2022-23 UC Combat Robotics Drum-atic Team

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by

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Research

Background of the Problem

The concept of combat robotics is based on the idea of creating a robot that can defend hits from other robots while also dealing hits to incapacitate the other contestants in the ring with you. Combat robotics uses machines that are usually controlled by remote-control instead of autonomous control as this allows for more unique battles as the controller of the machine can drastically affect how the battle can be fought.

Combat robotics has been around since the 1980's and gained a large following when the show 'Battlebots' started in the early 2000's (1). This large burst of popularity after the show led to many small shows to be created across the country which includes the tournament in which will be competing in called XtremeBOTS. XtremeBOTS is very similar to larger combat robotic tournaments but on a smaller scale mainly involving high schools and colleges from around the area (2). In all competitions, there are weight classes which ensure there is no discrepancy in the fights.

The weight classes are commonly separated into (3):

- Beetleweight - 3 lbs
- **Hobbyweight - 12 lbs**
- Educational- 15 lbs
- Featherweight - 30 lbs
- Lightweight - 60 lbs
- Middleweight - 120 lbs
- Heavyweight - 240 lbs

For this project, we will be fighting in the hobbyweight class which is the class that is commonly used by combat robots created in high school and college. The majority of the famous battlebots are in the heavier classes such as middleweight and heavyweight. This allows us to use those heavier battlebots for inspiration to help improve over previous years.

The three main factors when developing our combat robot will be the weapon, drivetrain, and frame.

The weapon is defined as a motorized device whose intent is to damage or incapacitate the opposing robot within a combat robotics competition. The device can be anything that is not banned in the competition's rulebook, which is usually flames, lasers and projectiles in smaller competitions. Some of the common types of weapon types are drum spinners, spinning discs and spinning bars. Each type of weapon can drastically change how your robot is designed as the weapon can be considered offensive or defensive and that decision determines how your robot intends to fight and traverse the arena.

The frame of the combat robot has two important tasks, one is to hold all the components secure such as the battery, motor, electronics, and weapon so that they do not become loose during collisions or hits from an opponent. The other major task for the frame is to be made to be able to take hits and keep the components secure and intact inside. This is a fairly complex task as weight is a critical factor of the design and material selection must consider a numerous number of variables when building the frame.

The considerations include:

- Availability of Material
- Performance Properties
- Cost of Material
- Wear of Material
- Ability to Manufacture

These are just some of the design considerations that have to be accounted for when it comes to the frame of the weapon and that is why it is one of the most important aspects to a successful combat robot.

The final factor in a combat robot is the drivetrain of the robot which mainly consists of figuring out the best way to connect your robot's transmission to the drive axles of your wheels. The drivetrain of your robot is mainly based on the power you want the transmission to use and the number of wheels that your robot is going to have. The drive trains for combat robots are one of the simpler tasks in terms of how they are designed. Almost all combat robots use wheels attached to chains/sprockets that rotate the wheels as this design is easy to maintain and can take a considerable amount of damage to destroy. The main job of designing the drivetrain is the placement of the drivetrain and wheel within the robot. The wheels and drivetrain are one of the most important aspects of the robot as if they are damaged during the fight then your bot has lost the majority of its mobility and if they are destroyed then you have lost the fight in its entirety. Although the drivetrain is not necessarily the most complicated, it is one of if not the most important parts of the entire robot assembly and the placement must be done correctly to have a well-designed robot.

The main objective of our senior design project is to go through a rigorous design process which will go over idea creation, development of concepts, prototyping of concepts and final development. This design process will go through our three important concepts: weapon, frame and drivetrain. Our concept will then be manufactured, built, and tested before being displayed in the Norwalk Havoc Robot League in May where many competitors of all skill sets will be competing (2).

Applicable Standards

The Norwalk Havoc Robot League (NHRL) has released guidelines for judging head-to-head matches for full combat-robotics that does not end in a knockout or a tap out. We will focus on emphasizing these areas as our combat robot is focused on defense and should be able to endure a match for scoring. The three metrics used for judging are Aggression, Control, and Damage.

The NHRL defines Aggression as the "intensity and frequency of intentional attacks, preferably with an active weapon. To score points here, you need to make attacks that could conceivably affect your opponent (4)." This demonstrates the need for a weapon that is both reliable and durable. In order to continuously score well in this area, it is imperative that the weapon on the combat robot can deal damage to the opposing bot, while also maintaining its integrity. That being said, it is still possible to score points with a disabled weapon, as long as the bot demonstrates a willingness to attack and engage with its opponent. Strategic driving should also be employed as a Bot is allowed to wait for an opportunity to attack or to allow its weapon to prepare. This can best be summarized from the quote on aggression given by NHRL, which states, "A bot that attacks consistently over the length of an entire match should score more aggression points than a bot that clumps all its attacks into a short duration of the match but spends significant portions of the match not attacking (4)." This demonstrates that you do not need to put yourself in harm's way in order to score points in this category. Aggression is also seen as the least important metric as it is weighted with only 5 points while control and damage have 6. Judging in this category will focus on how often and with how much vigor attacks connect with. Afterall, Battlebots is a Combat Sport (4).

Control is defined by the NHRL as "Control is how well you dictate the flow of the match. To score points here, you want to put your opponent in a bad spot, like pinning them or getting them stuck (4)." That being said, there is a lot to consider when trying to control another combat robot during the match. The main things the judges look for when looking for control are either inverting or pinning their combat robot. Control can also be displayed by getting the opponent stuck against the wall, stuck on debris, stuck on a rough area on the floor, or even getting it stuck on a certain side of the robot that was not designed to sit right up on. According to NHRL, if a bot sticks itself, it will still count for the same number of points the opponents would get if they stuck them. When a robot gets stuck for a brief period of time it shall not count against the operator for control. The only way a bot can lose points is if the bot is stuck long enough to alter the flow of a match. Within a match there is a house bot that is designed to help unstick bots to help keep the match flowing. If at any point a bot unsticks its opponent instead of letting the house bot do it shows a lot of control, and if a bot unsticks itself that also shows more control for not needing the house bot help it get unstuck. Points are also not awarded to the bot if it interferes with the house bot. In a match, a bot can also receive a control point if its minibot is able to stick its opponent, however, if their own robot gets stuck by the opponents minibot then they would lose a control point as well. If both bots control the match pretty equally then the judging goes to focus on each driver's control of their own bot to help break the tie. The judges will focus on whether the driver had great control throughout the match, and they didn't frequently lose control. If one driver gets their bot stuck and the opponent doesn't throughout the match, then their opponent would get more control points (4).

Damage focuses more on the condition of the bot at the end of the match compared to the bot's conditions at the beginning of the match. NHRL defines damage as "Damage is the condition of your opponent's bot at the end of a match compared to how it started. To score points here, you need to hurt your opponent's critical systems (4)." The highest damage scores a team can receive is if they completely destroy or disable their opponent's bot to a point where it can no longer operate. Points are then awarded based on if there's a reduced effectiveness of the subsystem, amount of damage to components of the robot that are critical, damage to ablative components, and then aesthetic or cosmetic damage. If a bot damages itself, then it will be weighted the same as if their opponent were to deal that damage to them. If a bot's weapon or drive is not working at the start of the match before any contact with its opponent, it does not count as damage. Damage must occur while the match is in progress. Judges pay close attention to bots at the start of the match so they can determine each bot's starting state (4).

Ablative armor is defined as a non-structural component that is mainly used to absorb damage by simply consuming it. During the match, if a minibot takes on more damage than its opponents minibot, or if only one team brings a minibot with their bot and it takes Level 3 or even worse in damage, then the bot with the minibot will take up two levels of damage more than it would normally. For example, if a team's bot takes level 6 of damage, but their minibot gets completely destroyed then their damage score shall decrease to level 4. The damage done to a team's minibot will affect their overall damage score. Judges are also able to request cage managers to show damage to a bot on the livestream. This will only occur when it is truly needed by the judges to make a big decision in a battle because it can take up a decent chunk of time. If a team bot at any point does any damage to the house but they won't receive any points for it. Overall, if at any point the bot takes damage from either itself, its opponent, or even the house bot it will be considered damage points. If the bot's weapon gets caught up in debris from its opponent bot and is unable to function correctly then that is not considered damage to their bot (4).

State of the Art - Weapon

When designing a combat robot, the weapon is usually what dictates the form of the frame and other aspects of design. There are many different types of weapons to choose from when it comes to building a combat robot. When selecting a weapon, it is usually a good idea to investigate the pros and cons of each weapon to help figure out which one will be the best selection for our design. For our team to better understand the function of each weapon, we watched several videos of different weapon designs on battlebots to help us come to a decision on our weapon. While watching the videos we noticed that certain weapon matchups can alter the overall damage of one's weapon. One weapon can be very effective against one opponent’s weapon while another one could be completely useless. So, we have to take that into account when coming up with our weapon design.

There are several different kinds of weapons to use for combat robots, but the main three that we looked at are the Solid Drum Design, Vertical Plate Spinner Design, Horizontal Blade. Below are descriptions of each weapon design and the description of what some previous combat robot teams did with their design.

Drum Design:

The rotating drum spinner is considered to be one of the hardest hitting weapons in the world of combat robotics (5). The drum is laid out horizontally on the robot typically on the front, but it can be placed in other spots as well. Typically drum weapons have teeth either welded or machined on. The more teeth on the drum the more likely it is to deliver a blow to the opponent's bot. One of the greatest features of this weapon is that it can still function the same when flipped over, however, the rotation of drum shifts when being flipped unless the weapon is powered by a dual motor. A majority of drum designs rotate upward, so when striking their opponent it will send them upward, and then there is a downward force exerted on their own bot, which is usually contained with some kind of wedge that presses into the floor. When the bot gets flipped and the direction of the drum is going downward it puts the bot in a vulnerable position. Hitting their opponent with a downward force will cause their own combat robot to do the opposite. It will go upward because there's nothing stopping the robot from going upward.

Drum weapons are typically driven by either a chain drive or belt drive that is usually powered by an electrical motor. One of the nice things about having drum weapons is that the majority of the drivetrain is surrounded by the frame, so damage to the drivetrain doesn’t have to be a concern. The design can also be very difficult to drive when the drum is spinning at such high RPM’s. With such a high moment of inertia it can cause the bot to flip when taking turns. The drum weapon design is often looked at as more of a defensive type of combat robot, but at the same time it is able to do damage to its opponent while defending itself. Drum weapons usually do pretty good with most robots, but wedge robot designs tend to be harder to flip (5).

Figure 2: Drum Robot

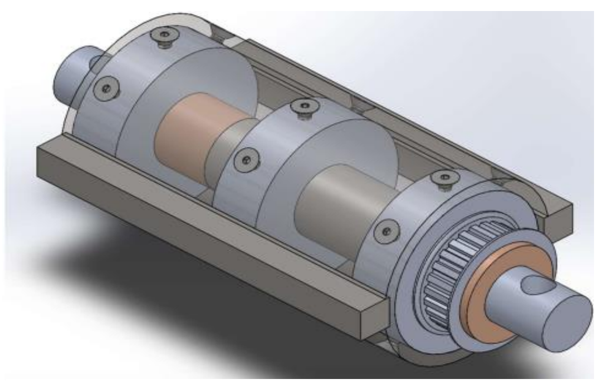


Figure 1: Drum Weapon Design

A previous UC Combat Robotics Team from 2020 decided to go with drum design for their weapon, but never got the chance to build it and put it through competition since Covid was going on. Their idea for the drum design was to make it hollow with 3 rings inside with a shaft going through the hollow tube and three rings (6). They were looking for a cheaper manufacturing design for their drum. The drum also had two edges placed on the outside that had no rake angle. Here is a 3D model of their weapon design since they never got to manufacture it because of Covid.

Their weapon went in the upward direction like most drum weapon designs. They did have the edges of the drum welded on, which made it difficult to change parts of the weapon. They were concerned that the edges would break off. Based on their calculations they believed that the spin up of their weapon was much faster than most, which would have given them an advantage at the beginning of the match (6). They said with the high RPMs of their weapon that it would have also been very difficult to control their weapon.

Pros:

- Low center of gravity (single block of material usually)
- Functional when flipped over
- Drivetrain is very well protected within the frame
- Can deliver heavy blows compared to other robots (depending on the number of teeth)
- With a good drivetrain the weapon is capable of accelerating quickly
- With most of the hardware being surrounded by the frame it makes the bot very damage resistant

Cons:

- Upward force when being flipped over
- Difficult to drive
- Not effective against wedge opponents
- If a bearing is hit the whole weapon assembly can become completely useless
- A high moment of inertia placed on the front end can make it difficult to drive

Horizontal Blade:

The horizontal blade is also a very effective weapon that can deal a lot of damage to their opponents. It typically is placed on the front of the bot and is connected to a belt or chain that is powered by an electrical motor. While horizontal blades can be very deadly against other bots, it still is pretty difficult to drive if the weight of the robot is not distributed correctly. Depending on the frame of the robot as well the chain or belt that spins the blade is exposed and could potentially be destroyed by their opponent leaving them with a non-functional weapon. When attacking opponents as well since there is no way to counter the force being pushed against the

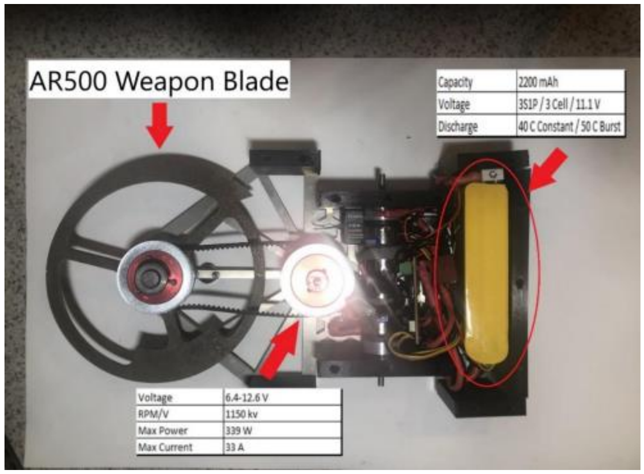


Figure 3: Horizontal Blade

bot when hitting the opponent. When hitting the opponent with a horizontal blade it tends to send their own bot the other direction spinning.

A previous UC Combat Robotics team from 2021 in the 1.5 kg class went with a horizontal blade design and actually did pretty well when it came to competition. They had an open frame with their weapon, so the belt connected to the blade and the motor was slightly exposed. The blade took the shape of a disc with a single rake angle tooth pointing out. They decided to use AR500 as their material for their weapon (7).

When it came to competing, they did pretty good. They lost their first match because they didn't finish the match, but that was because they had faulty soldering on a wire for their robot. When they re-soldered the wire, the robot was back to normal, and the weapon was working just fine. For the second battle they dealt a lot of damage to their opponent. It only took one strike to take out their opponent, however, it completely destroyed their own weapon. For the final battle they took off their weapon that was no longer functional and used the front as a ramming weapon (7). They won in a free for all against 3 other bots.

Overall, the robot did pretty well, but their team believed that there were a couple things they could have changed that would have helped them perform better. They believed the AR500 material was too heavy for their robot and that they should have gone with a lighter material or even just made their original weapon smaller with the same material. Ultimately whenever the robot's weapon started spinning the driver would have a hard time controlling the robot. Also, when hitting their opponent, they experienced a lot of force being exerted on their own bot, which did a decent amount of damage to their own robot.

Pros:

- Can deal a lot of damage
- Simple mechanism
- Can have multiple teeth on blade
- Large attack radius
- Operational when flipped over

Cons:

- Bad recoil upon contact
- Bad control
- Chassis is exposed to weapon
- Belt or chain is exposed

Vertical Plate Spinner:

The vertical plate spinner is not a weapon you typically see very often when dealing with weapons for combat robots. This design is actually very similar to the drum design because it is a vertical spinner, but it's just completely hollow with only two edges on it horizontally. The weapon is placed on the front of the frame structure and is either spun by a chain or belt powered by an electric motor. Much similar to the same way the power is transferred for a drum design.

Figure 4: Vertical Drum Blade Design

Here is the model made by a UC Combat Robotics team from 2019 in the 15lb division (8).

They used a driven pulley with a timing belt to spin their weapon. Their vertical plate spinner used two flared edges that allowed them to hook their opponent and throw them. Their shaft was connected directly to their weapon, which allowed them to easily disassemble their weapon and replace it in case it was damaged in a match. Instead of welding they decided to bolt their weapon assembly instead because they didn’t want something permanent. The material they selected for their shaft was made of 4340 steel and their weapon was made of 4140 steel (8).

When it came to competition time, they passed all the inspection requirements. During their first match they had several weapon-to-weapon hits with their opponent, and it caused their weapon to bend in several areas. Their weapon edges were bent along with their shaft. Since the weapon was bent it made it almost impossible for their motor to spin the weapon, so they went through the remainder of the match without a weapon (8). They did say, however, that their robot was very easy to control. Overall, they found that their material was too thin and had too low of a material yield strength.

Pros:

- Simple
- Good control
- Easy to replace weapon if no internal damage is done
- Easy to fabricate
- Cheap (depending on size and material)

Cons:

- Easy to damage
- Hitting range is low
- Too light
- Cannot deal a lot of damage

State of the Art - Frame

There are several different armor configurations used for competition in combat robotics. The choice of frame will often dictate what weapon and drive system will be needed to accommodate this frame. Because of this, the frame configuration is one of the most critical choices in designing a combat robot.. Once a frame is decided upon, there is a clear direction of what weapon will be used and how the internal components of the bot should be laid out. Examples from the 2020, 2021

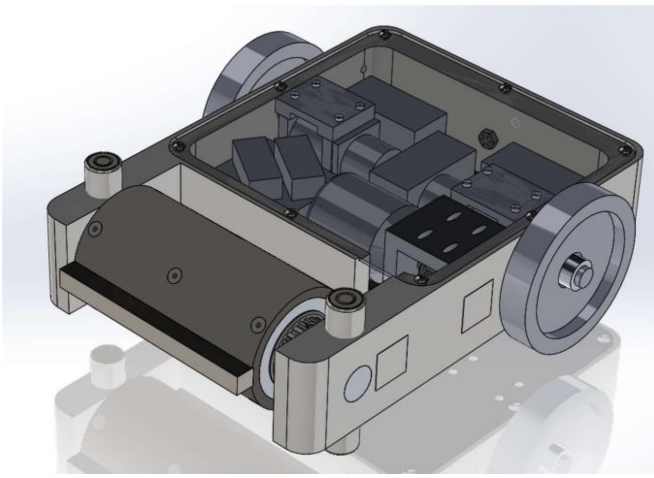


Figure 5: (2020 UC Combat Robot) (6)

One of the most commonly seen frame types is the boxed frame; this design was used by the 2020 UC Combat Robot Team. This design allowed for the use of a vertical drum spinner and two-wheeled drive train. They would choose a one-piece design for their frame for simple assembly and structural integrity. However, they later detail in their report that this has potential drawbacks. If the bot were to sustain any serious damage, it would be difficult to repair and require a full frame replacement. A boxed frame is an appealing structure as it is highly adaptable to different weapon types and has good maneuverability. An area of improvement for this design is providing protection for the wheels. Leaving these areas unguarded could expose your robot to other attacks and malfunctions that would otherwise be preventable. (6)

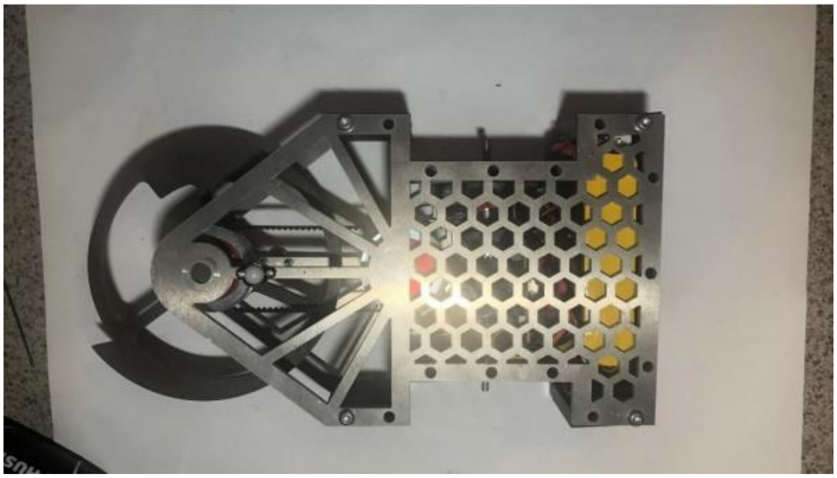


Figure 6: 2021 UC Combat Robot Team (7)

Another example of a boxed frame is seen in the 2021 UC Combat Robotics Team. Their design would use a box frame, but this frame would be designed to incorporate a horizontal spinner. This frame would consist of two pieces of aluminum that sandwich 12 Nylon walls. This design should allow for easy replacement of parts but runs the risk of structural issues as nylon does not offer the same integrity as other materials. Additionally, the water jet top and bottom pieces allowed for complex geometry which can maintain its integrity while reducing the weight. This design could be improved by making the nylon blocks modular so there could be an abundant supply on hand to replace walls as necessary after fights. In the competition, this team would experience a nylon wall breaking as a result of the force of their weapon colliding with another bot and coming dislodged from its centering hole. Proving that this would be an area of concern with this design. (7)

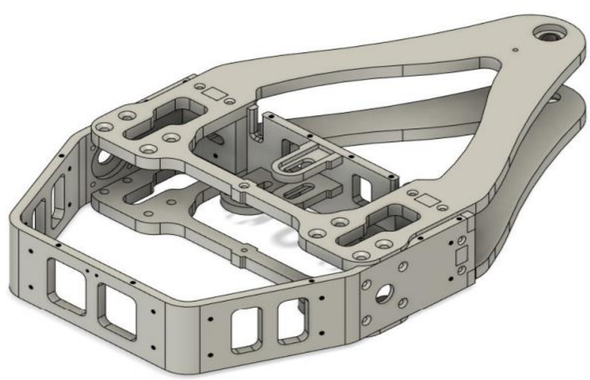


Figure 7: (2021 UC Combat Robot Team) (8)

The last example of a recent combat robot project is another 2021 UC Team that also made use of a box frame but would instead incorporate an aluminum frame with UHMW as an external support. This team would create custom tooling to add bends to the rear component of the frame and have water jet parts with slots and extruded features to allow for an easy assembly. And additionally create a mold for the UHMW to be set in for the exterior portion of the bot. Including two measures of defense should ensure that the only thing keeping this bot from continuing would be an electrical or weapon error. After competing this would be the exact issue as the loss would come from a shoulder bolt being used throughout testing and then in competition which would lead to the bolt shearing and causing a weapon failure. (8)

State of the Art - Drive Train

In order to analyze the current state of the art for drive trains in combat robotics, we will be analyzing three previous University of Cincinnati Combat Robotics senior design projects.

