communication difficulties. When completing a project that is set to be completed by the end of February and has a very strict timeline in general, every little bit of time loss is detrimental to the completion of the project. For this reason, a great deal of work had to be completed prior to the official start date of the project, in the previous semester. As mentioned previously, having to learn Fusion 360 was a bit of a challenge for all team members and therefore there was a large buffer period where we had to do some research into the software prior to being able to get the project on its feet. Finally, with a project that is so hands-on and so involved, intrateam communication is of the utmost importance in order to ensure smooth sailing and proper work delegation. This was one notable aspect of the project that could have been handled much better to prevent double work, the ordering of incorrect components, and improper workload allocation.

How the project went

Overall, the project went very well. As the idea of building a combat robot is a brand-new concept to every member of the team prior to undertaking this task, the project is sure to have its own hiccups and bumps, but by and large – and with the help of club mentors and faculty advisors from time to time – the project has not had any major obstacles that could not be overcome.

Preliminary Findings

The preliminary findings of the project are as follows: building a combat robot under the supervision of the University of Cincinnati BattleBots Club is a very enjoyable baccalaureate capstone project that has many benefits seen both personally and professionally. By UC's involvement with NHRL, we are able to introduce students to the world of combat robotics and widen their horizons, as well as introduce fans of combat robotics to one of the leading universities in CEAS and co-op programs.

Sustainability and Material Usage

Since the beginning of the project, we have considered the use of materials in our design that were recyclable. The components comprised of UHMW, polyurethane, aluminum, steel, titanium, and carbon fiber are all recyclable. The only material that typically does not get accepted into recycling facilities was the PLA that was used for the hub of the wheels.

To increase the sustainability of the project even further, we could have recycled the materials that we used at the completion of the event. With the majority of Dumbot's components being recyclable, we could have planned for end-of-life disposal by considering take-back programs for each recyclable material. By doing so, we could have minimized the environmental impact of the robot to almost zero, all while still competing in the competition and gaining valuable insight into the world of combat robotics.

Results

The entirety of this project culminates in the participation in the NHRL March Event held in Norwalk, Connecticut. Dumbot competed in this event in the 12 lb. weight class bracket. For the first fight, Dumbot was pitted against Grim Ripper, driven and built by Nelson Bairos of the Bairos Family Team. Grim Ripper is a horizontal spinner design with excellent ground game making it especially strong against vertical spinners. Grim Ripper’s horizontally spinning weapon is the sole reason why the team made the decision to switch from two front wedges to one massive wedge that extends the width of the robot. As mentioned previously, up until the day before the fights, Dumbot had never spun up its weapon system, let alone practice driving with the weapon spinning. Because of this, much of the Grim Ripper fight was spent learning how Dumbot maneuvers, attacks, and responds to being attacked. The Grim Ripper fight was a multibot fight; Nelson’s son drove a minibot that was able to wedge itself underneath Dumbot and immobilize it. The fight came to a head when Dumbot lost control from the gyroscopic forces of the weapon and flipped upside down, unable to right itself. The team called for an unstick from the house bot but was unable to recover, resulting in a loss due to knock out decision. Nelson and the whole Bairos Family Team are excellent sports and very friendly competitors that the team is glad we had the pleasure of fighting against.

Figure 29: First opponent, Grim Ripper (5)

The second fight Dumbot participated in was against Weather Report, built and driven by Carey Weaver. Weather Report is a vertical spinner utilizing a shuffler method of transportation, meaning the robot qualifies for the non-traditional locomotion bonus. Because of this, Weather Report weighs in at 18 lb., 50% heavier than Dumbot. This, alongside the team being wet behind the ears when it came to driving Dumbot, we were at a pretty significant disadvantage in the arena. The fight resulted in another loss by knock out decision when Dumbot once again flipped upside down and became immobilized. Carey and his team were very formidable opponents and very friendly faces. The team is glad to have been able to compete against them.

