2023-24 UC CEAS 12lb BattleBot Team
"BRRT (Battle Ready Robot Terrorizer)"

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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April 2024

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Contents

Problem Statement

The University of Cincinnati Combat Robotics Club will be participating in the National Havoc Robot League competitions. This league is a competitive organization in which BattleBot hobbyists face off in a series of matches and tournaments in which the bots will try to destroy the opponent. This team will design, create, test, and compete with a 12-pound BattleBot in these competitions.

Research

Background of the Problem

This battle bot will be used in competitions hosted by the National Havoc Robot League (NHRL). The NHRL is the world's largest and most accessible robot combat league (1). A series of tournaments are hosted throughout the year, typically one every two months. The NHRL is "working to shine a spotlight on a sport that should matter to more people…" (1). The organization values supporting creators, making robotics accessible to all, and providing a safe environment for creativity and innovation.

The NHRL has set forth rules and design specifications for the competitions. The bots are divided into classes based on the bot's weight. There are 3, 12 and 30-pound classes of bots (2). The NHRL also sets rules for other design features such as the type of weapons allowed on the bot, the types and size of batteries to be used, the use of multiple bots, and more. Along with the organization sets safety guidelines to ensure that there is limited or no risk to participants or spectators. For example, weapon locks must be used and engaged when the bot is not engaged in battle to ensure that the bot will not behave unexpectedly and cause injury to participants. The NHRL has these rules and all others posted on their website.

The NHRL also has a handbook that can be found on their website describing the whole process of competing. They look at the different weight classes for competition, weapon types to choose from, but also power transmissions, dc motor knowledge, tips for beginners in the sport (3). This handbook is meant for anyone looking to get into the sport but may have little knowledge about what truly goes into all of it.

There are several other BattleBot leagues that host competitions and tournaments. BattleBots: Champion, which operates under BattleBot Inc., is another organization similar to the NHRL. BattleBots: Champion allows bots of up to 250 pounds to compete and host a television series on the Discovery Channel (4). This increase in maximum weight provides less constrictive design constraints which allows for more innovative designs. These bots provide a good reference for ideas and features to be implemented into smaller 12-pound bots.

Applicable Standards

The National Havoc Robot league has implemented a great deal of design standards for participating BattleBot teams to ensure each competition is not only fair, but also safe. Each year, the NHRL publishes design guidelines that each team must take into consideration. These standards cover all aspects of the robot's design. Before each competition, Battle Bots Inc. must review and accept the robot design prior to competing.

Robot Design Basics

The senior design teams within the University of Cincinnati Combat Robotics club are expected to design and produce a robot with a maximum weight of 12lbs. Each robot must be operated by a remote control with the capability of traveling over 4 miles an hour. The combat robot must include an independently powered weapon that is capable of inflicting damage to other competitors.

Safety Standards

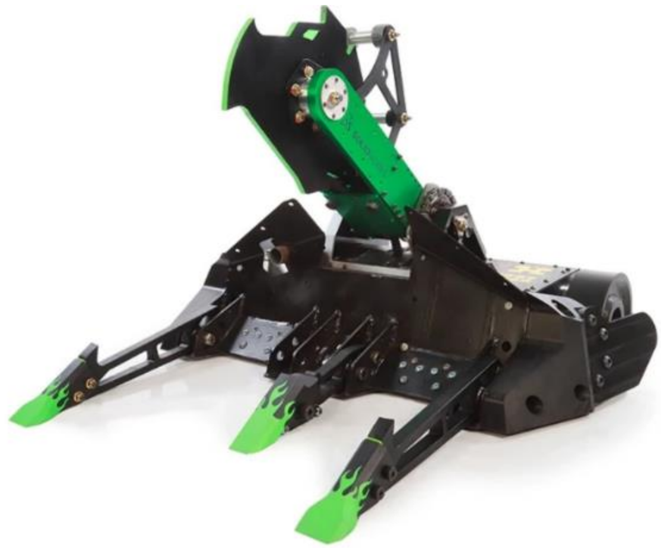
NHRL has implemented safety standards for all competing robots to ensure that the driver, team members, and the audience have a safe experience. Robots must be able to be activated/deactivated safely and efficiently by one person within the maximum time provided (30 seconds). If any robot fails to abide by this rule, will be immediately disqualified. The maximum allowed voltage used for the weapon and motion system is 60 volts, while the maximum voltage for any low-power auxiliary systems anywhere else in the bot is 240 volts. The battle bot must have a removable protective cover to shelter any sharp edges or corners. Any team that is concerned about their design, has questions about the rules, or plans to make any significant changes to the design during or after construction should consult BattleBots Inc.

State of the Art

The University of Cincinnati first competed in BattleBot competitions in 2007. In 2022, 7 bots from the university's Combat Robotics Club competed in competitions. The BattleBots television show started in 2000 and had 9 seasons of fights to analyze and NHRL was created in 2018 and has held dozens of events since conception. By learning from the experience of previous club members and utilizing the variety of resources available, this team will use this knowledge to choose the best design configuration for competition.

Weapon

One example of a state-of-the-art design is the current world champion Battle Bot winner SawBlaze. SawBlaze (5) competes in the 250-pound class of BattleBots. One design feature that is unique to SawBlaze is its front forks used to help control the movements of the opponent bot. The front forks slide under the opponent and force its drive wheels off the ground. This prevents the opponent from driving away. The opponent robot is then immobile, and the attacking robot can push the opponent around the arena or use its own weapon to attack the immobile bot. This method proved to be very effective by allowing SawBlaze to win a world championship. Since then, other bots in the competition have implemented similar systems.



SawBlaze (2023) – BattleBot World Champion (5)

The front forks on sawblade also have a barbed design. This effectively hooks onto the opponent and farther immobilizes them and aids in preventing the opponent from backing away once on the forks (6). SawBlaze then uses its vertical spinning weapon to inflict damage on the opponent by lowering the lever arm, so the spinning blade contacts the opponent. A potential problem with the fork design is also with the environment. The arena where the bots will fight is made of a wooden floor and plexiglass walls. The biggest problem with the forks is when the wood from the floor gets torn up and mangled from the chaos that occurred in the fights before. If the weight isn't distributed correctly the forks can get the robot stuck and that is visible in some fights of SawBlaze (5). The robot can move around on good ground, but when the floor is not totally flat, then the forks can find a notch and stick into the floor stopping the robot in its tracks for a split second which can cost them. Also, when facing a horizontal spinning robot this gives them more area to hit the bot and spin out of control. When facing a horizontal bot, SawBlaze (5) would need to maneuver around the bot to be able to get under the bot and the spinning blade to inflict damage. This then brings to the topic of maneuverability when designing a bot.

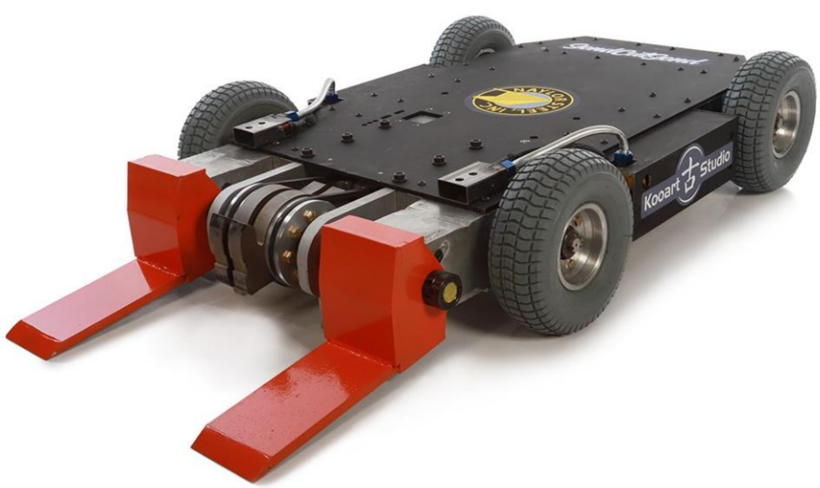
Another example of the current state of the art is a bot that is the 250-pound BattleBot division and that is End Game (7). End Game is a battle bot with a vertical spinner and design that we as a group like a lot. The bot uses a slim design for the base and internal side of the robot, while having a sort of snowplow on the front of the robot. The snowplow then has a slight cutout in the middle for the spinner to be placed. The idea behind this design is that End Game will be able to run into other bots head on and they will get launched by the front spinner which is spinning at about 200 miles per hour. With the base encasing the wheels, there is no chance to really destroy the wheels and keep moving. End Game also has an arm on the back of the robot that when turned on will flip the bot over if it ever gets turned upside down. This is a big problem with the vertical spinning bots, because if you cannot flip back over, then you can't do any damage to your opponent. Now End Game has been competing for a long time with a combined 34 total matches. 11 losses are a large amount for a world renown battle Bot. Looking back at old footage and videos of previous fights, End Game has had a lot of problems with the drivetrain. Their spinner is deadly and with their snowplow design can ram and inflict a lot of damage on their opponents, but not being able to withstand the blows from other robots has put them in a lot of losing situations. With their enclosed wheel design, after taking a hit the wheels can easily become stuck within the frame not allowing the bot to move. The bot has good protection of internals and their spinner, which is important, but hitting around the outside to try and get to the wheels may be its biggest downfall. Overall, End Game is a good basis for our vertical spinning robot idea, with an overall record of 23 wins, 11 loses, and 18 wins by knockout, this bot can do some serious damage and withstand its own.

End Game (2023) - BattleBot (7)

A good example of a state of the art is a bot designed and constructed by Jake Hoffman, president of the Combat Robotics Club, named Maximizer. This robot is a 12-pound implementation of the thagomizer concept. Maximizer's drive sports 30a urethane wheels, 'liftoff' style titanium cleats. Recently, maximizers team implemented a unique upgrade which was the "toe-in" wheels. The angle of the wheels pushes the axis of rotation further back on the robot, closer to the center of mass, which allows the robot to turn quicker. To put it in perspective, the human reaction time to visual stimuli is roughly 0.2 seconds. Maximizer is capable of turning 180 degrees from a dead stop in 0.3 seconds. The biggest piece of technology looking at this robot is the horizontal spinner it uses at its back end. The hook still spinner is able to spin up to speeds of around 210 miles per hour. The centrifugal force of this spinner makes it easier for the robot to fully whip around and hit its target. Using the AR600 15 mm think steal weapon on the back of this robot is able to pack a large punch against its opponents. The canted wheel design helps Maximizer stay low to the group and keep as much grip as possible. Although the wheels being used have caused Maximizer trouble in the past, with different wheels for better grip, it is able to succeed. This robot has only competed within the 2023 season with an ongoing record of 13-1. Maximizer is ranked #2 nationally for the 12-pound weight class and has inspired many teams to incorporate a similar drive train concept.

Maximizer – NHRL Record: 13-1 (8)

Another state of the art when looking at technologies currently being used, is a robot called Free Shipping who uses flipper technology as his main weapon. With 21 years of competition experience and 18 fights Team Special Delivery has certified their weapon to do some serious damage. This design of the robot is very simple. A very flat body design with two angled forks that slide underneath their opponent and flip them upside down so that they can't move but also do damage from the fall back down to earth. This idea is very cool, but their record says that it might not be the best for winning. With a record of 6 wins and 12 losses, Free Shipping shows that just having a flipper doesn't do enough damage to take out a lot of robots. 5 of their losses have been by knockout from other robots with better weapons like spinners or hammers, they have not lost a fight against a flipper bot. With the integration of another weapon, Free Shipping could better its record rather than having to hope that fall damage will help it win.



Free Shipping (2023) - BattleBot (9)

Drivetrain

When designing a battlebot a lot of consideration must be put into the driving system of the robot. This is what truly keeps your robot alive in a fight. If your weapon is busted and does not work, the only thing that you have left to stay in the fight is to move around and try some kind of ramming to do damage. The drivetrain of the robot is very important, and it is crucial to decide what kind of wheel configuration is perfect for each specific bot. Most battlebots have 2 wheels or 4 wheels driving their system. This depends a lot on the size and shape of the robot. Looking at the Free Shipping robot above, it uses the four-wheel design because the base of the robot is very long where if they used anything under 4 wheels, their speed and maneuverability would hinder. They have the front two wheels to steer the robot and the back two wheels to power and move around. This allows for better traction, balance, and control of the robot, but maybe a smaller turn radius compared to a two wheeled bot. We can see this with the Maximizer robot that runs on a two wheeled system which allows the robot to whip around very fast to engage opponents with its back spinner. Power being supplied to both wheels gives a lot of power and maneuverability to the bot, with the right power ratio for turning. The problem with the two-wheel design can be the overall weight of the bot being too heavy to move around and determining the true center of gravity is located on the machine.

Now looking at how to power these wheel configurations, there are many ways to drive them. Belts are very commonly used in battlebot designing. They are very cheap, simple, flexible, and can be placed in small, confined spaces. Two common belts being used are timing belts, like what is used in automotives, and v-belts. Timing belts are great to prevent slippage for the belt and having constant contact with the pulley. The problem with timing belts is that if the motor were to suddenly stop or be damaged in some sort of way, the belt can break or even bend the motor shaft because there is little to no slippage. This is where the benefits of the v-belt come in. V-belts are usually a thinner belt that relies more on tension between the pulleys to generate friction to move. They also allow for slippage so if the pulley were to suddenly stop, the risk of snapping the belt or bending a shaft is greatly reduced. Using belts is simple, but the most important part is finding the correct pulley sizes for the gear ratio needed. 3-1 is a common gear ratio used for battlebots so that could be a 10-tooth pulley on the drive motor and some kind of belt connecting to a 30-tooth pulley to achieve that ratio.

Looking more into the End Game battlebot you can see that they utilize a chain drive system. This is very similar to using a timing belt in that they always have direct contact with the sprocket allowing for instant power to the wheels. The biggest problems with chain drive in the 12lb weight class are weight and cost. The chains add a lot of extra weight for a small robot that does not need as much torque to move around and ordering a custom chain length or having chains made for a specific size can become pricey.

Finally, we looked at a direct drive system from a UC battlebot BAKA. The BAKA bot used a direct drive system by ordering electric skateboard wheels that have motors directly in the wheel. The wheels they found are brushless hub motor wheels that are connected to the bot and can simply be plugged into the system and used. This system is very simple with a “plug and play” type of installment, but the weight of the wheels came out to around 1.5lbs per wheel and for a 12lb weight class that is a big sacrifice. Also, they had problems with the traction of the wheels on the battle floor which is wood. They later needed to add cleats to the wheel assembly to get traction and move around the arena, so that is something to consider.

Armor

Armor is a crucial part of designing a battlebot as it is how to protect the inner mechanisms of the bot so it can continue to function. Looking at past and current battlebots in the field sport many different types of armor. Some of these include a simple box shape, a ramped trapezoidal design, or a circular design. Along with the purpose stated above, the armor of the robot should de designed in a way that the team knows they will be impacted or struck by a different bot. Designing a bot with armor to lower the destruction or deflect shots caused by another bot is very important.

Looking at one of the top ranked 12lb robots Maximizer, you can see that there are no sharp corners that can be hit by other robots. Rounded edges all around the robot allow for the income impacts to graze off the robot and not make full and complete contact. Along with an AR500 steel front plow, maximizer can deflect impacts from the front to protect the tail and weapon when it needs to whip around and deal damage.

The heavy class bot Beta is a perfect example of zero sharp edges. The bot is equipped with a steal sheet that is bent and goes around the perimeter of the bot and only exposes the back end, always pushing forward would make it unnecessary to wrap the back end. This scooped and bent design allows beta to drive into other bots and scoop them off the group to then use its hammer to do massive amounts of damage. With the smooth edges of the steel, the incoming blows from the other bots will graze off the shield and do little to no damage to the internals of the robot. Their main hammer weapon is also used to flip the robot over if it were to be turned over.

Again, looking at the 2020 national battlebots champion EndGame, they use two sheets of steel that are sloped in the front and in between them falls their vertical spinner. The idea behind this design is that the bot can ram into an opponent, scoop them up to the weapon and flip them over with the force of the spinning weapon. They also include a long tail with a separate motor to flip them over if they get overturned. The only disadvantage to this is if the motor stops working for some reason, not being able to drive right side up and upside down can make the bot tap out and lose the match.

The end goal for the robot is to be able to be able to drive normally and flipped upside down. Not having to worry about trying to flip right side up is a huge advantage as it takes away time needed to flip back over. With this ability the bot can still move around and deal damage to other bots. For the armor of the bot we are looking into the split plow design like End Game as to feed robots into the impact zone of the spinner. Using AR500 steel for a front plow, like End Game, and also a UHMW body, like Maximizer, it gives us protection from the front and the depth on the sides to keep the internals safe from other robot spinners be that horizontal or vertical.

End User

The BattleBot being designed will be funded through the University of Cincinnati Combat Robotics Club. The bot will be operated by the members of the team during the March 2nd, 2024 NHRL competition. The end user of this design will be the members of this team and by extension the University of Cincinnati and the Combat Robotics Club.

Summary of Research

There are several weapon design features and configurations to consider: vertical spinners, horizontal spinners, full body spinners, flipper bots, and dead-blow bots. The most popular weapon configurations are inertia spinners in either the vertical configuration like End Game or in a horizontal configuration like Maximizer. Flipper bots and dead-blow bots are not commonly used because of the amount of damage they can cause during the fight. Also looking at these configurations the consideration of movement must be taken into account. A full body spinner in the NHRL is usually two driving wheels that spin the bot, but that doesn't allow the robot to precisely move around or towards the other robot to engage, but rather aimlessly spin around and hopefully hit the bot. Dead-blow bots have normal movement and drive, but the damage from the robot may not be sufficient to stop another robot from working and take the win. Inertial spinning robots can be in many configurations for driving from two wheels on up. Having two wheels may give more speed to the robot and less weight, but not the stability that a wheel system would have. These weapon and drive configurations each have advantages and disadvantages to their design that will need to be taken into consideration when designing a bot for competition. Of the weapon types researched, inertia spinners tend to be the most effective when it comes to winning matches and will be the weapon of choice for this BattleBot.

The research and information that has been laid out will provide crucial information in the design and decision-making process when designing this bot for competition. By learning from previous fights, the successes, and failures of previous senior design BattleBots, and a variety of other information available online, the team will design, build, and test a bot that is competition worthy.

Quality Function Deployment

Customer Features

Customer features were recorded by presenting a survey to individuals with basic robotics knowledge and previous participants in UC combat robotics club. This survey consisted of 12 questions that tracked the importance of several characteristics and had short response answers for more complex topics. Over 30 responses were recorded which were considered for the HOQ. Listed below are customer features that are being considered for the combat robot design.

- Weapon Type
- Weapon Strength
- Weapon Modularity
- Frame/Armor Strength
- Frame/Armor Material
- Traction
- Robot Maneuverability
- Invertibility/ Self Correcting Orientation
- Weight
- Cost

Engineering Characteristics

Shown below are the engineering characteristics that were developed to meet the customer requirements.

- Torque [N/m]
- Angular Velocity [rpm]
- Angular Momentum [kg-m^2/s]
- Weapon is Vertical Spinner [double tooth]
- Spinner Diameter [m]
- Weapon Material is AR500 Steel
- Hardness [HB]
- Frame Material is UHMW Polymer
- Strength [MPa]
- Armor Material is 7075 Aluminum
- Robot will be able to flip itself back over
- Weight [kg]
- Cost [USD]

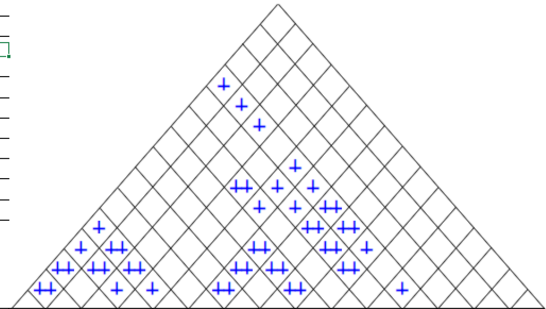
Product Objectives

Between the House of Quality and survey results, each engineering characteristic was given an weighted importance which is shown below.

1. Weight (20.9)
   I. Battle Bot must be under 12-lbs.
2. Hardness (12.4)
   I. Hardness needs to be considered for the spinner, frame, and the armor.
3. Yield Strength (12.0)
   I. This will vary between components.
4. Frame Material is Aluminum-7075 (11.7)
   I. 7075 Aluminum is much stronger than 6061 Aluminum and has an approximate yield strength of 500MPa.
5. Frame Material is UHMW Polymer (11.7)
6. Torque (6.9)
7. Able to Flip Back Over (5.6)
8. Weapon is Vertical Spinner (5.2)
   I. This was chosen by the group.
9. Angular Velocity (5.1)
10. Angular Momentum (5.0)
11. Cost (2.3)
12. Spinner Diameter (1.2)
    I. Depends on overall size of base and components.

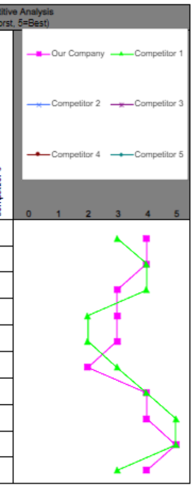
House of Quality

Title: 12lb BattleBot BRRT
Author: Connor Deer, Travis Baker, Eli Cambell
Date: 10/19/2023
Notes:



Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)					
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▲	▼	▲	▲	▼	▼	▲	▼	▲										
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Torque [Nm]	Angular Velocity [rpm]	Angular Momentum [Kg*m^2/s]	Weapon is Vertical Spinner	Spinner Diameter [m]	Hardness [HB]	Frame Material is UHMW Poylmer	Armor Material is 7075 Aluminum	Yield Strength [MPa]	Able to Flip Back Over	Weight [kg]	Cost [USD]				Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
1	9	6.1	2.3	Weapon Type	▲	O	O	Θ	O	▲			▲	▲	▲	▲				4	3				
2	9	11.7	4.4	Weapon Strength						Θ			Θ		O					4	4				
3	3	12.8	4.8	Weapon Modularity				O												3	4				
4	9	10.9	4.1	Frame/ Armor Strenth						Θ	Θ	Θ	Θ		Θ	▲				3	2				
5	9	8.5	3.2	Frame/ Armor Material						Θ	Θ	Θ	Θ		Θ	▲				3	2				
6	9	10.1	3.8	Traction	Θ	O	O			▲					Θ					2	3				
7	9	11.4	4.3	Robot Maneuverability	O	O	O	▲						O	Θ					4	4				
8	9	12.5	4.7	Invertability/ Self-Correcting Orientation	▲	▲	▲	O	▲					Θ	O					4	5				
9	9	13.3	5.0	Weight	O	O	O			O	Θ	Θ	O		Θ	▲				5	5				
10	9	2.7	1.0	Cost	▲	▲			▲		Θ	Θ			▲	Θ				4	3				



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Target or Limit Value				Vertical Spinner Weapon	0.25m		UHMW Polymer Frame	7075 Aluminum Armor		Self Correcting Orientation	< 12-lbs	$1000 USD			
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)				1	3		2	2		7	8	6			
Max Relationship Value in Column	9	3	3	9	3	9	9	9	9	9	9	9			
Weight / Importance	186.4	138.0	135.4	142.3	33.5	336.2	318.4	318.4	326.1	152.9	569.7	62.8			
Relative Weight	6.9	5.1	5.0	5.2	1.2	12.4	11.7	11.7	12.0	5.6	20.9	2.3			

Powered by QFD Online (http://www.QFDOnline.com)

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▲	▼	▲	▲	▼	▼	▲	▼	▲				
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Torque [N/m]	Angular Velocity [rpm]	Angular Momentum [Kg*m^2/s]	Weapon is Vertical Spinner	Spinner Diameter [m]	Hardness [HB]	Frame Material is UHMW Polymer	Armor Material is 7075 Aluminum	Yield Strength [MPa]	Able to Flip Back Over	Weight [kg]	Cost [USD]			
1	9	6.1	2.3	Weapon Type	▲	O	O	Θ	O	▲			▲	▲	▲	▲			
2	9	11.7	4.4	Weapon Strength						Θ			Θ		O				
3	3	12.8	4.8	Weapon Modularity				O											
4	9	10.9	4.1	Frame/ Armor Strenth						Θ	Θ	Θ	Θ		Θ	▲			
5	9	8.5	3.2	Frame/ Armor Material						Θ	Θ	Θ	Θ		Θ	▲			
6	9	10.1	3.8	Traction	Θ	O	O			▲					Θ				
7	9	11.4	4.3	Robot Maneuverability	O	O	O	▲						O	Θ				
8	9	12.5	4.7	Invertability/ Self-Correcting Orientation	▲	▲	▲	O	▲					Θ	O				
9	9	13.3	5.0	Weight	O	O	O			O	Θ	Θ	O		Θ	▲			
10	9	2.7	1.0	Cost	▲	▲			▲		Θ	Θ			▲	Θ			
				Target or Limit Value				Vertical Spinner Weapon	0.25m		UHMW Polymer Frame	7075 Aluminum Armor		Self Correcting Orientation	< 12lbs	$1000 USD			
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)				1	3		2	2		7	8	6			
				Max Relationship Value in Column	9	3	3	9	3	9	9	9	9	9	9	9			
				Weight / Importance	186.4	138.0	135.4	142.3	33.5	336.2	318.4	318.4	326.1	152.9	569.7	62.8			
				Relative Weight	6.9	5.1	5.0	5.2	1.2	12.4	11.7	11.7	12.0	5.6	20.9	2.3			

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Author: Connor Deer, Travis Baker, Eli Cambell

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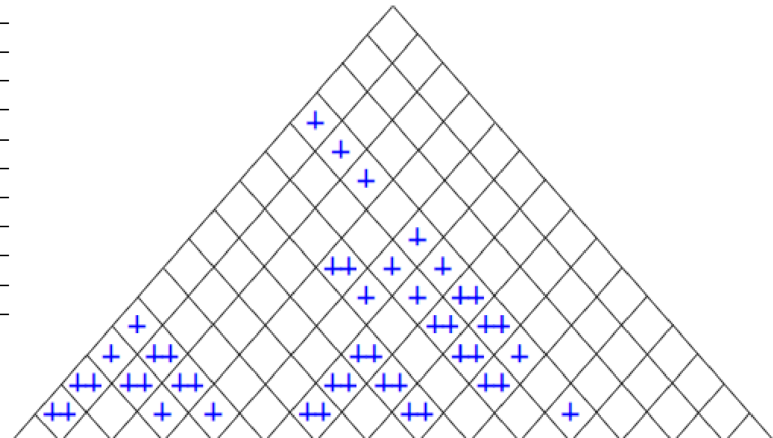
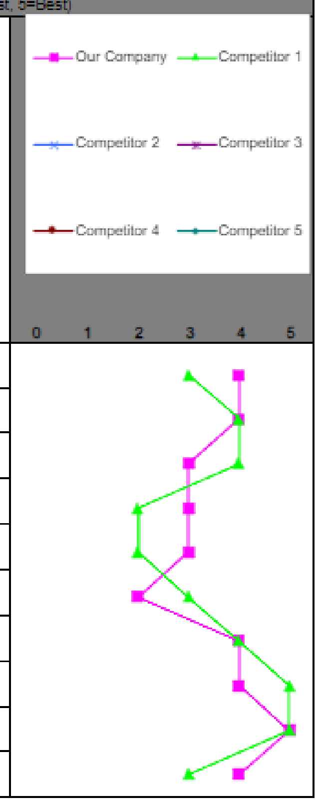


Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▲	▼	▲	▲	▼	▼	▲	▼	▲				
Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Torque [N/m]	Angular Velocity [rpm]	Angular Momentum [Kg*m^2/s]	Weapon is Vertical Spinner	Spinner Diameter [m]	Hardness [HB]	Frame Material is UHMW Poylmer	Armor Material is 7075 Aluminum	Yield Strength [MPa]	Able to Flip Back Over	Weight [kg]	Cost [USD]			

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats")

Competitive Analysis (0=Worst, 5=Best)

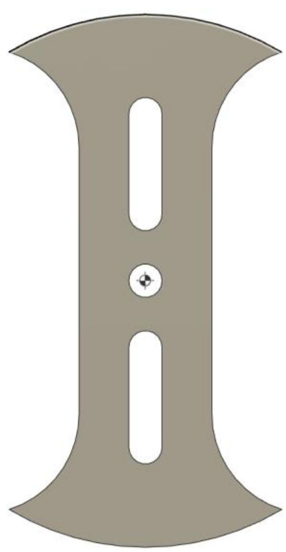
Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
4	3				
4	4				
3	4				
3	2				
3	2				
2	3				
4	4				
4	5				
5	5				
4	3				



Design Concepts
Weapon Concepts
Concept 1: Bar Spinner

Bar Spinner - Isometric View

This design is similar to a design from a previous senior design BattleBot team, BAKA. This design is a spinning bar with teeth. The idea is that the teeth will dig into the opposing bot and inflict damage. The double tooth design allows for a higher likelihood of making first contact in a weapon-on-weapon impact with an opposing bot when comparing to a single tooth weapon. The symmetric design means the center of mass is conveniently located at the axis of rotation and allows for the weapon to be flipped in the other direction in the event the teeth start to show wear.