<u>Types of Drive Trains</u>

These are the three main types of drivetrains that are used in combat robotics (9).

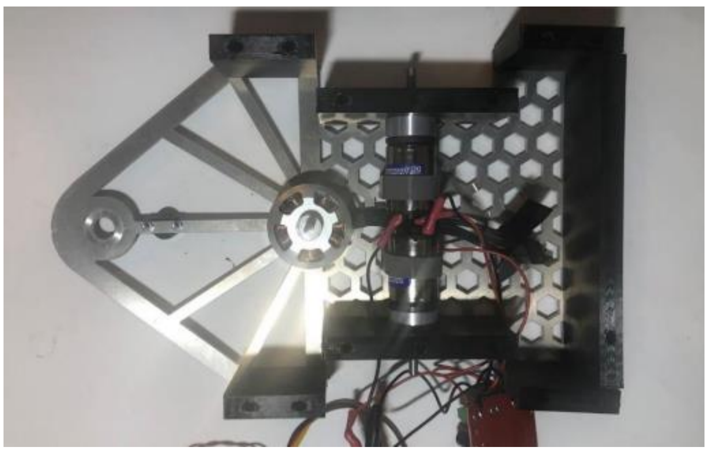
- Gear Drive: A rigid gear drive is a type of transmission that transfers rotary motion/torque to another shaft by using toothed wheels also known as gears (9).
    - Pros
        - Compact fit
        - Light frame and components
        - Efficient power transfer
        - Large amount of torque variation
    - Cons
        - Is not able to be fixed
        - Vibration failure

- Belt Drive: A belt drive is a flexible system that uses a rubber tensioned belt to transmit rotary motion to connecting shafts (9).
    - Pros
        - Belt can be replaced if damaged
        - High torque
    - Cons
        - Large surface area
        - Heavier components
        - Requires a tensioner that may come loose

- Chain Drive: A chain drive is a flexible system seen mostly in bikes that uses a roller chain and sprocket gear to transmit power to connecting shafts in a system (9).
    - Pros

        - Difficult to break
        - High torque
        - Chain is easily replaced if damaged.
    - Cons
        - Heavy components
        - Large surface area
        - Requires tensioner

<u>2021 UC Combat Robot "Hash Slinging Slasher"</u>



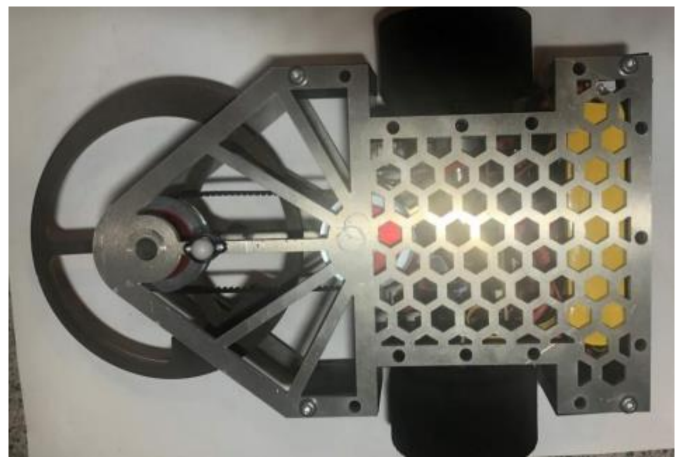


Figure 8 &9: Hash Slinging Slasher Robot

The 2021 UC team built a 3 lb robot and decided to make their drivetrain very simple by using a gear drive to raise the torque ratio in order to have faster turns and a more agile robot. They used two "22MM Gearmotor with Aluminum Gearbox" (7) drive motors which allowed for a high amount of torque to be used in the fight. These motors were extremely powerful and let the robot move at over 2.2 m/s which would allow them to be much faster than the average beetle bot competition. After they had performed in their competition, they did not note any changes that they would make to the drive motors they chose. In the battle reports, they noted that when their weapon became inoperable, they were able to use their speed from the drive motors to use their body like a spinning wheel and cause damage to other robots. This design seemed to be very well executed and worked well during their fight and even helped them earn a win.

The Hash Slinging Slasher decided to use a two-wheel drive that was pre-designed for combat robot type competitions, these wheels were called "Combat Robot Wheels with Foam Tires" (7) and placed them on the outside of their armor near the middle of the frame. According to the team's recommendations, this was a big mistake as this left the wheels open for damage throughout the match. They recommended that covering the foam wheels would result in much better protection from their drive train assembly from damage in future competitions.

Overall, their two-wheel drive system allowed them to have quickness and agility, but the exposed wheels were one of their weaknesses that they did not expect during the competition. This design has some flaws but was overall very well done.

<u>2020 UC Combat Robot</u>

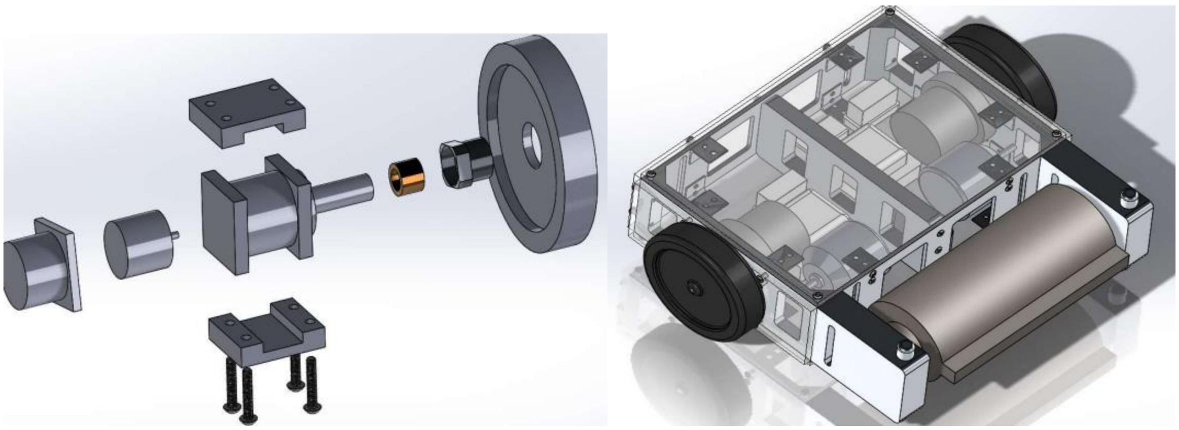


Figure 10&11: Drive Train, 2020 Combat Robot

The 202 UC Combat Robotics team created a 15 lb robot that also used a direct gear drive as it saved a considerable amount of space within the frame of the robot and provided a considerable amount of speed and maneuverability for the tournament. This motor and gearbox were a “Turnigy D2826/10” and a “P61 20:01 gearbox” (6) which used a gear ratio that would be able to create enough torque to have a smoothly driven bot. This team was not able to fight as all tournaments were canceled because of Covid-19 but they believed that their drivetrain was assembled very well and would likely not have been a source of failure in the battles. The drive train was able to get to a speed of up to 17 MPH (6) during the testing runs without any failures or loss of power. Although no official battling was done, this drivetrain was well assembled and clearly had a lot of thought put into its design and installation.

The robot used a two-wheel system that put the wheel on the outside of the frame which left them open to all attacks during the match. These wells were hard plastic and therefore would be able to absorb considerably more attacks than soft or foam wheels but when these wheels do break, they will most likely crack and make the wheel useless until replaced. The main part of the wheels where this team was whether or not the shaft would be bent after a considerable amount of hits.

This robot was never tested and had a similar design to the 2021 UC Combat Robot but used hard plastic wheels instead of foam or soft rubber. This was very well designed and most likely would have performed well in the competition.

2017 UC Combat Robot

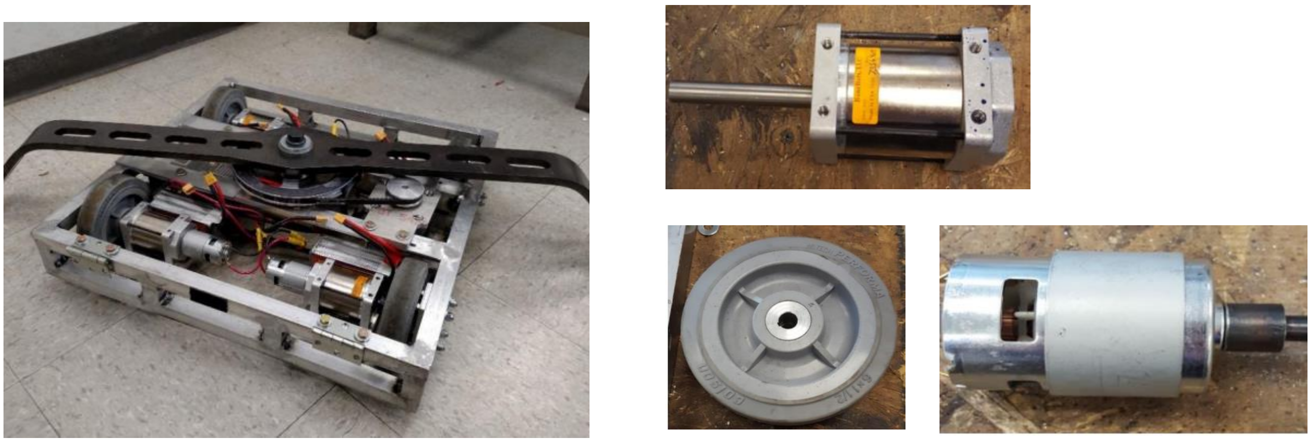


Figure 12: Drive Train, 2017 UC Combat Robot

The 2017 team decided to build a 120 lbs which also used a direct gearbox that had a gear reduction ratio of 27:1 and was able to move the robot at around 8 MPH (10) which would allow them to maneuver quickly around the area. The gearbox they used was a P-980 Gearbox and for their motor, they used an RS775 motor as it used 24 volts which they wanted for consistency, and it also only weighed 11.9 ounces (10). They did not put the results of their competition, but they did drivetrain testing after the robot was fully constructed which went very smoothly as the robot was able to move around without many problems even when the weapon was running. This drive train seemed to be well designed, but the high gear reduction ratio and custom parts added to the gearbox could make it more susceptible to damage when hit with a hard hit.

Since this was a 120 lb robot, they had to consider how the wheels were going to be placed, they initially wanted to do a two-wheel drive system but since their frame was a large square it was not going to work. The two-drive system would result in lower cost and weight, but the frame shape would make this kind of system impossible (10). This made their decision clear, and a four-wheel system was selected. The wheel selection was a six-inch Colson wheel which was made out of a strong rubber that according to the team was extremely popular among the combat robotics community. The wheels seemed to perform very well during testing and the design seemed to be well researched.

End User

The main end user for this project is the Xtreme collegiate Clash 15lb combat competition and the judges at the competition. When looking at different characteristics for the end user the age, gender and demographic of the judges doesn’t really have an impact on the customer features we focus on. We don’t plan on letting the end user’s characteristics decide what our main customer features are. We will mainly focus on research and surveys that will allow us to come up with the best design for our Combat Robot that will meet all of the competition requirements. There are a bunch of rules/compliances we must follow in order to compete in the competition, and we plan on meeting them all while at the same time focusing on our customer features to help us build a Combat Robot that will defeat our competition and stun the judges.

Summary of Research

Weapon

Based on the research on the current state of the art, it seems like the Drum weapon design is the most effective weapon, but it can be pretty difficult to control at times. It has a great start up speed and can deal a lot of up force damage to its opponent. The vertical plate spinner weapon design is a great idea if you are looking for maximizing control, but it isn’t the best decision when it comes to dealing damage to your opponent. When looking at the horizontal blade design there are a lot of great perks to the design, but it also has its lows. It can deal a lot of damage with its horizontal blade, but when hitting its opponent, it almost always sends their own bot in the other direction and at the same time the bot is very hard to control. It is functional when flipped over, but it's driving belt can be exposed in those scenarios.

The drum weapon design functions when flipped over and nothing is exposed within its belt or chain drive. We plan on coming up with different concepts for the drum weapon design because we believe there is a lot to be explored in that area. There are a lot of areas to explore within the drum design. The size of the drum, the layout, number of teeth on the drum, and obviously material. We’ve seen drums that are completely solid and ones that are completely hollow, but we have yet to see one that is made of multiple blades with separators in between, so we plan on looking more into that design. We plan on testing different teeth designs and the number of teeth as well. Based on our research 4140 steel is a great material, but it is too dull and can break very easily. There is also AR500, which is a great material with a very high yield strength, but too much of the material can make it very hard to control. So that’s why we are going to try to find the perfect size of AR500 that helps us maximize our RPMs and moment of inertia while still being able to completely control our bot. It will take a lot of FEA simulations, but it will help us come up with a combat robot that can both deal heavy damage and be easy to control. We also plan on testing the drum design with wedge design in the front. Wedge weapon designs are designed to send the opponent's robot through the air by simply running straight into it with the wedged design. If we can implement a wedge on our robot that can be used on both sides when being flipped over, we may be able to even maximize damage even more because lifting the opponent's robot up with a wedge and then getting underneath their robot with our drum teeth will send them even higher into the air.

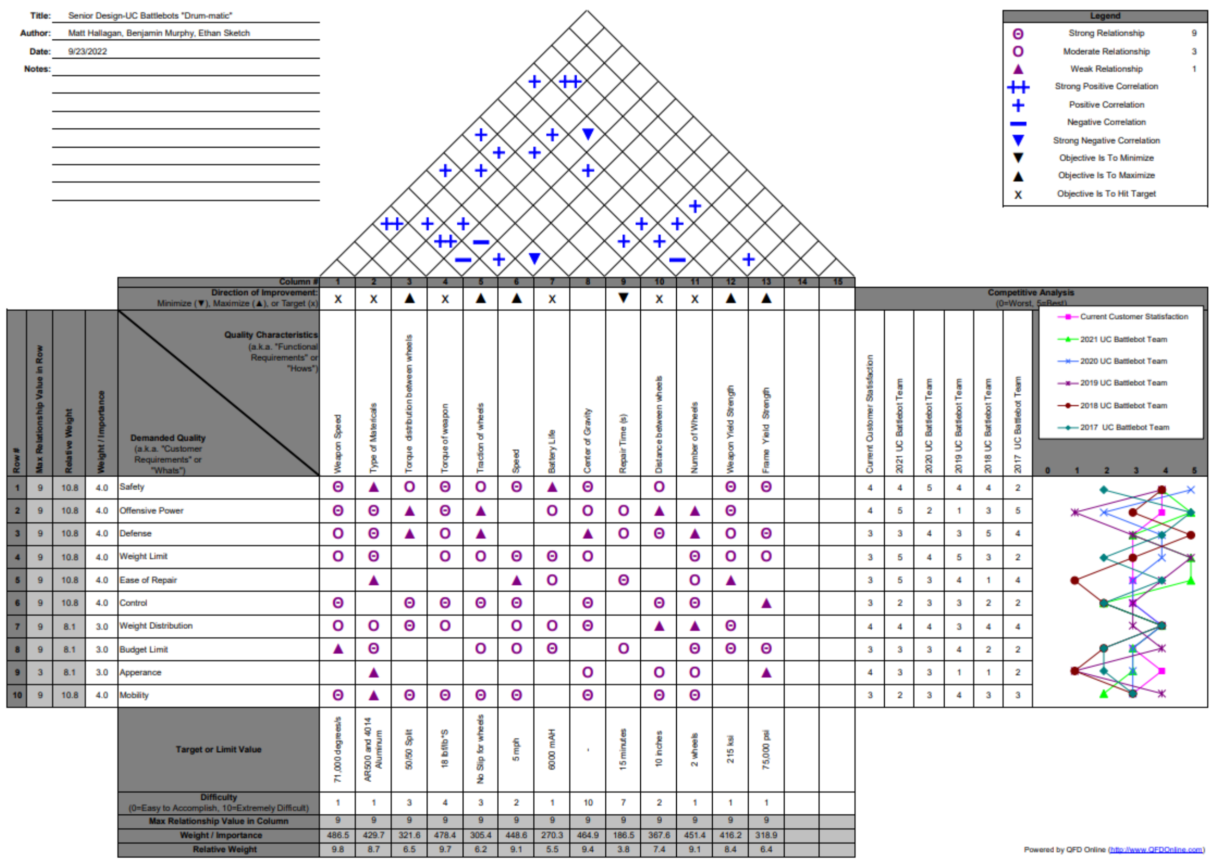
Drivetrain

The drivetrain of a robotic combat vehicle is one of the most vital aspects of the design. It lets the robot move around the area in which the speed and torque is determined by the motor and gearbox selected to fit your vehicle. After a considerable amount of research into the previous University of Cincinnati combat robotic teams, there is a clear answer to what kind of gearbox is used in the majority of robots. All three of the teams that I looked at for my state-of-the-art used a gear drive which is gears are used to create torque for your robot. This seems to be the transmission of choice as it is a compact, versatile, and safe option to be used in your robot. I am still going to create concepts that use belt and chain drives, but a gear drive seems to be the option that is used for the majority of combat robots in all levels from local competitions to TV tournaments.

The other aspect of the robot that I focused on was the wheel which had a lot more differences between the different teams that I studied. The different wheels used were foam wheels, plastic wheels, and rubber wheels. These all have different properties which can affect how your robot is going to perform as the foam wheels were able to take more hits, but the damage was getting chunks taken out of them and lowering the performance of your robot. The plastic wheels would also be able to take hits but when they cracked, the entire wheel would most likely fail, and the robot would lose a considerable amount of its movement. The last wheels, which were rubber, seemed to be the best option as it will be able to absorb even the toughest hits while also not cracking or breaking entirely when it is damaged. The other dynamic of the wheel was the placement as two of the teams placed the wheels outside of the frame while one team placed the wheels on the inside of the frame. The main reason for placing the wheels on the inside is for protection from hits but this adds weight and increases the size of the frame which increases the hitbox of your robot. Keeping the wheels on the outside exposes them to damage but allows you to utilize that extra weight elsewhere around the robot. These both have their merits and seem to be utilized in all stages of combat robotics although we are leaning towards keeping our wheels inside our robot for extra safety.