Figure 30: Second opponent, Weather Report (6)

Preparation for the Competition

Two days before we were to leave for Connecticut was when we received notice on who our competitors were. As we had previously discussed battle strategy in more generalized situations, this was the first time we knew exactly what we were up against. In order to adequately prepare Dumbot defensively, changes were made to Dumbot's AR500 wedges. Grim Ripper's shell rode extremely close to the ground, as seen above in Figure 29, not permitting our large weapon to wedge up underneath. To combat this issue, we obtained scrap metal and created the new current wedge design to hopefully allow Dumbot to get underneath Grim Ripper's shell and reach into the internals. These adjustments were possible since Dumbot was previously weighing in around 11.22 lb. After the addition of the new wedge, Dumbot weighed 11.89 lb., still under the 12 lb. weight restriction. After the fight with Grim Ripper, in order to try and prepare for Weather Report, the fabrication and addition of the rear wheelie bar steel plate was undergone. Ultimately, the addition of this armor plate did not do much in the way of preventing Dumbot from flipping upside down as that was the untimely result of the second fight as well.

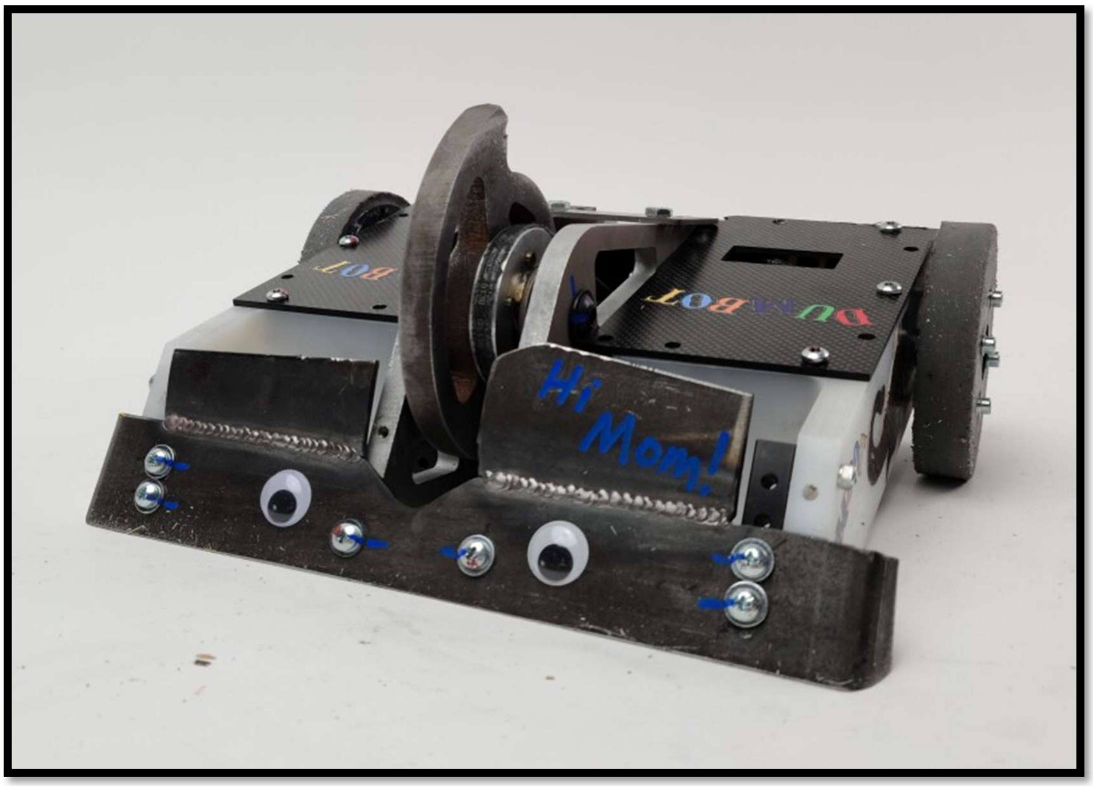


Figure 31: Dumbot at NHRL event

Results from the Competition

Both fights unfortunately ended the same: loss by knockout. The weapon motor ESC was set to spin the weapon at the full 100% power – an estimated 208mph – resulting in extreme and uncontrollable gyroscopic forces. As evident in the official NHRL live stream (6), the amount of gyroscopic force can be seen just by simply trying to turn the robot. These forces would throw Dumbot upside down after we tried moving in any sort of evasive maneuver. From there, our weapon would dig into the arena's wooden floor and create a massive divot, rather than doing what was anticipated and flip the robot back over. Dumbot could drive quick in a straight line, but that was the only maneuver it was able to achieve in a stable manner.