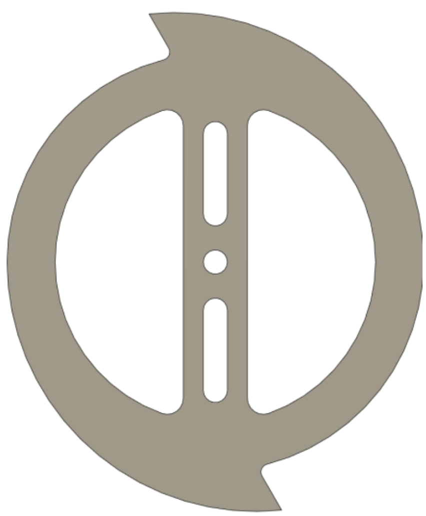


Bar Spinner - Top View

The largest downside of this weapon design is the lack of moment of inertia when spinning about its center of mass relative to the weight of the weapon. Having a higher moment of inertia means that more energy will be transferred to the opposing bot when the tooth of the weapon makes contact. But adding more to the moment of inertia means adding more mass to the spinner which then adds to the total weight of the bot.

Concept 2: Disk Spinner

Disk Spinner - Isometric View



Disk Spinner - Top View

This design is similar to design 1 with an emphasis on improving the strength of the weapon as well as the energy that can be stored and transferred to the opponent. The outer disk helps redistribute the force of an impact of the tooth against the opponent throughout both inner arms.

The outer disk also moves some of the weight of the weapon farther from the axis of rotation, increasing the moment of inertia allowing for greater storage and transfer of energy.

A major downside of this weapon is the increased weight of the weapon because of the extra material required in the outer disk. While this weight is beneficial when taking into consideration energy transfer, this extra weight in the weapon will need to be considered when designing other components of the bot.

Concept 3: Final Disk Spinner

Disk Spinner - Isometric View

Weapon concept 3 is very similar to concept 2. The major change is the hole in the center of the weapon was changed to allow for needle roller bearings to fit inside the weapon to reduce friction as the weapon spins. Also, 6 M3 bolt holes in a circle were added to allow for the pully and a spacer to be attached to the weapon. The pully will transfer rotational force from the motor to the weapon, and the spacer will keep the weapon centered on the bot and align the drive and driven pulleys. The spinner is 8 inches in diameter and weighs 48 ounces.

Using a 970 kv electric motor and a 3 to 1 gear reduction, the 8-inch diameter spinner is able to spin at 7178 RPM, giving a tip speed of 170 MPH. Using the moment of inertia about the center of mass given by Fusion360, it can be calculated that the weapon can store up to 1.90 KJ of energy.

Motor KV	970	KV
Battery Voltage	22.2	Volts
Driven Gear Dia	3	any unit
Driving Gear Dia	1	any unit
Diameter	8	in

Weapon RPM	7178	rpm
Weapon Deg/s	43068	Deg/s
rad/sec	751.6784022	Rad/s
tip speed	170.8360005	mph

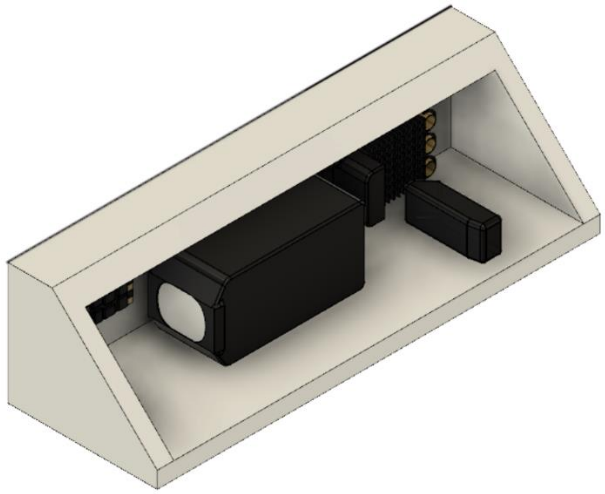
MOI Weapon	6730712	g/mm^2
MOI Weapon	0.006730712	kg/m^2

Weapon Energy	1901.5	J
Weapon Energy	1.90	KJ

Weapon Energy and Speed Calculations

Frame Concepts

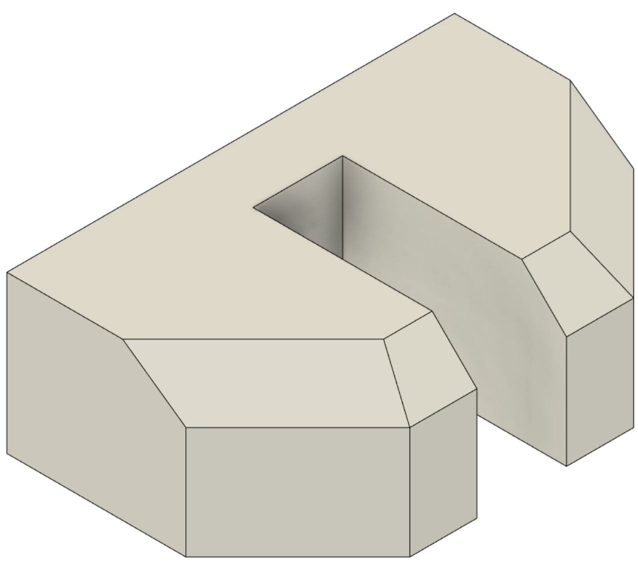
Concept 1: Frame Design



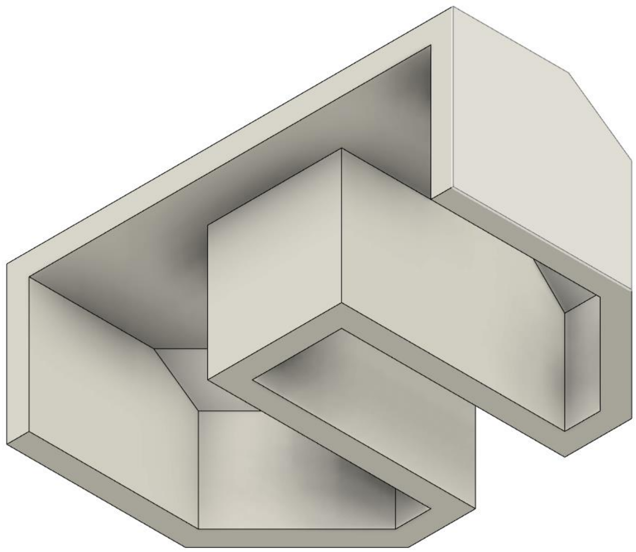
First Frame Design

The very first frame design that was created is a trapezoidal-ish frame. The main goal of this frame was to hold all the internal components of the robot. This idea was similar to a previous senior design team in BAKA. The body of the robot is a box to hold the internals while still having drive holes to feed wires from the motor which would sit on the outside of the frame. Very quickly it was determined that this design would not be beneficial for the robot the team wanted to create. Team members from BAKA also informed the group that this design is not very useful or modular when assembling the bot. There are no place holders for the internals, and they would simply be placed into the box and plugged into the battery.

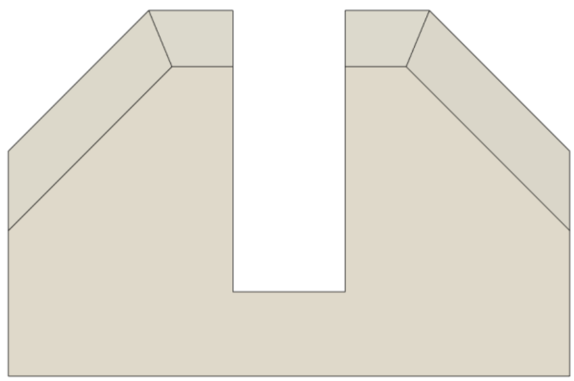
Concept 2: Split Frame



Split Frame - Isometric Top View



Split Frame - Isometric Bottom View

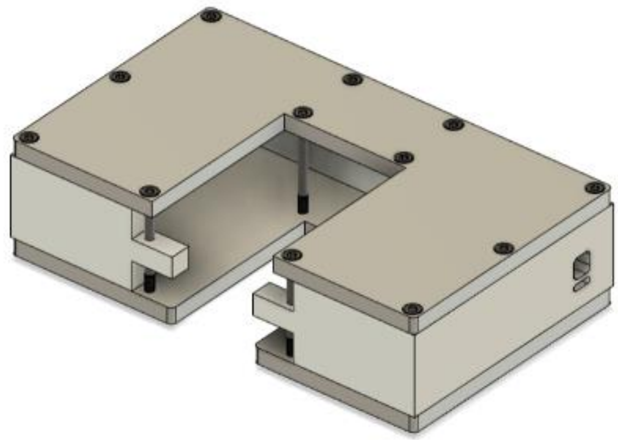


Split Frame - Top View

This frame is designed to allow the weapon to be mounted closer to the center of the bot. The weapon will be mounted in the center gap of the frame design with just the front of the spinner protruding from the front of the bot. This design allows the bot to be more compact and move the center of mass of the entire bot closer to the center of the volume of the bot, making it more stable when driving. The electrical components will be inside the frame on either side of the weapon fully enclosed. The angled front faces will help deflect impacts from an opposing bot's weapon.

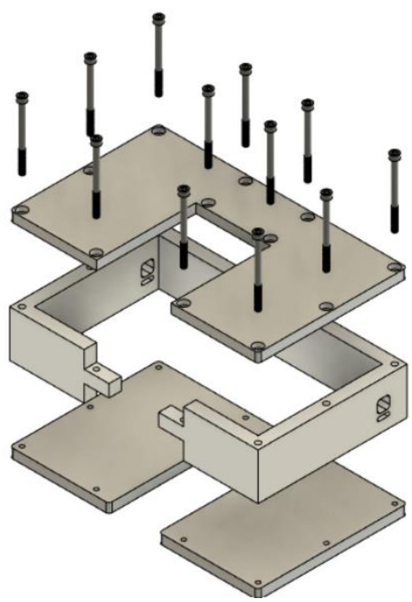
The drawback of this frame design is the split design may prove to be weaker. Because there is a smaller amount of material connecting the two sides of the frame, this could be a weak point of the design. To counter this, a metal bottom and back plate will be mounted to the frame to fully enclose the internal components and provide extra rigidity.

Concept 3: Split Frame Sandwich Design



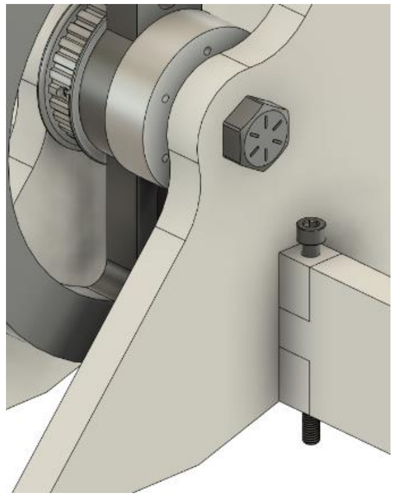
Sandwich Design Isometric View

For the next concept design for the frame of the battlebot we investigated a "sandwich" type design. For this we still have a UHMW center but on the top and bottom we added two pieces of 7075 aluminum to "sandwich" the frame together. With the inclusion of 60mm through bolts and a threaded bottom aluminum plate, we can easily take off the top or bottom plate to access the internals of the robot.



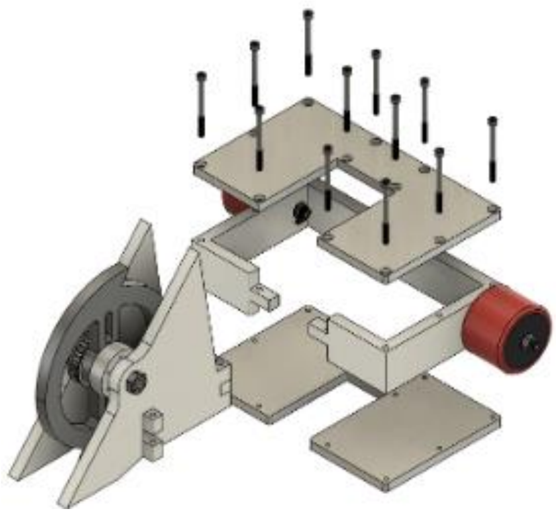
Sandwich Design Exploded View

From the picture above, you can see how the frame would be assembled for the robot. We have a bottom aluminum plate, the UHMW center, the top aluminum plate and the through bolts to hold the assembly together. From this picture the UHMW shows tabs on the inner cutout of the frame. This is to allow the uprights to slot into the frame and then be bolted on the back of the cutout.



Uprights Mounting View

With this new design of the frame, we needed to redesign how the uprights were going to be incorporated into the bot. The uprights include a slotting piece that sticks out of the side of the upright so the frame can slot in then the bolt will connect them.



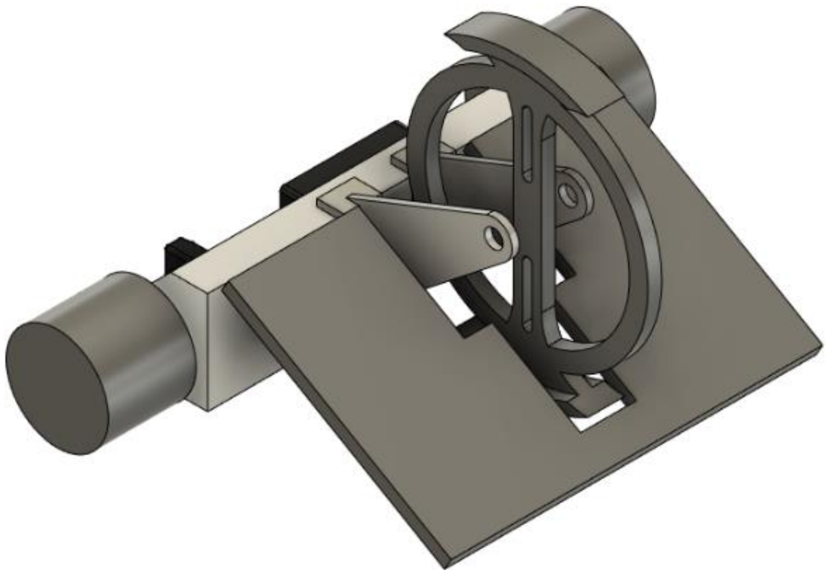
Exploded View with Upright Assembly

This new design will allow us to remove the uprights and weapon assembly away from the main body/frame of the robot. This will allow us to easily change anything in the weapon assembly if something is wrong or a belt has been broken. Removing the front screw to the upright and the two back screws from the middle cutout will let the center uprights to come out from the bot.

Overall, this design is good modularity of the robot and ease of access to the internals. The weight of this frame design is a major problem that needs to be addressed because with this design the bot is weighing around 14.5 pounds. Also looking at the manufacturing of this frame, the uprights add a very large step for machining. With the two ears on the uprights this means that to manufacture the upright it would start at double the thickness then have to be machined down to have the jut outs of the ears.

Bot Concepts

Concept 1: Vertical Spinner Prototype

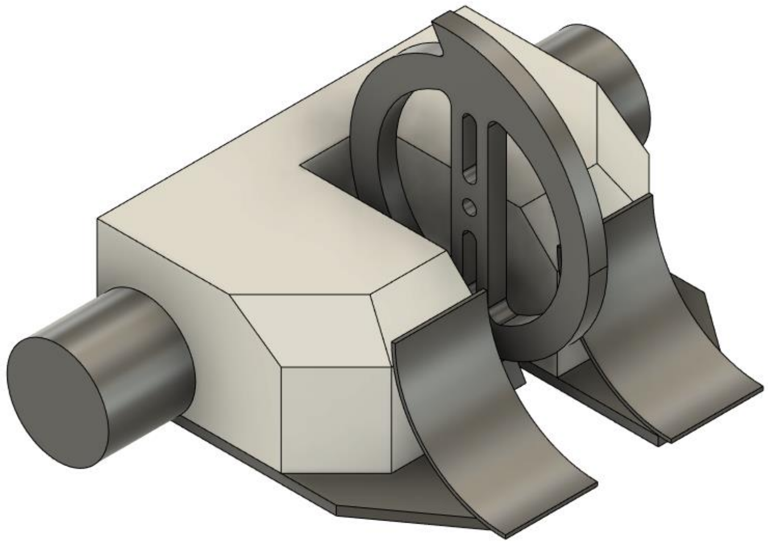


Single Body Frame Ramp Design

The team’s first complete concept for a battlebot is shown above. Looking at past senior design teams, we grab a lot of inspiration from the BAKA team. They had a similar design in that there is a long box like frame to hold the internals along with two uprights to hold the weapon spinner. After watching videos of their matches, the biggest problem with their bot is that they did not have very much defense. With no type of ramp or plow on the front of their design, allowed other bots to hit the robot and do lots of damage. From those videos, the group decided on adding a front plow/ramp system to attach to the robot frame. This would give the robot better defense when it comes to incoming attacks. The other benefit to the ramp is that when driving into another robot, the ramp would push the robot up and into the weapon spinner doing a great amount of damage and hopefully flipping the robot over.

This being a very rough draft of the battlebot, the group could see many downsides to the design. Weight being a big factor is something to look at. The weight of this design was around 18 pounds and when competing in a 12-pound weight class, the robot would need to somehow shed 6 extra pounds. Also, the maneuverability of the design was something of concern because of the weight. With using only two wheels for the robot, not having the wheels near the center of gravity hinders the movement as more of the weight is towards the front of the robot. We will still use these first concepts for thlater design because it holds a lot of ideas that, if created efficiently, can really put the robot in the high ranks.

Concept 2: Vertical Spinner Split Frame with Ramp

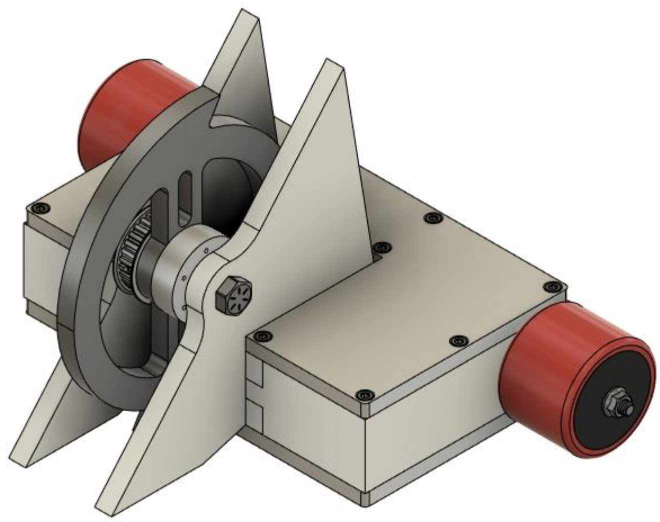


Vertical Spinner with Ramp - Isometric View

This concept includes the split frame design with the spinning disk concept. This bot will also have a ramp to act as armor for the body of the bot as well as to lift or scoop the opposing bot into the weapon. This bot will also feature a two-wheel drive system. This will allow for a reduction in weight because it requires fewer drive motors. This will also allow the ramp to slide along the ground so that opponent bots cannot get under the ramp to inflict damage and the ramp will lift the opponent into the weapon.

The main drawback to this concept is the lack of means to self-right in the event that the bot has been turned upside down. The weapon could be used as a means of flipping the bot back to its right side, or an arm could be mounted to the top that would push the bot back onto its wheels if needed. Also being a very crude 3D model, the team doesn't know the true weight of this design and from experience this will be very heavy and hard to cut weight if sticking with this design. The large mass of the body of the robot would take away too much weight from the big weapon and electric skateboard wheels.

Concept 3: Vertical Spinner with Uprights



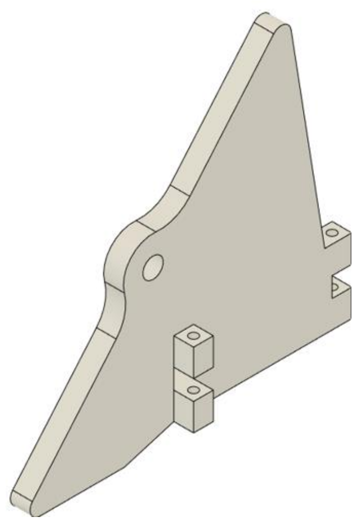
Vertical Spinner Split Body Sandwich Design

This design consists of UHMW uprights located on either side of the weapon. The intent of the uprights was to make the robot invertible, in case the robot was to flip over during competition. After examining the 1st concept design, the group realized that the bot must be able to either flip itself back over or drive upside down during the competition. This is a "must-have feature" that was ranked with high importance (7th) from the House of Quality. A portion of this project's research was watching previous competitions and analyzing the strengths and weaknesses of all the combat robots. From watching previous competitions, the group came to an understanding that the majority of the successful battle bots had the capability of driving upside down or flipping back over. Whereas some robots didn't have that capability, making the robot vulnerable for heavy attacks. The uprights allow the robot to drive upside down, if the robot were to flip over during competition. In order to maintain wheel engagement for both orientations, the wheels needed to be located near the back of the frame (vertically centered) with the uprights symmetrical. This allows the wheels to have the same amount of engagement if it's orientated upside down.

The first design concept had the weapon located inside of the frame, which limited the amount of bite the spinner was able to generate. Due to the weapon being a vertical spinner, the amount of bite was crucial to the offensive success. To increase the amount of bite, the spinner center point of the spinner had to be located outside of the frame. This point was determined from the XL series belt the group had selected, for obtaining a gear ratio of 3:1. The gear ratio was derived from the pulleys that were selected (10 tooth driving pulley | 30 tooth driven pulley). After selecting an appropriate gear ratio and pulley, the center-to-center distance was able to be calculated. This allowed the group to determine where the spinner should be mounted on the uprights, relative to the weapon motor. The 30-tooth driven pulley mounts directly to the spinner with needle rolling thrust and ball bearings, located on either side of the spinner. These bearings are intended to reduce the amount of generated friction within the weapon assembly which allows the spinner to rotate much smoother.

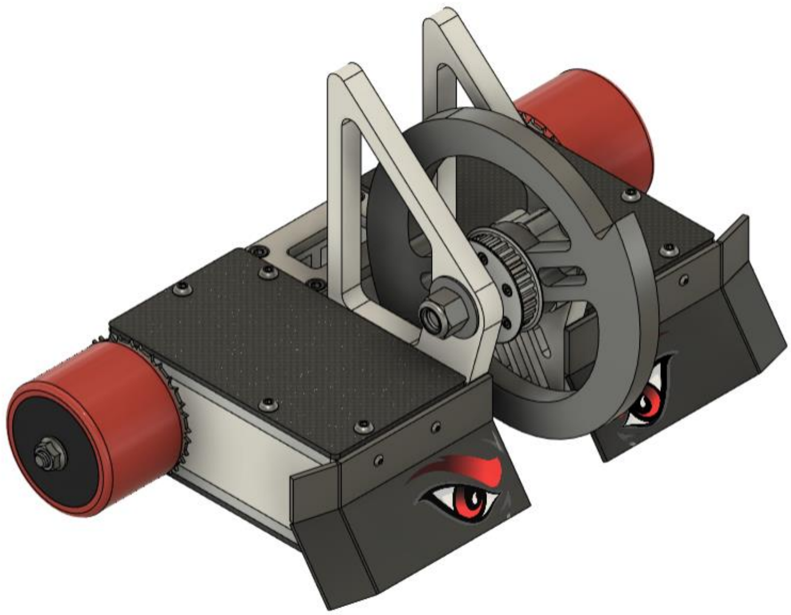
Another aspect of the robot's offensive success is being able to “scoop” components into the spinner. The 1st design concept had ramps located on either side of the spinner. To decrease the overall weight and improve the robot's manufacturability, the ramps were removed and replaced by uprights. Each upright was designed at a steep angle, which allowed the robot to scoop the robots without needing a ramp. This concept was eventually scrapped, because ramps provide armor for the frame and have a wider scooping range in competition.