Quality Function Deployment

House of Quality



Customer Features

- Safety
- Offensive Power
- Defense
- Weight Limit
- Ease of Repair
- Control
- Weight Distribution

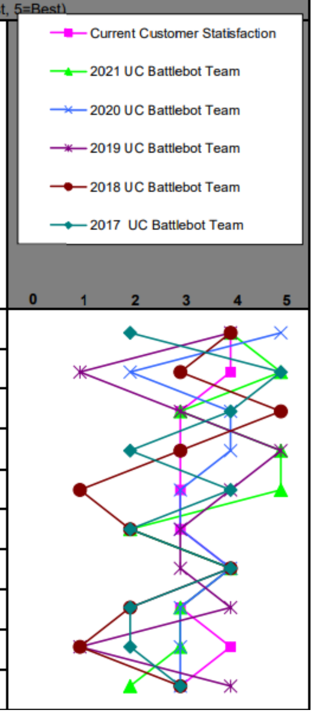
- Budget Limit
- Appearance
- Mobility

Engineering Characteristics

- Weapon Speed
- Type of Materials
- Torque distribution between wheels
- Torque of weapon
- Traction of wheels
- Speed
- Battery Life
- Center of Gravity
- Repair Time
- Distance between wheels
- Number of Wheels
- Weapon Yield Strength
- Frame Yield Strength

Competitive Analysis
(0=Worst, 5=Best)

Current Customer Statisfaction	2021 UC Battlebot Team	2020 UC Battlebot Team	2019 UC Battlebot Team	2018 UC Battlebot Team	2017 UC Battlebot Team
4	4	5	4	4	2
4	5	2	1	3	5
3	3	4	3	5	4
3	5	4	5	3	2
3	5	3	4	1	4
3	2	3	3	2	2
4	4	4	3	4	4
3	3	3	4	2	2
4	3	3	1	1	2
3	2	3	4	3	3



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")
1	9	10.8	4.0	Safety
2	9	10.8	4.0	Offensive Power
3	9	10.8	4.0	Defense
4	9	10.8	4.0	Weight Limit
5	9	10.8	4.0	Ease of Repair
6	9	10.8	4.0	Control
7	9	8.1	3.0	Weight Distribution
8	9	8.1	3.0	Budget Limit
9	3	8.1	3.0	Apperance
10	9	10.8	4.0	Mobility

Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Weapon Speed	Type of Matericals	Torque distribution between wheels	Torque of weapon	Traction of wheels	Speed	Battery Life	Center of Gravity	Repair Time (s)	Distance between wheels	Number of Wheels	Weapon Yield Strength	Frame Yield Strength
Target or Limit Value	71,000 degrees/s	AR500 and 4014 Aluminum	50/50 Split	18 lbf/lb*S	No Slip for wheels	5 mph	6000 mAH	-	15 minutes	10 inches	2 wheels	215 ksi	75,000 psi
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	1	1	3	4	3	2	1	10	7	2	1	1	1
Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9
Weight / Importance	486.5	429.7	321.6	478.4	305.4	448.6	270.3	464.9	186.5	367.6	451.4	416.2	318.9
Relative Weight	9.8	8.7	6.5	9.7	6.2	9.1	5.5	9.4	3.8	7.4	9.1	8.4	6.4

Product Objectives

Ranked in Order of Importance

1. Weapon Speed: 71,000 Degrees/s, Difficulty: 1
2. Type of Materials: AR500, 4014 Aluminum, Difficulty: 1
3. Speed: 5 mph, Difficulty: 2
4. Repair Time: 15 minutes, Difficulty: 7
5. Traction of wheels: No Slip Wheels, Difficulty: 3
6. Number of Wheels: 2 Wheels, Difficulty: 1
7. Battery Life: 6000 mAH, Difficulty: 1
8. Torque of weapon: 18 lb/lb*s, Difficulty: 4
9. Distance between wheels: 10 inches, Difficulty: 2
10. The torque distribution between wheels: 50/50 Split, Difficulty: 3
11. Weapon Yield Strength: 215 KSI, Difficulty: 1
12. Frame Yield Strength: 75,000 psi, Difficulty: 1

Weapon Concepts Drawings

Concept 1: Single Drum Blade

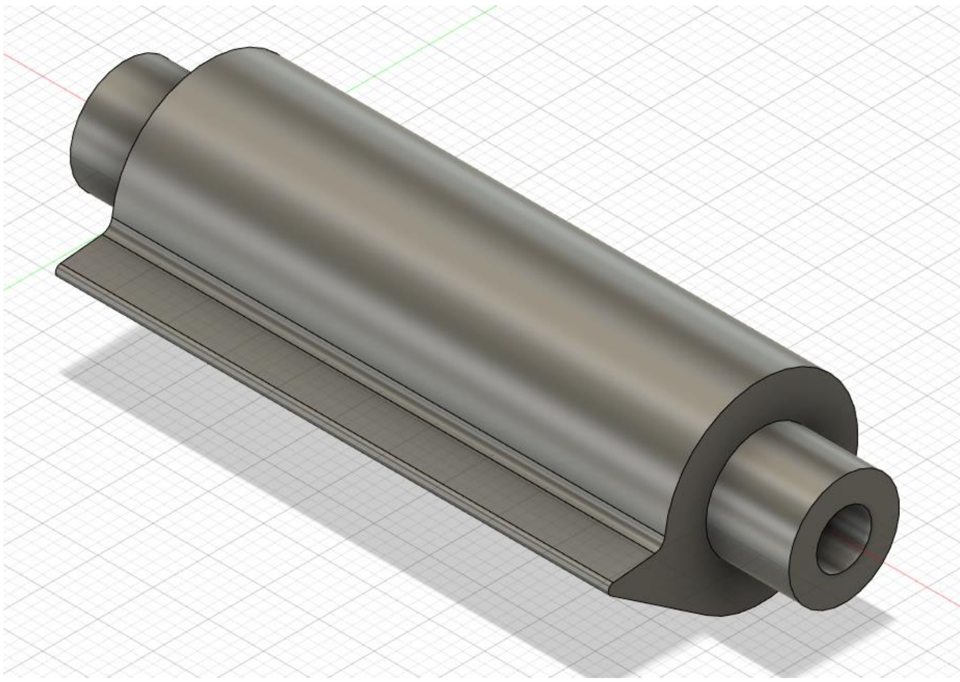


Figure 13: Single Blade Drum

For our weapon design we mainly focused on different concept designs for the drum weapon. A single bladed drum is our first concept, and it is a relatively simple weapon design. It has a singular tooth blade that runs all the way across the drum. The benefit of this design concept is that it is pretty easy to manufacture and the calculations behind its properties are simpler as well. With a singular blade across the blade, it increases the chance of making contact with our opponent's robot, however it will have less of a bite because it is relatively heavy. The heavier the weapon the lower our Moment Inertia is, which makes our hits less effective. Making the blade a single form across the entire drum does increase our chances of hitting our opponent, but at the same time it decreases the chance of our weapon doing great damage to our opponents. If we are able to continuously hit our opponents' frame and not take much damage in doing so then this is a great direction to go in when designing our weapon. The blade also has a filet at each corner where it meets the drum to allow for more stress to be experienced. The more stress that can be allowed the less likely our drum weapon will fracture when hitting either its opponent or getting hit by its opponent.

Another great aspect of this concept is that the weapon is only one part, which makes it very easy to replace in between matches. The weight of the weapon is another concern though because the weapon is one piece in whole it makes it weigh more. We could hollow out the inner diameter more, but we don't want to increase the stress point between the shaft of the drum and where it connects to in the frame. The speed of this type of design is also slower compared to drums with multiple separate blades because it is much more mass to rotate. The material for this weapon would be AR500, which is a very strong type of Steel that can experience a maximum yield stress of 1100 MPA. This weapon will also be powered by a belt pulley system. Using a pulley system will allow us to alter the gear ratio between the motor and the weapon, which will help us increase our weapon start up time and our maximum RPMs.

Concept 2: Altered Single Drum Blades

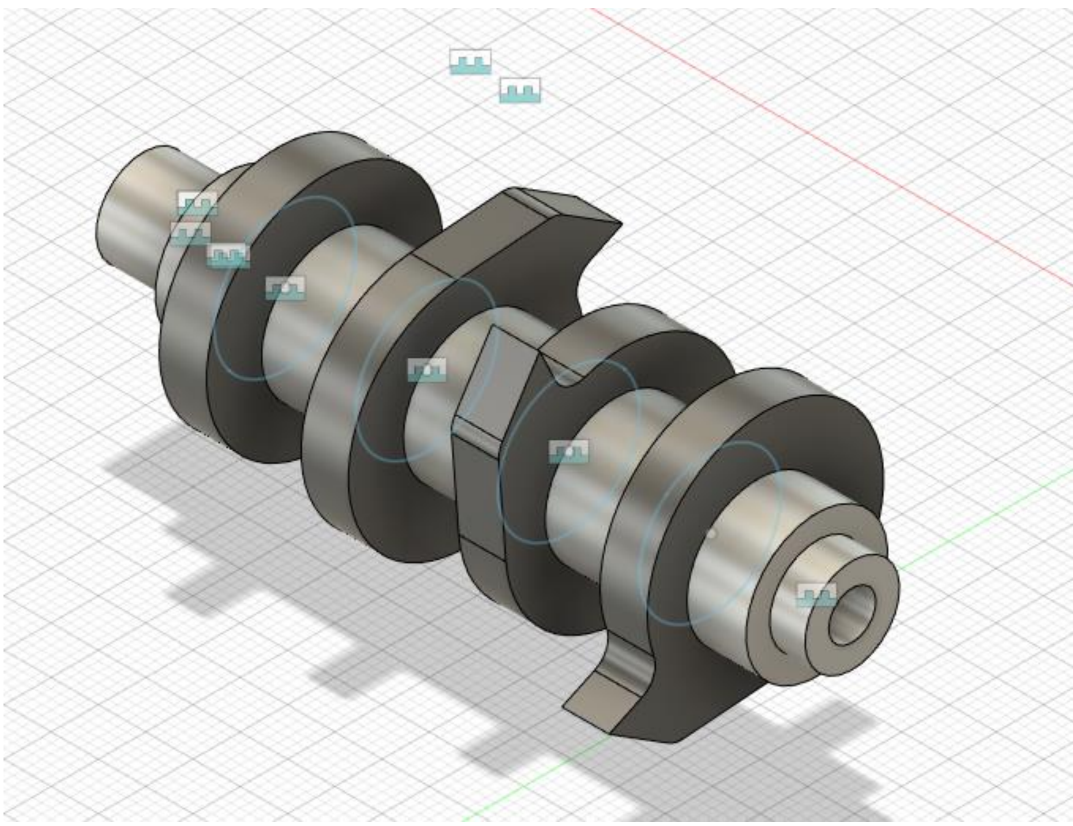


Figure 14: Four Single Altered Bladed Drum

This drum design is much more complex compared to Concept 1 because it has multiple single blades that are spread out across the entire drum. It also only uses AR500 Steel for the blades and has a normal steel shaft. Having a steel shaft makes the weapon much lighter, which allows us to spin our weapon at much higher RPM. Having a higher RPM allows us to hit our opponent much harder as well. The lighter the weapon the higher our Moment of Inertia will be, which will allow us to hit our opponents much harder compared to a single blade drum design like in Concept 1. The blades of the drum are altered across the shaft because we wanted to increase the chance of our weapon getting a bite on our opponent. Spreading the blades out and altering them gives a higher range and higher chance of delivering a bigger hit to our opponent. Compared to the drum with a single blade across the entire weapon where it does have a large range of landing a hit, but since the weight is so high it reduces the chance of doing any significant damage to the opponent's design.

A couple negatives of this concept is that it is a multi-piece weapon, and the manufacturing time will take longer compared to Concept 1. The blades will have to fit around the drum perfectly and we will have to weld the blades symmetrically, so the weapons center of mass isn't thrown off completely. The cost of this weapon will be much lower compared to Concept 1 because we will only have to purchase AR500 steel for the blades and not the entire drum. With a lower cost it also opens our options to possibly having a backup weapon if our weapon is fractured by our opponent. This weapon design will also require a belt pulley system to help power the weapon. It may require a different gear ratio, however, because it is much lighter compared to Concept 1. We are leaning more toward this weapon concept for our combat robot.

Concept 3: Multiple Separate Drum Blades

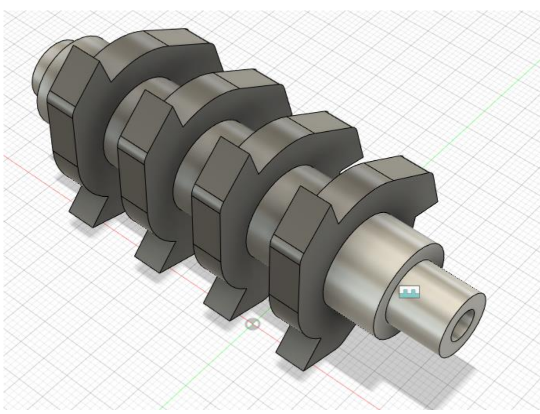


Figure 15: Multiple Separate Drum Blades

Concept 3 is similar to Concept 2, but it has multiple teeth on each blade across the drum. Each blade is aligned perfectly with the other blades across the entire drum and all of them have the same rake angle. Having multiple teeth on each blade will increase the chance of our combat robot landing a hit on our opponent, but it won't hit as hard compared to Concept 2. The weight went up by adding more teeth to the blade. It increased the weight of the weapon, which will reduce our Moment of Inertia making our hits not do so much damage, but it will do more damage than Concept 1 because this weapon Concept is lighter. Adding more teeth to the blade increases the weight of the weapon, which reduces the RPMs and also reduces the startup time of the weapon. This weapon design is lighter compared to Concept 1, but it is heavier than Concept 2 because of the extra teeth that were added to the blade. This concept also has a steel shaft for the blades to be secured on by welds like Concept 2 but having multiple teeth on the blades will make it more difficult to weld the blades to the shaft. Therefore, the manufacturing of this part is more difficult than manufacturing Concepts 1 and 2. Since there are more teeth on the blade it will also increase the cost of the weapon because we will have to order more of the AR500 material to make our part.

This Concept does give our weapon more of a chance to strike the opponent’s frame, but it doesn’t guarantee we will disable it and defeat it in combat. The whole objective of this competition is to disable/destroy the other team's design while protecting our own at the same time. If we can’t deliver big blows to our opponent then we will have a very hard time defeating them in the ring. This concept however will be able to hit its opponent constantly, but it will have a tough time getting that KO hit with having so many teeth on the blade. The main advantages to take away from this concept is that it has a large range when it comes to hitting objects, it is light, and cheap to manufacture. This concept will also use a pulley system to power its weapon from the motor, but the distance between the weapons pulley and the motors pulley will be less because the weapon is less weight, so we don’t have to meet a certain gear ratio.

Frame Concepts Drawings

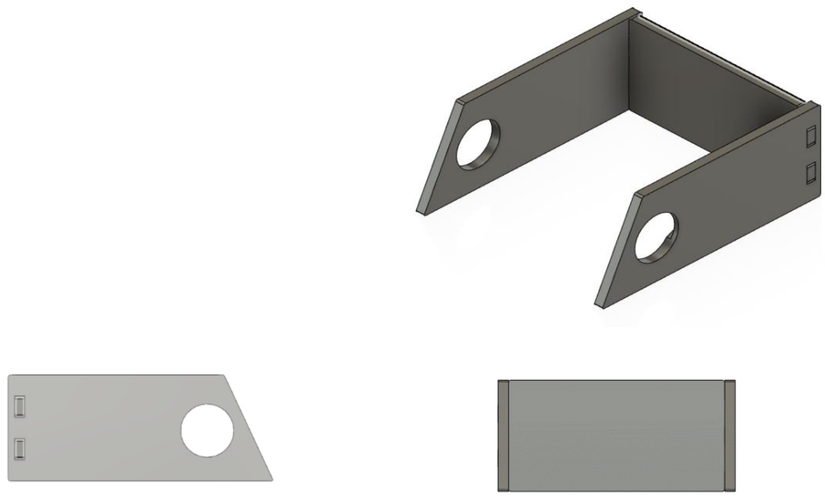


Figure 16: (Front, Side, & Iso View of Concept I)

Concept 1

The first concept shows a boxed frame constructed from 6061 Aluminum with two side pieces that are supported with a back panel that is keyed into both of the side pieces. This would allow for the weapon to be supported and plenty of room for the implementation of the drivetrain and electronic systems. This design would also be easy to manufacture and simple to assemble due to the modular side panels and keyed parts that would slide into place.

This design falls short in that the design of the back of the robot would be susceptible to being stuck vertically with the weapon and wheels in the air because of the flat side on the back. Additionally, having flat edges would rely on having high maneuverability of the bot to turn the drum to defend the back panel as the panel is slightly offset and could easily be sent flying into the air. Three separate flat pieces will also deform and not distribute the forces as efficiently as other designs during competition. The side profile also leaves much to be desired in terms of tooth engagement. With this design the frame will be contacting the opposing bot first which could result in misses with the weapon.

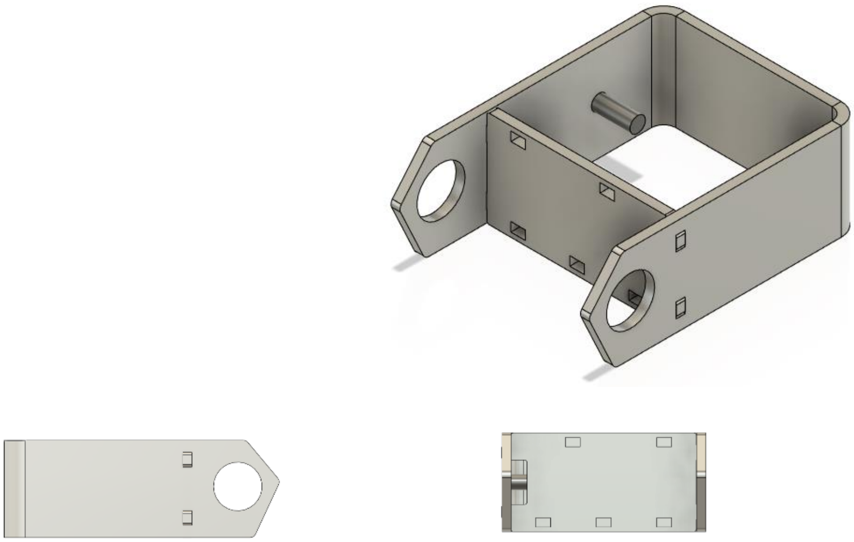


Figure 17: (Front, Side, & Iso View of Concept II)

Concept 2

Concept II has a similar shape to concept one, remaining with a boxed design for the ultimate freedom of electrical and drive components. Also made from Aluminum 6061, this design is differentiated by the three bends to be created on a single sheet as opposed to three separate components. This should allow for stress to be distributed uniformly across the frame of the bot instead of being focused on a particular side. This design will also incorporate a keyed mid-plate to add rigidity and improve the structure of the battle bot. The side profile should also allow for more weapon engagement than the previous design.

This design also suffers from the same fate as Concept I but to a lesser extent as the rear of the frame is relatively flat and could be prone to being stuck vertically. There could be external components designed and added to diminish the likelihood of such an event occurring. During competition if there was any serious damage to the frame it would require a complete replacement of the entire structure which would be infeasible to rebuild in the allotted time between matches. Additionally, once a top and bottom plate are added to the keyed mid-plate, it would require a full disassembly to replace and repair any internal components of the bot during a competition.

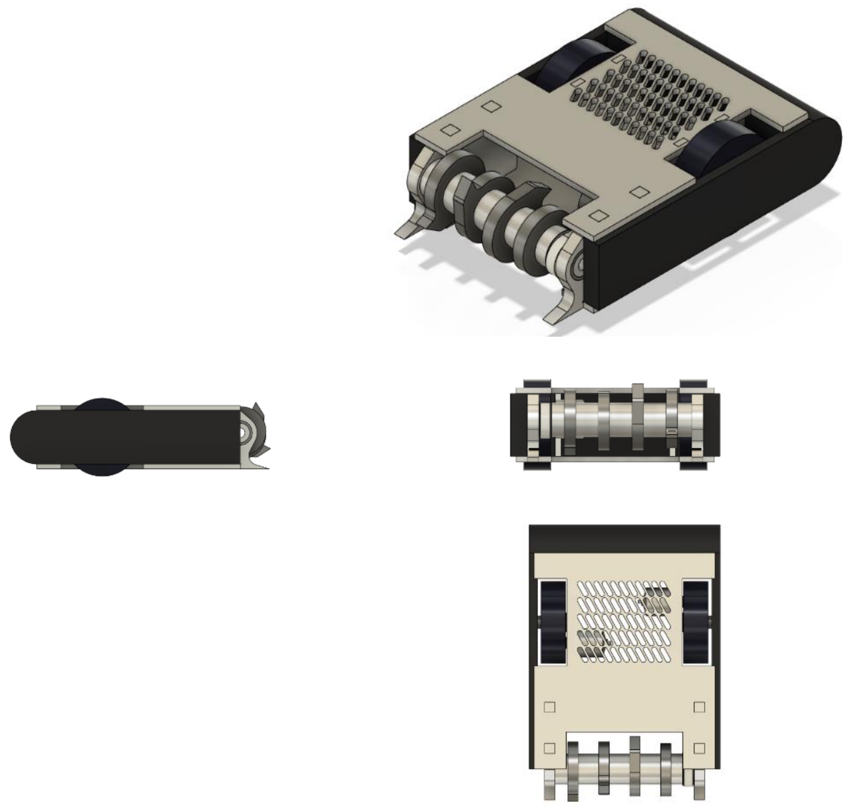


Figure 18: (Front, Side, Bottom & Iso View of Concept III)

Concept 3

Concept III is another boxed design that utilizes a UHMW mold for additional defense of the side panels and rear of the bot. This design also implements weight reduction and the ventilation of motors and electronics with slot patterns across the middle of the bottom and top portions. The weapon supports are now also coincident with the floor surface of the bottom plate which will allow for the downward force received from striking up on our opponent to be transferred into the floor instead of throughout our combat robot. These improvements continue as the support structure has also been modified to allow for more engagement of teeth on the weapon which was lacking in previous concepts.

Concept III should also fare better when repairs are required as the side support pieces are designed modularly so pieces could be kept on hand and be used for either the left or right side. In addition, the bottom and top pieces can easily be removed and allow full access to the bot which was not possible in previous concepts. Overall, this concept appears to be the strongest, offering the best options in protection, repair, and assembly. More work could be done to determine the most effective UHMW exterior shape, but the core components of this frame can be built upon further to establish our final concept.

Drivetrain Concepts Drawings

For my concepts, I went with three concepts that have an array of positives and negatives when applied to our combat robot. These concepts are two-wheel drive, four-wheel drive, and a custom drive known as a "Jake" drive which was created by a fellow student. I will go over how these concepts are going to work in relation to our robot as well as the positives and negatives of each concept. The concept that we will use will be chosen by using the weighted rating method which will help us get a real understanding of what concept will benefit us most.