Although we were disappointed at our maneuverability, we were extremely pleased with the way that the robot held up against impacts. The durability and structural soundness of Dumbot is evident in the fact that even though massive hits were inflicted, there is very little damage to show for it. The impacts that were recorded after the fights proved the 10mm theory (Figure 1) correct in that there were no deviations or material loss deeper than 10 mm. The deepest damage spot on the robot was found in the left UHMW component box, shown below in Figure 32. This impact measured to be 8.25 mm deep, coming nowhere close to breaking through the half inch thick box and compromising the electronics. The weapon also experienced some damage and chipping at the tip due to direct impacts with opponents but managed to perform well and stay intact throughout the duration of the fights, which was a success. Other than one of them being annihilated in the first fight and having to be replaced with a backup, the wheels performed excellently and the grip provided was sufficient when maneuvering.

Figure 32: Deepest impact from opponent

Figure 33: Additional damage from impacts

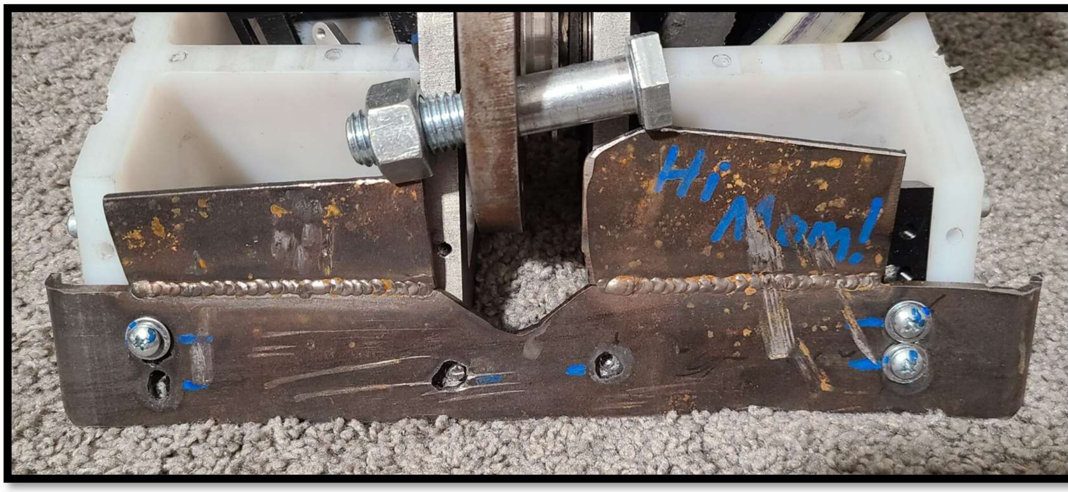


Figure 34: Wedge aftermath

Moving Forward

In order to continue fighting Dumbot, some shortcomings need to be resolved, most notably design issues. The primary issue in the design of Dumbot has been determined to be the lack of ears in the design. Ears – in the world of combat robotics – are small pieces of material that protrude upward and are the highest point of the body of the robot. The purpose of ears is to aid in maneuverability of the robot if the robot finds itself upside down. If ears had been incorporated into the design of Dumbot from the beginning, the team is confident that the results from the NHRL March Event would be very different.