The overall concept of the uprights proved to be beneficial, however the uprights for this concept faced many issues. Firstly, the uprights had two ears that mated with the front walls of the frame. The idea was that the uprights would be secured into place through the lap joint and through-bolt that goes through the ears & wall. However, the group later determined that ears provided minimal support for the uprights and could break off with even a small amount of force. Another problem these uprights faced was their manufacturability. Including the ears on the frame essentially doubles the thickness of the stock used for manufacturing, even with the ears being a small feature. Shown below is a rendering of the upright used in design concept #3.



Left Upright V2

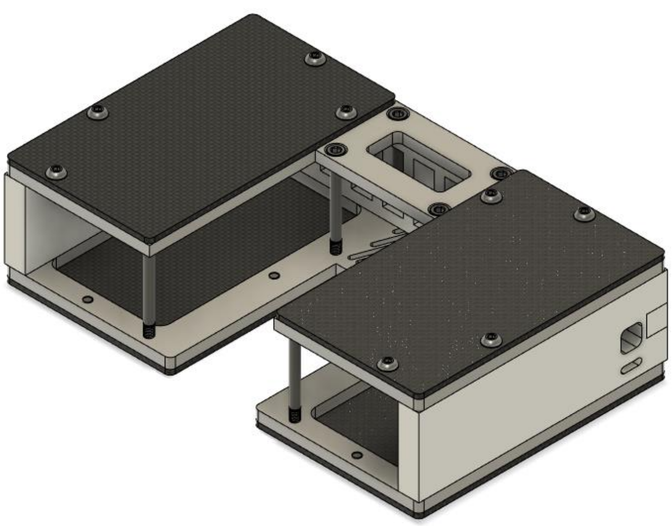
Final Model



BRRT Final Model

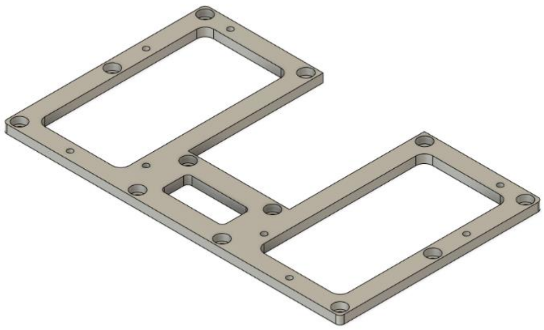
The final design concept is a combination of all the best design concepts for each component. The completed assembly is a combination of five different sub-assemblies, the frame, weapon, center cutout, drive train, and plow. Having the final assembly be a combination of sub-assemblies allows damaged parts to easily be swapped between rounds if needed.

Frame Sub Assembly

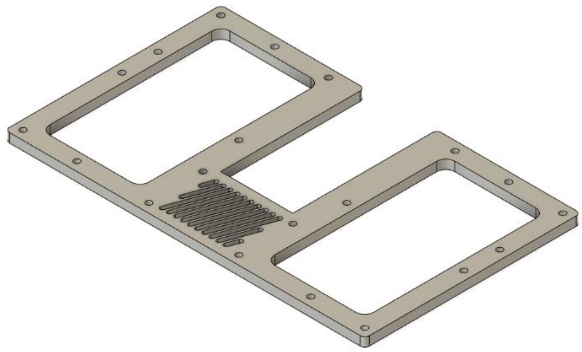


Final Body Isometric View

The final frame design incorporates everything the group has learned over the course of the fall semester. First, the group decided that a split frame design would allow the weapon to be pushed into the center of the bot and save some considerable amount of weight. From the second frame design, the team went with the “sandwich” design of aluminum top and bottom plates with UHMW center to encapsulate the internals of the robot. For this final design we mainly focused on the weight of the robot.

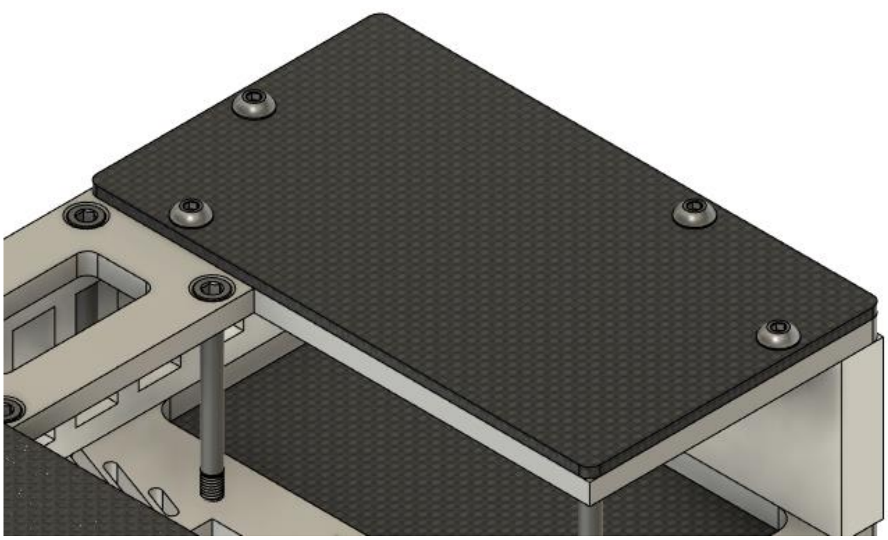


Base Top Plate



Base Bottom Plate

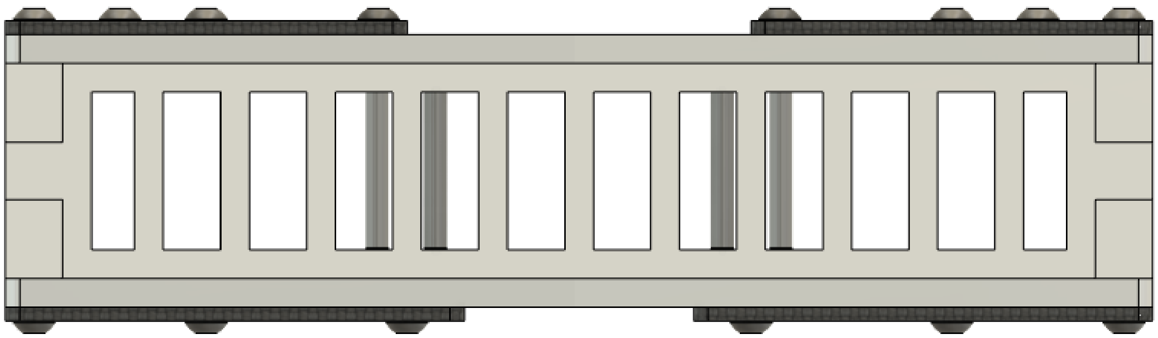
Here we took the top and bottom plate of aluminum which we created large cutouts with a clearance of ¼ inch around all sides. This will keep the rigidity of the frame while also shedding lots of weight from the robot. With the same through bolt holes and counter sunk holes on the top of the frame this will allow the bolts to sit into the frame and be flushed with the frame for the carbon fiber to be placed on top. Another thing added is a cutout for the master switch that is needed per NHRL regulations on the top plate along with some weight reduction/airflow holes on the bottom plate. The weight of the top plate before the cutouts came to be 18.98 ounces and with the cutouts the weight dropped to 8.19 ounces so about a 10-ounce difference. The same goes with the bottom plate started at 31.5 ounces and ending at 9.03 ounces.



Carbon Fiber Mounting for Top and Bottom

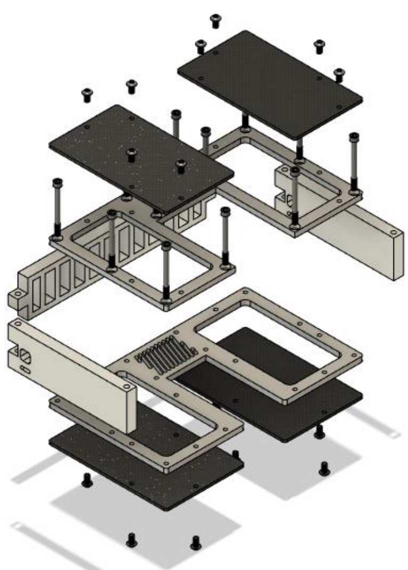
We have designed carbon fiber plates for the top and bottom of the bot. With the cutouts of the aluminum to save weight, there still needs to be a way to encapsulate the internals of the robot so that they are not completely exposed. For this we used CNC Madness to keep about an 1/8th inch thickness carbon fiber plates. These will be screwed into the aluminum plates with M5 button screws on the top and bottom. All the carbon fiber plates are the same, but mirrored to the other side so one carbon fiber plate weighs 2.04 ounces, so in total all the carbon fiber weighs 8.16 ounces.

Also, we have taken out the front UHMW pieces for the front of the bot and that is because of the inclusion of the newly designed plow that will be talked about later. This then allows the new uprights to be flat pieces that still will get connected by the through bolt on the backside.



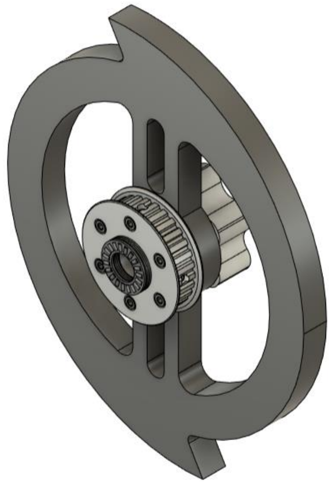
Base Back Plate

Finally, for the back wall of the frame, the robot was still weighing over the limit at around 12.5 pounds, so we added cutouts to save weight. The backside of the robot is the least affected side when it comes to combat so creating these cutouts should have no effect on incoming damage.



Final Base Exploded View

Weapon Sub Assembly

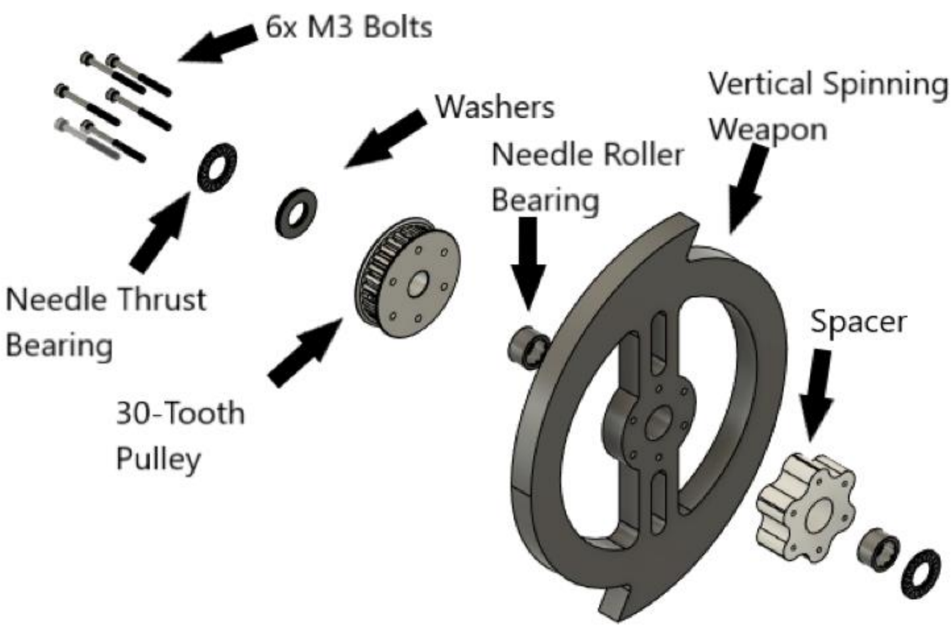


Final Weapon Assembly Isometric View

Front View

The weapon sub-assembly contains all of the parts attached to the weapon. This includes needle thrust and needle roller bearings, the 30-tooth driven pulley, the UHMW spacers and washers used to make small spacing adjustments.

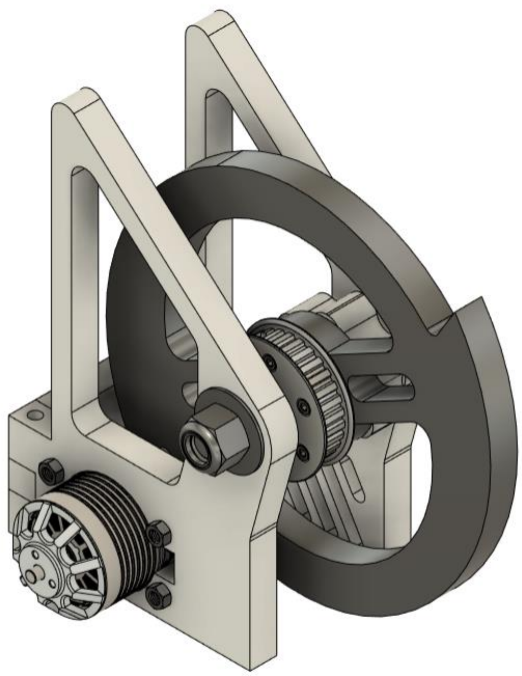
This spinner itself will be manufactured out of 0.25-inch thick AR500 steel. AR500 steel is an extremely hard steel alloy. This will allow the weapon to hit opponents with a massive amount of force without causing damage to the weapon. The spinner will be plasma cut to create the 2D profile of the weapon.



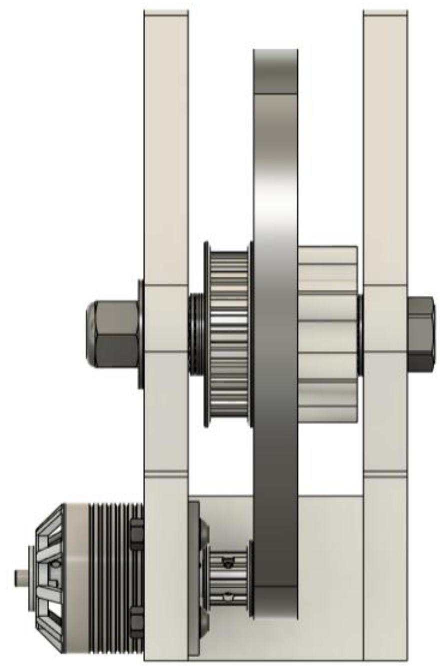
Weapon Assembly Exploded View

Referencing the exploded view above, two needle roller bearings go on the inside of the weapon to reduce friction as the weapon spins on a shaft. The 30-tooth pulley and UHMW spacer both attach directly to opposite sides of the weapon. Then washers for making smaller spacing adjustments. Finally, needle thrust bearings reduce friction against the body of the bot as the weapon spins, and also provides spacing. Six M3 screws go through the pulley, into the spacer to attach them to the weapon. This is important for transferring the rotational motion from the pulley to the weapon, causing it to spin.

Center Cutout Assembly

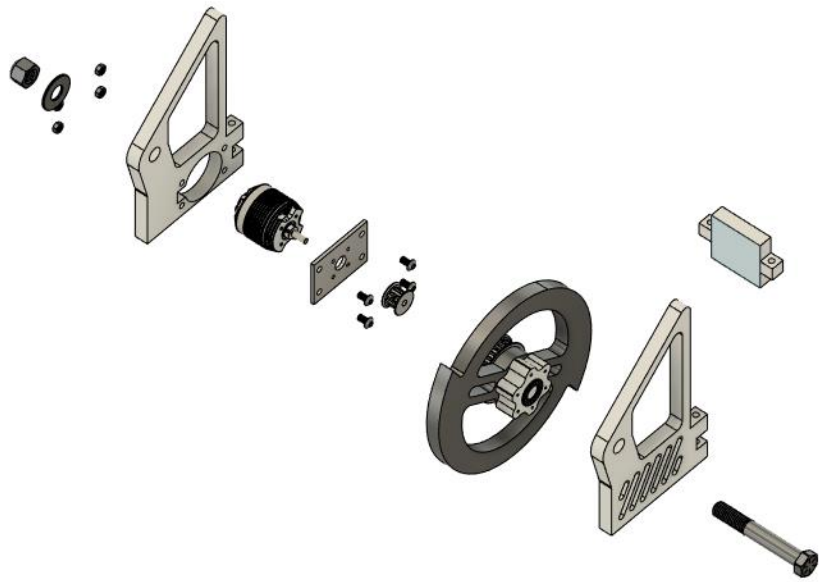


Center Cutout Assembly Isometric View



Center Cutout Assembly Front View

The center cutout assembly also houses the weapon assembly. The center cutout is designed to be able to be “cut” away from the rest of the bot. The center cutout can be easily removed from the rest of the bot for repairs or replacing damaged parts. This is most significant when mounting the weapon drive motor. The drive motor will be a Badass Power BA-3520, 970 KV, brushless DC motor. This will accelerate the weapon to over 170 MPH.



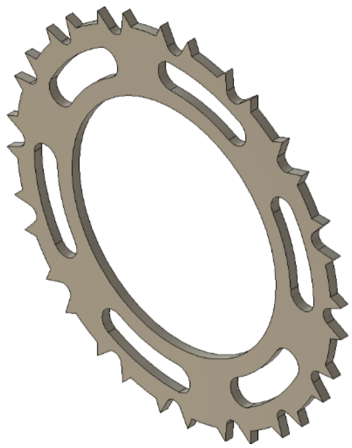
Center Cutout Assembly Exploded View

The motor requires a mounting plate to mount to the UHMW because the UHMW is a plastic-like material that is somewhat flexible. The aluminum mounting plate gives a ridged surface for mounting the motor that prevents flex. The plate is mounted to the UHMW with 4 M3 screws and nut. The two side and back UHMW pieces are held together with M5 bolts interfacing through a lap joint.

The weapon assembly and its components will sit on a ½ inch thick steel bolt. This will provide ample strength and rigidity for the weapon when it contacts another bot. The bolt will also sandwich the components between the UHMW body pieces, ensuring a tight fit of the components.

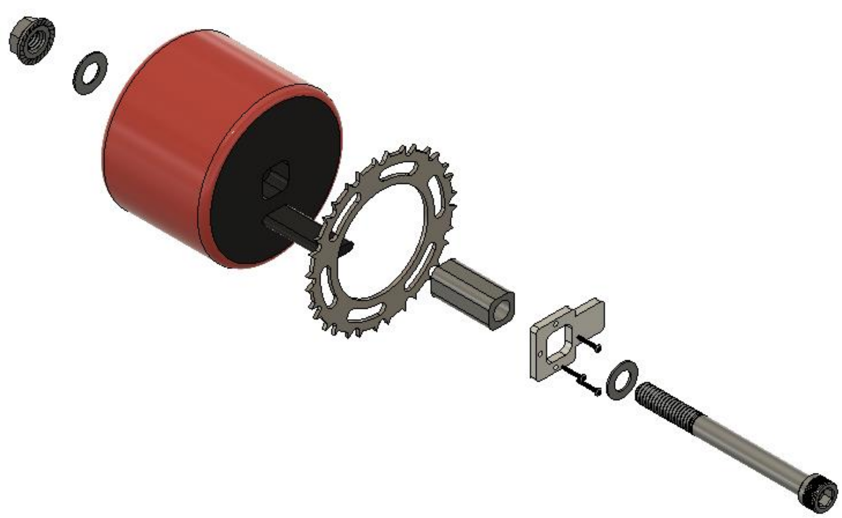
Drive Train Assembly

The drive train for this robot was inspired by a previous senior design team's robot, Baka. The Baka robot had two booster board wheels located on either side of the frame. These booster board wheels have integrated brushless motors inside of the hub that has a maximum of 1600RPM. Implementing these wheels eliminates the need for any external drive train motors, which allows more weight to be consumed in the critical locations. The only downside of these wheels is the amount of traction they can provide. Looking at previous competitions, it's obvious that the floor is wood, uneven, and can be damaged from previous battles. Therefore, it is crucial that the wheels provide a higher level of traction. To increase the amount of traction, cleats have been designed for the wheels. The wheel cleats are made of titanium so that they are durable and lightweight. These cleats mount directly to the wheel and not only provide more traction and engagement with the floor. The BAKA robot had a similar concept that proved to be extremely beneficial when driving on the competition floor. Shown below is a rendering of the wheel cleats that will be used to improve the battle bot's traction.



Wheel Cleats *Electric Skateboard Wheel*

To secure the wheel to the frame, a steel key will be fabricated that will pilot into the wheel and frame. The intent of the wheel key is to lock the wheel in place without the possibility of the shaft rotating. The shaft key has a clearance hole for a 5/16” bolt to run through it that will be secured with a flanged nut on the outside of the wheel. The side walls of the frame will have a cutout for the key and a cutout for the wheel wires to run through. A concern that was mentioned during the 2nd club presentation the UHMW walls deforming around the cutout of for the shaft key. To provide an additional support to the UHMW walls, an aluminum support plate was implemented into the design. This plate is located on the inside of the frame with a cutout for the shaft key to run through. There are through holes located around the cutout with through-holes for plastite screws that mount to the frame. This plate also runs into the frame’s lap joints for additional support and prevents the plate from rotating. In preparation for the NHRL competition, spare parts have been ordered for the drive train assembly in case robot needs repaired.

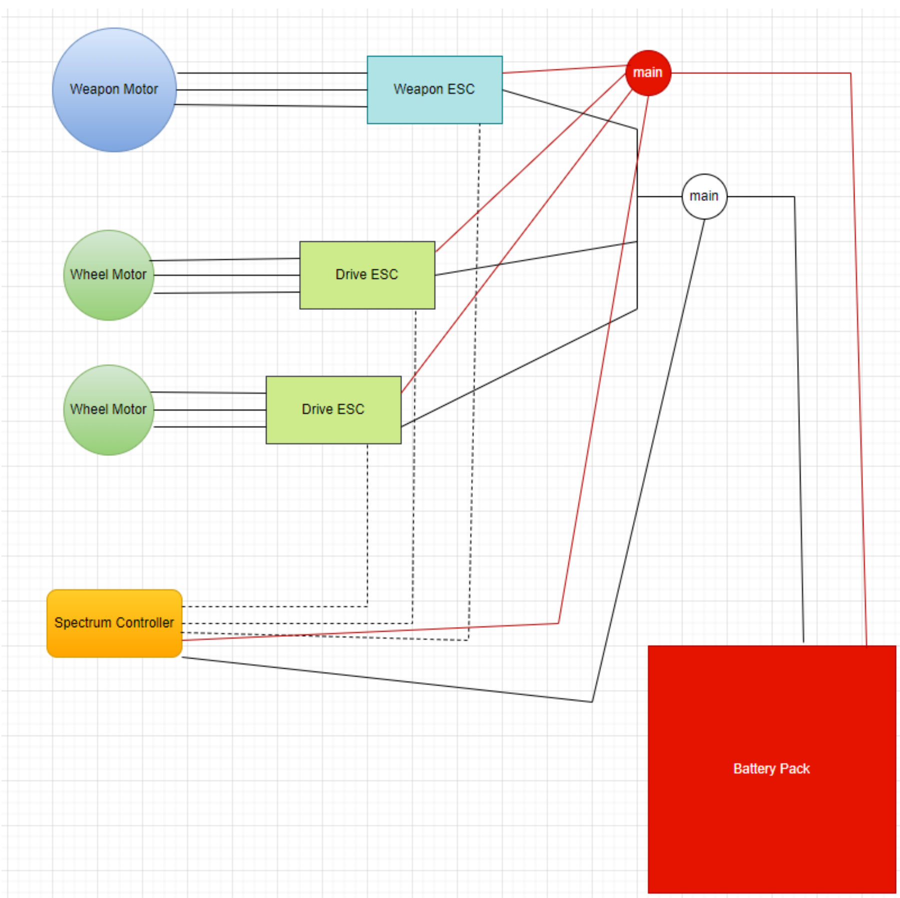


Wheel Assembly Exploded View

Electronics

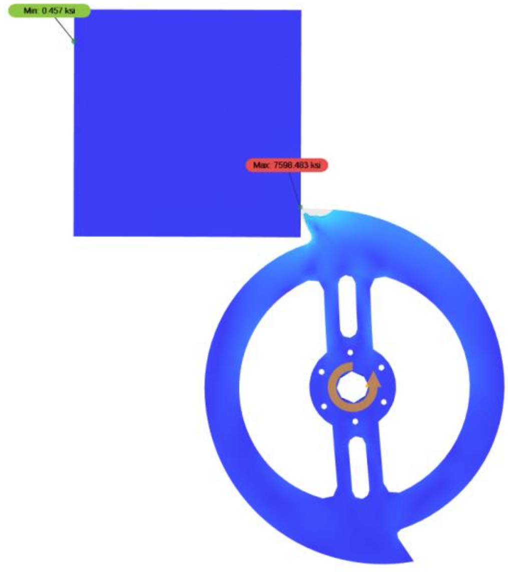
The team will be given a standard component package of electronics from the University of Cincinnati Combar Robotics Club. This makes it easy to bring spare components that each team can exchange if necessary. The package consists of a BA-3520 970 kv weapon motor, two Tempest-2814 850 kv drive motors, and a selection of standard XT60 connectors and wiring. The package will also include a ESC for each of the motors, a radio receiver, and a 1550 mAh 6S Lithium Polymer battery. For BRRT, the team has made plans to not use the Tempest 2814 drive motors and instead use the electric skateboard wheels ordered online. These wheels are internal hub motors which allows for more space inside the robot to arrange wiring and other protection.

Now for wiring the robot, the weapon motor will connect to the weapon ESC, the two wheels will connect to their own drive esc, and these three motors are connected to the spectrum controller. This spectrum controller sends the signal from the handheld controller to the esc's and gives them the power they need at any instant. All of these are then connected to the battery to ensure everything has power to run the system. But before everything reaches the battery, we installed a "kill switch" per rules of NHRL. This switch will be located at the end of the wire harness near the battery. The "kill switch" is made up of two connectors completing the circuit of electricity, but one of the XT60 connectors can be removed, cutting all power from flowing into the robot. This switch needs to be easily accessible after the fight is completed in order to easily turn off the robot.