Concept 1: Two Wheel Drive

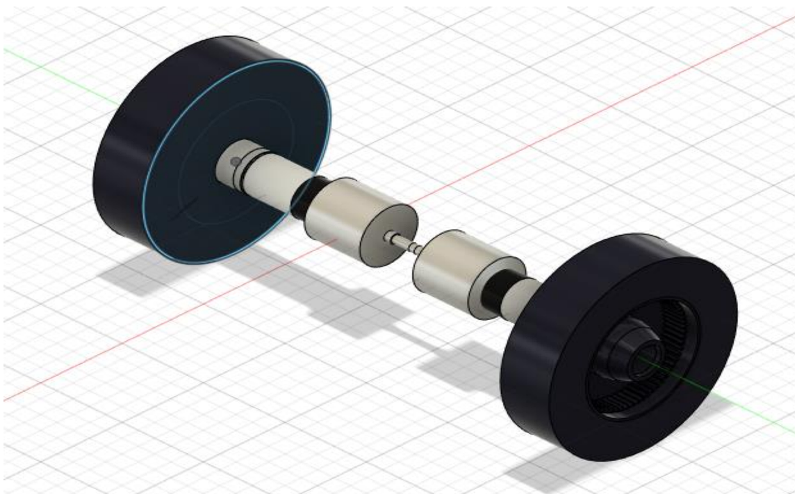


Figure 19: Two Wheel Drive Assembly

Two-wheel drive on a combat robot is the most common approach throughout the majority of weight classes and competition levels. Two-wheel drive for combat robots usually means that only two wheels are powered by your robot, and this is usually applied in robots that only have two wheels on their frame. Two-wheel drive systems use a standard wheel that is attached to a gearbox which is then attached to the motor.

This is an extremely simple system that has numerous benefits which is why it is the most popular use across all combat robotics. It is a lightweight system that is extremely reliable as gearboxes are well made and can take many strong hits from opposing robots during three-minute matches. Since this system is so light, the extra unused weight can go to reinforcing my frame, weapon, and other parts of the robot that may be lacking in certain areas. The use of only two wheels allows you to spend more money on quality components such as the wheels which can vary in size, material, and weight depending on choice and budget. The motor can also be more customized for your two-wheel drive.

The two-wheel drive component is not perfect and has many flaws that need to be addressed. The major flaw is the lack of control that you have on a two-wheel drive vehicle. This lack of control is the result of only having two points of contact with the ground which results in sudden jerking-type movements that do not feel natural and take time and practice to get right. This can be partly reminded by adding a third point of contact along your bot which is usually located near the front by the weapon, this allows you to use that third point of contact as a pivot point which allows for easier rotation of your robot.

One of the main driving mentalities for two-wheel drives is to keep your weapon pointed at the opposing robot and be much more reactionary than aggressive in your driving. This will allow you to land big hits without risking getting significant damage to the back of your robot. Overall, the two-wheel drive system allows for a light simple drive train that allows more flexibility in the budget and weight of the overall robot. Its major but manageable downside is one of poor control which can be altered using more points of contact and practice on controlling the robot before a fight.

Concept 2: Four Wheel Drive

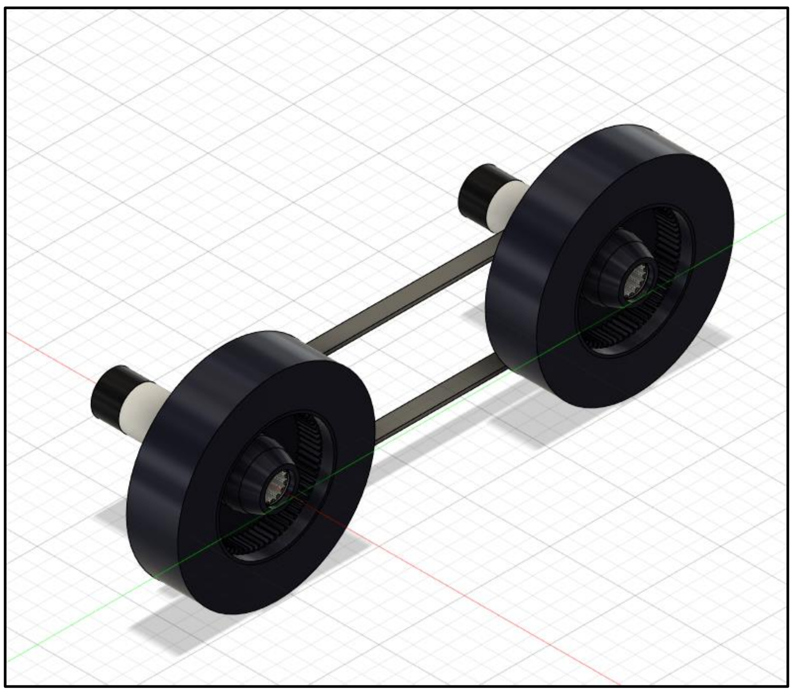


Figure 20: Four Wheel Drive Side Assembly

Four-wheel drive is the concept of using four wheels with either two motors that are directly driven to two wheels with pulleys that connect the motion to the other wheels or four motors and gearboxes straight into the four wheels. This type of drivetrain is common in the higher weight classes as well as in larger robots that need four wheels to be balanced.

Four-wheel drive systems provide numerous benefits such as unmatched drivability and mobility which can be driven in a similar way to a racecar as well as powerful torque which will allow you to overpower your opponent in almost any pushing match you would get into. It also allows your robot to be able to survive even if one of your motors runs out, which is important during a three-minute match. The two different ways of making a four-wheel drive system also have certain pros and cons.

The first way of creating a four-wheel drive system as stated above is using a pulley to create direct motor motion. All four wheels are less commonly used but we will still go over their pros and cons. One of the most prevalent advantages of this specific type of four-wheel drive is the lighter weight and cost in comparison to having individual motors for each wheel. The method of powering each wheel with its own motor and gearbox results in unmatched control as the degree of error in movement will be drastically shortened. It will also be much more resistant to brakes in comparison to the pulley that connects the other four-wheel drive method.

The negative of a four-wheel drive system is that both concepts are very heavy, and the frame and weapon need to be designed around that fact. It will result in making your drive train the main focus of your robot as well as needing to fit four wheels into your frame as well. The method of using a pulley in four-wheel drive results in a very risky weak spot in which the pulley could be cut and you could lose power to one of your wheels.

The driving mentality for the four-wheel drive will be one of speed racing as it will have a similar feel to a regular car and be much easier to drive. This makes your strategy to use your movement to your advantage and exploit other drivers' lesser control to hit their weak spots. Overall, the four-wheel drive system is one that allows for unbeatable control and mobility but is brought down by the weight and cost of the drivetrain.

Concept 3: “Jake” Drive

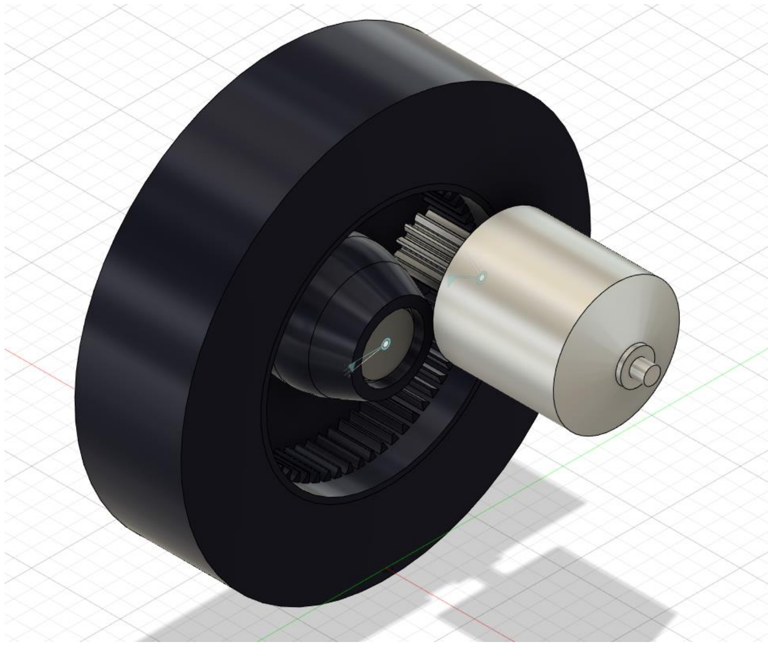


Figure 21: "Jake" Drive Assembly

The “Jake” drive is a drivetrain that was created by fellow combat robotics peer Jake Hoffmann who is the leader of the UC Combat Robotics club. Its main function is using an action similar to a planetary gear where the internal gear rotates the sun gear which rotates the wheel itself. This drive is different from other drivetrains as the wheel itself is the gearbox instead of having a separate heavy gearbox attached to each wheel. This has never been used before and the kinks are still being smoothed out but the potential for this drive train is off the charts in the combat robotics scene.

The advantages of the “Jake” driver are that it is extremely light as these wheels eliminate the need for gearboxes which are usually heavy and clunky. The mechanism that it uses is also extremely simple which makes the parts easier to replace and fewer things that can break during impacts while the fight is ongoing. The final advantage of this drive is that it's extremely fast as the motor is closer to the wheel and the gear-down ratio is significantly less.

The disadvantages of the “Jake” drive are mainly based on its experimental nature. This drive has never been tested during an actual combat robot fight and therefore could have a ton of unknown problems. These unknowns make this drive a high-risk high-reward drive that needs to be taken into account.

The drivability of this drive will be similar to a mix of the two and four-wheel drive systems. It most likely will have control and mobility that is between the two and the driving mentality has to be similar. Since we are only using two wheels, we will still not be aggressive drivers, but we can use our speed to get behind our robots and hit their weak spots with our weapons. Overall, the “Jake” drive allows for a new unique approach to drivetrains that allows for a light and fast drive that is a risky investment that may pay off at the end of the day.

Preliminary Final Design

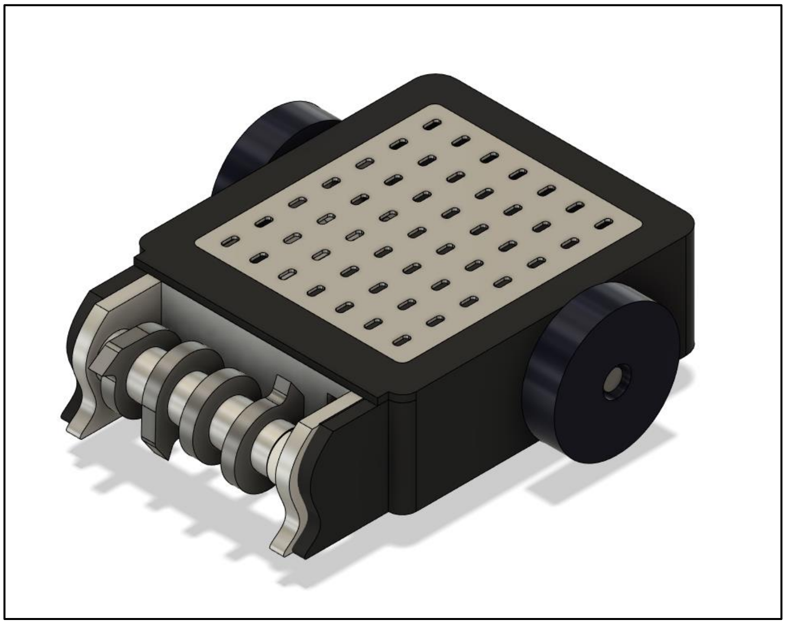


Figure 22: Final Concept

Our preliminary final design was a mixture of all the concepts that we have researched and talked about above. Our final decisions for each concept may have been slightly altered between the concept and final design as we continued to optimize our design and choose the concepts that best fit our combat robot.

The weapon design that we talked about in our concept stage has stayed exactly the same as in our decision, as it is a vertical drum spinner with four blades that each have one tooth. The blades are going to be fabricated out of AR500 steel and the shaft out of steel to ensure that damage inflicted is maximized and the damage that the weapon takes is minimized. The weapon will use a pulley system with a gear ratio of 1.83 to 1 and use a motor that will move the weapon at 123 mph and 11,856 rpm.

The drive train design that was reached and decided above has stayed the same with minor tweaks. The Jake drive is still being used but the size of the wheel has changed to better fit the overall size of our design. It uses a 780-kilovolt motor that has a wattage of 1200.

The frame of our combat robot has changed drastically in comparison to what we initially decided during our concept phase as we needed to reduce weight as well as add more protection. Our frame design now is a TPU frame which is a type of plastic with aluminum aspects to ensure rigidity and strength.

All aspects of this design are subject to change but as of the end of senior design I, this is our current concept that will continue to be optimized throughout senior design II.

Changes in Background/Design

About halfway through our Fall Semester, our background objective changed drastically which led to many design changes that altered our combat robot in almost every aspect. Initially, we were creating a 15-pound combat robot that was going to fight in the XtremeBOTS competition which is held at a local high school. We are now creating a 12-pound combat robot that will be fighting at a professional competition called the NHRL (Norwalk Havoc Robot League) located in Norwalk, Connecticut. The focus for our group is that we must reduce our combat robot by three pounds in order to participate in this new competition which will involve drastic design changes as seen below.

Finalized Concepts

Weapon Changes

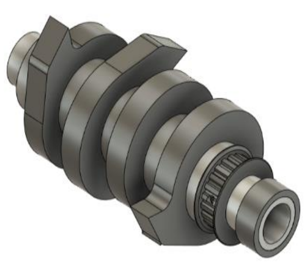


Figure 23: Original Concept

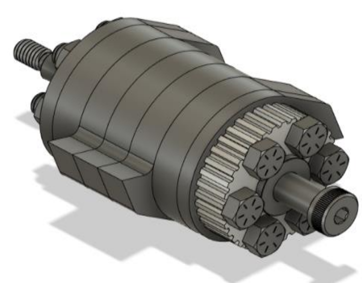


Figure 24: New Concept

When preparing a manufacturing plan for our weapon we ran into a few problems. Since our weight class had been decreased, we had to make some adjustments to our weapon. Going down a whole weight class forced us to reduce the size of our weapon because it was taking up too much weight. The problem with shrinking the size of our weapon was that it reduced the size of the gap between each blade. We planned on welding the blades onto the steel shaft, but the gaps were no longer big enough for us to get in there to weld the parts together. The manufacturing process for the altered blade design was only going to work if we reduced the number of blades on the weapon, but we didn't want to reduce the chances of hitting our opponent. So, we ended up coming up with a beater drum design that uses multiple blades that are stacked together. Each blade has a hole all the way through to allow for a shaft to slide through the middle. The blade will be connected using bolts that slide all the way through.

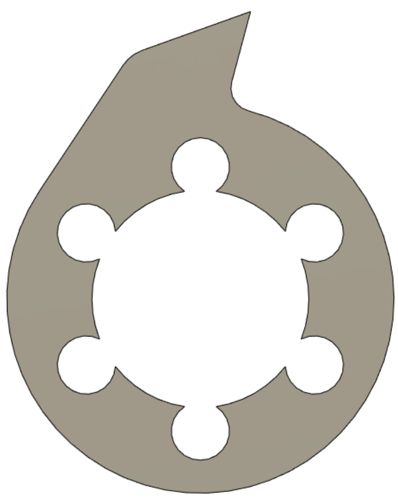


Figure 25: ½" blades

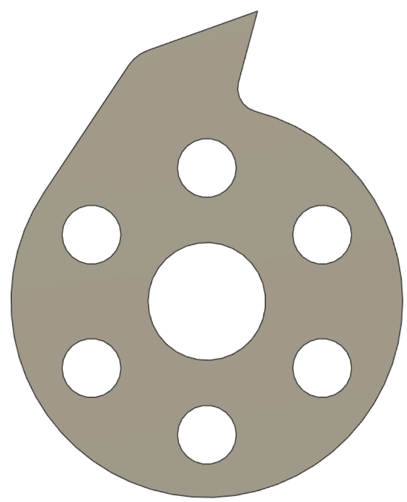


Figure 26: ¼" Blades

Here are the two different blades that will be used in the beater drum. The one on the left is a ½" thick blade that has 6 bolt holes through it to allow the bolts to slide through to connect all the blades. The blade on the right has a smaller shaft hole because it is being used on each end of the drum to hold the bearings. The thickness of those blades is ¼". The pulley will also have holes drilled through it to allow it to relate to the drum. There are 7 blades in total on the drum. There are 2 ¼" thick blades on the ends of the drum and there are 5 ½" thick blades in the middle. We also altered the blades a little bit because we wanted to try to keep our old design with the altered blades. Switching to the beater drum is making our weapon much easier to manufacture and it will also be easy to assemble it to our weapon assembly Now it can just be placed in between the sides of the weapon assembly and the shaft can slide through and hold it together.

Due to the new constraints brought on by the change in weight class, we have changed the diameter of the weapon blades to 3" instead of 3.5" and the minor diameter from 2.5" to 2.35". This change will remove approximately 2.1 ounces of weight per ½" blade, and 1.05 ounces per ¼" blade, for a total reduction of 11.7 ounces for the blades. When moving to this weapon type, the removal of the large steel shaft proved to be beneficial in removing and redistributing the weight to other aspects of our design.

Drivetrain Changes

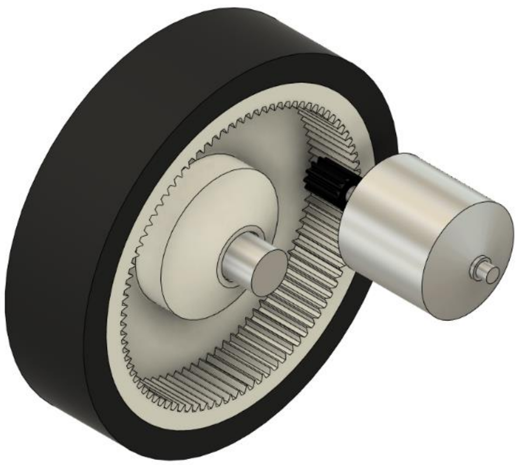


Figure 27: Selected Drivetrain

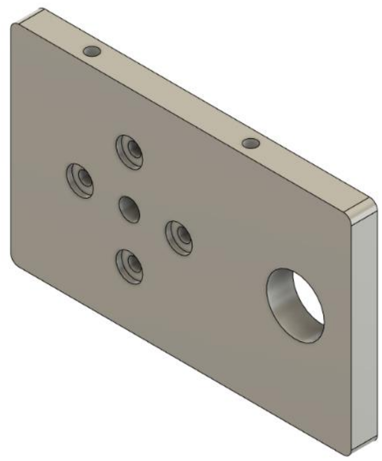


Figure 28: Wheel bracket

The drivetrain did not have a drastic change when we had to change our combat robot from 15 to 12 pounds in comparison to our weapon or frame. That is because our drivetrain was low in weight and could be custom made to whatever size we required as we changed the shape and size of our robot. The biggest question mark with our drivetrain was that it had previously not been tested in a battle, so the robustness of the drivetrain was unknown. This question was finally given an answer when Jake Hoffmann went to NHRL in early November in order to compete with his combat robot that he had been working on for the past 6 months. During one of his fights, he was hit very hard by another robot and the impact broke the shaft of the drive motor which rendered him unable to move, which lost him the match. After this failure of the drivetrain, we had serious discussions about switching back to a classic drivetrain that we know will work and be better reliability. We decided to stick with the “Jake” drive as we loved the concept, and our weight was already teetering on the weight line and this drivetrain was much lighter than other alternatives. The main benefit that this information gave us was that we needed to increase the shaft size of our motor in order to ensure that it would not break on impact after a big hit. Other than that, the motor performed very well during the event, which gave us the needed confidence to move forward with this drivetrain decision.

The other aspect of our drivetrain was the bracket for the motor and the shaft. Since we are using a TPU frame, we needed the bracket to be made from something that was rigid and strong to reduce flex. We decided on using 0.25 aluminum in order to fulfill those needs. In order to attach this wheel bracket to our frame, we are using a total of 4 screws per bracket with two on the top and bottom. The drive motor will be held on using the 4 screws that came with the motor that will connect the TPU and drive motor.

The drivetrain mainly stayed the same during the last couple of months with a couple of changes to the size and assembly of the wheel into our frame. The benefits of this custom-made wheel outweigh the disadvantages that may come with using such a new concept.