Figure 35: Uppercut's "ear" design (7)

The second shortcoming in continuing to fight Dumbot is cost. Building combat robots is a very expensive hobby to partake in. A general rule of thumb is $100 per 1 lb. This means a 12 lb. robot should theoretically cost $1200. And that is material alone, not including design time, prototyping, errors in manufacturing, and more. Also not to mention the fact that it could all go down the drain after you have one bad fight. If able to obtain sponsorships from an employer or organization, continuing to fight and make design changes to Dumbot becomes much more feasible. If these considerations can be overcome, one of the team members who is moving to Connecticut for work anticipates continuing the story of Dumbot with a Dumbot 2.0.

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APPENDIX A

Calculations

tip speed calculator		
Motor KV	970.00	KV
Battery Voltage	22.20	Volts
Driven Gear Dia	2.00	any unit
Driving Gear Dia	1.00	any unit
Diameter	6.50	in
Weapon RPM	10767.00	rpm
Weapon Deg/s	64602.00	Deg/s
rad/sec	1127.52	Rad/s
tip speed	208.21	mph
MOI Weapon	1505000.00	g/mm^2
MOI Weapon	0.00	kg/m^2
Weapon Energy	956.65	J
Weapon Energy	0.96	KJ

Figure 36: Tip speed calculator

Weapon Target Values:

Weapon tip speed: 208mph

Weapon spin up time <1.5sec

6s Lipo Battery: 22.2V

Weapon diameter: 6.5in

Weapon moment of inertia: 10505000g/mm^2 = .001505kg/m^2

Weapon RPM for desired for desired tip speed:

$$= \frac{tip\ speed\ (mph) * (5280ft/mi)}{(weapon\ diameter\ (in)/12in/ft) * (60min/hr) * \pi}$$

$$= \frac{208mph * (5280ft/mi)}{(6.5in/12in/ft) * (60min/hr) * \pi}$$

$$weapon\ speed\ (rpm) = 10756.33rpm$$

Motor RPM:

$$= weapon\ rpm * (\frac{driven\ pulley\ T}{driver\ pulley\ T})$$

$$= 10756.33 * (\frac{2T}{1T})$$

$$motor\ rpm = 21512.66rpm$$

Minimum Motor kv:

$$= \frac{motor\ RPM}{battery\ voltage}$$

$$= \frac{21512.66rpm}{22.2V}$$

$$motor\ kv = 969.04kv$$

Weapon speed (deg/s)

$$= weapon\ speed\ (rpm) * \left(\frac{360\ deg}{60sec}\right)$$

$$= 10756.33rpm * (\frac{360\ deg}{60sec})$$

$$weapon\ speed = 64537.97deg/s$$

Weapon speed (rad/s)

$$= weapon\ speed\ (deg/s) * (\frac{\pi}{180})$$

$$= 64537.97deg/s * (\frac{\pi}{180})$$

$$weapon\ speed = 1126.40rad/s^2$$

Weapon energy (J)

$$= .5 * weapon\ MOI\ kg/m^2 * weapon\ speed\ (rad/s)^2$$

$$= .5 * .001505 * 1126.40^2$$

$$weapon\ energy = 956.65J$$

Minimum motor wattage:

$$= \frac{weapon\ energy\ (J)}{spin\ up\ time}$$

$$= \frac{956.65J}{1.4sec}$$

$$= 681.97W$$

Drivetrain

Travel the length of the arena in 2 seconds

6s Lipo Battery Voltage: 22.2V

Arena Size: 16ft x 16ft

Wheel diameter: 5.5in

Gearbox ratio: R = 20:1

Coefficient of friction for UHMW: $\mu_{static} = .2$

NHRL BattleBot arena floor material: ½" mild steel, $\mu_{static} = .6$

Motor rpm RECR Goldibox 12/15:

$$rpm = kv * voltage$$

$$= 850kv * 22.2v$$

$$motor = 18870rpm$$

Wheel RPM:

$$= \frac{motor\ rpm}{R}$$

$$= \frac{18870rpm}{20}$$

$$= 943.50rpm$$

Wheel circumference:

$$= wheel\ diameter(in) * \pi$$

$$= 5.5in * \pi$$

$$= 17.28in$$

Linear velocity:

$$= wheel\ circumference(in) * (\frac{\frac{wheel\ rpm}{60}}{12})$$

$$= 17.28in * \left(\frac{\frac{943.50}{60}}{12}\right) = 22.64ft/sec$$

$$= \frac{22.64ft}{sec} * \frac{1mile}{5280ft} * \frac{3600sec}{1hr} = 15.44mph$$

Wheel load:

$$= \frac{weight\ of\ robot(lb)}{\#\ of\ wheels}$$

$$= \frac{12lb}{2} = 6lb/wheel$$

Friction force:

$$= \mu_{static} * wheel\ load$$

$$= .2 * \frac{6lb}{wheel} = \frac{1.2lbs}{wheel}$$

Wheel friction torque:

$$= \frac{friction\ force}{wheel} * \frac{wheel\ diameter}{2}$$

$$= \frac{1.2lbs}{wheel} * \frac{5.5}{2} = 3.3in - lb$$

APPENDIX B

Survey Questions

1. Which orientation delivers the most damage?
    a. Horizontal.
    b. Vertical.
    c. Hammer.
    d. Flipper.
    e. Flame thrower.
    f. Boxing glove.
2. On a scale of 1-10, how important is the speed of the robot?
3. On a scale of 1-10, how important is the weapon's power and effectiveness when delivering damage to the opponent?
4. On a scale of 1-10, how important is the robot's maneuverability?
5. What device should the robot have to correct itself after being flipped over?
    a. Ears.
    b. No device in particular. Use the wheels to try and flip the robot to correct its orientation.
    c. Mechanical arm that pushes to correct the robot's orientation.
    d. Other
6. On a scale of 1-10, how crucial is the ease of maintenance and repairability to you?
7. On a scale of 1-10, how important is the visual appearance of the robot?
8. In INCHES, what width of wheel do you prefer?
9. Do you prefer the wheels to be protected by a shield or let them be exposed?

a. Protect the wheels using a shield.

b. Leave the wheels exposed.

c. Other

10. On a scale of 1-10, how durable are successful robots?

11. Do you prioritize weapon strength or armor strength?

a. Weapon strength.

b. Armor strength.

c. Both are equally important.

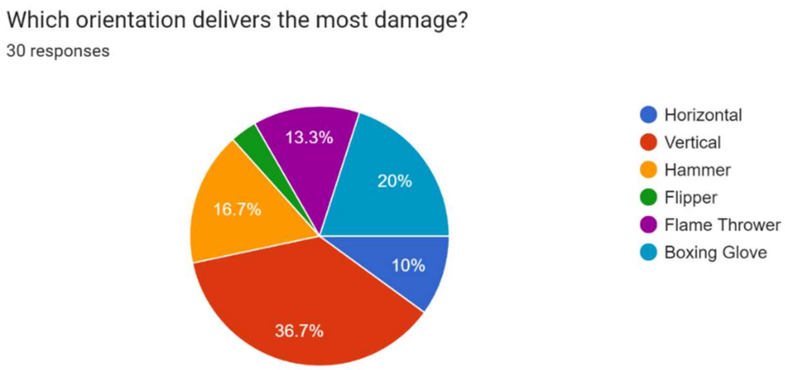
d. Other

12. Are there any specific safety features that you would like to see incorporated into the design (*****NOT INCLUDING THE WEAPON LOCK*****)