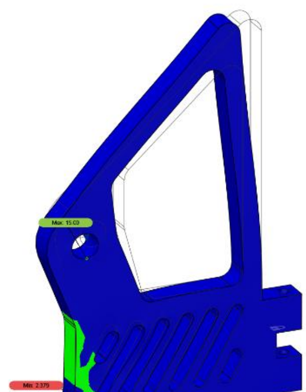
Electronics Wiring Diagram

Stress Analysis and Safety Factor



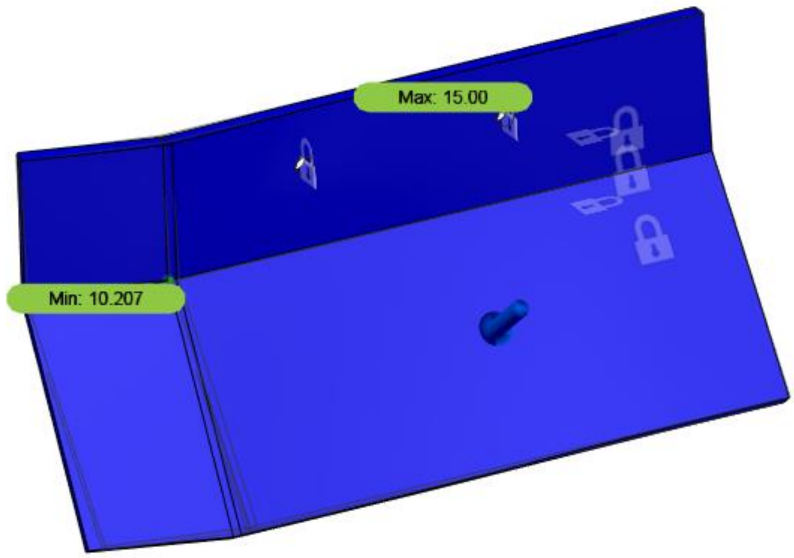
FEA of Weapon

Based on the dynamic FEA, the maximum stress is over 8,000 ksi. The yield strength of AR500 steel, the material the weapon is manufactured from is 180 ksi. The FEA shows that the concentration of stress is generally isolated at the tip of the weapon that impacts the opponent. The image above shows in blue the areas of the weapon that are subject to less than 90 ksi of stress. Based on the experience of previous bots, it is expected for the tip of a weapon to be worn down significantly quicker over time than the rest of the body of the weapon. Based on this information, the team is comfortable in assuming that the weapon will be able to withstand the impacts it will be subject to.



Force Simulation w/ Safety Factor Upright

Looking at the stress analysis of the new uprights, it shows that there is a max factor of safety of 15 but a low factor of safety at 2.379. For the final design it is determined that this number is far too low and will continue to improve and update these uprights to have a larger factor of safety of closer to 8. This will probably include extending below where the weapon sits to the bottom of the frame and making the cutout holes smaller. The slight overhang of the weapon shaft hole shows the stress point of the uprights and where the upright wants to buckle. Recreating or redesigning this upright to have material going to the floor below the weapon bolt hole will stop this buckle point in the design and give a more rigid structure overall.



Force Simulation w/ Safety Factor Plow

The force simulation for the flow includes a 70lbf load located at the center of the plow. 70lbf was calculated to be roughly 10% of the total ideal force transfer capability of BRRT. Because force transfer in these bots is generally very inefficient, 10% was determined to be an acceptable amount. The max stress was calculated to be roughly 20,000 psi, giving a safety factor for the plow of 10. This safety factor is very good and believed to be sufficient for the possible impacts the bot could face in competition. The two plow pieces being welded together have a chance at breaking at the weld, but there is no way for a simulation test on welded pieces in Fusion 360.

Fabrication

The final design of the robot was intended to be easily manufacturable. Aside from the off-the-shelf components, all parts were designed to be 2 dimensional. The carbon fiber plates will be manufactured through CNC Madness, and all designed components, other than the weapon and cleats, will be manufactured through SendCutSend. These manufacturers will be responsible for machining the overall profile of the components from one plane. DXF files were generated for all fabricated components to send to the manufacturers for quotes which were incorporated within the project budget. The cleats for the wheels and weapon were both waterjet cut at 1819 Innovation Hub. The group will then drill and tap all required holes to cut costs. The plow design requires AR500 steel to be welded which will be performed at Victory Parkway Campus. All components will be inspected once they are received to ensure that they were manufactured to the specified tolerances.

Aluminum Plate(s) Fabrication

The top and bottom aluminum frame plates were purchased through SendcutSend. To reduce costs and fit within the club's budget, the aluminum was ordered without the tapping operations for the mounting holes. Thus, the mounting holes were sized for the appropriate tap drill diameter so the plates could be tapped at Victory Parkway Campus. The intent of the aluminum plates was to mount the top and bottom covers, along with the UHMW frame. Due to the design of the frame, it was crucial that the tapped holes were entirely perpendicular to the plate's top and bottom surfaces. Furthermore, if the holes were tapped at an angle, it could prevent the frame components being able to mate with one another. To ensure that the taps were perpendicular, a fixture was used at VPC for tapping the plates. The plate was simply loaded into the fixture with a locking mechanism to prevent the plate from turning when performing the tapping operation. The corresponding tap was loaded into the fixture with a set distance (in the z-axis) away from the plate's top surface. Other concerns addressed before tapping the aluminum included the tap breaking within the part, and the internal threads becoming damaged from poor tapping technique. As students learned from the machining operations course, using tapping fluid was a vital resource when tapping any solid material. After all mounting holes were tapped, an M5 button head cap screw was used to test the quality the female threads.

Wheel Lock & Shaft Fabrication

The wheel shaft locking mechanism was ordered to be 1/8" aluminum. When these components were received, it was apparent that they were machined out of UHMW. This was problematic because the whole intent of the component was to support the UHMW frame when securing the shaft, preventing it from any amount of rotation. It was later decided that titanium would be a more appropriate material for this component due to it being lighter and its durability. To ensure that the part was machined with a high level of precision, a two axis CNC milling machine was used to manufacture the components. This was performed at the Victory Parkway Campus and the team had to program each step of the milling operation. This machine was also used to machine the steel wheel shafts. The steel shafts were machined a day before the wheel lock plates were machined, and they were inspected to ensure they would fit within the booster board wheel cutouts. The fit was tight, as expected, which prevented from any form of slippage. After the first wheel lock plate was machined, the team tested the fit with the steel shaft itself. The fit was looser than anticipated and required a different tool radius to provide a snugger fit. Therefore, the tool was swapped out for an end mill with a smaller radius that could provide a more precise cutout. The new end mill tool proved to be effective, as the fit between the wheel shaft and the locking plate was a tight fit and prevented any amount of rotation. The other fit that required testing was the fit in between the UHMW back wall and side wall. The shaft locking plate was designed so it could sit flush against the side wall and have it keyed into the frame's joint at the rear side of the robot. This would provide additional support from the plate from rotating and becoming worn down over time.

Machine Used to Fabricate Wheel Shaft & Locking Plate

Weel Shaft & Locking Plate Installed on Side Wall

Pulley Fabrication

BRRT usesg two main pulleys to drive the weapon to immense speeds of around 170 miles per hour. To achieve this speed two pulleys were selected, the motor shaft pulley is a 10-tooth pulley, and the weapon stack pulley is a 30-tooth. With this ratio of 3:1, the robot can reach these speeds. After receiving the pulleys, the 30-tooth pulley needed to be prepped for drill and tapping as this will hold the weapon stack together with the weapon, pulley, spacer, and bearings. Using the mill at the Victory Parkway Campus laboratory, the pulley was drilled out completely at a diameter of 2.5mm to allow for tapping to 3mm. After it was drilled, it was then tapped using a kit the team had purchased to tap the holes for 3M screws to secure the stack together. The process of drilling and tapping the pulley was easy because the pulley is made out of aluminum, but that meant when putting it into a vise to not tighten too much or the pulley will start to bend at the edges and maybe allow for belt slippage.

Drilled and Tapped Weapon Stack Pulley

Plow Fabrication

For the main source of defense on BRRT, an AR-500 plow is made to place on the front of the robot to absorb impact from other robots, but also to push other robots into the weapon to initiate contact. The plow was made into two sections, so each upright has a plow connected to it. Each section had a top and bottom piece of AR-500 steel and were manufactured to be bent. The bottom section has a tab on the side of the piece to allow for bending around the bot's edge and to be aligned with the top piece for welding. The top piece has two 3mm holes to allow for mounting to the front of the bot using nutstrips that will be attached on the underside of the top aluminum plate. The two pieces are then heated and bent at a 15-degree angle, using a hydraulic press, to align perfectly with one another around the edge of the bot. They are then welded together at the seam and before installation a tab was created by the team to go on the underside of the plow. The purpose of this tab is to be welded to the plow and use 3M screws to screw into the uprights. The plow now being attached to the front of the robot using nutstrips and being attached to the uprights using the AR-500 tab allows for a lot more rigidity in plow assembly. This is the main side of defense for this bot, it needs to be secured to the frame or it will be useless in a fight.

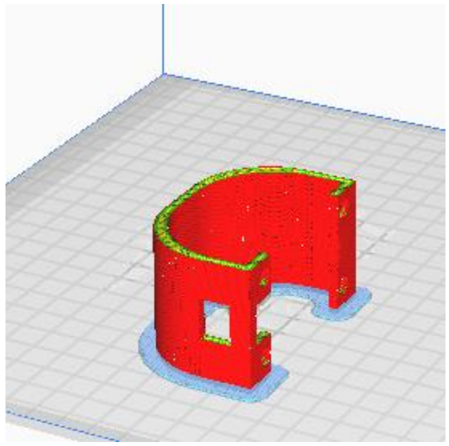
Top and Bottom Piece of Front Plow

Hydraulic Bending of Front Plow

Welded Tab on Plow Connecting to Upright

Weapon Motor Wire Divider

Once the weapon motor was installed to the bot's upright, the group saw that the wires for the weapon motor were just hanging loose within the bot. This means that at any point the wires could rub up against the motor hub. With the motor spinning at great speeds, a high level of temperature was expected to be concentrated around the motor hub. This could potentially melt or damage the cable jacket and expose the conductors. To prevent this, the group designed a small component that would guide the motor's wires away from the hub. The weight of the bot was already coming close to 12lbs, so using a low-density material was crucial. The wire divider component was to be located within the bot, protected by the armor and covers, so using any high strength material wasn't too important. A lightweight, rigid structured material that was selected was PLA +. This was convenient because it could be printed within an hour, and the group could print backups. Holes were drilled out in the UHMW uprights, so that an M4 screw could go through the wire dividers mounting face & the upright, with a M4 nut on the backside. Overall, this added a minimal amount of weight to the bot which was acceptable due to the alternative TPU covers. The wire divider had a cutout located on the side that could route the three cables through it to connect to the wire weapon ESC. The fit was fairly tight to prevent any slack rubbing against the motor. The PLA was printed at an infill percentage of 75% with a triangular infill pattern. The group tested its strength before finalizing the design, simply by clamping it to a vise and performing a stress test. The only time this component failed was during the 3rd match against the Ambiguously Dynamic Duo. This competitor was a mutli-bot flame thrower duo that has been known for scorching other bots. After the drive system went down in that match, the bot became immobile where the body took consistent flames from two different directions. Because PLA has relatively low melting temperatures (when compared to the other materials used), the wire divider became deformed and was partially melted.



Wire Divider Sliced in Cura Ultimaker

Weight Optimization

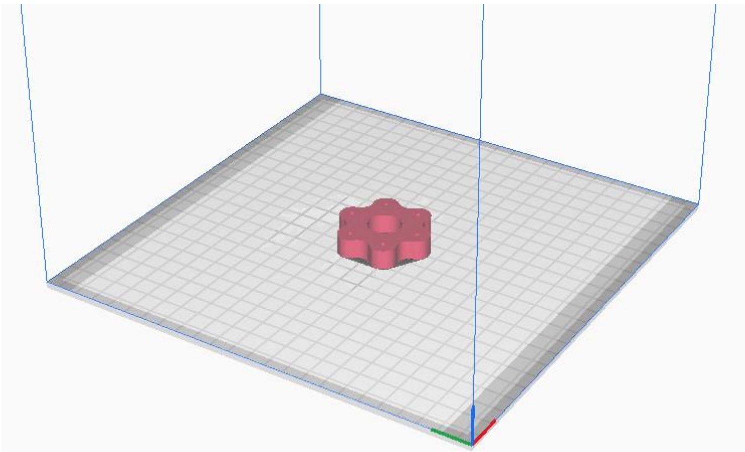
The team anticipated that the weight of the bot would be roughly over 12lbs before fabrication, which is why the design incorporated slots within the rear UHMW wall. It was later determined that the rear UHMW wall would provide more protection with pocketed out sections within the wall. This was performed using a vertical mill machine with a ball end mill tool. The team pocked out approximately 80% of the back wall, bringing the thickness from .500" to .375". This wasn't a major concern, because the majority of the collisions at competition are located towards the front of the bot, where the plows are positioned.

Pocketed out UHMW Backwall

Another way to reduce weight was to substitute the carbon fiber plates with TPU based covers. These covers were intended to be mounted onto the bottom and top aluminum plates to protect the internal electronics during competition. For example, if the bot were to flip over, the covers would provide protection from immediate contact with the internal components. TPU has a much lower density than carbon fiber and allows for more flexibility. Thus, reducing the chances of the cover cracking or shattering within the bot. This reduced the weight of the bot significantly, as there were four (4) carbon fiber covers initially. Furthermore, another component that was able to be replaced by TPU was the UHMW spacer used in the weapon stack assembly. With the TPU being printed at 75% infill, it provided the structural integrity required while reducing the weight. Overall, substituting these components with TPU saved approximately .09lbs. Before each match at the NHRL competition was initiated, each team had to weigh in to verify that their combat robot was under 12lbs. Each time the bot was weighed, the total came out to roughly

11.97lbs. This provided enough room to add heavy duty rubber bands to the wheels. The rubber bands were wrapped around the wheel several times, ultimately increasing the wheel diameter by a small amount. One of the biggest issues the group faced was maneuverability due to the size of the wheels, so any increase within the wheel's diameter improved the driving.

TPU Weapon Spacer installed on Spinner



Weapon Spacer in Cura Ultimaker

Final Assembly

Having completed all fabrication and modifications necessary, the team worked together to assemble the battle bot BRRT. There are 8 steps to fully assemble BRRT.

1. **Motor Mount.**

The very first step of the assembly is placing the motor into the right upright. Using the machined motor mounting plate and screwing that into place using M3 screws, the weapon motor can be mounted and locked into the plate and the upright. Also attach the 10-tooth weapon pulley to the motor shaft and lock that in with the included setscrew for the pulley.

2. **Wheel mounting**

To make the assembly easier, the wheels need to be mounted to the side UHMW walls first. With the machined holes for the wheel shaft and separate holes for the wires, the machined wheel lock and frame attachment needs to be placed first. Feed the weapon lock into the UHMW wall slot and the frame lock together. Then taking the wheel bolt, push this through each section and into the wheel. Once this is done, the wheel lock nut can be placed at the end of the wheel to ensure the wheel is secured in place. The wheels should already be equipped with the special cleats which are mounted to the end of the wheel using M3 screws.

3. **Plow Mounting**

The front plow of the robot is attached to the two uprights in the center of the frame. Take the two uprights and the plow and screw in the plow to the uprights using the tab on the undersection of the plow. Using M3 screws, nuts, and washers the plow can be attached to the uprights.

4. **Assemble the Frame**

Now moving onto the assembly of the frame. To assemble the frame the top and bottom aluminum frame are needed along with the UHMW side walls and long back wall. Line up the plates with the holes in the UHMW walls to then push through 4 M5x60mm bolts and screw them into the bottom aluminum plate. Then take the two uprights and the smaller backplate and place those in the middle of the frame. Once lined up, then place two more M5 bolts and screw them into the bottom of the frame. Now looking at the front of the robot, the plow needs to be attached. The two holes in the front of the plow allow it to be attached to the nutstips on the underside of the top plate of aluminum. Using M3 screws, screw in the two plow sections using lock tight to ensure a secure connection. The main frame assembly is now assembled and ready to insert the weapon stack.

5. **Weapon Stack**

Next, take the weapon stack and place it in the front section of the frame. There are 2 washers needed at each end of the weapon stack touching the uprights. To make sure the weapon stack is stable and to not allow for more horizontal movement from the weapon, 2 more washers need to be placed on each side of the weapon stack. To assemble this, first put the weapon belt on the 30-tooth pulley. Attach the belt to the weapon pulley and force the weapon stack into place. Then, push the weapon bolt through the first upright. Then add the needle thrust bearing and first washer before the weapon stack. Push through the weapon stack and before going through the next upright, add the other washer needed for the correct stack setup. Then the bolt can be pushed through and the nut for the bolt can be used to tighten the stack. Tighten the weapon stack down but be sure to not tighten too much to allow for the weapon to spin freely.

6. Bottom Plates

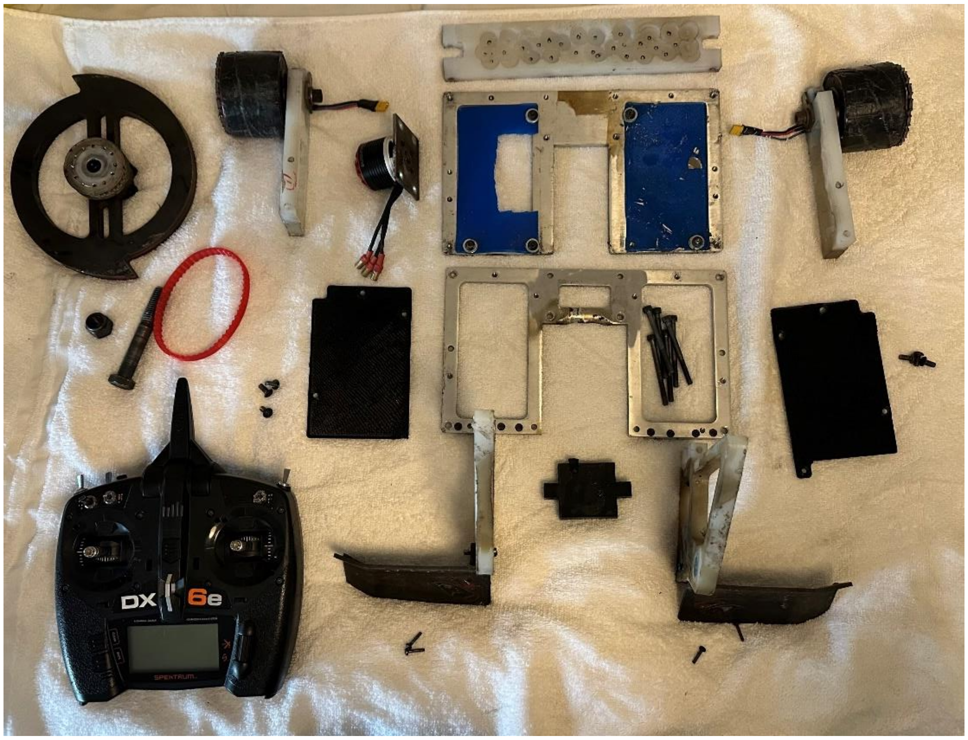
Now take the TPU bottom plates and screw those into the bottom aluminum plate using the M5 screws along with two washers to make sure no thread of the screws is sticking out of the plate. This blocks any debris from coming into the robot and allows the electronics to sit on a platform, but also save weight compared to the bottom plate being fully aluminum.

7. Electronics

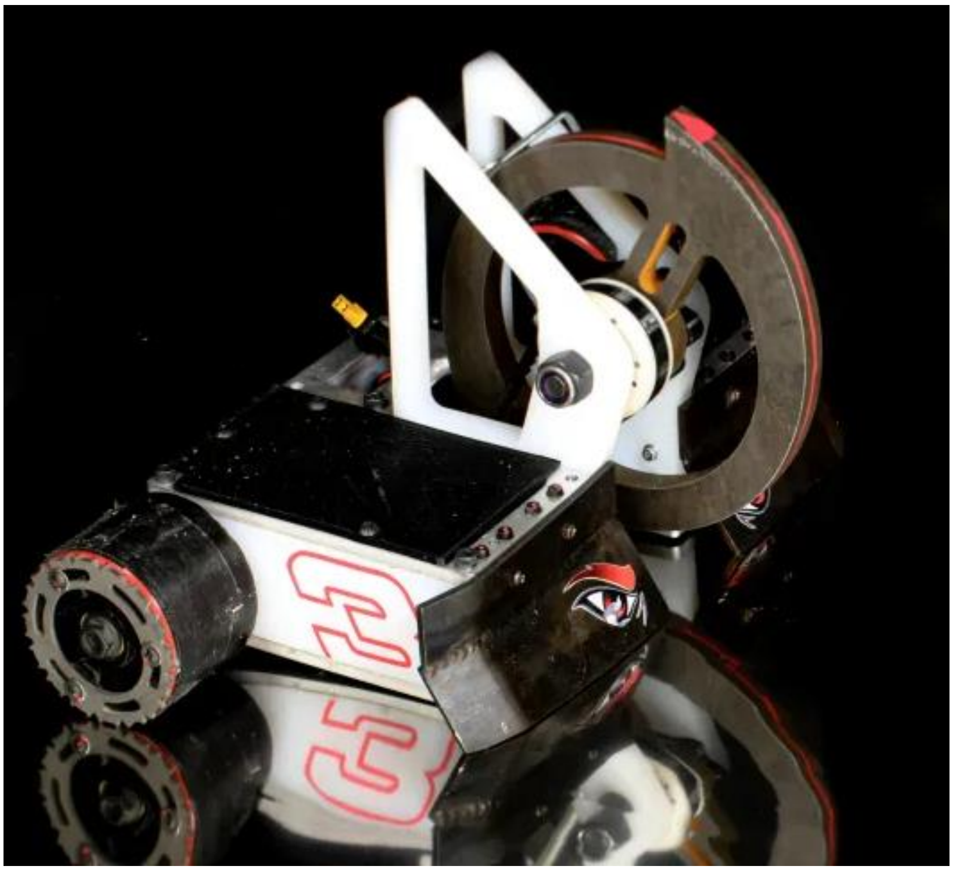
The electronics of the robot are not mounted or secured in the robot to save weight. The team did figure out the best configuration for where the wires should reside. At this time the major electronics can be added to the robot. First, connect the wheel wires to their respected ESCs and use the wires from the ESCs to connect to the receiver, the ground and the power connection. After this, take the weapon motor wires and connect them into the larger weapon ESC and place this at the front fright of the robot. The weapon ESC has the same connection as the wheels in that they connect to the receiver, the ground terminal, and power connection. Finally, the receiver and all the power connectors are connected to the battery kill switch. This kill switch is connected to the power and ground connection and then connected directly to the battery. Once the kill switch connection is secured the bot can be powered on. The battery will be placed on the left side of the frame and laying on its side. The wheel ESC wires, and weapon ESC wires will be placed in the back middle section of the frame to stay away from the weapon motor. The kill switch will stick out the opening in the back of the top aluminum frame to allow for easy access when need to turn on or off the robot.

8. Top Cover Plates

The final step for assembling the robot is attaching and securing the top cover plates. Take the two TPU cover plates and line up the threaded holes in the aluminum. Then using the short M5 screws, screw down the TPU top plates to close the robot. Before fighting a weapon lock needs to be placed over the weapon spinner to allow no movement so after adding this, the robot is ready to fight.



Disassembled BRRT BattelBot



Fully Assembled BRRT at Competition

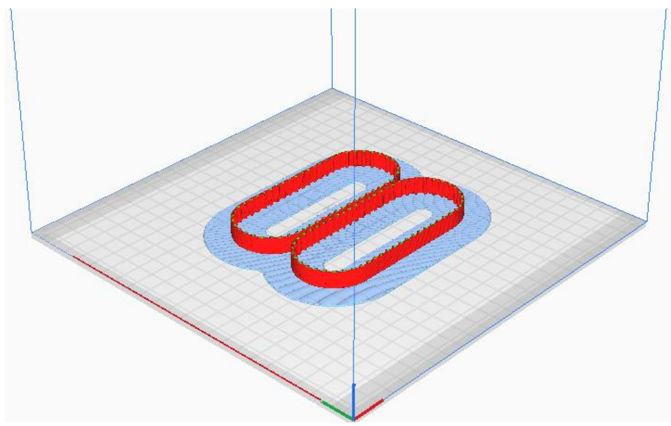
Modifications

Printed Belts

After assembling the battlebot, the team decided that that the XL series timing belt that was originally ordered wouldn't be sufficient. The belt ordered was incredibly tight, which ended up slightly bending the weapon motor shaft. This brought up concerns of the shaft potentially breaking after a short time of running the motor. Furthermore, the center-to-center distance between the motor shaft and the weapon pulley was off by a slight amount than anticipated. With the competition date being so close, it was determined that a new belt couldn't be ordered in time to replace the original belt. Therefore, it was decided that a TPU printed belt could be a worthy alternative. TPU has a high level of flexibility while having a decent level of tensile strength. It would be able to stretch to mount to each pulley without deforming the belt in any way. The STEP file was downloaded from the vendor, McMaster-Carr, so the team could alter the model to the proper size. This was a last resort option, as no teams within NHRL have ever used a TPU printed belt for competition.