Frame Changes

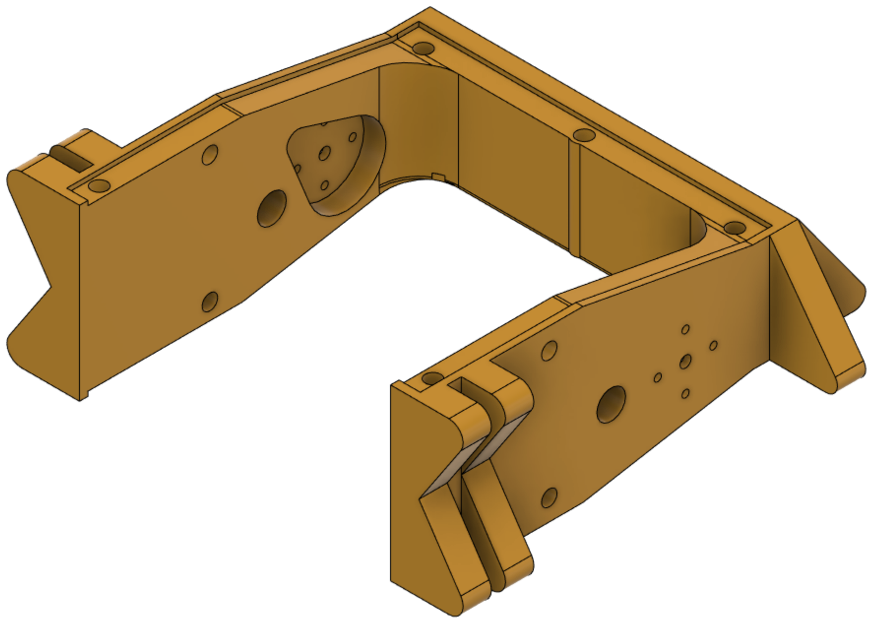


Figure 29: Final Frame

Our previous design was already over the 15 pounds allotted for the anticipated weight class that we would be participating in. This was a result of the body of our combat robot being composed mainly of aluminum with TPU to surround the aluminum and provide additional protection. In order to drastically remove weight from our design it was proposed that we instead make a bot that utilizes TPU as the main body to protect and store the electrical components of our combat robot. Only using aluminum when absolutely necessary for rigid aspects of our design such as the weapon support and wheel/motor mounts. Unnecessary material could be seen in the large top plate made from aluminum, which could instead be aluminum and much smaller in size. Other minor changes included separating the weapon and wheel supports into two different components. This would cut back on the amount of aluminum used and require cutouts to be made for the wheel supports to sit in, with additional holes and screws to hold everything in place.

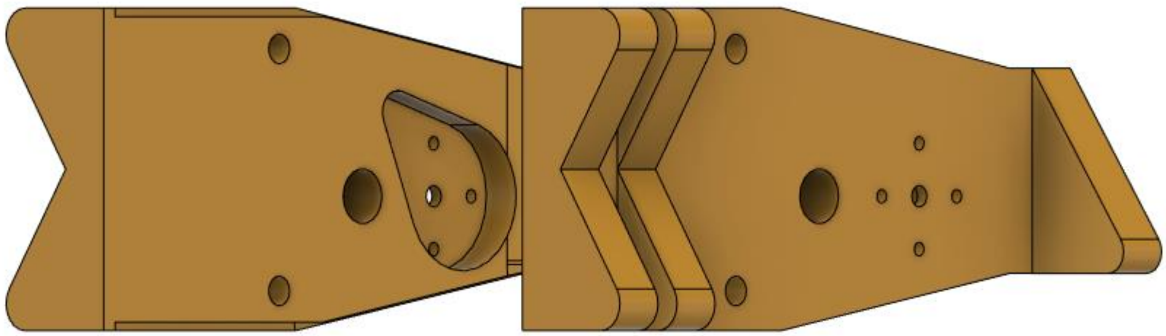


Figure 30: TPU Frame

New challenges that arose from moving forward with this proposed design are the requirements to increase rigidity and facilitate engagement between the TPU frame and the aluminum weapon support frame. To provide rigidity, additional design considerations were made to the weapon assembly to include a dead shaft that will be firmly bolted into position with a hollow active shaft that will spin around the shaft that is secured. This will ensure that the aluminum side plates do not bend inward as a result of a forceful impact which would be possible with our old design. To allow for full and proper engagement between the two frames, a middle plate was created. The mid-plate will be keyed into both side plates as well as inserted into a cutout in the TPU with the necessary shape and size shown above. Additionally, three 3-¼" bolts will be inserted vertically to tie into the middle plate, with smaller bolts being used horizontally to tie into the side supports. This middle plate will also serve to protect the electrical components from any debris that may be sent flying in the arena.

We would come to learn from the competition that Owen and Jake participated in that we need to dramatically increase the thickness of the TPU frame. A competing bot was capable of chewing through up to ¾" of TPU, which prompted a change to 1" in thickness to the exterior sides of our bot. These combined changes will ensure that our combat robot meets the weight requirements of the competition while not sacrificing the structure and integrity of our design.

Design Calculations

Weapon

$$Motor\ KV\ (KV)\ =\ 1820\ KV$$

$$Motor\ Wattage\ (MV) =\ 2220\ Watts$$

$$Battery\ Voltage\ (BV)\ =\ 22.2\ Volts$$

$$Driven\ Gear\ =\ 36 - tooth$$

$$Driving\ Gear\ =\ 12 - tooth$$

$$Diameter\ of\ Weapon\ (DW) =\ 3.5''$$

$$Weapon\ RPM\ (WRPM)\ =\ (BV * KV)\ * (Driving\ Gear/Driven\ Gear)$$
$$=\ (22.2 * 1820)\ * (12/36)\ =\ 13468\ RPM$$

$$Weapon\ Deg/s\ =\ Weapon\ RPM * 6\ =\ 13468 * 6\ =\ 80808\ Deg/s$$

$$Weapon\ Rad/s\ =\ (Weapon\ Deg/s\ *\ PI)\ /\ 180\ =\ (80808 * PI)/180\ =\ 1410.37\ Rad/s$$

$$Tip\ Speed\ =\ (DW/12)\ * PI * WRPM * (1/5280)\ * 60$$
$$=\ (3.5/12)\ * PI * 13468 * (1/5280)\ * 60\ =\ 140\ mph$$

$$MOI\ Weapon\ =\ 1229000\ g/mm\hat{}2$$

$$MOI\ Weapon\ in\ kg/m\hat{}2\ =\ MOI\ Weapon/10\hat{}9\ =\ 1229000/10\hat{}9$$
$$=\ 0.001229\ kg/m\hat{}2$$

$$Weapon\ Energy\ =\ (½) * MOI * WRPM\hat{}2\ =\ (½)\ (0.001229)\ (1410.37)\ =\ 1222.32\ J$$

$$Weapon\ Energy\ in\ KJ\ =\ Weapon\ Energy/1000\ =\ 1222.32/1000\ =\ 1.22\ KJ$$

$$Spin\ up\ Time\ =\ Weapon\ Energy/MW\ =\ 1222.32/2220\ =\ 0.55\ seconds$$

Drivetrain

Badass 2820-780Kv Brushless Motor

$$Motor\ KV\ (KV) = 780\ RPM\ per\ Volt$$

$$Battery\ Voltage\ (BV) = 22.2\ Volts$$

$$Driven\ Gear = 96 - tooth$$

$$Driving\ Gear = 11 - tooth$$

$$Drivetrain\ RPM\ (WRPM) = (BV * KV) * \left(\frac{Driving\ Gear}{Driven\ Gear}\right)$$

$$= (22.2 * 780) * \left(\frac{11}{96}\right) = 1984.13\ RPM$$

Frame Optimization/Weapon FEA

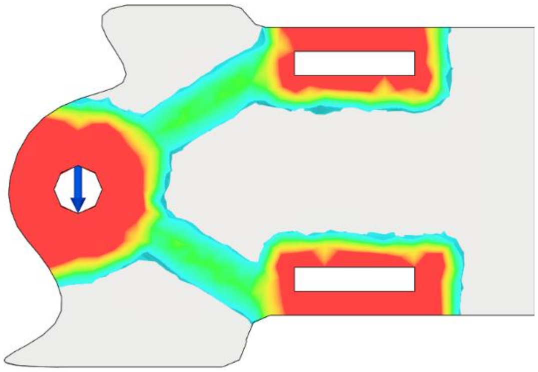


Figure 31: FEA of Weapon Assembly Side Frame

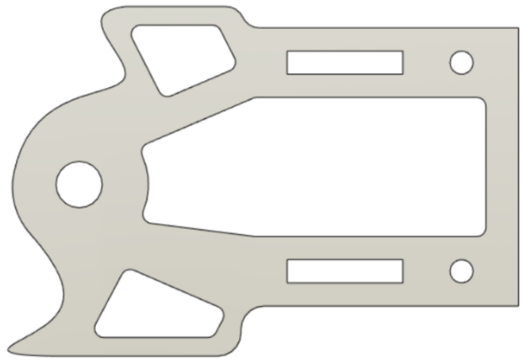


Figure 32: Optimization of Side Frame

The weapon side supports were an area of focus for weight reduction when transitioning to the 12-pound combat robotics class. Using the built-in simulation tools available in Fusion 360, we applied a downward force where the shaft of our weapon will be supported. It was imperative that the regions surrounding the hole for the shaft and keyways for the mid-frame be preserved for this simulation to keep the parts in the proper position. There must also be no less than a ¼" surrounding the cutout regions to maintain structural integrity of the material during the high stress loads that will be experienced in competition. The results of the simulation allowed us to make the changes displayed above to each side plate, saving 5.105 ounces per plate and 10.21 ounces total.

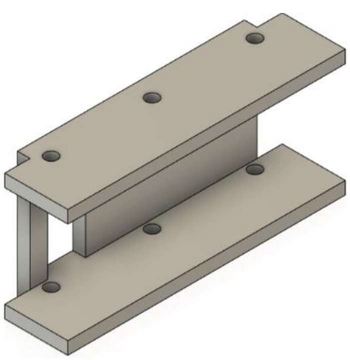


Figure 33: Middle Frame

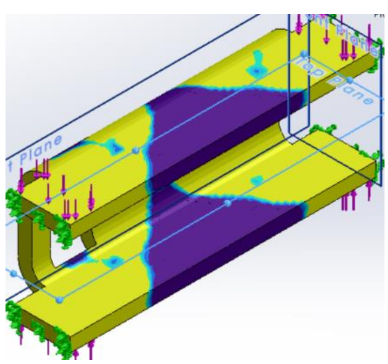


Figure 34: FEA of Middle Frame

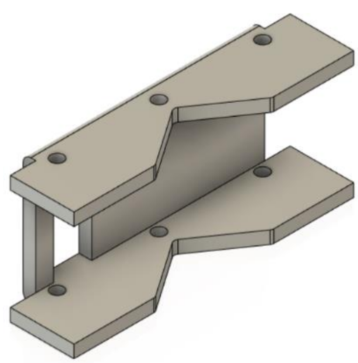


Figure 35: Optimized Middle Frame

Another component that can be optimized is the middle plate that will be used to add horizontal rigidity to our design. For this simulation, the mid-plate was constrained at each side and an area of force corresponding to the width of the side plate was applied on each end of the bent piece of 5052 Aluminum. The results of this simulation displayed that more area could be removed from this design saving only 1 ounce of weight, however, when designing a combat robot every single ounce of weight matters and can be used elsewhere to meet the weight requirements for competition. Which is why performing optimization where applicable is a must for any given design in Combat Robotics.

Component Justification

During this section, each section and component will be explained in detail about the material chosen, its characteristics and why it was the best option for the application. The components where materials are the most important is where the focus will be.

Weapon

The component selection of our weapon assembly has changed drastically throughout our design process. This is the result of multiple complete redesigns of our weapon in order to better fit what our initial design idea was. The weapon assembly is broken down into two main parts: the weapon and the frame.

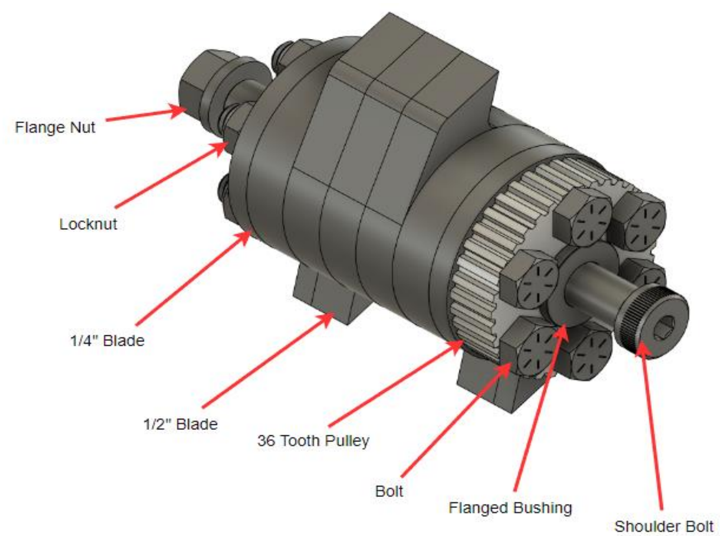


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Figure 36: Beater Drum Assembly

For our actual weapon blades, we wanted to choose a material that was able to take hits while also acting as a type of armor when we are on the defensive. The material that we decided to use was abrasion resistant 500 hardness steel (AR500), AR500 is commonly used as a type of body armor as well in any operations that require high strength materials. This material has a yield strength of 1380 MPa which blows away regular steel which has a yield strength of 350 MPa (11,12) and is the same or greater than regular steel in most other categories. The main downside of AR500 is that it is harder to weld and machine but this does not matter to our assembly as we will not be performing any welding or machining with this material. We will be using the AR500 on our ½" and ¼" blades located on our weapon. The main justification behind using AR500 is the easy access to getting the material and the use of it as a main material in combat robotics for many years as it has been used in all weight classes from 12 pounds to 250 pounds. There were other materials that we could have chosen but this highly reliable and tested AR500 was the best choice for our blades.

In order to hold our weapon together, we will need to bolt the blades together and have it spin around a dead shaft. The bolts that are going to be used to fasten the blades together will be alloy steel to ensure high strength and durability when in use. The bolts will be fastened with lock nuts on the ends to ensure no vibrations will loosen the bolts. The dead shaft that the weapon will rotate around will be an alloy steel shoulder bolt that has a high strength nut. A flanged bushing will be used as the rotation point in place of a bearing. The reason to use a bushing over a bearing is that bearings often wear down due to the high speeds of the weapon while bushing which have no moving parts can last significantly longer. The last part of the weapon assembly will be the pulley which will hold the belt and be the connection between the motor and the weapon. We are using an aluminum XL 36 teeth pulley in order to ensure strength and that it can take a couple of hits. The main reason to use these commercially accessible parts over something that is custom made is the cheaper cost and low complexity of the assembly. Using these alloy steel parts will allow us to use money elsewhere while also still getting high quality parts that will be a good addition to our assembly.

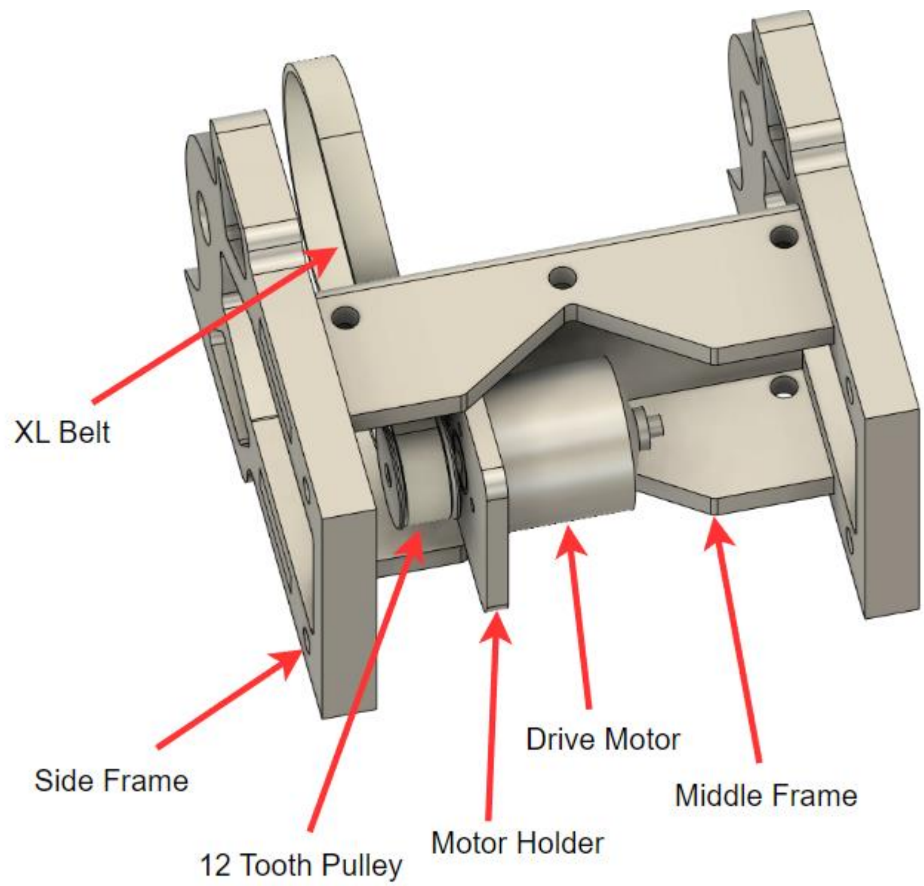


Figure 37: Weapon Assembly

The weapon frame needed to have rigidity while also being easy to machine as well as being lightweight. Steel and other heavier materials were out of the question based on the 12-pound weight requirement so we were left with 6061 and 5052 aluminums as the metals that we could use for our frame. The main reason behind choosing this aluminum was that our main weapon was already so heavier so using a lightweight metal would allow us to use weight on other spots throughout our robot as well as it fit most of the criteria that we were looking for in our frame. Aluminum is lightweight and rigid but has low tensile strength which means that it cannot be used as armor and will most likely be a weak point within our frame.

The last parts of the frame are the motor bracket and pulley which will connect to the weapon using an XL series belt. These belts are the same brand as the pulleys we are using, which ensures that they will work together smoothly. The smaller motor XL pulley has 12 teeth and has flanges around the edges of the pulley to ensure there is no belt slippage. The motor bracket will be made from 0.25” 6061 aluminum and will have holes so that the motor can be locked into place. The motor will be a Badass 2820 – 1820 Kv (13) motor which are high quality aircraft motors that will provide high power to our weapon.

Frame

Due to the high weight of our weapon assembly, we needed to choose a material for the base frame that would be lightweight, yet still able to provide ample protection for our chosen design. This led to the selection of Thermoplastic Polyurethane. TPU is known for its' high tear and abrasion resistance. Unlike other 3-D printed materials, depending on the infill percentage, TPU can also be very flexible. This should allow for the TPU to absorb impacts and distribute them more efficiently than say a rigid piece of metal. (14) Using a blend of differing infill percentages, our team can select areas of the bot to be more rigid or flexible based on the requirements of competition and the knowledge of our combat robotics mentors. Using TPU will also give us more control over the shape and form of the design when compared to other materials. We used this to our advantage to create slots for different parts of our weapon assembly to slide into the TPU as well as cutouts for the wheel supports to sit in. These features will work in unison with the bolt hole patterns to tie each different sub-assembly together to create our final design.

There are other special considerations to be made when switching to a frame that consists of only TPU. We had to include a dead shaft in our weapon as well as a middle support to provide horizontal and vertical rigidity. This will prevent the TPU from flexing too much and dislodging the components inside of the frame. Another consideration that went into our design is the required thickness for the walls of the frame. After participating in the November NHRL tournament, Jake Hoffman informed us that a competitor was capable of tearing up a ¾" Thick section of TPU. This prompted a switch to a wall thickness of 1" for all exterior walls of the TPU Frame. TPU is also known to be more difficult to print than other materials, which is a result of its aforementioned flexibility. (14) It is important that we monitor the feed rate of filament and seek the expertise of those available at the 1819 Innovation Lab to ensure a quality print that will meet the demands of competition.

Drivetrain

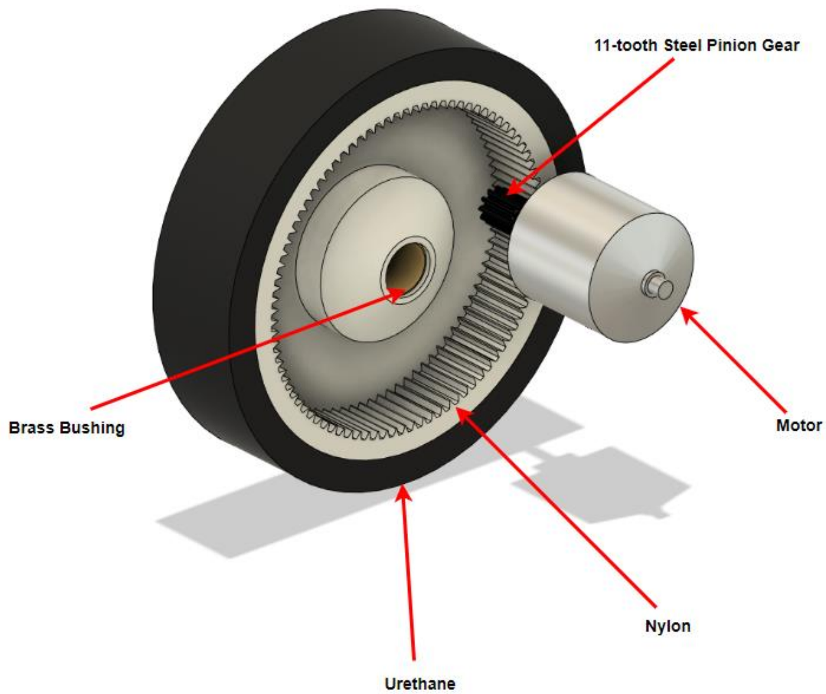


Figure 38: Wheel Assembly

For our drivetrain within our concept, we had to consider a lot of different factors when selecting our materials. We needed material that would be easy to manufacture and strong enough to withstand impact from our opponents' weapons as well. The material we selected for the outside of our wheels is urethane because it is made of a rubber material that is going to allow our wheels to have more traction on the surface of the arena floor. Urethane is also very flexible since it is a rubber material, and it also has tear resistance, which is perfect for us because our wheels will have to be able to take hits from our opponent's weapon throughout the match (15). The interior of the wheel will be made from nylon. We need to ensure that the interior of the wheel will be strong enough to withstand the impacts from our opponent and we plan on casting it into our desired form. Nylon is elastic, very strong, and resilient, which is perfect for our concept (16). Ensuring that our drivetrain can run after a hit from our opponent is crucial because if our weapon breaks and our robot is still able to move around with its drivetrain, we are still able to compete. The inside of the wheel will have internal gear teeth that will be rotated by the driven gear connected to the motor. Within the center of the wheel there will be a brass bushing there to allow for the wheel to rotate. The shaft that will connect to the center of the wheel is going to be made of Aluminum 6061 because it is strong and rigid to withstand big impacts. The shaft will connect to the wheel bracket which will also be made from Aluminum 6061.