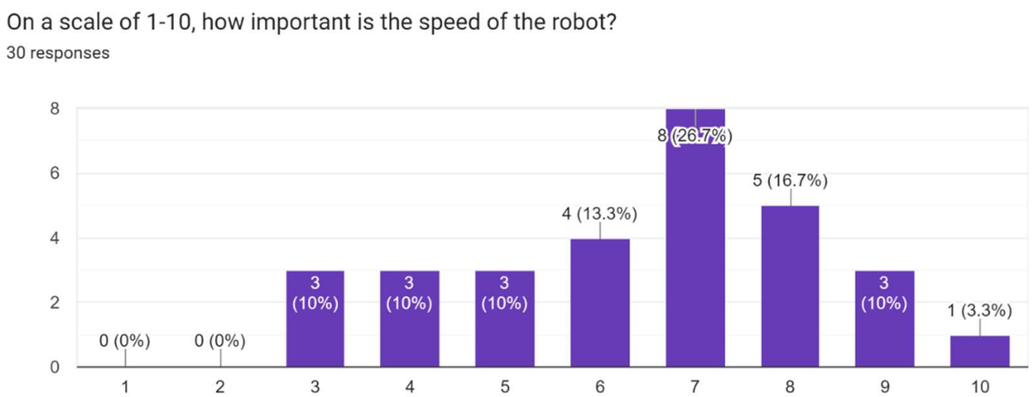
a. No.

b. Other

Survey Results



1.



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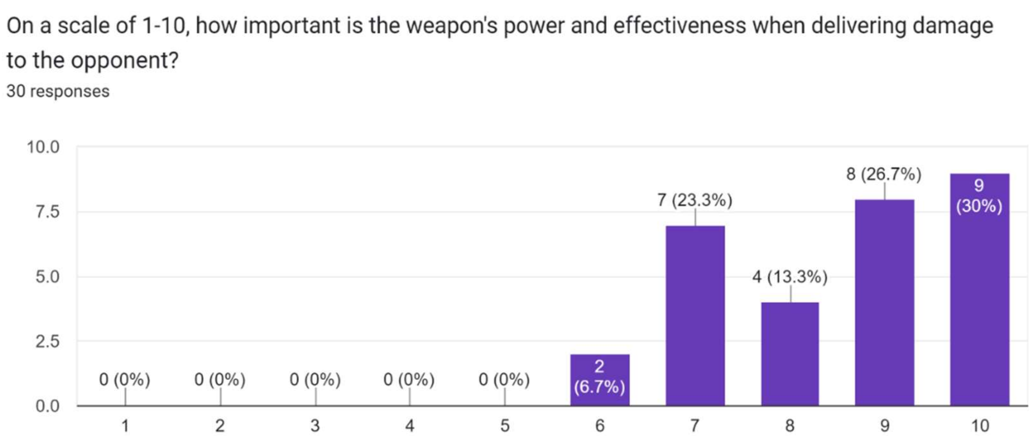
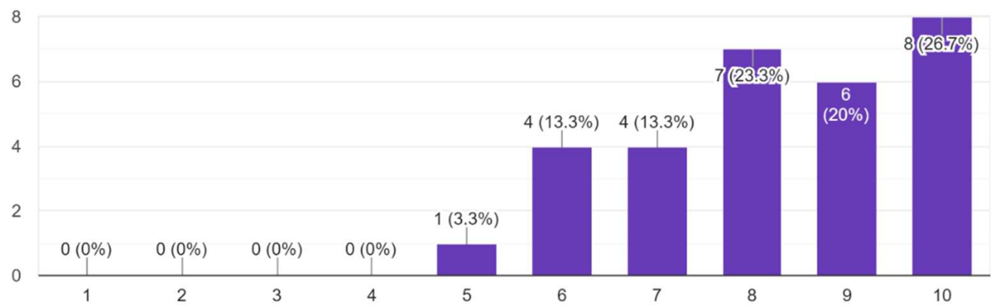


3.

On a scale of 1-10, how important is the robot's maneuverability?