The TPU belt was sliced through the CURA slicing program and printed through the Creality Ender V3. It took many attempts to be able to print the right belt. There are many settings in CURA that were altered to be able to print a flexible belt that would be able to withstand the constant stress of the pulleys running. The first setting that was addressed was the infill percentage. Initially, three belts were printed, one at 50% infill, 75%, and 100%. The team used a fishhook scale to secure the belts and applied a heavy amount of force to see if they could withstand it. The 50% infilled belt snapped immediately, while the 75% infilled belt became deformed after a heavy load was applied. However, the 100% infilled belt withstood its original form. The second test performed was the printing pattern for the belts. Like before, three belts were printed at 100% infilled, however this time, one belt was printed with a cubic infill pattern, one with a triangular infill pattern, and one with a linear fill pattern. After testing, it was determined that the linear infill pattern performed the best under high amounts of stress. Once the belt was tested on the bot, with the motor powered on, the belts snapped almost immediately. The belt was replaced, and the next test had the same outcome. After inspecting the belts, it was apparent that the belts were breaking at the same location where the seam was located. When a 3D printer prints a component, it starts each layer at the same location which provides a 'weak point' within the belt. To resolve this, the printer was set to print at a 'random z location', meaning that each layer was printed with a different starting point. The belts printed with a random Z location didn't break when running the motor. After running the weapon for 3 minutes, the belt was removed to inspect for any wear on the material. The teeth had

TPU Belt with Worn Down Teeth



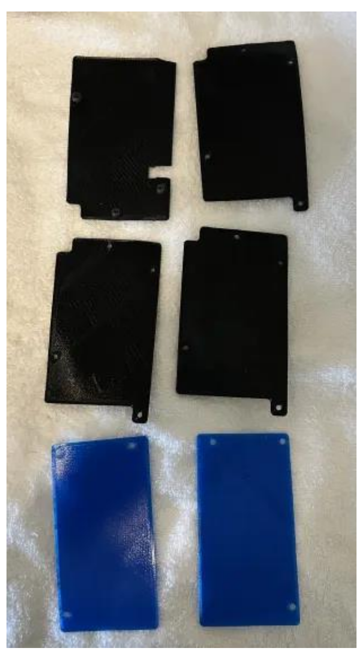
TPU XL Timing Belt Sliced in Cura Ultimaker

Z Seam Alignment Setting in Cura Ultimaker

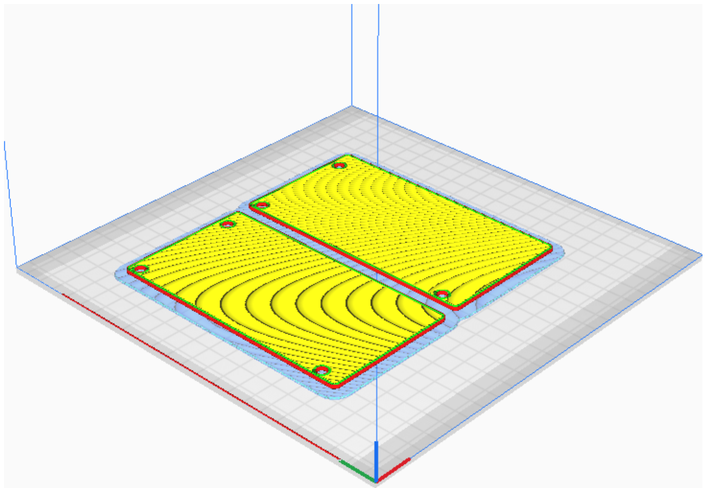
Infill Density & Pattern Setting in Cura Ultimaker

TPU Covers

The alternative covers used were made from TPU which required testing to ensure they could protect the internal components. There was initial talk about making the covers out of PLA because of how hard the material is. However, if the robot were to take a hit on the top side or bottom, the covers could crack due to their brittleness. Furthermore, the group anticipated that most of the impact would be concentrated towards the sides and front of the bot, so there was minimal concern with implementing the different material. Because of this, there was some margin for testing different infill percentages and patterns. The initial idea was to print them with 10% infill with linear pattern, starting each layer with a randomized Z-location (similarly to how the belts were printed). With the covers being approximately 2mm thick, the lowest infill percentage that was tested was 75%. Covers were printed at the following infill percentages with a linear infill pattern: 75%, 85%, and 100%. The covers were tested by inserting them into a vise while applying a high level of clamping force to determine how easily they could be deformed. While the covers were secured in the vise, the group took the ends of the covers to twist and bend them. Overall, each cover was able to return to its original state after roughly 20 seconds. The next test that was performed was intended to determine the durability of the center of the covers. These covers were to be mounted to the top and bottom of the bot, so the strongest areas would be located around the outside, where the aluminum frame was positioned for support. Thus, the weakest point of the cover was located near the center. The group mounted each type of cover to the bot, as if it were fully assembled. Then, the group took Phillips' head screwdriver and increased the amount of towards force at small increments. The cover with 75% infill snapped within the first 30 seconds when a reasonable load was applied. However, after putting a large amount of force onto the center of the cover, the 85% and 100% infilled covers remained undamaged. This eventually led to the decision that the 85% infilled cover would be sufficient for its purpose in competition while removing an additional small amount of material that could save weight.



TPU Top and Bottom Covers



TPU Frame Covers Sliced in Cura Ultimaker

Shown below are material properties that were taken into consideration when substituting TPU for carbon fiber:

Carbon Fiber Properties:

Density		1.15 - 2.25 g/cc
Elongation at Break	0.430 - 11.0 %	0.430 - 11.0 %

TPU Properties:

Density	0.140 - 1.36 g/cc
Elongation at Break	4.20 - 1000 %

Testing

Driving

There were two major issues experienced when testing the drive system of the bot. The first issue that was experienced related to the plow digging into the ground. Because there are no front wheels on this bot, the plow was intended to slide across the ground being pushed by the two drive wheels in the rear. Initially the bot was struggling to drive because the plow would get caught or dig into the ground, causing the bot to become stuck. This was able to be quickly remedied by grinding the bottom of the plow so it would sit flatter on the wooden floor.

The second major issue was caused by wheels not gaining enough traction. Despite the attempts made to increase the traction of the drive wheels with the floor, the wheels would quickly lose traction causing the bot to spin out of control. When trying to drive the bot forward, the wheels would begin to spin forward but would slip and not grip the floor. One side would have some amount of traction and cause the bot to spin in circles. This made the bot very difficult to control. This was also able to be remedied by changing the throttle curve so that the wheels would not spin as fast at low speeds, allowing the cleats to gain traction before the wheels would spin out of control.

Weapon Testing

Testing the performance of the weapon was difficult for all teams at the University of Cincinnati. There was no test cage at Victory Parkway Campus, and it was against the rules to test the weapon at any location that hasn't been certified, due to safety concerns. Because of this, all teams had to wait to test their weapon until the group arrived at Norwalk. This was worrisome for most, because if testing the weapon had poor results, there was only so much that could be done in time for competition.

Once the team arrived at Norwalk, the electronics were installed, and the bot was taken over to a testing cage where the entire robot could be powered on. There were also concerns about the performance of the TPU belts, as it has never been done before by any team in the UC Combat Robotics Club. Once the group passed the safety requirements, the bot was loaded into the test cage. The group intended to supply only 50% power to the weapon and let it run for roughly 30 seconds. Ideally, if the weapon and belt could continue running after the 30 seconds passed, the power would increase to 100% exponentially. This was done because going from 50% to 100% power instantaneously could damage the belt.

The motor was powered-on, and the weapon started to spin up. Even outside of the test cage, the sound of the motor was extremely loud, with a high pitch squeal, which was to be expected. Once the weapon reached full speed, the group let it run for a few seconds. The main concern was the potential damage to the TPU XL timing belt teeth. Typically, XL timing belts are reinforced with fiberglass, with the teeth covered in a nylon coating. Because the TPU cover had no finish, the group expected there to be some amount of wear. Once the bot was removed from the testing cage, the team immediately disassembled the bot to inspect the teeth. After inspecting the teeth, the group noticed that they presented only a small amount of wear which was considered a great success. This is because a different belt could be used for each match, meaning that the belt would only have to survive roughly 3 minutes.

The other concern with testing the weapon was how it would impact the driving. It was expected that there would be some sort of gyroscopic effect to the robot moving due to the rotational torque of the weapon. Before even testing the gyroscopic affect, the group had been working with eh struggles of driving. This was because the plow was so low to the group, and the majority of the mass was located towards the front, meaning that the bot drove at an angle. After driving around in the test cage, with the weapon motor powered on, the bot provided much better results. The gyroscopic effect of the weapon raised the front of the bot due to the weapon constantly spinning in an upward direction. Furthermore, this provided more engagement for the cleats and wheels to get a grip within the wooden floors, increasing the overall maneuverability of the bot.

The last test that was to be performed in the test cage, was determining the performance of the weapon during impact. NHRL provided a few old, beaten-up bots that were no longer usable. These bots were placed in the testing cage for any teams to hit. A new belt was installed so the wear could be inspected afterwards. The intent was to hit the test bot at two different speeds. One impact would be with the motor at 50% power, while the other hit would be with the motor at 100% power. Once the bot took a hit at the test bot at 50%, the bot flew back a foot and was powered off for inspection. The teeth showed more sign of wear; however, it could have continued for some amount of time before the teeth were completely unusable. The next time the bot hit the test bot at 100%, the results remained consistent. There was no noticeable sign of any increased wear on the belt between impact at 50% and 100%, which was promising.

Test Cage at NHRL Norwalk Competition

Controller Programming

The controller was tested using two different control methods for driving the bot. Conventional drive mode where the left stick is forward/reverse, and the right stick is turn left/right and tank mode where the left stick controls forward/reverse of the left wheel and the right stick controls forward/reverse of the right wheel.

Controller Setup for Conventional Drive

When setup for conventional drive mode, the controller operates the bot as shown in the picture above. The left stick forward causes both wheels to spin forward so that the bot drives forward, left stick back causes both wheels to spin in reverse and thus the bot to drive in reverse. The right stick left and right causes the bot to turn left and right respectively. This configuration allows the bot to spin in place by simply moving the right stick left or right and leaving the left stick centered. Programming the controller to operate in this configuration was slightly more difficult due to the need to mix the input from the right stick into two outputs for the left and right turn.

Controller Setup for Tank Drive

In tank drive mode, the controller operates the bot as shown above. The left and right stick moved forward or backwards controls the left or right wheel to move forward or reverse respectively. This method of programming the controller was simpler due to not needing to mix a single input to control two outputs. However, it was found that this method of controlling the bot was more difficult. Ultimately, the controller was programmed for conventional drive mode due to this reason.

Fight Results

Fight #1

For the first fight of the tournament BRRT was facing off against a two-bot duo called Creature. The main bot of this duo was a larger flipper bot similar to Free Shipping mentioned in the current state of the art. The role of this bot was to try and get under their opponent and flip them over so that others can't move and therefore cannot compete. The other bot in the duo was a small horizontal spinning robot with two-wheel drive in the front and the weapon located on the back. After loading BRRT into the arena, the bots drove to their colored corner to wait for the signal to begin fighting. Once the fight began all the bots drove to the middle of the arena to begin the fight. BRRT was able to get a couple hits on the horizontal spinning bot before the weapon motor shaft was completely ripped off and the weapon stopped spinning. At this point the robot can still earn points based on aggression, so BRRT continued to advance the opponent until they made solid contact with one of the wheels and the cover came off the wheel. This then stopped BRRT from driving correctly. At this time the team decided to "Tap Out" to stop any further damage to the robot.

The takeaway from this fight is that movement is the biggest advantage to have and if there is no drive system, then there is no way to damage or score points against the opponent. Also, the wheels of the robot are very exposed, so defense needs to be strictly enforced with the driver to make sure BRRT has the best chance of winning. Finally, the weapon motor shaft tearing could be from the XL timing belt and the torque it produces from the weapon hitting another bot. Using a different belt like a V-belt to allow for slippage is a better option moving forward.

BRRT Broken Wheel

Destroyed Motor Shaft

Fight #2

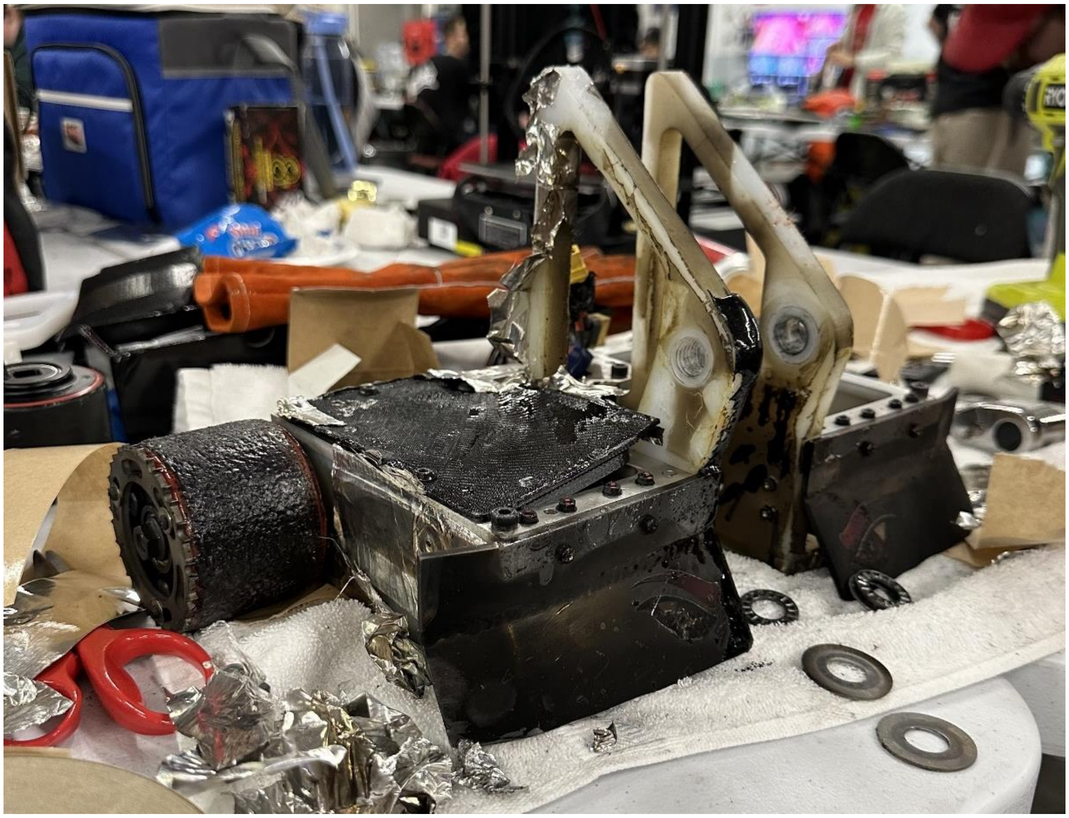
The second fight of the event for BRRT was going to be against a robot called Avalanche. This is a father son duo who have been working on this same bot for many years. Avalanche was expected, in early predictions, to advance very far in the tournament with a good shot at winning the 12lb division. The team decided to walk over and talk to the Avalanche team and get a good look at the robot before fighting. Avalanche uses a 4340 steel vertical drum spinner to inflict damage against its opponent. As the teams loaded the robots into the arena, the referees instructed each team to turn on their robots and remove weapon locks before closing the doors. While this was happening BRRT was turned on and ready to fight while Avalanche was having technical difficulties turning on. After some time not being able to power on, the referees gave Avalanche a 60 second period to try and get their bot working. After this time expired, BRRT was awarded the win by TKO.

Knowing that your bot is going to turn on and perform when asked is the big takeaway from the second fight. Having a total understanding of your robot is something very beneficial going forward to help fix issues in the future.

Fight #3

For the final fight of the tournament, BRRT was set to face Ambiguously Dynamic Duo, two flame throwing robots. After receiving the news of having to face this flame thrower duo, the team decided to cover BRRT in aluminum tape that another team from UC had brought with them. With most of the robot being plastic there needed to be some kind of protectant against the flames of the duo. After covering the robot in the aluminum tape, the team was ready to face their opponent. After setting the robot in the arena and going through the initial checklist it was apparent that something was not right with BRRT. The robot was not able to move as easily it did in the other fights before. By the time of this realization, it was too late, and the match had begun. The two robots quickly saw that BRRT was not able to move around, and they soon corned it. Once in position the two robots turned on their flames and proceeded to engulf BRRT in flames. Trying to move and do something against the opponent, BRRT tried to waddle back and forth but to no avail. The team decided to “Tap Out” to try and save the robot from being unsalvageable from the flames. After taking BRRT back to the builders table, the team found out that the bottom aluminum plate was put on backwards and the button head screws from the bottom covers were not allowing for any clearance for the wheels to drive.

The takeaway from this fight is to understand the unpredictability of robots each team is going to face. Designing a robot that is able to fight against any opponent is something everyone strives for but is very hard to implement. Scoping out the opponent is also very important to make any small changes necessary to give you the best chance of winning the fight. The other takeaway is the minor details of the robot. To perform well at these competitions everyone in the team needs to be concentrated and dedicated to the robot to ensure everything goes to plan.



BRRT After Fight#3

Suggestions For Improvement

V-belt Potential

The XL series timing belt used for competition brought up various problems throughout this project. Firstly, the center-to-center distance between the weapon pulley & motor shaft required a more precise fit than V-belt would provide. Because the center-to-center distance was slightly off, it forced the group to improvise with the TPU timing belt. V-belts are designed with a V-shaped cross section that allows it to fit within the grooves of the pulley, providing more flexibility. Another issue seen with the timing belt used was the teeth wear. After roughly 30 –45 seconds of the weapon motor running, the teeth of the timing belt started to wear down. Furthermore, the grip between the pulley's grooves and the belt's teeth became extremely weak over time and was at times ineffective. Using a V-belt would allow for slippage within the pulley system and would serve as a better shock absorber solution. Lastly, V-belts respond to sudden speed changes more effectively than an XL timing belt would. When the weapon motor is turned on, it speeds up to 50% almost instantaneously, which can damage the timing belt. There were three University of Cincinnati teams that used timing belts to drive their weapon, and every team had issues throughout the competition.

Drive ESCs

The drive ESCs used for this bot were running firmware intended for use in RC cars. While this is a standard for most bots in the competition, BRRT would have likely benefited from firmware intended for RC rock crawlers. Just prior to the competition, a new firmware was released for the drive ESCs used that is intended to be used for rock crawlers. This firmware allows the ECSs to operate at a slower top speed and provide more torque without causing the wheels to slip. This would have likely helped the issue of the wheels spinning up too quickly causing the wheels to slip. Given more time to test this, the improved firmware would likely be a better option in the future.

Cleats

The cleats in their current state were somewhat ineffective because they did not provide much clearance over the diameter of the wheel. In the future, making the cleats bigger would allow the cleats to get more bite into the wood surface of the floor and provide more traction. The image below shows the cleats in their current state with limited clearance.

Titanium Cleats on Wheels with Limited Clearance

Urethane Wheels

Another method of increasing traction with the arena floor would be to use urethan wheels. The advantage of the boosted board wheel utilized on BRRT was the internal hub design. This means the motor is built into the wheel. This is advantageous as it simplifies the electronics required for the drive motors and eliminates the need for a gearbox. The major downside is the plastic wheels are not great for traction on wood. It was later discovered that the outer plastic part of the wheel could be easily removed. In the future, removing the outer plastic of the wheel and using the internal motor hub to make a urethane mold would be better for traction, and allow the wheels to have a larger diameter, providing more ground clearance.

M3 Hardware

One of the biggest challenges when assembling the bot was handling the small hardware. The group had used M3 screws for mounting the cleats to the wheels, mounting the plow to the nut strips, and mounting the inside portion of the plow to the UHMW uprights. The reason behind the M3 screws being used for mounting to the nut strip was due to the amount of available space in the front side of the bot underneath the top aluminum plate. The M3 nut strip had a perfect fit which is why the group decided to proceed with the M3 hardware. All these M3 screws were button head cap screws, so there was less depth in the hex cutout on the screw heads which presented several issues. Firstly, there were a few occasions where the screw head became stripped even with a small amount of torque applied. Every time a screw was installed, the group ensured that the Allen wrench was completely perpendicular to the screw head, preventing the screw from being tightened at an angle. Tightening a screw at an angle increases the likelihood of the tool slipping and damaging the hex geometry, making a more rounded shape. Even while following correct practices, the M3 screws began to strip once a higher level of torque was provided. The plow and cleats were essential to the bot's success, so it was important that they were properly secured so that they didn’t fall off during competition. This added unnecessary time to the assembly process because screws needed to be drilled out to remove them, and overall became a hassle.

The other problem that the team experienced with the M3 screws was the cleat being mounted to the wheels. During the first match in competition, BRRT took a side hit from the competitor, Creature. Creature’s weapon hit the cleat at an angle, to which the cleat completely ripped out of the wheel and flew across the cage. Damage was to be expected, however once the match ended, the wheels were inspected to determine if they could be reused in the future. The team noticed that three of the M3 screws remained in the wheel female threads. The heads of the screws flew off when the cleat was torn off, but because the threads of the M3 screws remained inside of the wheel, it meant that the booster board wheel couldn’t be used in any future matches.

Weapon Motor Shaft

The shaft of the weapon motor was made of stainless steel. It was discovered that this material is not strong enough for this application. In the future, the weapon motor shaft should be replaced with a hardened steel shaft to ensure its durability over time.

Conclusion

After working to design and assemble BRRT over the span of 8 months has been nothing short of surreal. From modeling and designing the first concepts to seeing BRRT drive around the arena and do real damage is something our team will never forget. After this competition and leaving the tournament with one win and two losses, the team now understands what it takes to create a deadly battlebot. This experience has been very fun but also very informative on this exciting hobby that our team wants to keep competing in. We want BRRT to be a top ranked competitor some day and from this project and club, we are equipped with enough knowledge to get us there. We attribute our success in this project to time management, group cohesiveness, and practical engineering.

Time management is something every team needs for success. This being a senior design project and having strict deadlines, planning out the time to work on the project and getting everything done on time is very important. Starting this project back in August 2023, the team would meet once a week with the entire UCCR club to discuss battlebots. From here the team decided how to split up tasks evenly to ensure each person had enough time to work and that the parameters would be complete and submitted on time. These regular meetings helped us grow closer as a team because everyone knew what needed to be done and when. Also, with our group having very similar class schedules, this allowed for meetings outside of the club if the group was running behind or to bounce ideas off each other for designing. Closing in on the competition date is really where the time management side of the project began. Making sure the team has everything done to be able to compete is the main part of senior design. This time management skill was slowly worked on as a group, but by the end of the project our skill helped with the team dynamic, the value of work put in, and completing the tasks in a timely manner.

The group's cohesiveness is another big key to success within this project. Not picking a leader of the group puts the responsibility on everyone to finish their designated work and complete it on time to not slow down the project. If there were any problems, we always gave room for discussion within the group to decide what is good or bad within the design and what needs to be changed. We used a majority rule, but still allowed for any case to be made if there is a problem. This allowed the members to always know that their voice can be heard in the group and that no idea is dumb and should be talked about. As a group we all roughly knew each other's strong suits and weaknesses, so this made it easy to split up work between the three of us. This allowed for better, more complete work to ensure our robot does the best in the competition.

Finally, having a practical engineering approach takes away the pain and struggle of finding new ways to engineer parts. Our main idea behind BRRT was to create a battlebot with little manufacturing to ensure a quick build and setup time because our competition was very soon after the start of the semester. Creating mostly 2D parts allowed us to make simple modifications to meet our specs and be assembled right into our robot making it easier for everyone involved. Also knowing and using 1819 Innovation Hub and the Victory Parkway laboratory made it very easy to decide what parts need to be fabricated and what's the best place for it.

Over the two semesters working on this project, our team kept good time management, group cohesiveness, and used practical engineering to help us build a one of a kind batlebot. The group is very proud of the overall work and the results from the competition, now know how to change BRRT to be a better battlebot and are open to competing again.

Project Management

Proposed Budget

This project will be funded by the University of Cincinnati Combat Robotics club and its sponsors. UC Combat Robotics club required each team to request a budget through a formal presentation. The budget was determined by the material cost to build one robot, cost of all additional components needed for competition, and a margin of error cost. The cost of each purchased component was recorded, and the cost of all the fabricated components were determined through sending quotes to SendCutSend & CNC Madness. All hardware, pulleys, and belts will be ordered from McMaster Carr. Shown below is the master BOM to build one robot.

	Component	Qty.	Purchase U/M	Cost per Unit	Total Cost (USD)
Weapon	Weapon Motor	1	EA	74.99	74.99
	Plate - Motor Mount	1	EA	4.8	4.8
	BHCS M5 X 20 BO - Mounts Motor	4	PK(100)	13.75	13.75
	XL Belt	1	EA	8.25	8.25
	Pulley 30	1	EA	13.2	13.2
	Pulley 10	1	EA	21.33	21.33
	AR500 Material (Spinner) 12" x 12"	1	EA	64.9	64.9
	Needle Roller Bearing	2	EA	6.69	13.38
	Needle Thrust Bearing	2	EA	3.91	7.82
	Thick Washer for Bearings	3	EA	1.23	3.69
	Weapon Bolt	1	EA	3.65	3.65
	UHMW Spacer	1	EA	12.21	12.31
	Washer - Weapon	1	PK(25)	10.31	10.31
	LockNut (1/2"-13)	1	PK(10)	4.76	4.76
Wheel Assembly	Wheels	2	EA	58.89	117.78
	Wheel Bolts	2	PK(10)	8.4	16.8
	Washers	2	PK(100)	5.67	11.34
	Flanged Locknut	2	PK(10)	5.41	10.82
	Wheel Cleats	2	EA	11.42	22.84
	Steel Key/Shaft (Machined)	2	EA(12ft)	12.1	12.1
	Aluminum Spacer (Machined)	2	EA	1.45	2.9
Frame Assembly	Frame Backwall	1	EA	19.78	19.78
	Frame Sidewall	2	EA	13.09	26.18
	Top Plate	1	EA	38.3	38.3
	Bottom Plate	1	EA	38.3	38.3
	Plate- Backwall	1	EA	10.56	10.56
	Upright - LH	1	EA	28.56	28.56
	Upright - RH	1	EA	25.72	25.72
	Carbon Fiber Plates	4	EA	47.18	188.72
	Plow - Bottom	2	EA	43.76	87.52
	Plow - Top	2	EA	43.76	87.52
	Plow Side Plate	2	EA	8.43	16.86
	Nut Strip	4	EA	5.22	20.88
	M5 Hardware (BO) Frame	12	PK(25)	7.38	7.38
	M5 Hardware for covers	12		-	-
	M3 Hardware (BO) Plow	4	PK(100)	9.37	9.37
Electronics	Receiver	1	EA	34.95	34.95
	Battery	1	EA	31.99	31.99
	Weapon ESC	1	EA	21.79	21.79

Total Material Cost	$1,146
Spare Components	$250
Margin of Error	$150
Proposed Budget	$1,546

This preliminary budget is based on previous senior design bots and their expenses. An allotment of $1,550 will be used to design, manufacture, and assemble the bot. It was determined that the total material cost was roughly $1,150. The spare component cost was estimated to be $250, which accounts for a spare belt, battery, wheels, hardware, etc. The group determined that $150 is to be allocated for miscellaneous expenses will be used to cover any amount over $1,550 in the event that more funding is needed.   In conclusion, the proposed budget for the BRRT Battle Bot is $1,550.