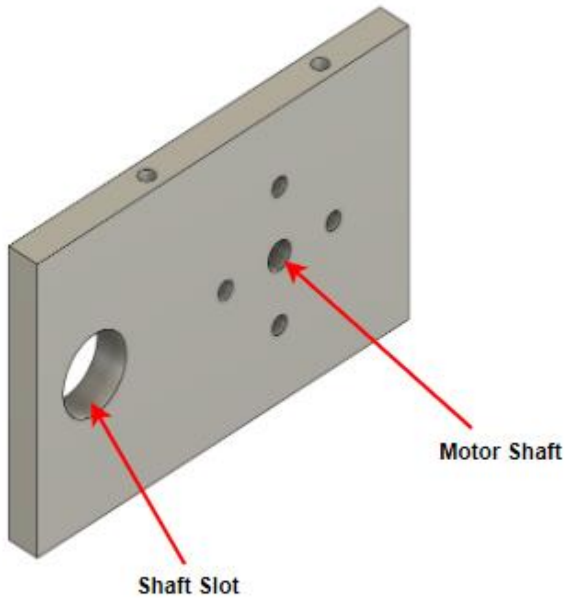


Figure 39: Wheel Bracket

We decided to go with Aluminum for both the wheel bracket and the shaft because it is obviously very strong and at the same time it is also very light (17). When designing our robot, we had to take weight into account because we needed to ensure we would not go over the maximum weight allowed for the competition.

Final Design

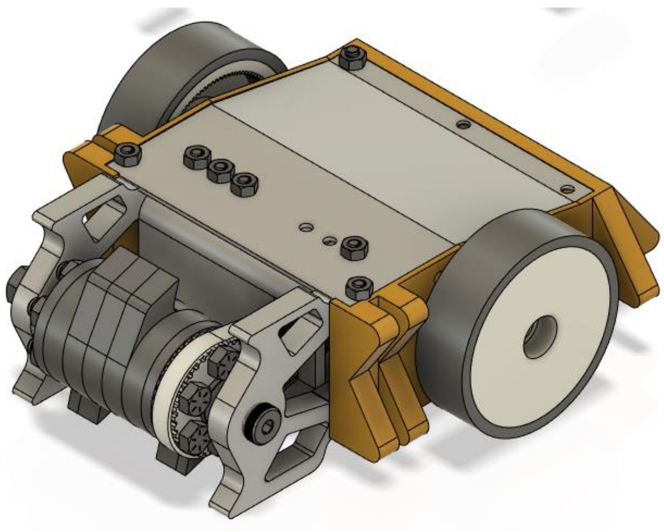


Figure 40: Final Design

Upon completion of Senior Design II there were still some aspects of our design that needed to be modified to create our final combat robot. The most notable change was optimizing the shape of our 3-D printed TPU. This was one of the many reasons that TPU was selected. The ability to easily modify and create a new print based on the information that we would learn from the previous one would prove very beneficial to our team. Through many iterations, we approached our now final design. The TPU structure now includes ribs on the exterior portion of the design. These ribs serve to extend the perimeter of our combat robot making it more difficult for an aggressor to do any damage to interior electronics encased in the frame. These ribs are also printed with a higher infill then other areas of the 3D printed frame so they will be more rigid and able to withstand higher impacts.

The top portion of our design was also changed to a more open design which would assist with inserting electrical components and the fastening of parts. Previously, there was only a small area of access to the interior components which proved difficult and time consuming to get the correct orientation to complete assembly steps. This change is also associated with having a different top cover to match the larger area that needs to be covered with the widening of our access point.

Other smaller changes that were made included switching from a pin that was press-fit into place for the drive train to now having a bolt with a locking nut. This change was made to make the connection point between our wheel and frame more secure, but also made the assembly and disassembly of our design during the allotted time in competition more feasible. Now if a wheel is damaged, it would only take a matter of seconds to take off the old wheel and replace it with a new one. Another minor change was including tabs on the weapon motor bracket that would slide into a newly created slot on the mid-frame; this would make positioning the bracket at the correct distance and orientation easier than what was previously designed. This would also provide additional surface area for welding that would allow for even more support and structure to be added to the design.

Final Component Fabrication

Based on the design decisions made for the final design of our combat robot, our fabrication involved mainly primary processes of having parts either laser cut or water jet to obtain the geometry required. In this section each component will be broken down into the steps that were required to create the finished product. By analyzing these parts and the processes required to make them, a better understanding should be gained of what steps were taken by our group to make our final assembly.

Weapon Discs

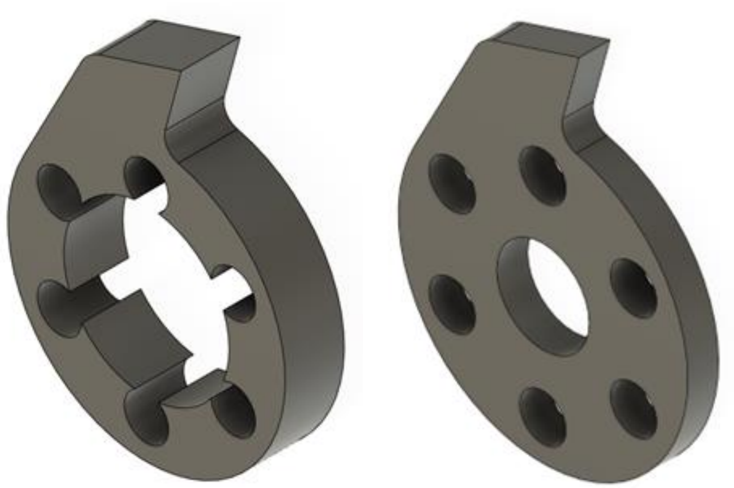


Figure 41 and 42: 1/2" and 1/4" AR500 Blades

The discs of our weapon assembly were ordered through a vendor known as Send Cut Send (SCS). To complete these parts all that was required was to send over the DXF file to SCS and select the material that they were to be manufactured from, AR 500 Steel. When we received the parts from SCS there was some extra material left on the tip of the blade that was easily cleaned up with a hand grinder. This was done in an effort to make the parts more uniform. This was the only step that was required to finish these components and have them ready for assembly. After being joined together with the nuts and bolts, an oil embedded bushing was press-fit into both ends of the weapon assembly that would allow the weapon to spin freely upon the dead shaft that slides through both side support pieces of the frame before being secured with a lock-nut.

Weapon Pulley

Figure 43: 32-tooth weapon pulley

For the weapon pulley, this part was sourced from McMaster-Carr. The inner hole diameter was too small for our application, so it was required for this hole to be enlarged with a lathe at the victory parkway campus to the appropriate diameter so the pulley could easily slide onto the shaft of the weapon. This pulley is also designed to attach to the weapon discs with screws that run through the pulley and discs secured with locking nuts. The 6 holes were added with a CNC Milling machine that was able to space the holes equidistantly via a circular pattern function on the Mill. Now the part is capable of both sliding onto the weapon shaft and being secured with six bolts, making it ready to be assembled.

Weapon Motor Pulley

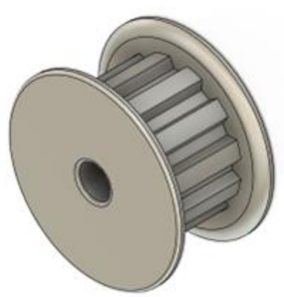


Figure 44: 12-tooth weapon motor pulley

Similar to the larger pulley, when ordered from McMaster-Carr this hole diameter was too small for its application in the design. The hole was increased using a lathe so that it could accommodate the weapon shaft. The chosen tolerance allowed for a tight fit up onto the shaft where it could then be press-fit snugly into position to be in mesh with the belt and larger pulley.

Weapon Support

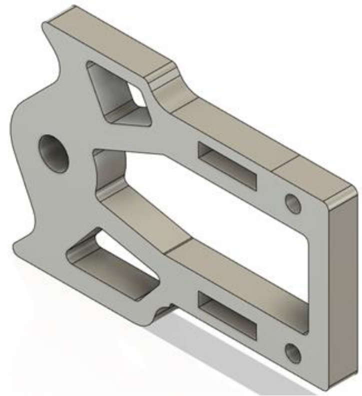


Figure 45: Weapon Assembly Side Pieces

The weapon support was very simple in terms of manufacturing. All that was required was to have the part Water Jet cut at 1819 and then use a file to smooth out the keyholes that would accept the mid-frame so it could sit into the side support comfortably before being welded into position.

Mid-Frame

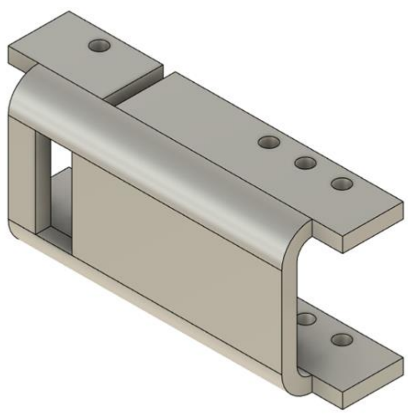


Figure 46: Weapon assembly mid-frame

The mid-frame component of our assembly was ordered along with the weapon discs through Send Cut Send. Using this resource, we had the cutouts for both the pulley to fit through and the weapon motor bracket to sit in added. SCS also added the clearance holes that will be used to assist in securing the top and bottom frames together. Once we received the part as a flat sheet, we used the brake press at Victory Parkway to add the 90-degree bends to both sides. Upon assembly we would come to realize that the cutout for where the pulley was intended to fit through needed to be enlarged. This was done with a mill and did not require any specific dimension but just enough to accommodate the pulley. After these steps this component was now complete and ready for final assembly.

Weapon Motor Bracket

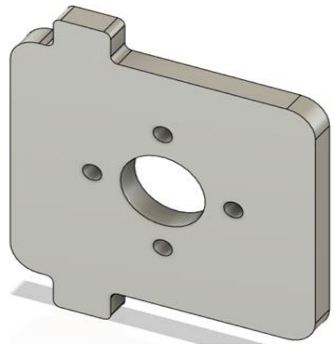


Figure 47: Weapon Motor Bracket

The weapon motor bracket had its internal and external geometry added via water jet cutting at the 1819 Innovation Hub. Upon receiving the part from 1819 all that was required was to countersink the holes with a drill. Countersinking these holes allowed for countersunk screws to sit flush and prevent any interference between the weapon motor shaft and weapon belt.

Wheels

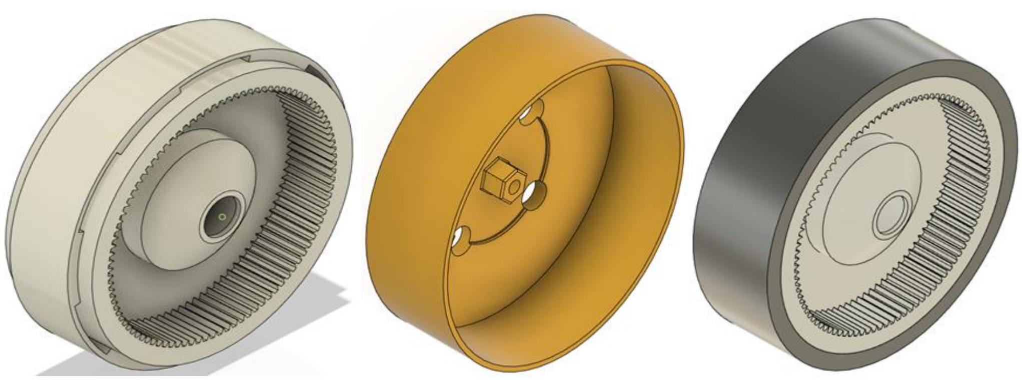


Figure 48: Wheel Pieces

For the wheels of our combat robotics, we purchased a roll of nylon that was 3D printed which allowed for the 96 teeth to be added easily to the internal structure of the wheel. A 4-inch mold was also 3D printed which would provide a structure for Urethane to be poured around the nylon. By selecting Urethane for the external portion of our wheel, there was more friction as well as improved impact absorption when compared to the inner nylon print. The design of the nylon structure also included small cutouts along the outer diameter which would improve the

Urethane's ability to adhere to the wheel and ensure that it would not become dislodged during competition.

Wheel Bracket

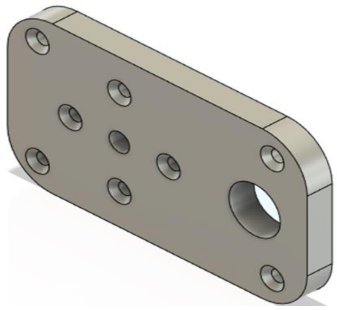


Figure 49: Wheel Bracket

This component will be responsible for attaching the wheels to the frame of our design. This part was waterjet cut at the 1819 Innovation Hub. This created the external geometry and added the clearance holes for the fasteners that will attach to the motor and frame. Due to the capabilities of water jet cutting it was necessary for our group to add the countersunk holes using a drill with a countersinking bit. This was easily achieved and after these steps this component was ready for final assembly. By making these countersunk holes, it would ensure that there would be no interference between the screw heads and the wheel.

TPU Frame

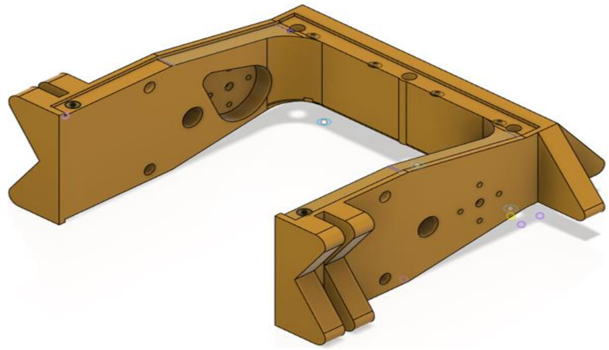


Figure 50: TPU Frame

The external frame of our design was 3D printed from thermoplastic polyurethane. This allowed for all geometry to be added in one step and did not require any further action in order to be added to the final assembly.

Top and Bottom Covers

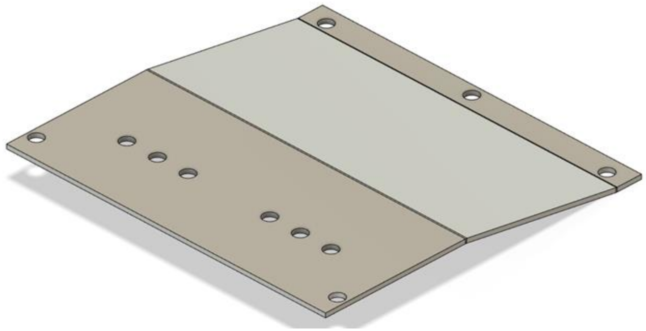


Figure 51: Top and Bottom Aluminum Cover

The top and bottom covers will serve to contain the electrical components in our combat robot. The ¼ inch holes and exterior geometry was added via water jet cutting at the 1819 innovation center. Our group received this part as a flat sheet of aluminum with the necessary holes leaving only the requirement to add the 10-Degree bends to allow the part to fit up against the TPU frame of the bot. The bends were added using the brake press at Victory Parkway. The bend lines were located and all that was left to do was insert the part in the press and perform slight bends measuring with a protractor until the 10-Degree requirement was met. After this step the top and bottom covers are finished and ready for assembly.

Weapon Frame Assembly

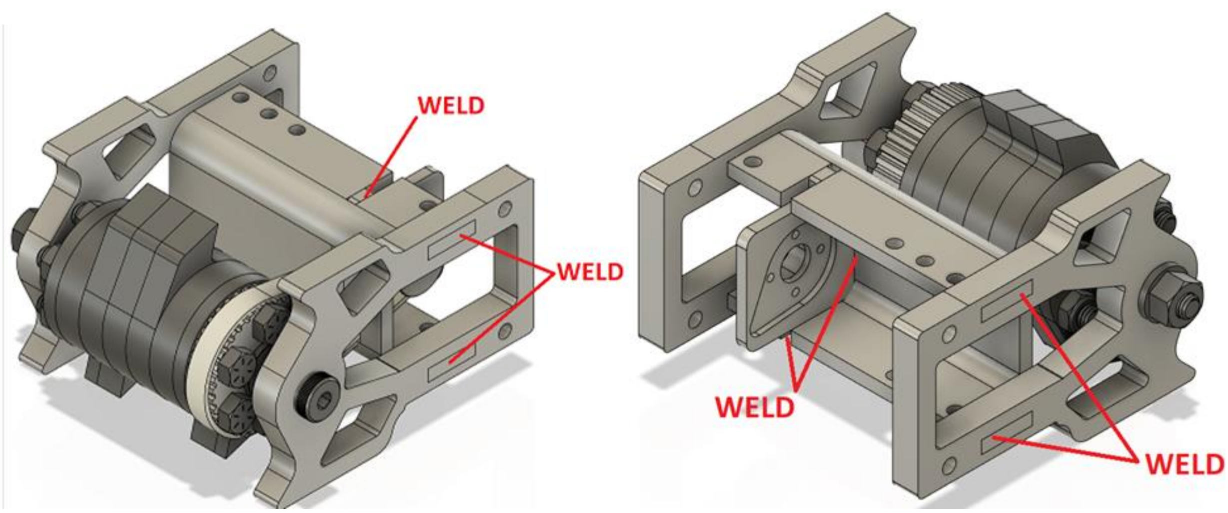


Figure 52: Weapon Motor Assembly

After the manufacturing of all of the components there was still one more step required to complete the fabrication of our final design. This involved welding in 7 different locations. The welds added to keyed portions of the mid frame and side supports would serve to improve the rigidity of our design and ensure that there would be no chance of the internal structure of our combat robot coming dislodged during competition. The second purpose of these welds was attaching the weapon motor bracket to the mid-frame. The weapon motor bracket needed to be held in place at a specific location that would keep tension on the belt that attaches to the weapon pulley. If the bracket moves away from its position, this would lead the weapon to stop spinning rendering it ineffective. With these additions, our combat robot has become even more rigid, and it would require a great deal of force to cause any of these components to come apart from one another.

Electronics

Electronics were the most foreign concept of engineering that we had to work with during our senior design project. All three of us have had little to no experience with soldering and making wiring diagrams. This was a great learning experience for us, and the electronics turned out to be one of the simpler aspects of our combat robot.