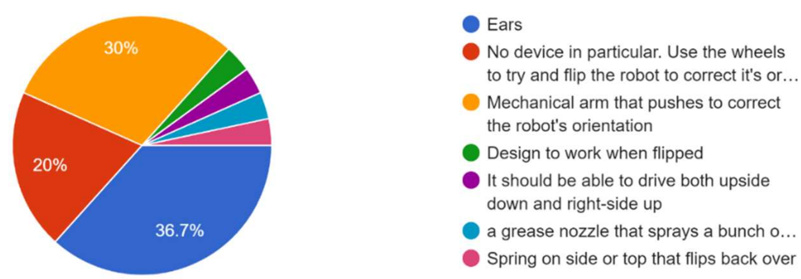
30 responses



4.

What device should the robot have to correct itself after being flipped over?

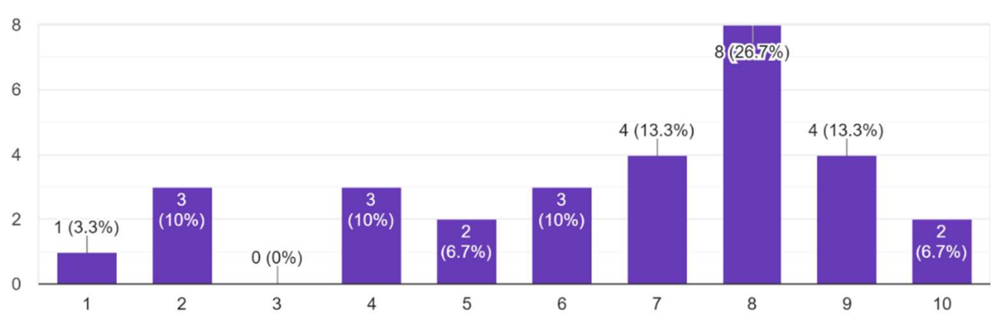
30 responses



5.

On a scale of 1-10, how crucial is the ease of maintenance and repairability to you?

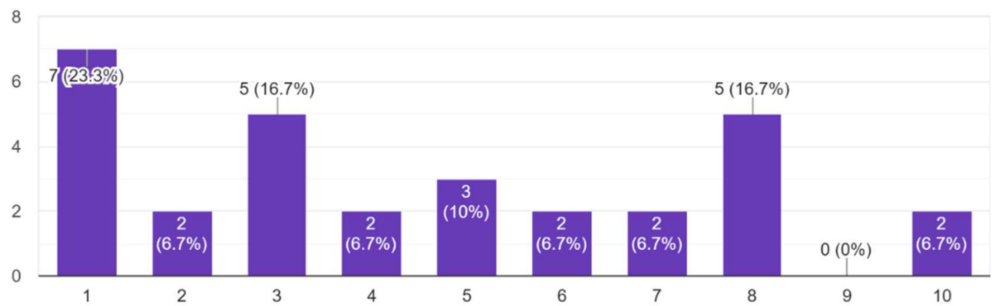
30 responses



6.

On a scale of 1-10, how important is the visual appearance of the robot?

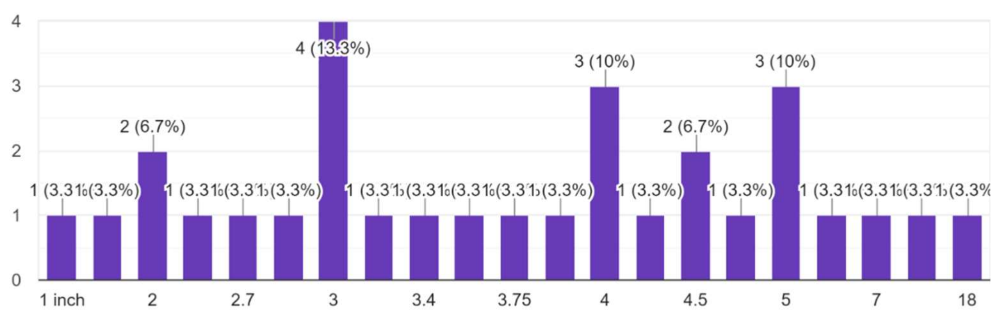
30 responses



7.