Actual Budget

After receiving all ordered parts, the team had zero cost for manufacturing or spare components missing from the design. The spare components section of $70 is from 3D printing material for the top and bottom covers along with the belts we used. Also included in this cost are tools needed for tapping 3mm screws. These taps are not readily available and took some time to find, but after buying this tool the team was able to tap the aluminum plates and the weapon pulley. Overall, the team was under the proposed budget by about $330 without needing too much money for spare parts or even going into the margin of error.

	Component	Qty.	Purchase U/M	Cost per Unit	Total Cost (USD)	Purchased From?	Manufacturer PN
Weapon	Weapon Motor	1	EA	74.99	74.99	Badass Power	BA-3520-650
	Plate - Motor Mount	1	EA	4.8	4.8	SendCutSend	N/A
	BHCS M5 X 20 BO - Mounts Motor	4	PK(100)	13.75	13.75	Mcmaster Carr	91239A233
	XL Belt	1	EA	8.25	8.25	Mcmaster Carr	6484K222
	Pulley 30	1	EA	13.2	13.2	Mcmaster Carr	1277N771
	Pulley 10	1	EA	21.33	21.33	Mcmaster Carr	1277N735
	AR500 Material (Spinner) 12" x 12"	1	EA	64.9	64.9	SendCutSend	N/A
	Needle Roller Bearing	2	EA	6.69	13.38	Mcmaster Carr	5905K334
	Needle Thrust Bearing	2	EA	3.91	7.82	Mcmaster Carr	5909K31
	Thick Washer for Bearings	3	EA	1.23	3.69	Mcmaster Carr	5909K44
	Weapon Bolt	1	EA	3.65	3.65	Mcmaster Carr	91268A495
	UHMW Spacer	1	EA	12.21	12.31	SendCutSend	N/A
	Washer - Weapon	1	PK(25)	10.31	10.31	Mcmaster Carr	90107A033
	Wire Divider	1	EA	-	-	3D Printed	N/A
	LockNut (1/2"-13)	1	PK(10)	4.76	4.76	Mcmaster Carr	90630A125
Wheel Assembly	Wheels	2	EA	58.89	117.78	Amazon	MAGTbvc7w4s62g
	Wheel Bolts	2	PK(10)	8.4	16.8	Mcmaster Carr	91251A596
	Washers	2	PK(100)	5.67	11.34	Mcmaster Carr	91090A110
	Flanged Locknut	2	PK(10)	5.41	10.82	Mcmaster Carr	95922A112
	Wheel Cleats	2	EA	11.42	22.84	SendCutSend	N/A
	Steel Key/Shaft (Machined)	2	EA(12ft)	12.1	12.1	Mcmaster Carr	6552K67
	Aluminum Spacer (Machined)	2	EA	1.45	2.9	SendCutSend	N/A
Frame Assembly	Frame Backwall	1	EA	19.78	19.78	SendCutSend	N/A
	Frame Sidewall	2	EA	13.09	26.18	SendCutSend	N/A
	Top Plate	1	EA	38.3	38.3	SendCutSend	N/A
	Bottom Plate	1	EA	38.3	38.3	SendCutSend	N/A
	Plate- Backwall	1	EA	10.56	10.56	SendCutSend	N/A
	Upright - LH	1	EA	28.56	28.56	SendCutSend	N/A
	Upright - RH	1	EA	25.72	25.72	SendCutSend	N/A
	Carbon Fiber Plates	4	EA	47.18	188.72	SendCutSend	N/A
	Plow - Bottom	2	EA	43.76	87.52	SendCutSend	N/A
	Plow - Top	2	EA	43.76	87.52	SendCutSend	N/A
	Plow Side Plate	2	EA	8.43	16.86	SendCutSend	N/A
	Nut Strip	4	EA	5.22	20.88	McasterCarr	REV-41-1732
	M5 Hardware (BO) Frame	12	PK(25)	7.38	7.38	Mcmaster Carr	91290A268
	M5 Hardware for covers	12		-	-		91239A224
	M3 Hardware (BO) Plow	4	PK(100)	9.37	9.37	Mcmaster Carr	91239A115
Electronics	Receiver	1	EA	34.95	34.95	ICARE	AR410 4
	Battery	1	EA	31.99	31.99	Tattu Batteries	TA-RL3-120C-1550-6S1P
	Weapon ESC	1	EA	21.79	21.79	AliExpress	BLHELI-32 BL32

Total Material Cost	$1,146
Spare Components	$70
Actual Budget	**$1,216**

Project Deadlines

These project deadlines have been set according to Senior Design due date, club presentations and design reviews, and the NHRL competition dates. These time frames were based on previous senior design club experiences and mentor recommendations. The NHRL competition is set for March 2nd, 2024. Shown below is a Gnatt chart that lays out all important project benchmarks and deadlines that have to be met. The goal of utilizing this timeline is to have the battle Bot fully prepared in February for the NHRL competition.

	Preliminary Schedule - Senior Design Capstone									
	Benchmark	Due Date	September	October	November	December	January	February	March	April
Senior Design 1	Advisor Approval	9/3/23								
	Background Research	9/15/23								
	Survey Results	9/25/23								
	Club Presentation #1	9/27/23								
	QFD - Quality Function Deployment	9/29/23								
	Final Proposal	10/10/23								
Senior Design 2	Senior Design Report #1	10/13/23								
	Club Presentation #2	10/18/23								
	Final Design	11/15/23								
	Club Presentation #3	11/18/23								
	Senior Design Report #2	12/6/23								
	Senior Design Presentation	12/7/23								
	Parts Ordered	12/15/23								
	Bill of Materials Finalized	12/17/23								
Senior Design 3	Parts Received	1/24/24								
	Fabrication	2/8/24								
	Testing	2/22/24								
	NHRL Competition	3/2/24								
	Tech Expo	4/9/24								
	Capstone Presentation	4/25/24								

BRRT Gnatt Chart for Senior Design #1 - #3

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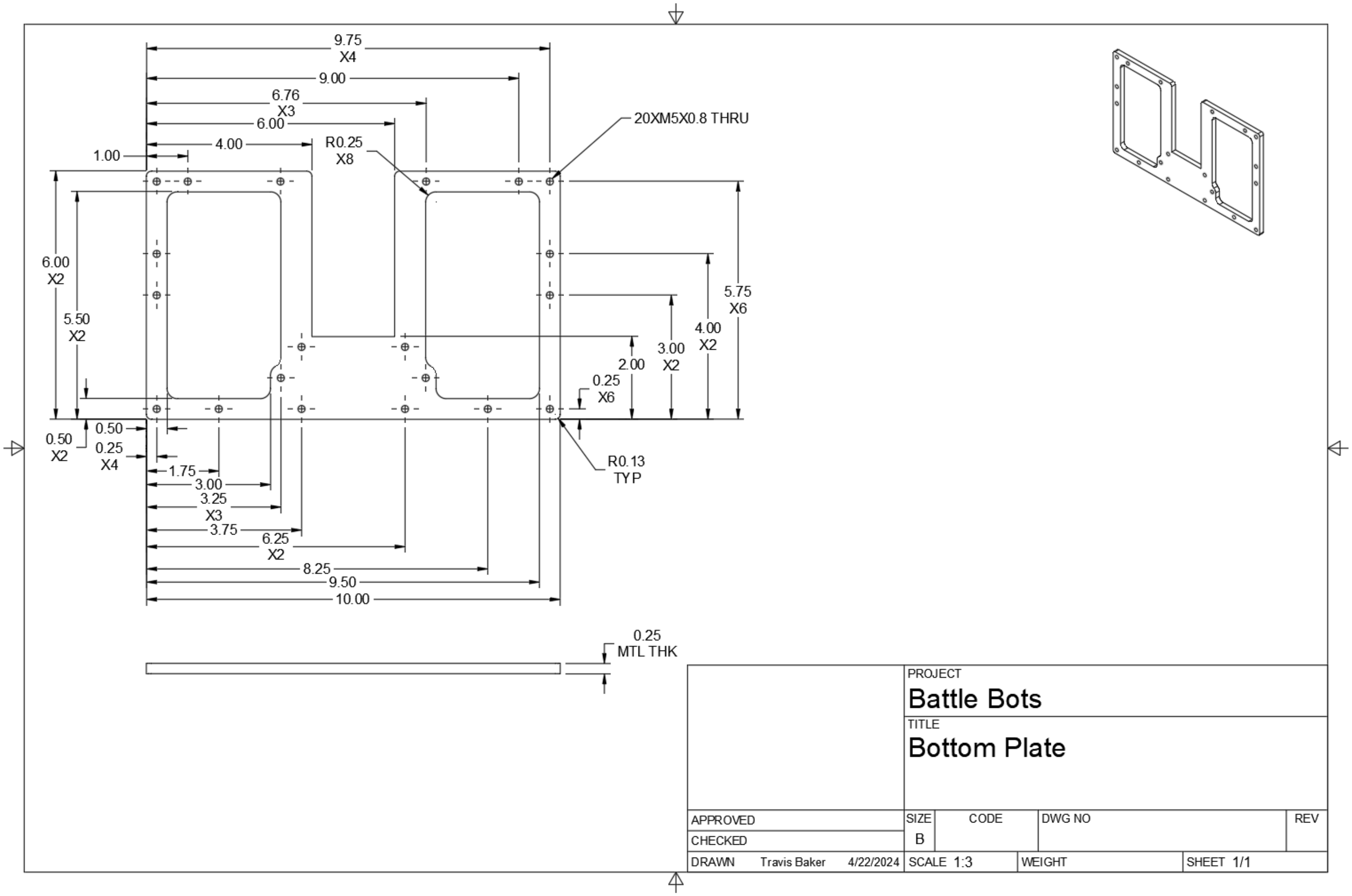
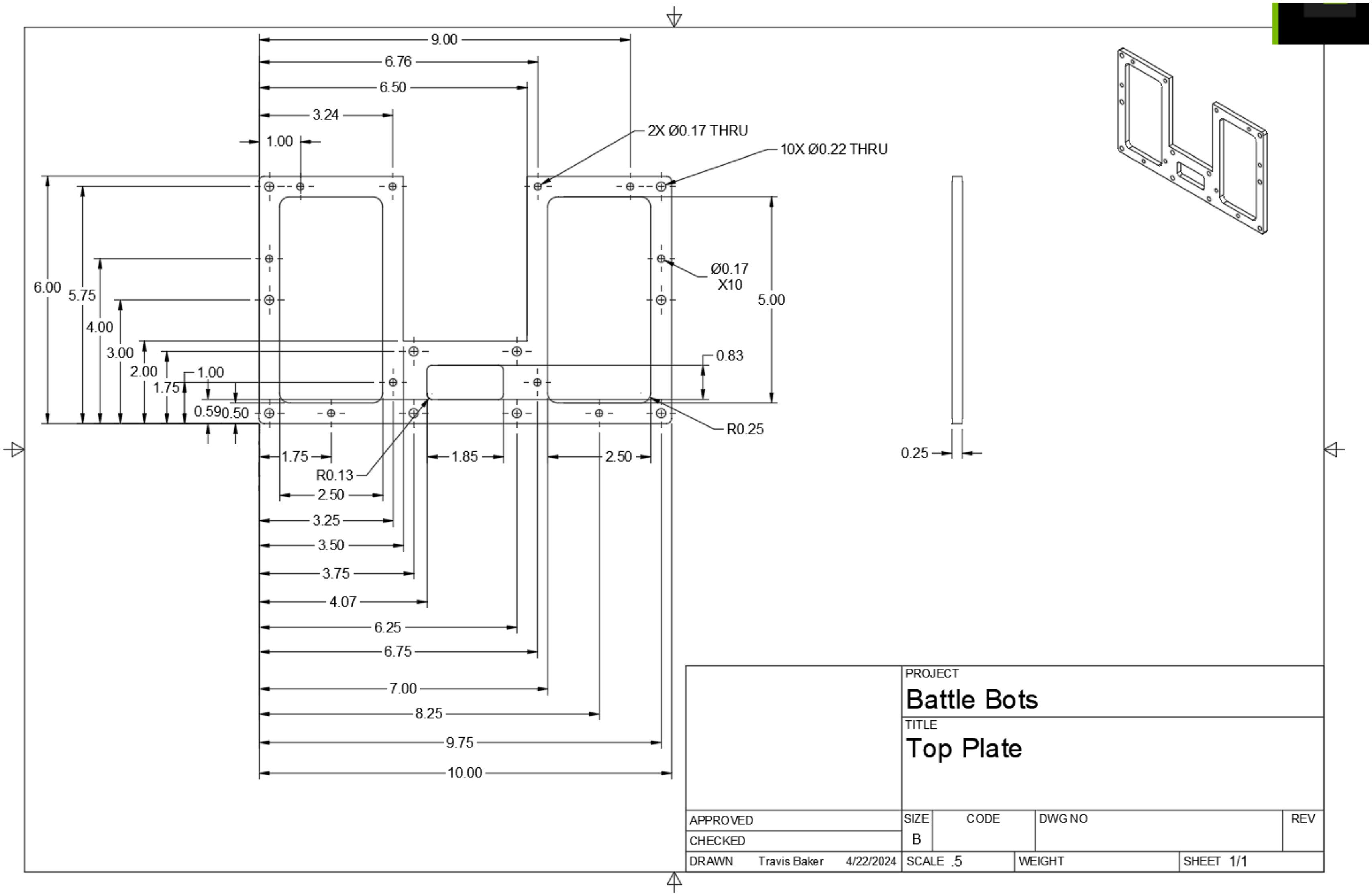
Appendix

A. Part Drawings

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4/22/2024
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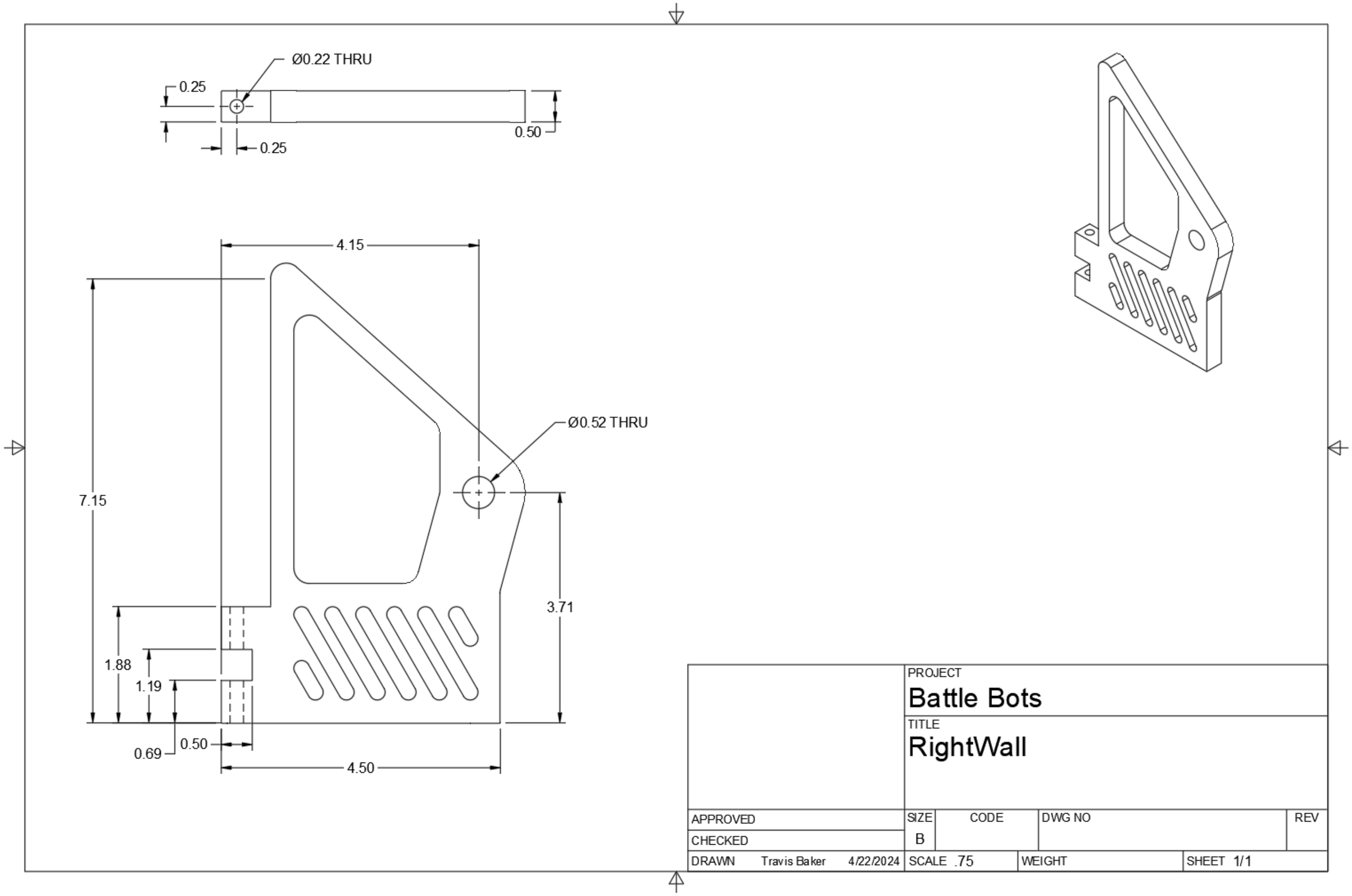