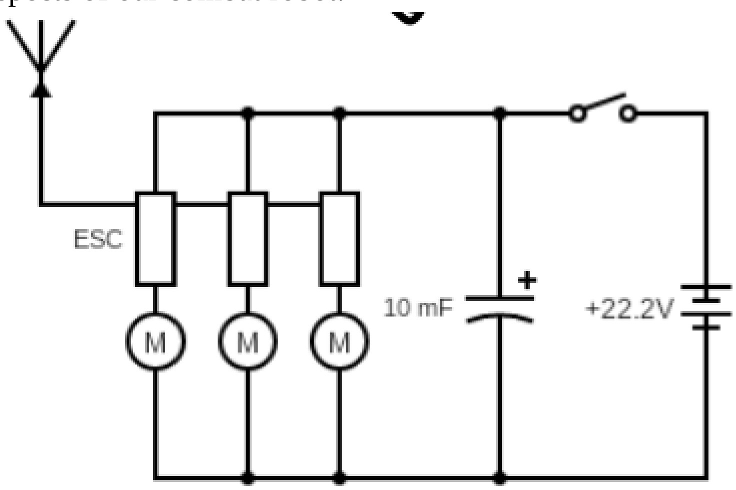


Figure 53: Electronic Schematic

Our wiring diagram resembles that of a remote-control race car which logically makes sense. The main addition is that of a third brushless motor that is connected to our weapon. Our electronics consist of:

Figure 54: Battery

- LiPo Battery
    - 6S
    - 22.2 Volts
    - 1300 mAh

Figure 55: Drivetrain Motor

- Three BadAss Brushless Motors
    - 780 Kv (RPM per Volt)
    - 1200 Watts (6S)

Figure 56: Electronic Speed Controller

- Two Flycolor ESCs (Electronic Speed Controller)
    - 50 Amps
    - Included BEC (Battery Eliminator Circuit)

Figure 57: Reciever

- Spektrum AR410 RC Sport Receiver
    - 4-Channel

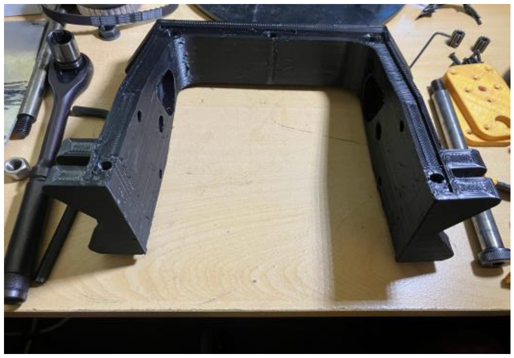
Figure 58: Sidewinder

- Sidewinder 8th ESC
    - 25.2-volt ESC
    - 8-amp peak BEC

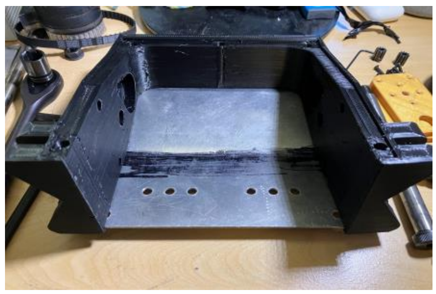
Figure 59: Capacitor

- Capacitor
    - 25 Volt
    - 10000 µF (microfarads) -> 10 mf (millifarads)

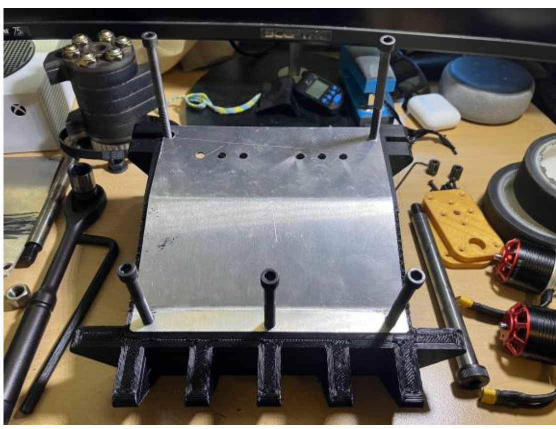
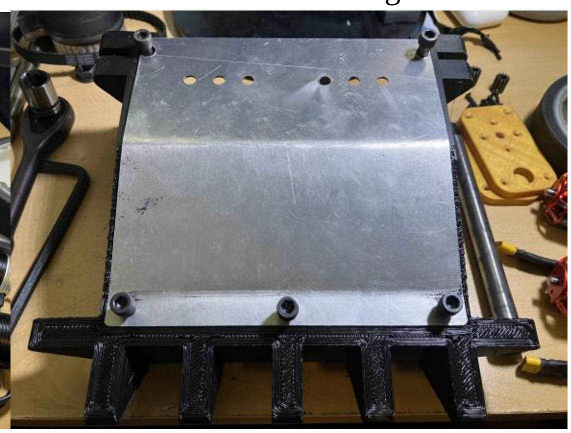
Assembly Steps and Process



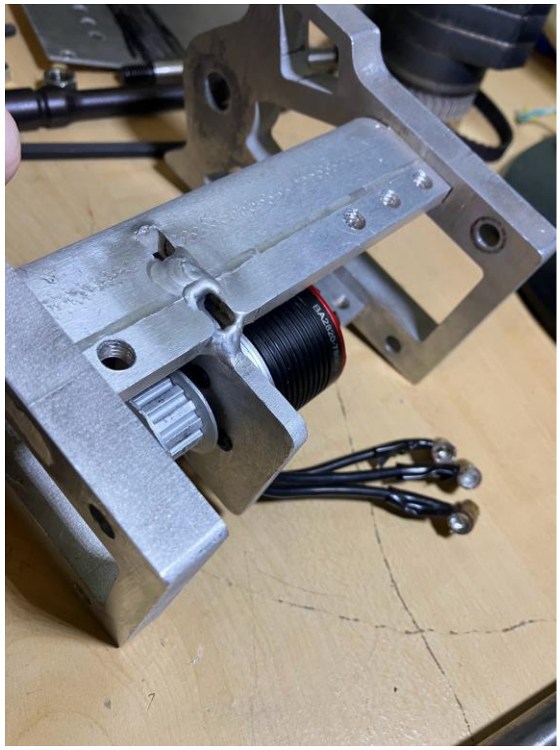
1. Place the TPU frame on the table with the back fins flush with the table.



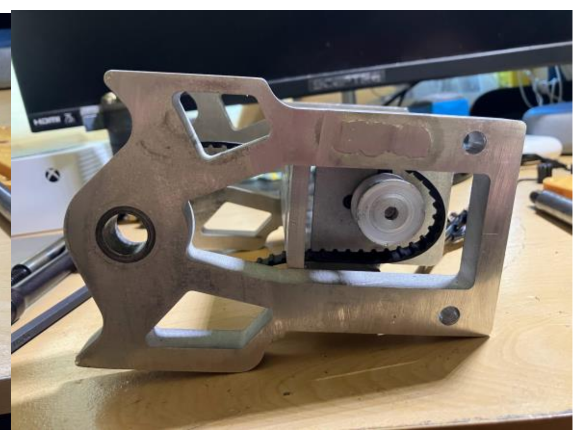
2. Place the bottom aluminum cover under the TPU frame with bolt holes aligned..

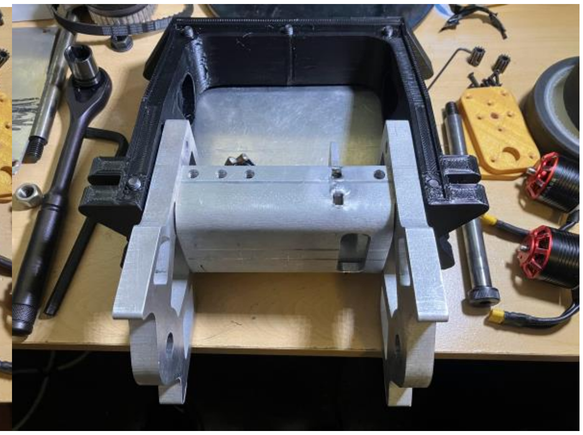
3. Drill five socket head screw ¼”-20 Thread size, 3-¼” long through the bottom cover holes into the TPU using a power drill with hex bit.



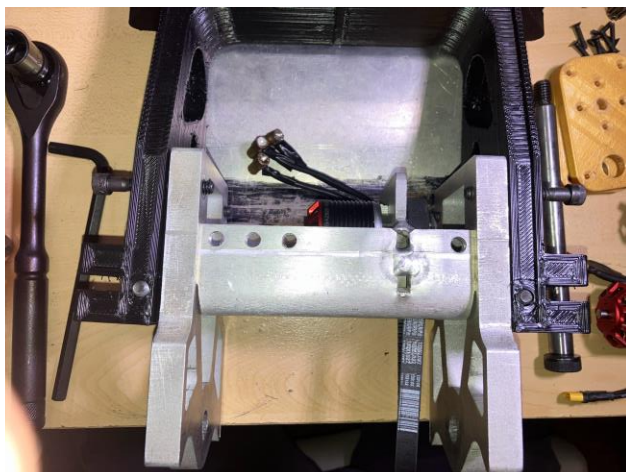
4. Screw four Black-oxide alloy steel drive flat head screws into the weapon motor through the weapon motor bracket connected to the weapon assembly using a 5/64” hex key. Insert the 12-tooth pulley on the shaft of the weapon motor and screw the safety set screw of the pulley also using a 5/64” hex key.

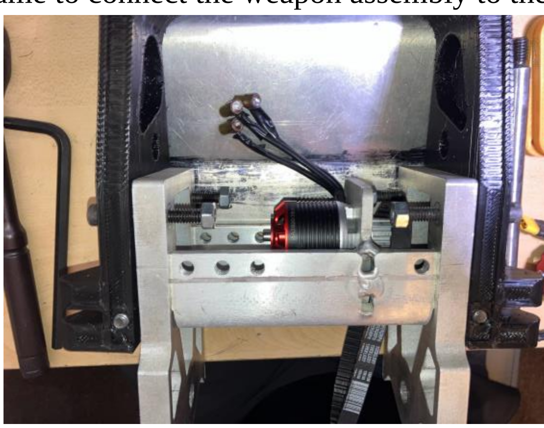
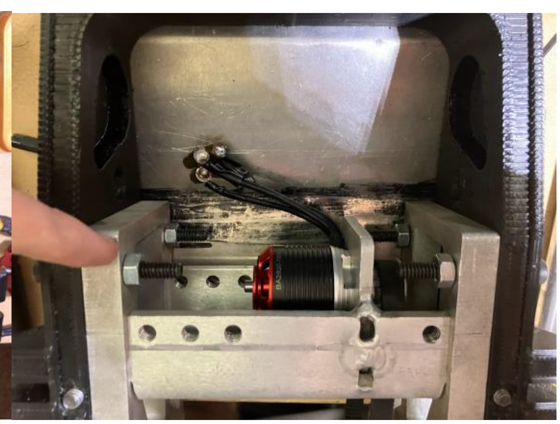
5. Insert pulley belt through gap in the weapon assembly around the 12-tooth pulley.

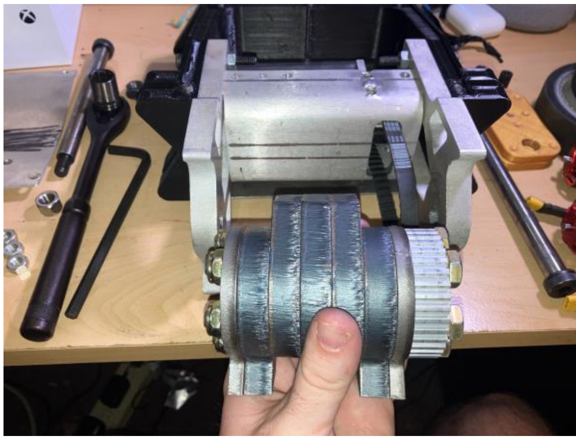
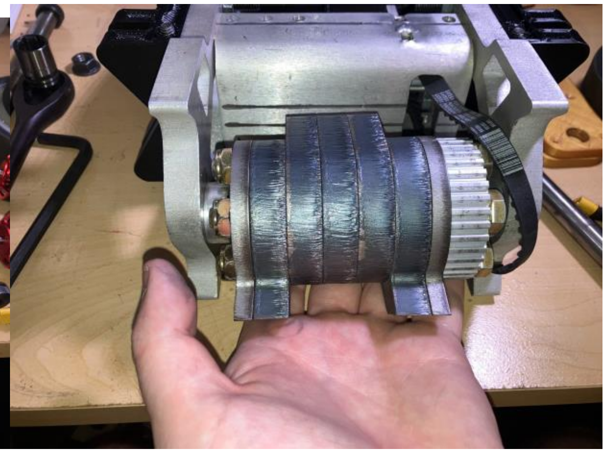
6. Flip the TPU frame with the cover and take the weapon assembly and insert it into the front of the TPU frame to where the holes line up for the TPU frame and weapon assembly.



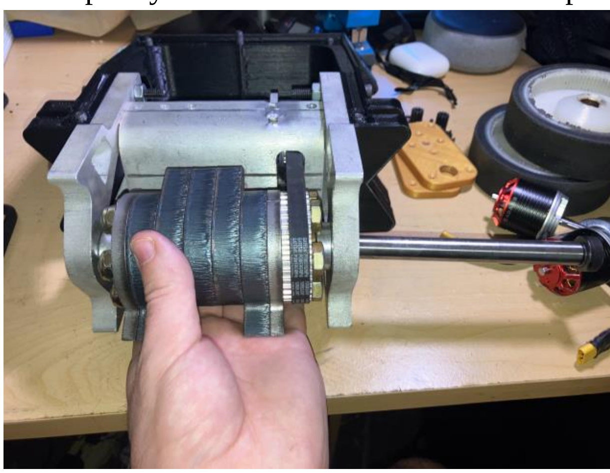
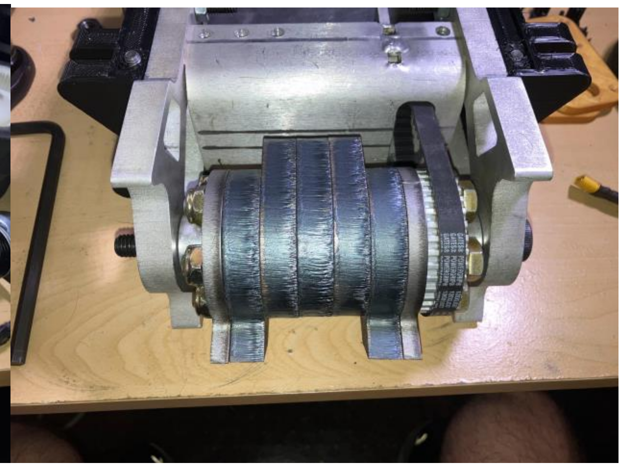
7. Insert four socket head screws ¼”-20 thread size, 1-¾” long into the side of the TPU frame to connect the weapon assembly to the TPU frame.

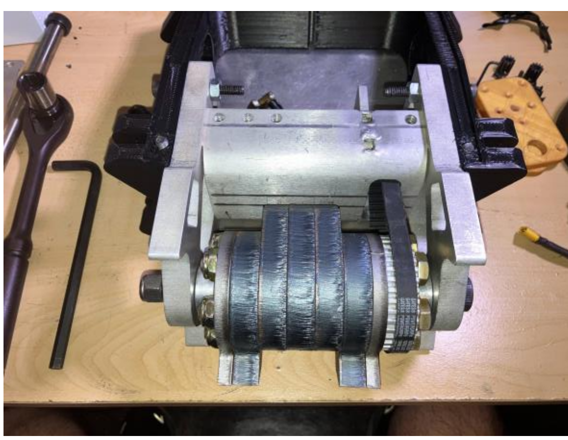
8. Screw on the four Steel hex nut grade 5, zinc-plated, ¼”-20 thread size onto the socket head screws inserted into the sides of the TPU Frame.

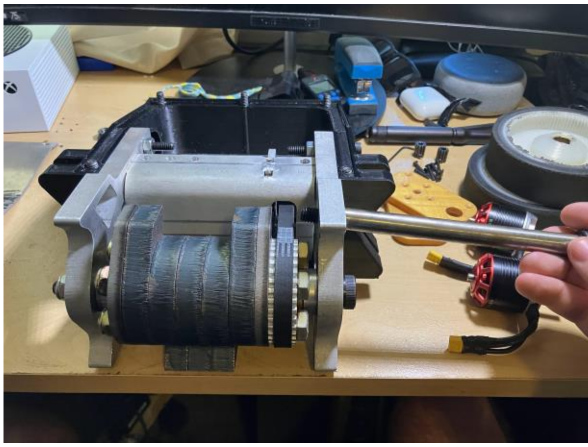
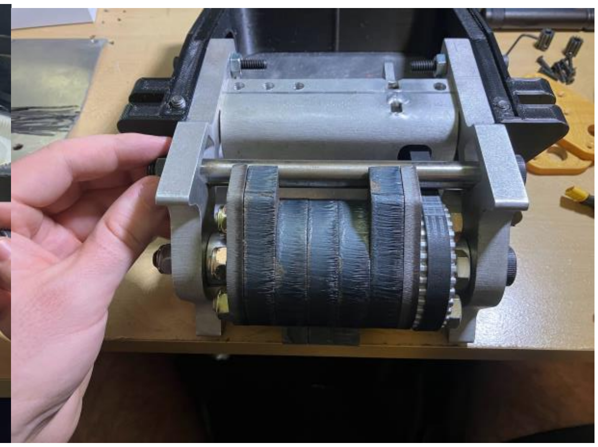
9. Insert the drum weapon into the weapon assembly with spacers on both sides. Move the pulley belt around the side of the weapon drum when being inserted.

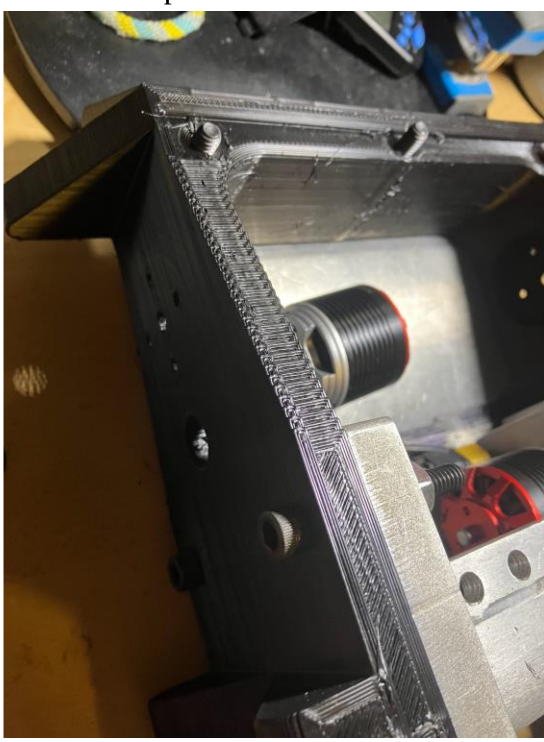
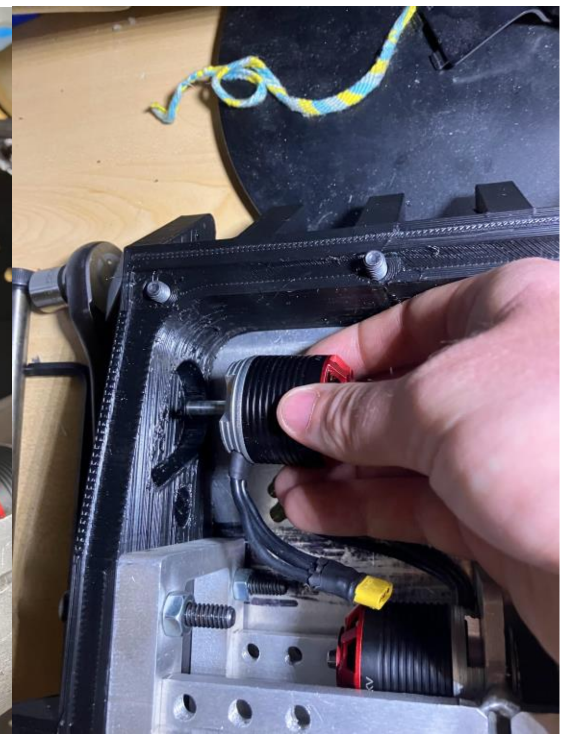
10. Insert the ½” diameter, 5-½” length, ⅜”-16 thread shoulder screw through the weapon assembly hole to connect the weapon drum to the weapon assembly.




11. Screw a ⅜”-16 thread lock nut onto the shoulder bolt using a 9/16” socket wrench and a ¼” hex key.



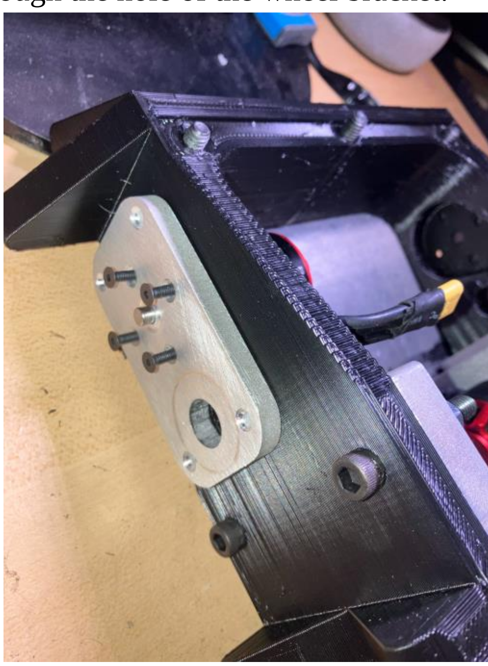
12. Insert the weapon safety key through the weapon assembly and screw on the nut to ensure the weapon cannot rotate.



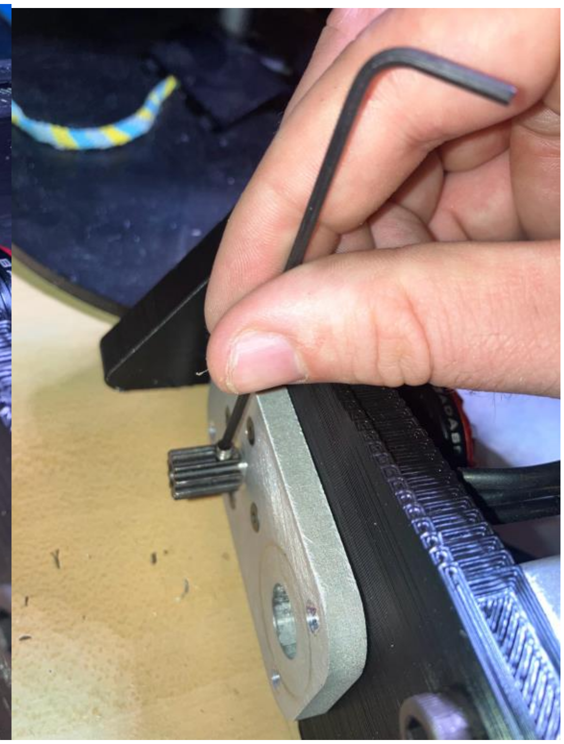
13. Place the drivetrain motor into the drivetrain holder inside the side of the TPU frame.

14. Place the wheel bracket on the side of the TPU frame by inserting the drivetrain shaft through the hole of the wheel bracket.