In INCHES, what width of wheel do you prefer?

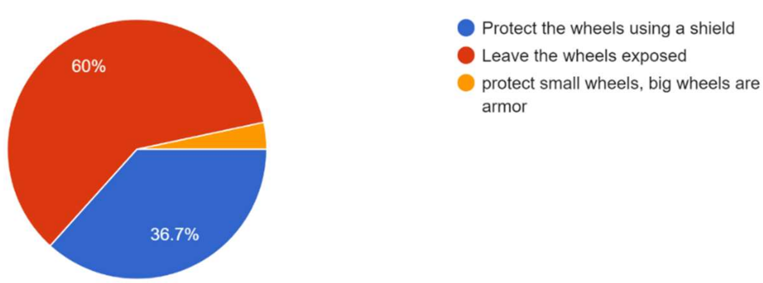
30 responses



8.

Do you prefer the wheels to be protected by a shield or let them be exposed?

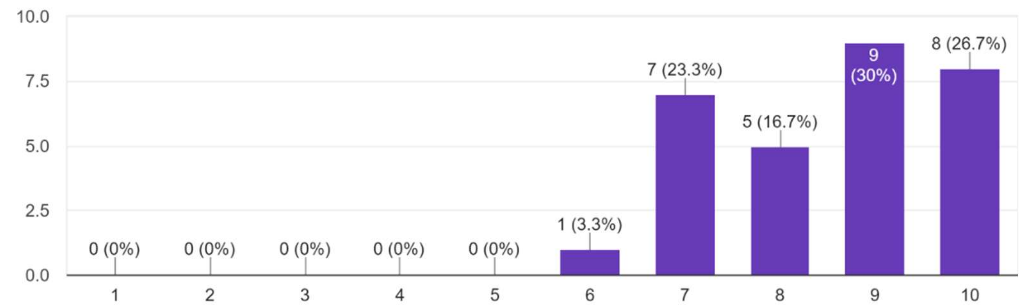
30 responses



9.

On a scale of 1-10, how durable are successful robots?

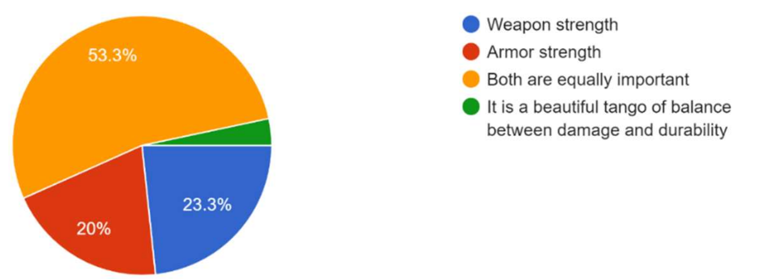
30 responses



10.

Do you prioritize weapon strength or armor strength?

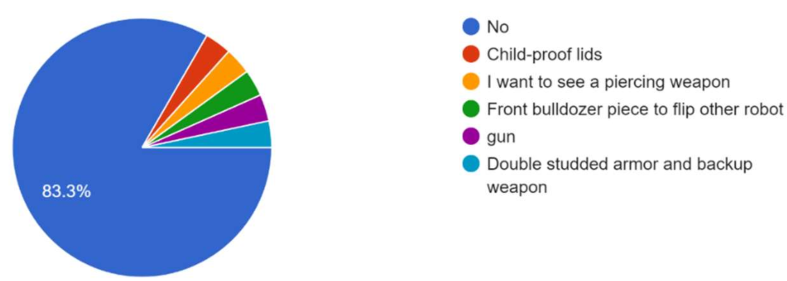
30 responses



11.

Are there any specific safety features that you would like to see incorporated into the design (*****NOT INCLUDING THE WEAPON LOCK*****)

30 responses



12.