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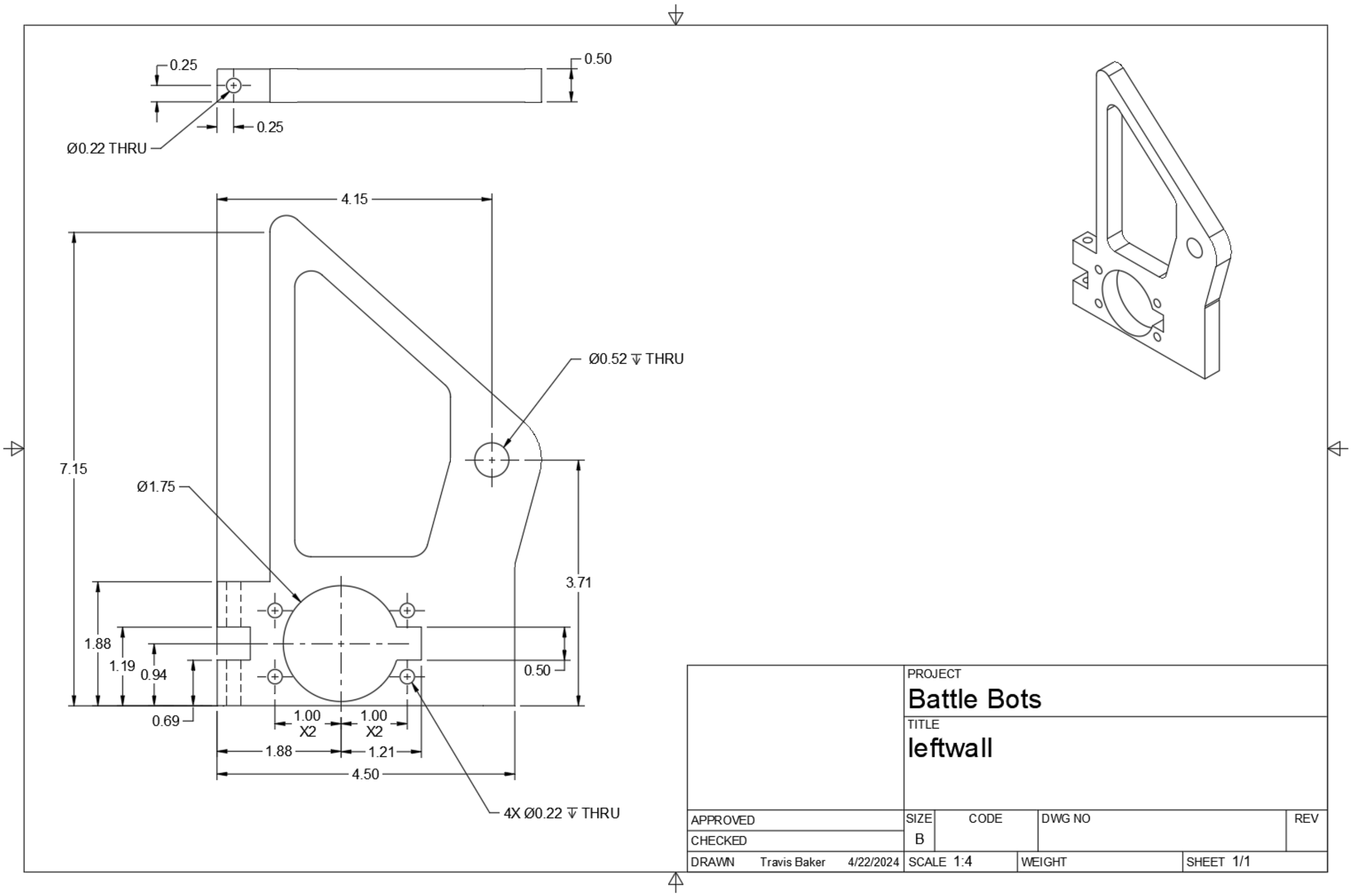
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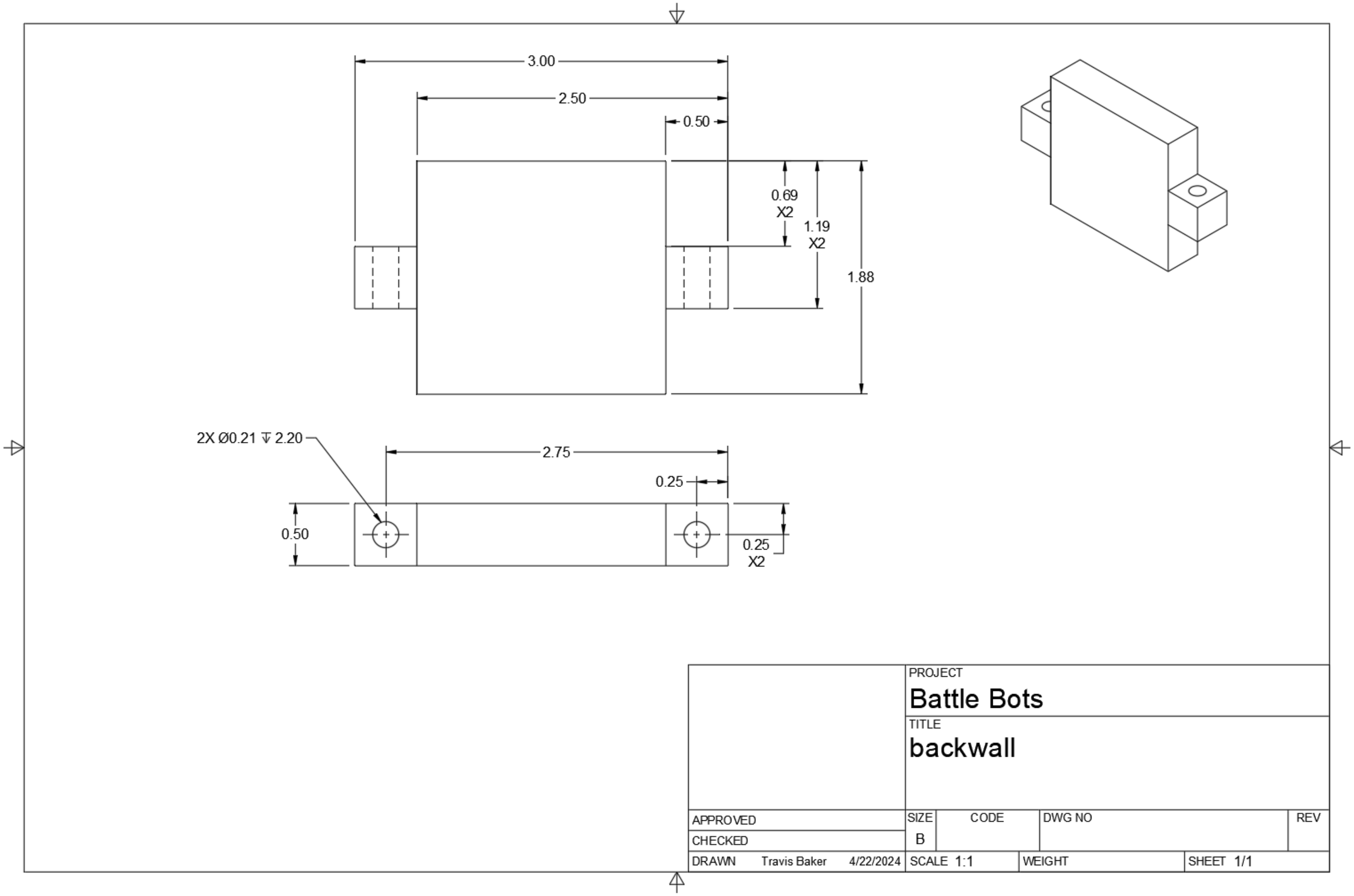
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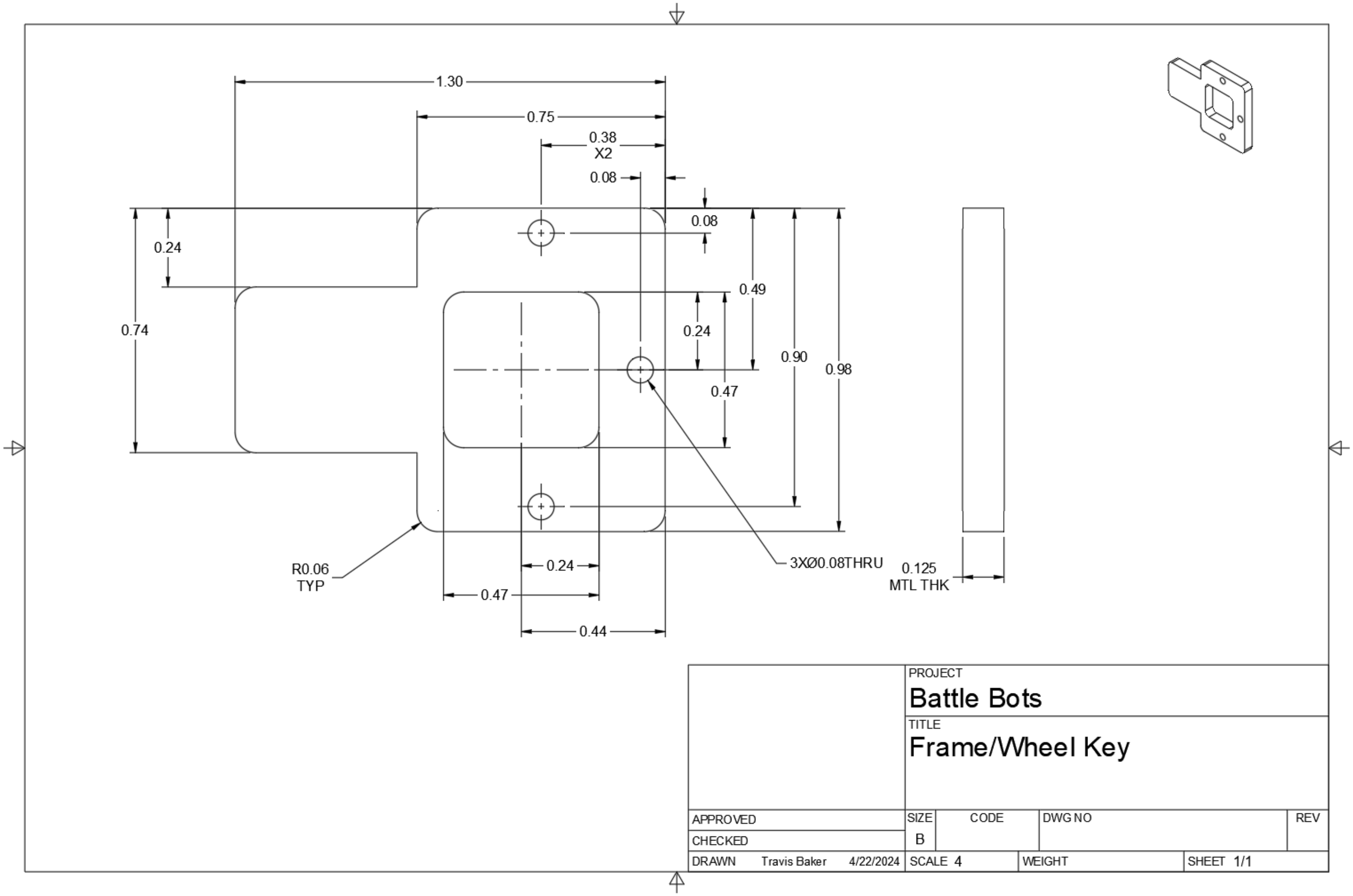
WEIGHT
SHEET 1/1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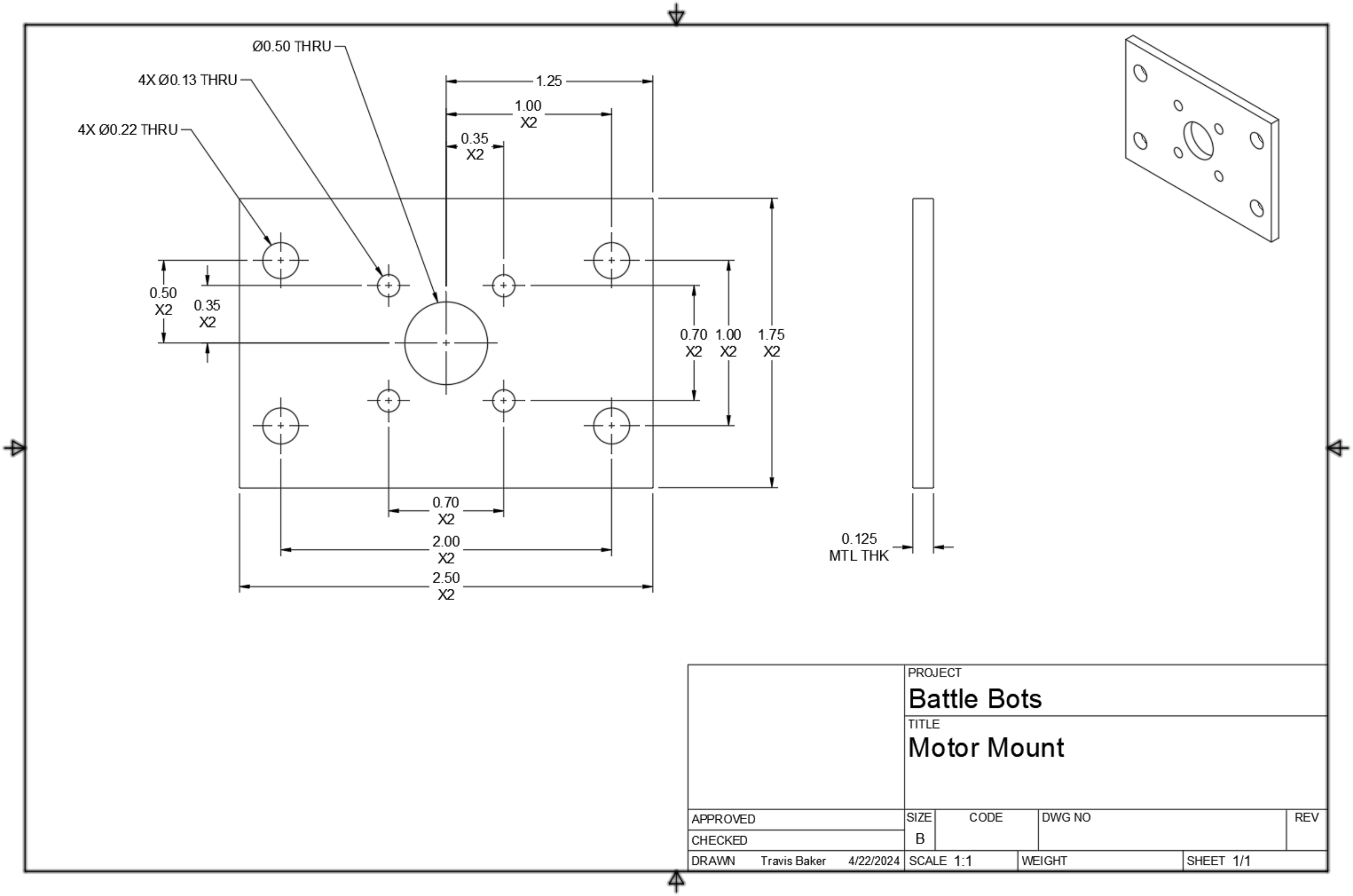
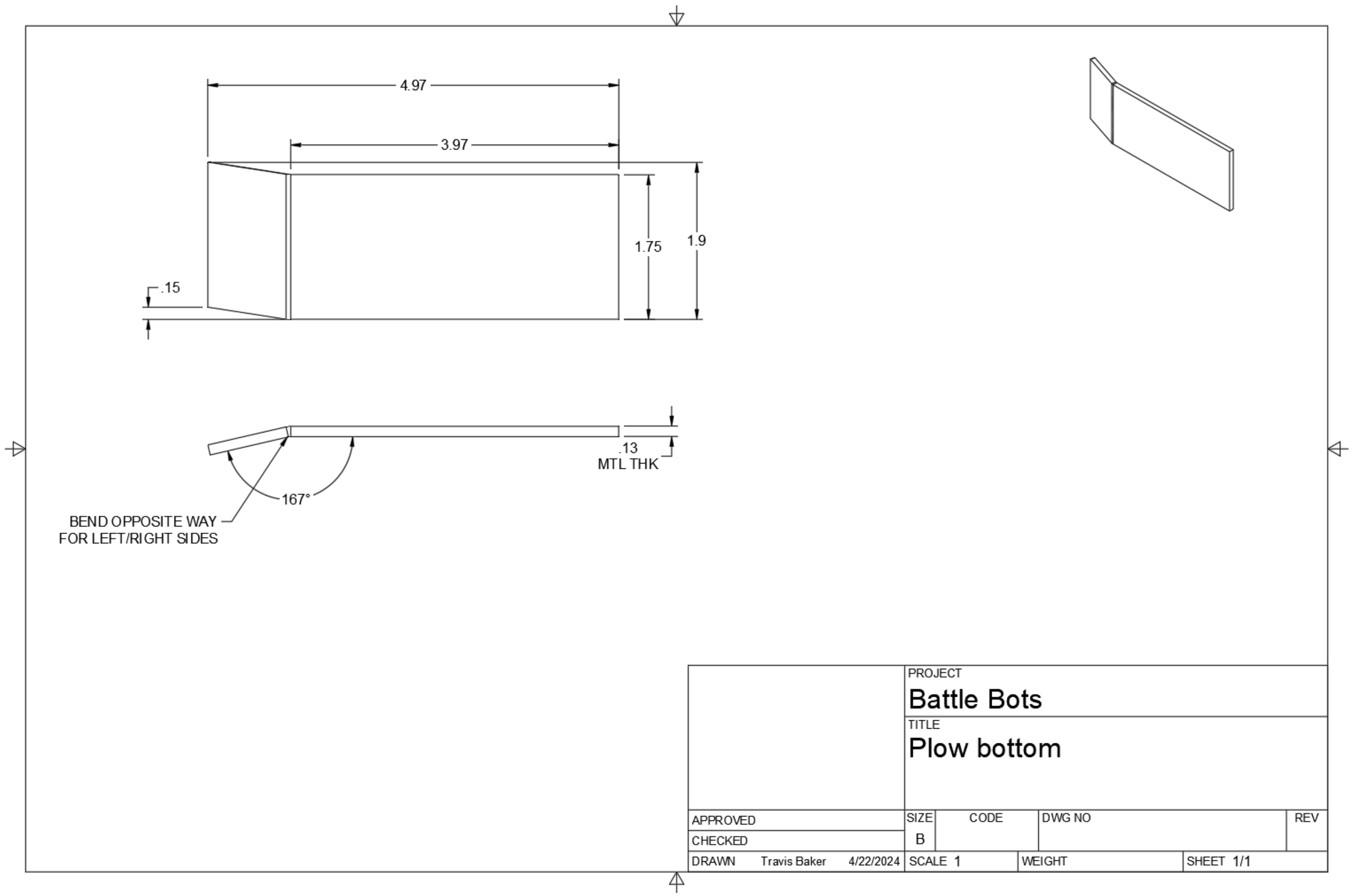
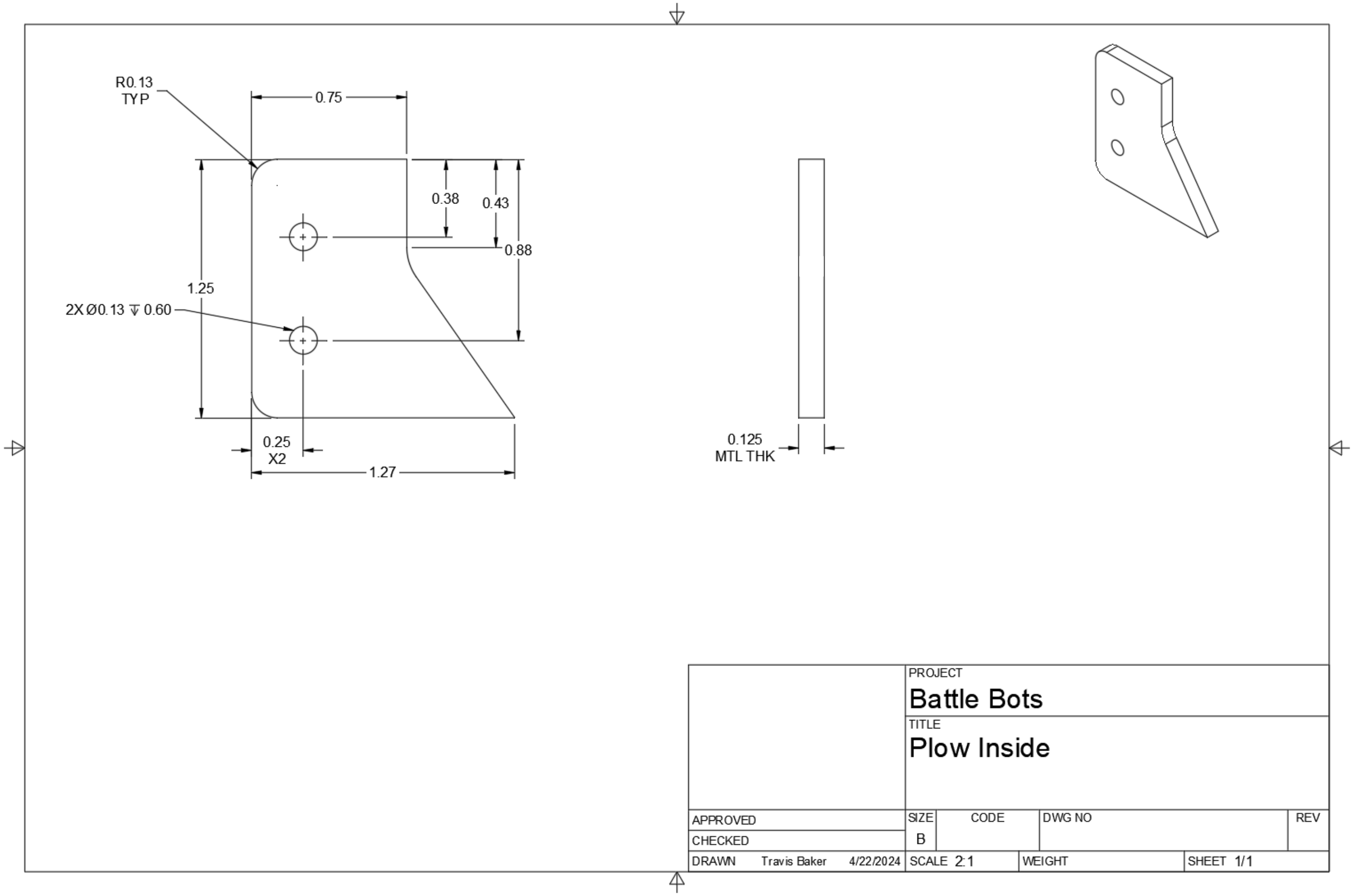
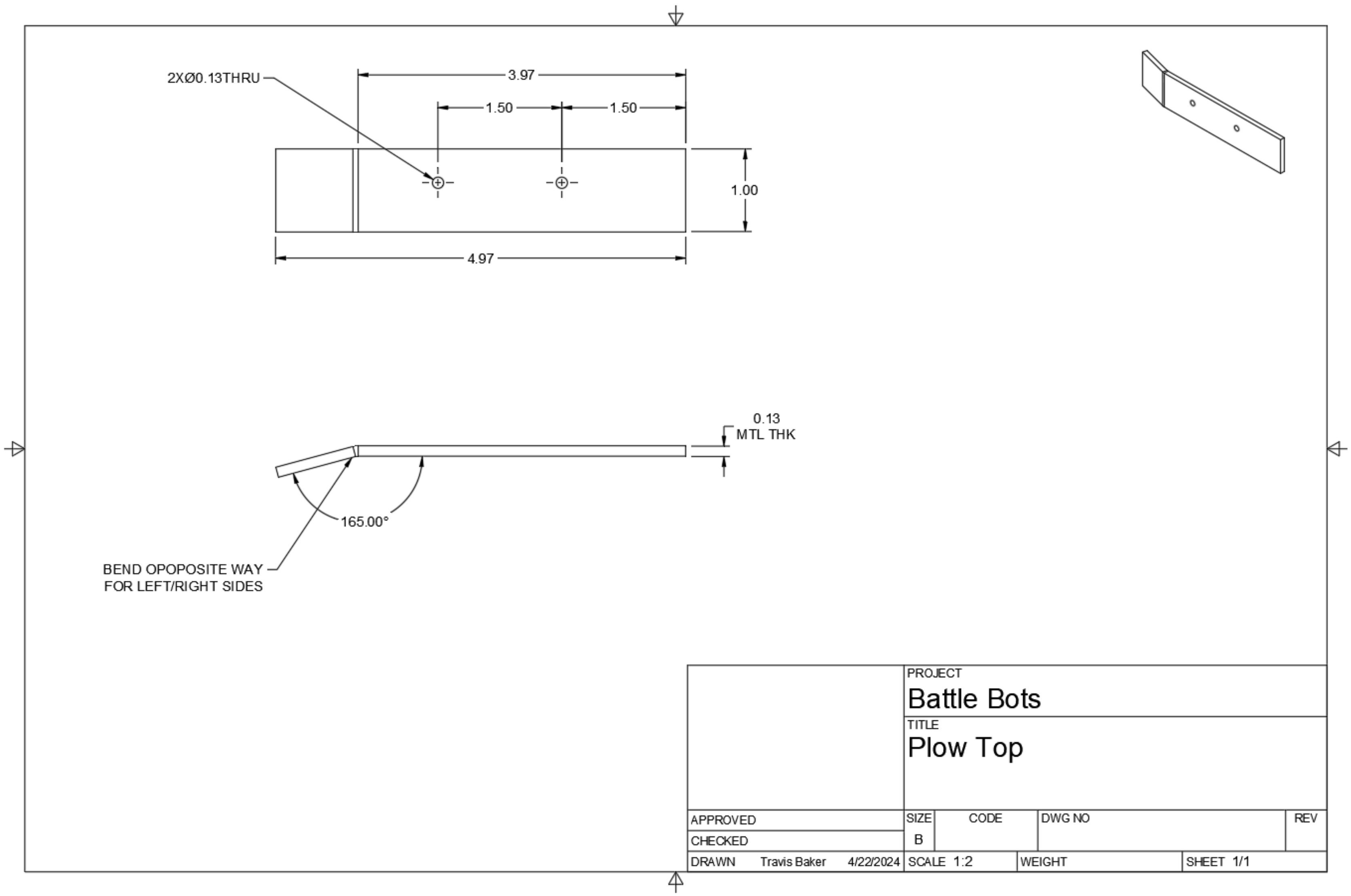
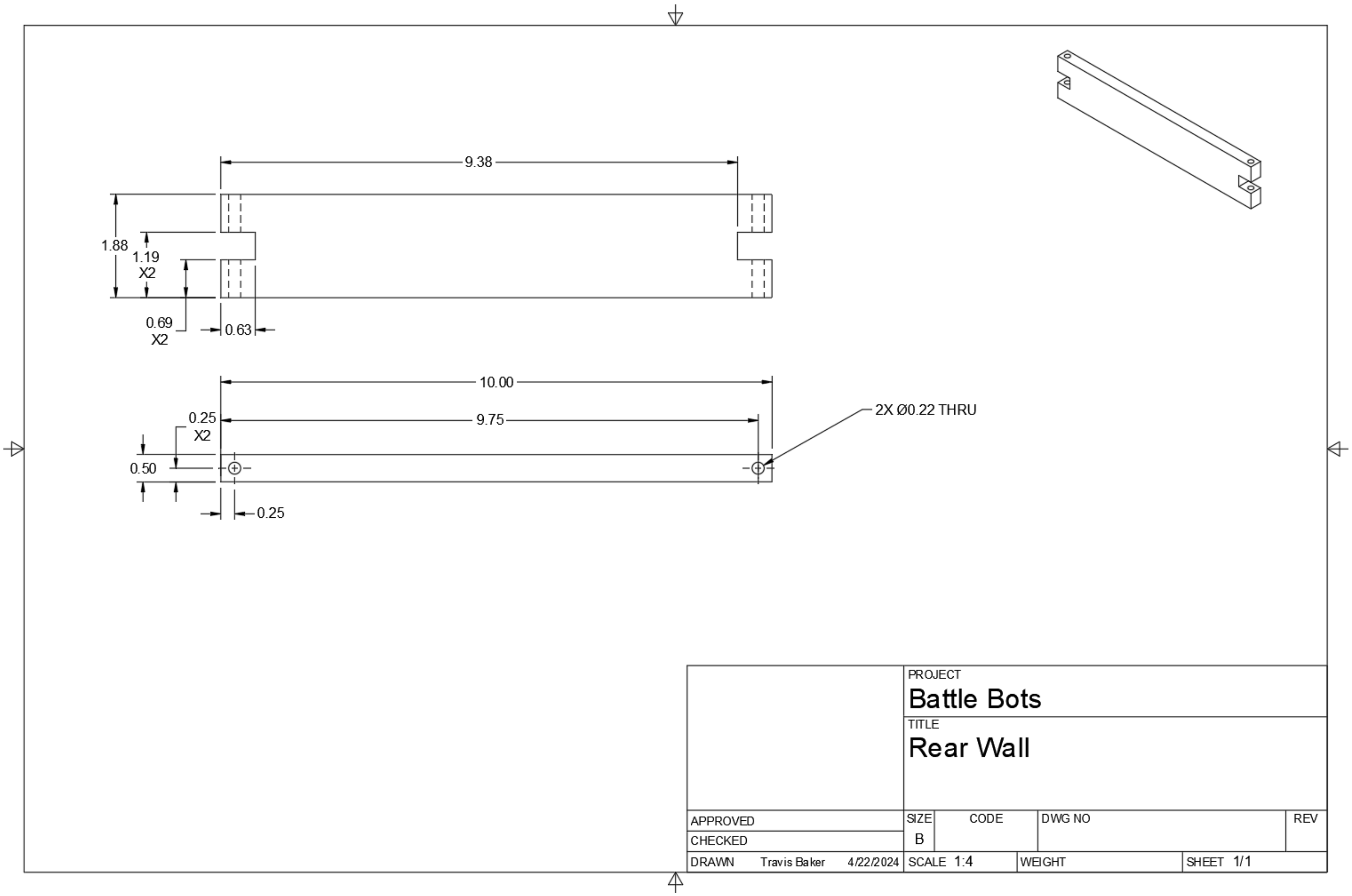
0.38
X2
0.08
0.08
0.24
0.74
0.49
0.24
0.90
0.98
0.47
R0.06
TYP
0.24
0.47
0.44
3XØ0.08THRU
0.125
MTL THK
PROJECT
Battle Bots
TITLE
Frame/Wheel Key
APPROVED
CHECKED
DRAWN Travis Baker 4/22/2024
SIZE B
CODE
DWG NO
REV
SCALE 4
WEIGHT
SHEET 1/1


Ø0.50 THRU
4X Ø0.13 THRU
4X Ø0.22 THRU
1.25
1.00 X2
0.35 X2
0.50 X2
0.35 X2
0.70 X2
1.00 X2
1.75 X2
0.70 X2
2.00 X2
2.50 X2
0.125 MTL THK
PROJECT
Battle Bots
TITLE
Motor Mount
APPROVED
CHECKED
DRAWN Travis Baker 4/22/2024
SIZE B
CODE
DWG NO
REV
SCALE 1:1
WEIGHT
SHEET 1/1


4.97
3.97
1.75
1.9
.15
.13
MTL THK
167°
BEND OPPOSITE WAY
FOR LEFT/RIGHT SIDES
PROJECT
Battle Bots
TITLE
Plow bottom
APPROVED
CHECKED
DRAWN Travis Baker 4/22/2024
SIZE B
CODE
DWG NO
REV
SCALE 1
WEIGHT
SHEET 1/1


R0.13
TYP
0.75
0.38
0.43
0.88
1.25
2X Ø0.13 ↧ 0.60
0.25
X2
1.27
0.125
MTL THK
PROJECT
Battle Bots
TITLE
Plow Inside
APPROVED
CHECKED
DRAWN Travis Baker 4/22/2024
SIZE
B
CODE
DWG NO
REV
SCALE 2:1
WEIGHT
SHEET 1/1


2XØ0.13THRU
3.97
1.50
1.50
1.00
4.97
0.13
MTL THK
165.00°
BEND OPOPOSITE WAY
FOR LEFT/RIGHT SIDES
PROJECT
Battle Bots
TITLE
Plow Top
APPROVED
CHECKED
DRAWN Travis Baker 4/22/2024
SIZE B
CODE
DWG NO
REV
SCALE 1:2
WEIGHT
SHEET 1/1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X2
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X2
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10.00
9.75
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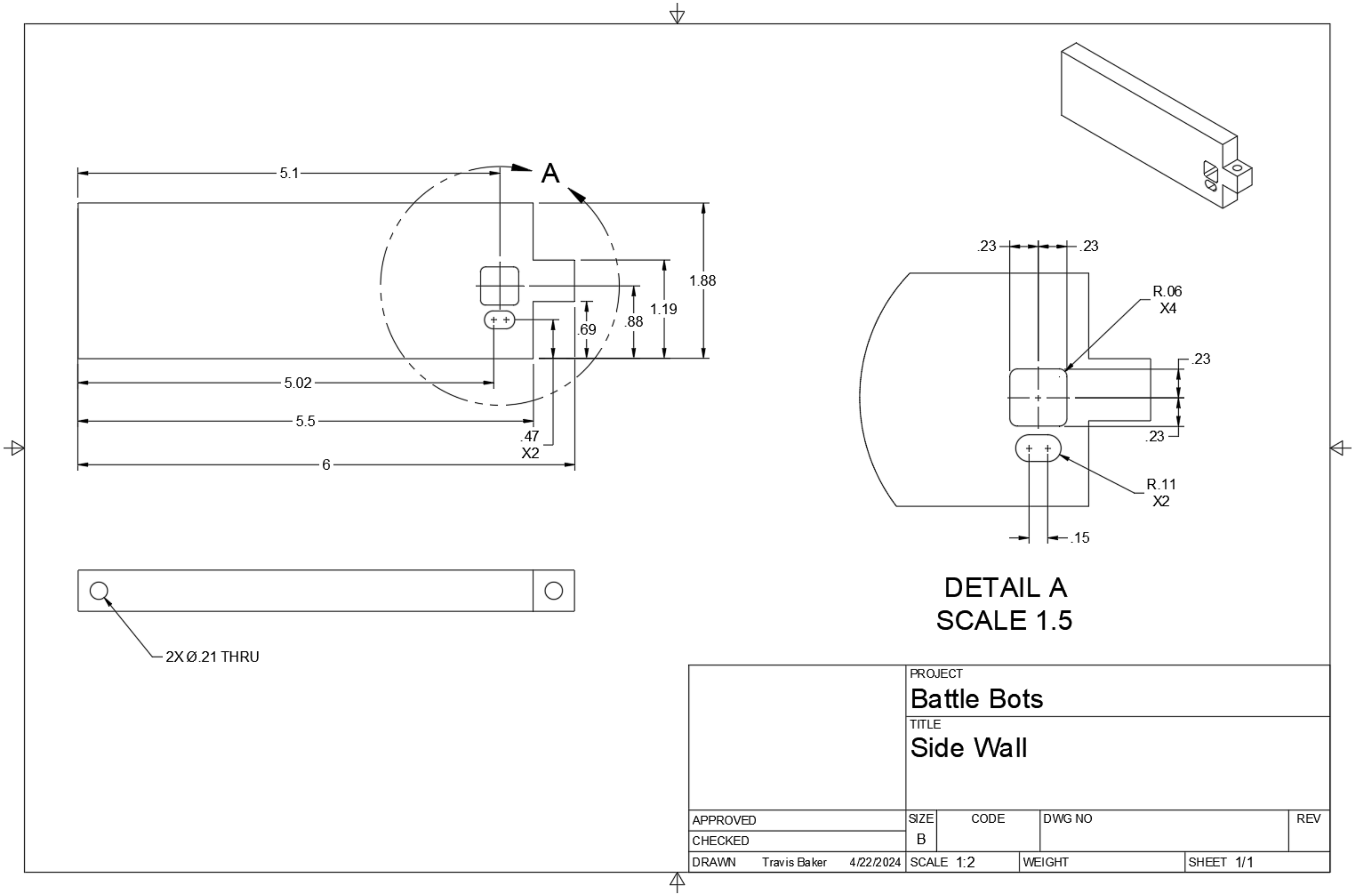
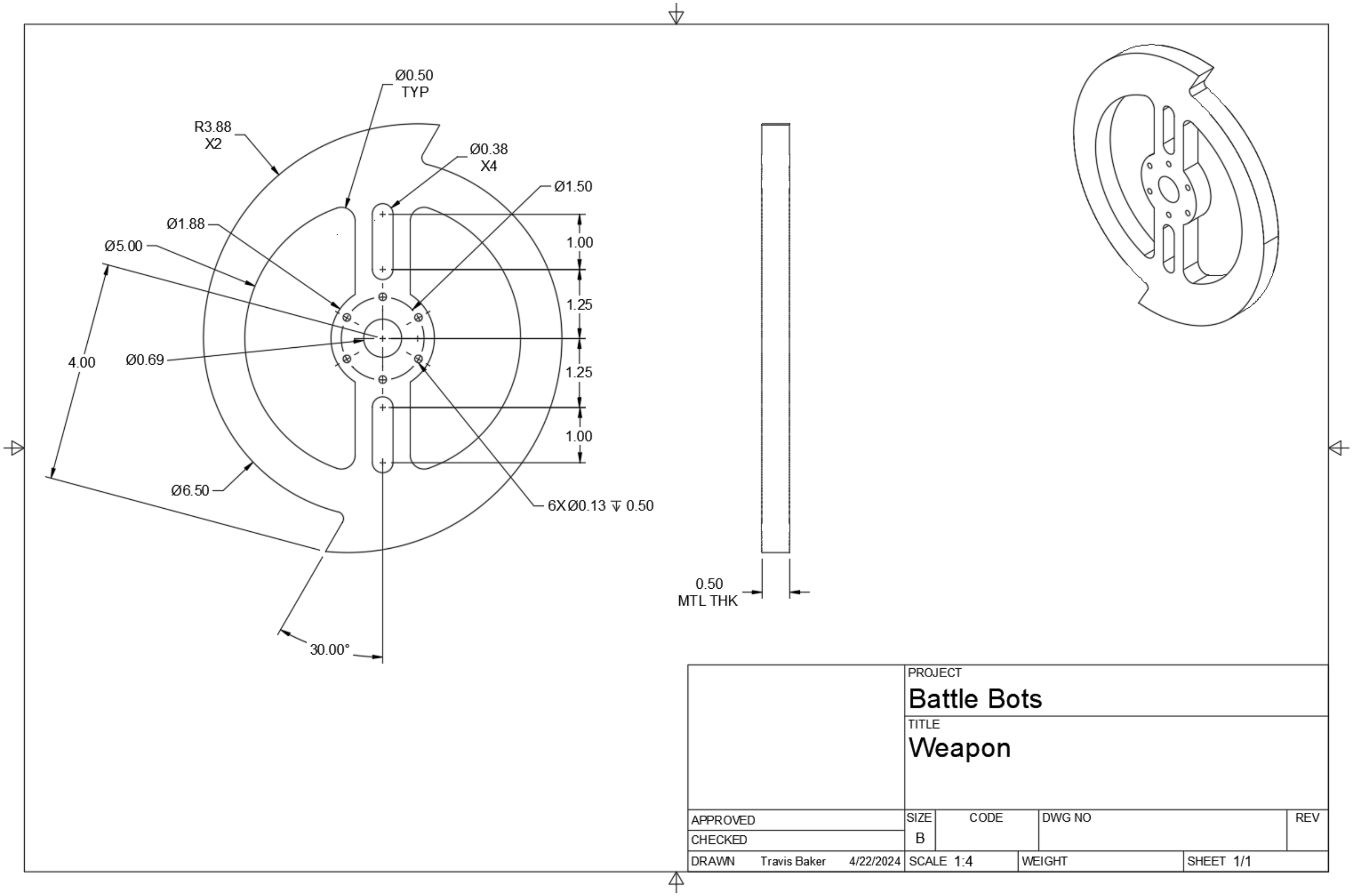
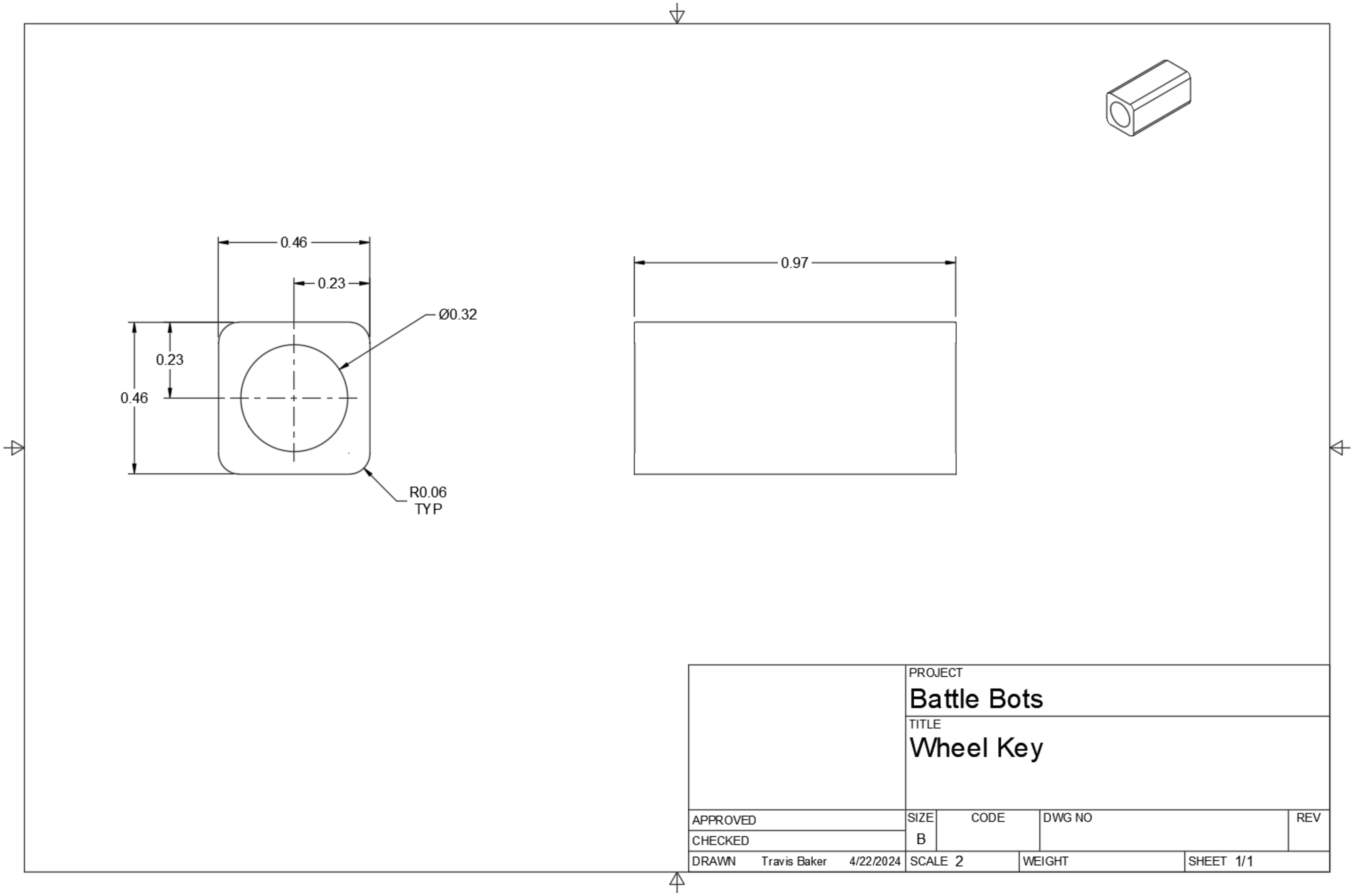
X2
0.50
0.25
2X Ø0.22 THRU
PROJECT
Battle Bots
TITLE
Rear Wall
APPROVED
CHECKED
DRAWN Travis Baker 4/22/2024
SIZE B
CODE
DWG NO
REV
SCALE 1:4
WEIGHT
SHEET 1/1


5.1
A
1.88
1.19
.88
.69
5.02
5.5
.47
X2
6
2X Ø.21 THRU
.23
.23
R.06
X4
.23
.23
R.11
X2
.15
DETAIL A
SCALE 1.5
PROJECT
Battle Bots
TITLE
Side Wall
APPROVED
CHECKED
DRAWN Travis Baker 4/22/2024
SIZE B
CODE
DWG NO
REV
SCALE 1:2
WEIGHT
SHEET 1/1


Ø0.50
TYP
R3.88
X2
Ø0.38
X4
Ø1.50
Ø1.88
Ø5.00
1.00
1.25
4.00
Ø0.69
1.25
1.00
Ø6.50
6XØ0.13 ↧ 0.50
30.00°
0.50
MTL THK
PROJECT
Battle Bots
TITLE
Weapon
APPROVED
CHECKED
DRAWN Travis Baker 4/22/2024
SIZE
B
CODE
DWG NO
REV
SCALE 1:4
WEIGHT
SHEET 1/1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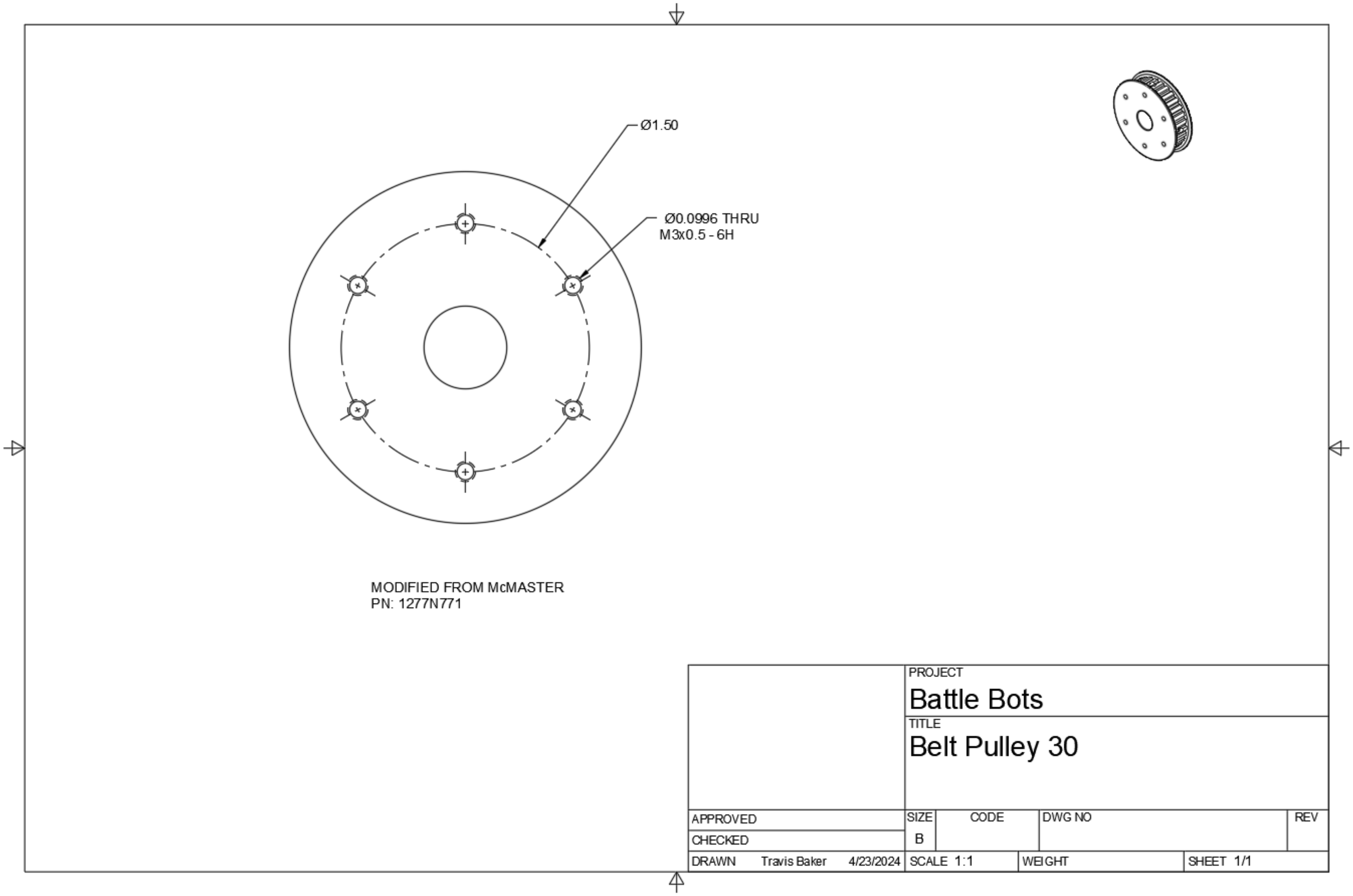
R0.06
TYP
0.97
PROJECT
Battle Bots
TITLE
Wheel Key
APPROVED
CHECKED
DRAWN Travis Baker 4/22/2024
SIZE
B
CODE
DWG NO
REV
SCALE 2
WEIGHT
SHEET 1/1


Ø1.50
Ø0.0996 THRU
M3x0.5 - 6H
MODIFIED FROM McMASTER
PN: 1277N771
PROJECT
Battle Bots
TITLE
Belt Pulley 30
APPROVED
CHECKED
DRAWN Travis Baker 4/23/2024
SIZE B
CODE
DWG NO
REV
SCALE 1:1
WEIGHT
SHEET 1/1

B. Survey Questions

Q1. From 1 (no experience) to 5 (very experienced): how much experience/knowledge do you have with designing a battlebot?

Q2. What kind of weapon have you worked with?

- Horizontal Spinner
- Vertical Spinner
- Hammer/Blunt Object
- Full Body Spinner
- Multiple Types

Q3. If you have worked with Multiple Weapons, in your experience what is the best weapon for a 12lb robot?

Q4. Does a robot NEED to be able to flip itself back over, or should the robot be able to drive upside down?

Q5. One a scale of 1 (lowest) to 5 (highest importance), how important is it to make your design modular?

Q6. Approximately how much energy (kJ) should the robot's spinner be able to exert on another robot?

Q7. On a scale from 1 (low importance) to 5 (high importance): how important is the overall speed of the robot?

Q8. On a scale from 1 (low importance) to 5 (high importance): how important is the maneuverability of the robot?

Q9. What material would you select for your robots' armor?

Q10. Is it more important to put extra weight into armor/plow or the weapon?

Q11. On a scale from 1 (low importance) to 5 (high importance): how important is the armor of the robot?

Q12. On a scale from 1 (low importance) to 5 (high importance): how important is the weapon effectiveness?

C. Calculations

Weapon Motor Parameters:

- Motor KV Value = 970 RPM/Volt
- Wattage = 2000 Watts
- Current = 90 Amps
- Driving Pulley = 10 teeth
- Driven Pulley = 30 teeth
- Weapon Diameter = 8”
- Weapon MOI = 6,730,712 g/mm^2

Weapon Speed Calculations:

$$Weapon\ Motor\ RPM = 970\frac{RPM}{Volt} * 22.2V = 21{,}534\ RPM$$

$$Weapon\ RPM = \frac{10\ teeth}{30\ teeth} * 21{,}534\ RPM = 7{,}178\ RPM$$

$$Weapon\frac{Degree}{second} = 7{,}178 * 6 = 43068\frac{Degree}{second}$$

$$Weapon\frac{Rad}{s} = \frac{43068 * \pi}{180} = 751.68\frac{Rad}{s}$$

$$Weapon\ Tip\ Speed = \frac{8\ in}{12\ in} * \pi * 7{,}178\ RPM * \frac{1\ mile}{5{,}280\ ft} * \frac{60\ min}{1\ hr} = 170.84\ mph$$

$$Weapon\ MOI\ in\frac{kg}{m^2} = \frac{6{,}730{,}712}{10^9} = 0.006730\ kg/m^2$$

$$Weapon\ Energy = \frac{1}{2}(0.006730)(751.68)^2 = 1901.30\ J = 1.90\ KJ$$

$$Spin\ Up\ Time = \frac{1901.30}{2000} = 0.951\ seconds$$

Battery Parameters:

- 6S LiPo Battery
- Capacity = 2600 mAh
- Voltage = 22.2 V

Battery Life Calculations:

$$Battery\ Life = \frac{2600\ mAH\ Capacity}{32000\ mA\ Load\ Current} = 0.081\ hrs * \frac{60min}{1hr} = 4.86\ min$$

Drivetrain Parameters:

- Wheel Motor RPM = 1,600 RPM
- Wheel Diameter = 70mm = 2.76”
- µ static = 0.9 (rubber and wood)

Drivetrain Calculations:

$$Wheel\ Circumference = 2.76" * \pi\ =\ 8.66\ inches$$

$$Linear\ Velocity = 8.66"\ * [(1600/60)/12]\ =\ 19.24\ ft/s\ *\ 0.681818\ =\ 13.12\ mph$$

$$Wheel\ load = \frac{12\ lbs}{2\ wheels} = \frac{6\ lbs}{wheel}$$

$$Friction\ Force = 0.9 * \frac{6lbs}{wheel} = \frac{5.4lbs}{wheel}$$

$$Wheel\ Friction\ Torque = \frac{5.4lbs}{wheel} * 2.76"\ =\ 14.9\ \frac{in - lb}{wheel}$$

D. Competition Rules

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 allowances may be allotted to entrants that meet certain criteria.

Non-Traditional Motion Bonus

Any robot that falls outside the definition of a “Traditional Motion System” qualifies for the Non-Traditional Motion 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 robots fighting under a single name qualifies for the Multibot Bonus. Each bot in a Multibot must have independent active control and be capable of influencing the fight. Only the heaviest bot in a multibot must have an active weapon. Additionally, for a multibot to benefit from the Non-Traditional Locomotion Bonus, only the heaviest segment of the bot needs to meet the criterion to qualify for the weight bonus.

The weight of any segment of a multibot may not exceed 110% of the ‘base weight’ for its respective weight class, except in the 3lb class. If the bot also qualifies for the Non-Traditional Locomotion Bonus, the additional weight may also be factored into the base weight.

For example, the heaviest segment of a 12 pound multibot may not exceed 13.2 lbs. However, if the robot also qualifies for the shuffler weight bonus, the maximum weight of the heaviest segment increases to 19.8 lbs (18lbs x 110%).

Competitors may choose to forgo their multibot bonus so long as their robot still meets the base weight for their weight class. If a competitor’s robot requires the multibot bonus to make weight, but arrives at the cage with a non-functional multibot, the match will be forfeited.

Any active cameras or recording equipment on the bot do not count towards the robot’s weight, but must be approved during safety inspection by an event organizer or head referee.

Weight Class	Non-Traditional Locomotion	Multibot	Absolute Maximum
3lb	+2 pounds	+1 pounds	6 pounds total
12lb	+6 pounds	+3 pounds	21 pounds total

30lb	+15 pounds	+8 pounds	53 pounds total

Batteries and Power

Bots must have an easily accessible master power cutoff in the form of a switch or 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 3lb bots, or 75 volts for 12lb and 30lb 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 and may require additional inspection. Email safety@nhrl.io to discuss your design!

Battery charging must be done safely! Batteries may be charged within your robot, except for robots with flame or heat-based weapons. Unsafe charging procedures may result in a penalty via the demerit system.

Safe charging practices:

- Inspect batteries for damage or puffiness before charging.
- A team member must be present while a battery is charging.
- Balance charge leads must be used for any OTS battery that has them.
- Keep a sand bucket or liposafe bag nearby.
- Set an appropriate charge rate based on your battery.

While not a requirement, it is a good practice to make sure your robot has enough power to be idle for up to 3 minutes prior to the start of your fight.

Robot Control Systems

Robot controls and communication systems must pass a failsafe test. 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 multibots 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.

Size Requirements

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

12 and 30 pound 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.

Weapons

All entrants 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.

"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.

In a multibot, only the heaviest bot is required to have an active weapon.

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.

Read more about weapon locks here.

Addendum on specific weapon classifications

Flame and heat-based weapons are allowed. This includes but is not necessarily limited to flamethrowers and low or medium-power rocket motors. Robots with flame and heat based weapons must be able to self light and self extinguish. In the case of signal/communication loss with the transmitter, flame and heat based weapons must self-extinguish in 30 seconds.

3lb robots are allowed up to 8 ounces of fuel. 12lb and 30lb robots are allowed 16 ounces of fuel. Consumable fuel and gasses do count towards your overall robot weight.

NHRL allows the use of propane, butane and other fuel sources that are gaseous at STP (standard temperature and pressure). Fuels cannot be self-oxidizing and flame systems must not include additional oxidizing systems (e.g. oxy acetylene torches and similar). Matches may be stopped and your robot disqualified if cage equipment, cameras or safety gear, is being damaged by fire.

Matches may be stopped and your robot disqualified if cage equipment, cameras or safety gear, is being damaged by fire.

Rocket motors (also referred to as rocket engines) and fireworks are not allowed as of May 2023. This may change in the future.

Drive systems and weapons powered by internal-combustion engines are allowed. Combustion engines may be manually or electrically started during load in, provided they do not cause the weapon to move. Consumable fuel and gasses **do** count towards your overall robot weight.

Projectile weapons, both tethered and untethered are allowed. A fired projectile's maximum speed may not exceed 150 miles per hour. Additionally, a tethered projectile must not be designed in a way that is likely to become entangled with the opposing robot.

Modular weapon systems are allowed. Modular weapon systems are defined as mechanisms, subsystems, or subassemblies that are interchangeable between fights. For example, a modular weapon system may allow a competitor to choose between a horizontal spinner and a vertical spinner configuration between fights.

No more than 50% of a robot's weight may change between configurations. Additionally, all configurations of the robot must qualify for the same weight bonuses.

Designs that utilize pneumatics, hydraulics and subsystems using airbags are allowed, but must be approved by NHRL staff through the Design Approval Process.

The NHRL Design Approval Process

Any design that falls outside the parameters outlined in the NHRL Competition Handbook, OR that includes airbags, pneumatic or hydraulic systems MUST be approved by NHRL Staff.

To receive approval or discuss your robot design, please email safety@nhrl.io at least 3 weeks prior to the competition. We cannot guarantee that any proposal sent later will be approved in time for the competition.

Your email should include sufficient information to communicate/demonstrate your design intent. This can be in the form of hand sketch, pictures, video, CAD models, or written word, etc. During the approval process, builders may be asked to provide additional details as necessary.

Spare Robots & Batteries

Due to the fast pace of the competition, bringing multiple copies of your robot is allowed and encouraged at NHRL. Spare robots must be as close to exact copies of the original as possible. All copies of spare robots must pass safety inspection before competing.

For any robot with modular weapon systems OR multiple armor configurations, all spare robots must be compatible with each modular system or armor configuration interchangeably.

NHRL highly encourages competitors to bring spare batteries! Builders are only guaranteed 20, 25 or 30 minutes in between matches dependent upon their weight class for repair and recharge, which may not be enough to fully recharge a battery.

Design Restrictions

Fabric, foam, and other ablative armor is allowed. However, ablative armor must not be designed in such a way that it presents a likely entanglement risk. The decision of what is a likely entanglement risk is up to the discretion of NHRL.

Entanglement devices are not permitted. An entanglement device is defined as a component, subsystem or armor configuration that is designed to be entangled in the rotational or moving parts of an opponent.

Liquids expelled from the robot are not permitted. However, liquids expelled from a robot that become gaseous shortly after leaving the robot and/or before hitting the opponent are permitted. Expelled liquids must be gaseous at STP conditions.

Electrical and shock weapons such as tasers and cattle prods are not permitted.

Weapons that primarily act by obstructing visibility are not permitted. However, weapons that produce smoke or fog as a by-product of their attack are allowed.

Any weapon that directly targets or that may result in harm to those outside the cage is not permitted. This includes, but is not limited to lasers, high luminosity or strobing lights, or excessively loud noises.

The Spirit of the Competition

Have a unique, groundbreaking, wacky or super-secret design that isn’t covered by the rules? At NHRL, we love creative and fun designs that push the boundaries of what can be done in combat robotics. If you are unsure if your robot design qualifies, please contact us at safety@nhrl.io. NHRL Staff would be more than happy to chat with you! We would rather see new and interesting bots fight than disqualify them!

Event Organizers, Safety Inspectors, or Head Referees may disqualify any robot that has been designed in such a way that skirts or violates the spirit of the competition, whether intentionally or unintentionally. See Spirit of the Rules above.