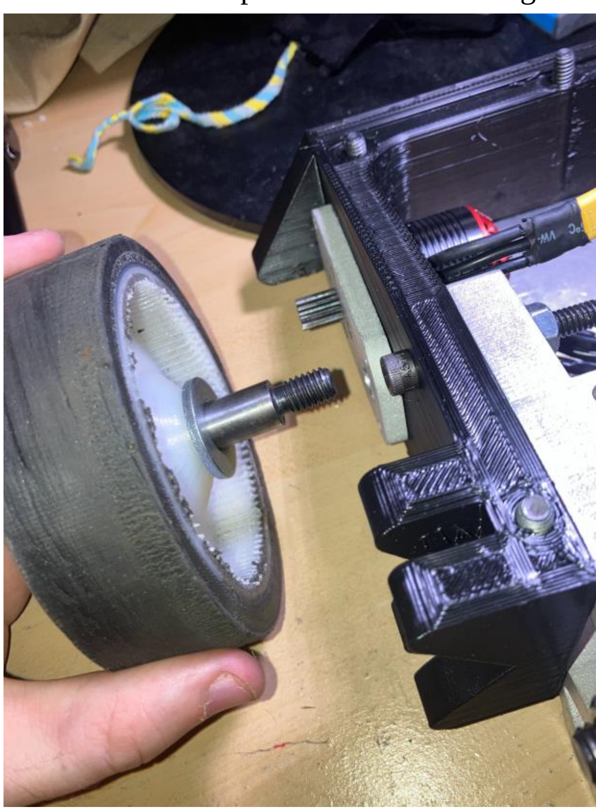
 

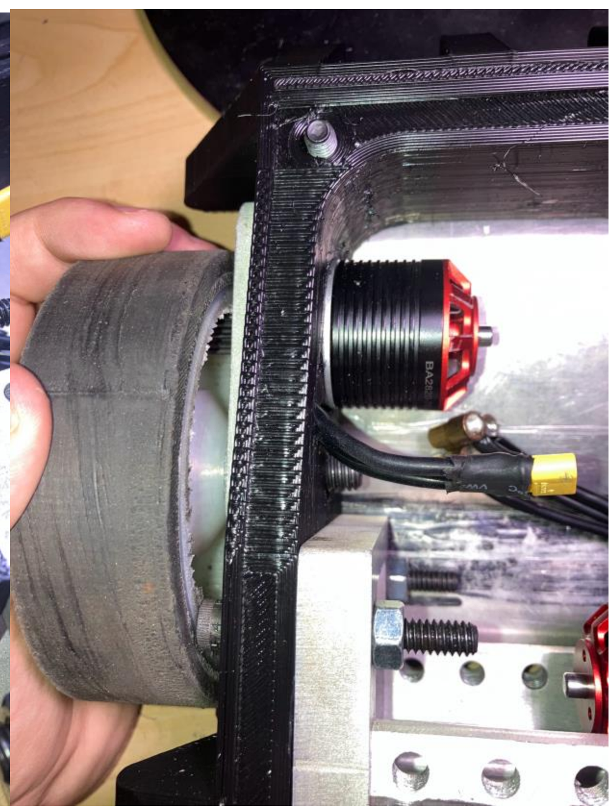
15. Use a 5/64" hex key to screw the four black-oxide alloy steel hex drive flat head screws through the wheel bracket, TPU frame, and into the drivetrain motor so it can be connected.

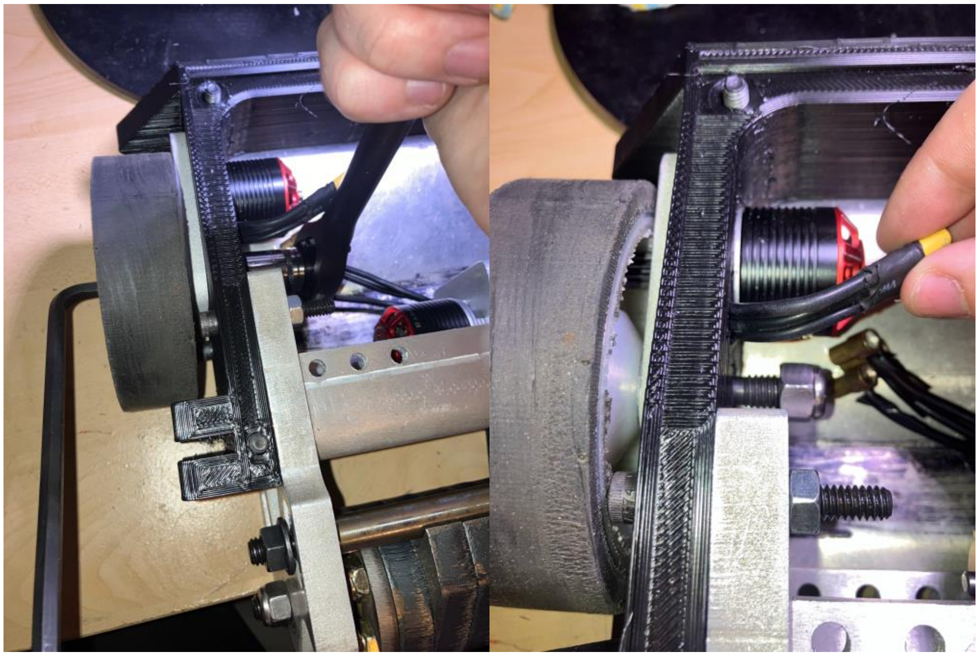
16. Insert 11-tooth pinion onto the shaft of the drivetrain motor and screw in the safety set screw using a 5/64” hex key to ensure it won’t slide off.


17. Insert ½” diameter, ⅝” housing ID, ½” long oil embedded sleeve bearing into the wheel, and then insert the ½” diameter, 1-½” length, ⅜”-16 thread shoulder screw through the wheel. Add spacer on after inserting the bolt.

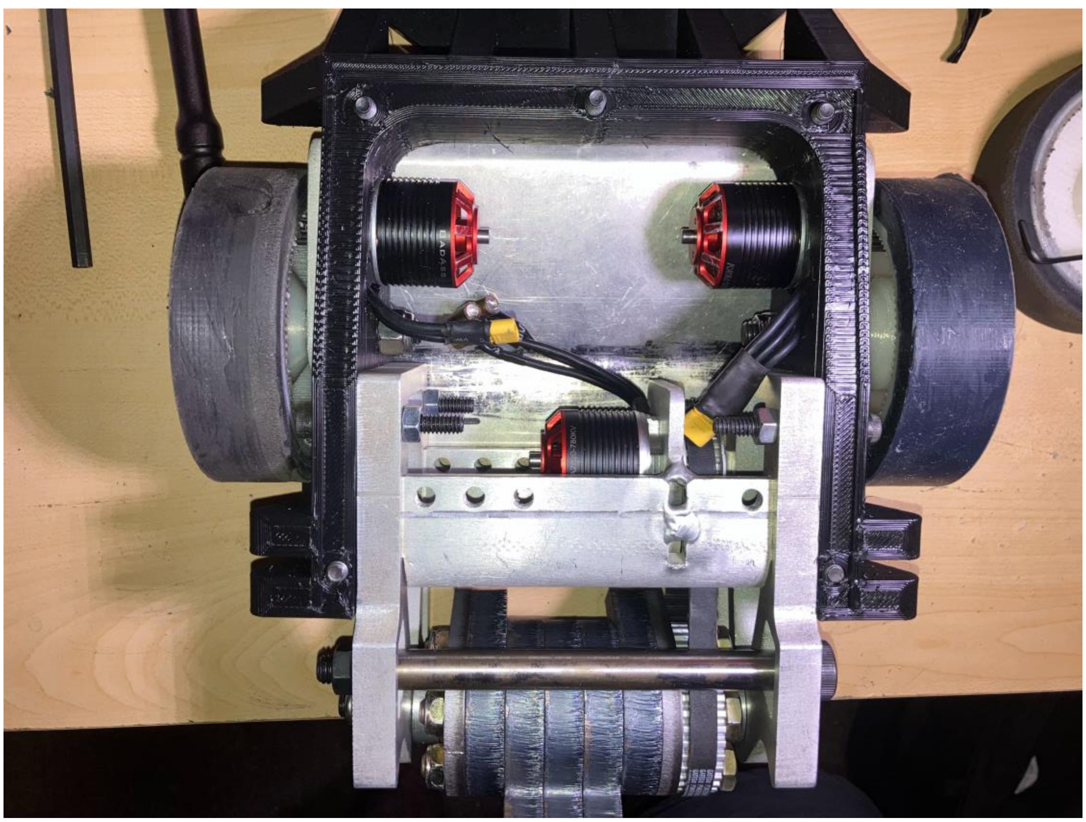




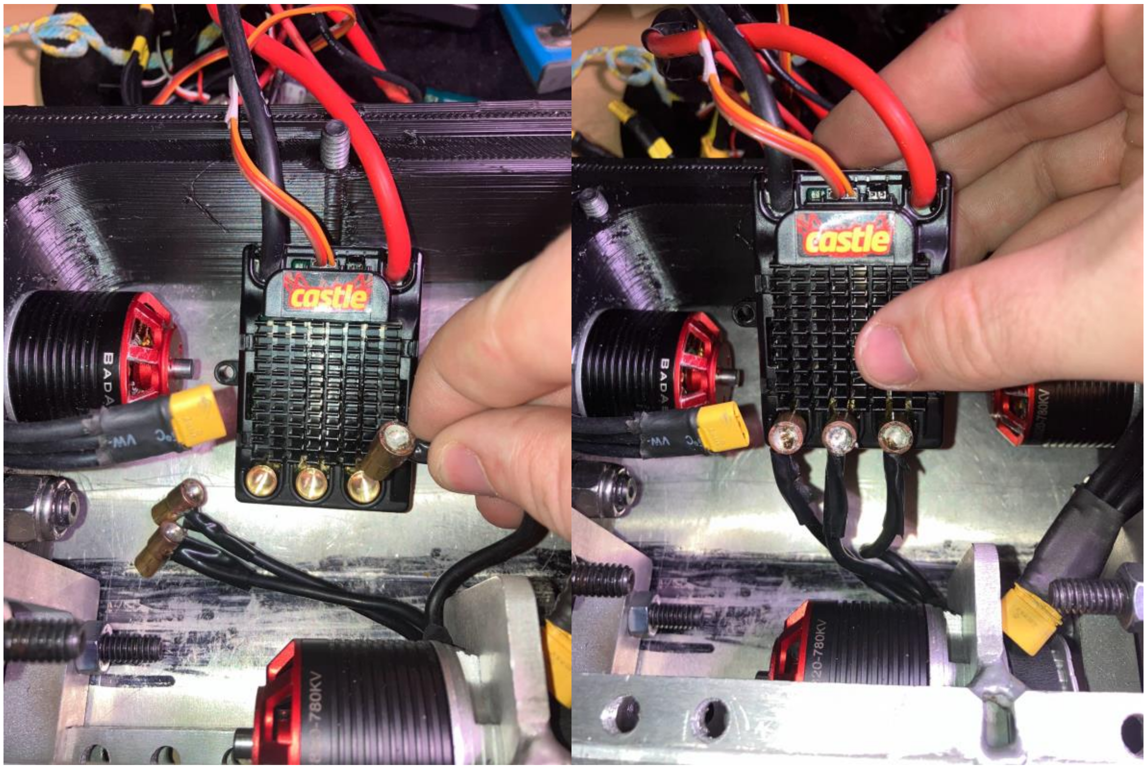
18. Take the wheel and insert the shoulder bolt through the wheel bracket hole and into position.



19. Screw a ⅜”-16 thread lock nut onto the shoulder screw threads using a 9/16” socket wrench and a ¼” hex key.

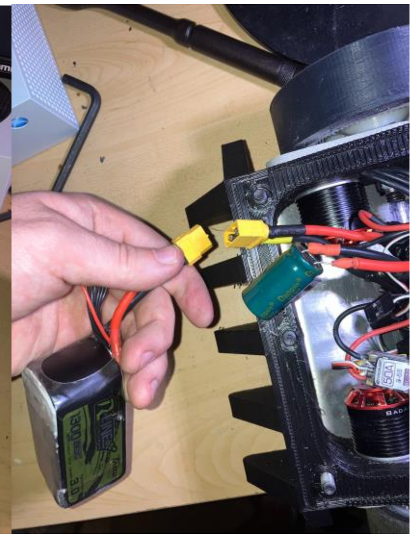


20. Repeat steps 12 through 18 for the other wheel.



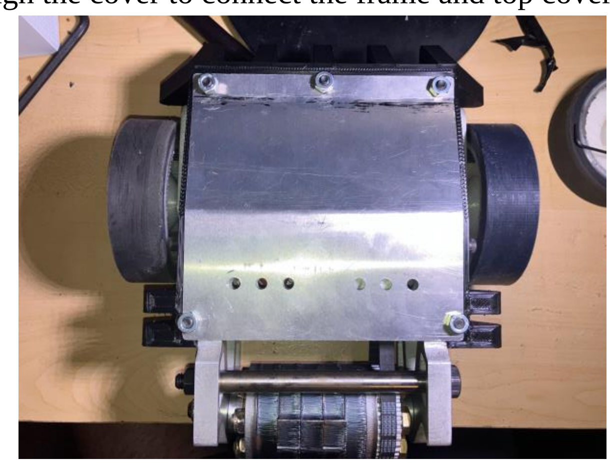
21. Insert the electronic wiring inside the robot and plug the weapon motor wires into the sidewinder.

22. Connect drivetrain motors to their corresponding ESC plugs.



23. Take the battery out of the lipo-safety bag and place it inside the combat robot and connect it to the electronics.


24. Place the top aluminum cover over the top of the frame and screw the five bolts completely through the cover to connect the frame and top cover.



25. Then finally screw on the five-steel hex nut grade 5, zinc-plated, ¼”-20 thread size on the five-socket head screw ¼”-20 Thread size, 3-¼” long to ensure max security.

Section	Assemble (min:sec)	Disassemble (min:sec)
Top Cover	1:10	0:40
Electronics	0:45	0:24
Drivetrain	6:00	3:00
Weapon Drum	1:15	1:00
Weapon Assembly	1:15	0:50
Weapon Motor	1:30	1:00
Bottom Cover	0:25	0:50
Total	12:20	7:44

Testing

Test settings

Safety tests for combat robotics are crucial to ensure that these machines can be operated safely and without posing a significant risk to human operators or spectators. Our combat robot had three main tests that it needed to go through in order to ensure that it will be available for the NHRL tournament in May. These tests were driving, weapon and weight tests which all help us get a better understanding of how our combat robot will perform and that all safety standards have been met.

The test settings for the driving test were to experiment the grip of our custom wheels on different surface types. We have two different grip types on our wheels: urethane and silicone. In order to test both types we used a force sensor and different surface textures. The surfaces we tested on were cement, wood and tile and a custom-made force sensor was used to test the pulling force that our robot was capable of generating on each floor type. Alongside the force sensor, the robot was driven around, and the general feel of the wheels was noted down. Another important aspect of this test was the wear and tear that was caused after driving the robot.

The test settings for the weapon were much more focused on safety and ensuring that the weapon was created in a way that minimized the chance of mechanical issues where an injury could occur. The other aspect of the weapon test is to make sure our calculations for weapon rpm and tip speed were correct. In order to test our weapon, we contacted the University of Cincinnati, and a room was given to us at VPC where the weapon could be spun safely. This room was completely sealed off therefore our testing was done through sound, which is not perfect, but it is all we were given that did not violate safety standards.

The final test setting was the weight test which was to ensure that we made it below the 12-pound threshold of our weight class. This means weighing the overall robot as well as each part individually so that you are able to see where you can optimize if needed.

Testing process

For the driving test, there are two processes that we did for each of the two-wheel types. Breaking down this test into two subtests allowed us to have the least amount of variability when testing each wheel therefore giving us the most accurate results. The two tests we used are the force test and the track test.

- Force Test
    1. Set up the force sensor against a solid wall
    2. Connect Arduino to force sensor
    3. Run calibration
    4. Set up combat robot next to force sensor
    5. Turn on the robot/controller and ensure the sensor is right up against it
    6. Start force sensor program
    7. Slowly increase the speed until you have hit 50% while tracking the data
    8. Decrease the speed until stoppage
    9. Get the max and average pushing force.

- Track Test
    1. Create a track with four 90 degree turns and two straightaways that will allow the robot to get up to 50% speed.
    2. Set up the robot at the start
    3. Ensure new or slightly used wheels are being used
    4. Get a freshly charged battery and turn on the robot/controller.
    5. Drive the track and keep note of the traction
    6. Perform a hard stop at the end to test the braking action
    7. Analyze the wheel and the overall wear.
    8. Perform this track (steps 1-7) on each of the three surfaces
        a. Wood
        b. Tile
        c. Cement

The weapon test had a single process which was to ensure the weapon started up and was able to spin up to 100% without much issue. In order to get as accurate of results as possible, the weapon was left on for a certain amount of time and given 5 minutes before you are able to enter the room.

- Weapon Test
    1. The robot is placed in the room with the weapon attached
    2. The battery is connected to the robot, but the controller is off
    3. The room is closed and locked
    4. Controller is turned on
    5. Weapon is slowly sped up until it hits 100%
    6. Weapon is the turned off
    7. 5-minute wait time is given to ensure weapon is safe
    8. Go in room and check status of weapon, motor and overall robot

- Weight Test
    1. Weigh the whole robot including the battery.
    2. Take apart each of the pieces and weigh
    3. Create a spreadsheet of overall weight distribution.

Testing results/analysis

- Silicone Wheels
    - Force Test
        - Max Force: 6.21 lbs.
        - Average: 5.43 lbs.
    - Track Test
        - Good Grip and Feel
        - Some Wear

- Urethane Wheels
    - Force Test
        - Max Force: 5.94 lbs.
        - Average: 5.33 lbs.
    - Track Test
        - Ok Grip/Good Feel
        - No Wear.

These testing results told us a lot about what material we wanted to use for our wheels. Silicone had a max force of 6.21 pounds which was significantly better than the urethane wheel which had a max force of 5.94 pounds. Although there is a difference, it is not something that we greatly considered when making the decision as our combat robot had such a front heavy weapon that the small difference in force will not be a dealbreaker. We mainly chose our material type based on the feel and wear of the wheel. Each material provided a different benefit in this area, the urethane had great wear resistance but had more slippage when going into the turns. Silicone had worse wear resistance as there were dead spots in the wheel where it had skidded and stopped abruptly but provided great feel and driving during the track test. In the end, we decided to go with our original material of urethane over the silicone due to the better wear resistance and the cheaper price at which we could make our wheels.

There is not much to say on the weapon test as we were able to start up our weapon without any issue to the structural integrity of our weapon frame. The main result of this test was that we were able to confirm that our calculations were correct and that our 57 mile per hour and 5772 rotations per minute were close to what we viewed and heard during weapon start up. Unfortunately, the next time that we will be able to see our weapon is when we fight on May 6th, but it is still good to know that it runs well and as expected.

The last test results are the weight tests which came in just around 11.24 pounds. The goal for this test was to come as close as possible to the 12-pound limit as you want to maximize the weight of your robot. This number is fairly close, and we can now mess with our TPU frame to adjust for the weight differential and hopefully come closer to the mark.

Project Management

Timeline

Senior Design Schedule

PROJECT TITLE	Combat Robot: Drum-atic
PROJECT MEMBERS	Matt Hallagan, Ben Murphy, Ethan Sketch

WBS NUMBER	TASK TITLE	START DATE	END DATE	DURATION	PCT OF TASK COMPLETE
1	**Project Conception and Design (Senior Design 1 and 2)**				
1.1	Research	8/23/22	8/28/22	5	100%
1.1.1	Project Ideation	8/28/22	9/5/22	8	100%
1.2	Initial Weapon Design	9/5/22	10/20/22	45	100%
1.3	Initial Drive Design	9/12/22	11/1/22	50	100%
1.4	Initial Frame Design	9/21/22	11/8/22	48	100%
1.5	Initial Electronic Design	10/20/22	11/10/22	21	100%
1.6	Refinement of Design	11/8/22	12/1/22	23	100%
2	**Project Prototype (Senior Design 1 and 2)**				
2.1	Proof of Design	11/10/22	11/28/22	18	100%
2.2	Source Parts and Hardware	10/20/22	11/29/22	40	100%
2.3	Plan of Fabrictaion and Manufacturing of Materials	11/2/22	11/30/22	28	100%
2.4	Finalize Design Concept	11/14/22	12/5/22	21	100%
3	**Project Manufacturing and Assembly (Senior Design 3)**				
3.1	Status and Tracking	1/2/23	4/26/23	114	100%
3.2	Prototyping	1/9/23	1/20/23	11	100%
3.2.1	Manufacturing	1/21/23	2/24/23	34	100%
3.2.2	Electronics	2/25/23	3/13/23	16	100%
3.3	Programming	3/14/23	3/21/23	7	100%
3.3.1	Testing	3/22/23	4/5/23	14	100%
4	**Key Dates**				
4.1	Tec Expo	4/6/23			
4.2	NHRL Competition	5/6/23			

Budget

Preliminary

Instructions	School Year*	Team Name*	Total Cost
This form Is to be filled out by a battlebot team to request the parts they need. All fields with a * next to them are required to be filled out.	2022-2023	Drumatic	$1,226.28

P/N*	Description*	Hyperlink*	Quantity*	Price Per Unit*	Total	Manufacturer	Vender*	What Sub Assembly and Other Comments*	Requester (First, Last)*	Contact Email*
010-0139-10	Sidewinder ESC	https://www.castl	1	$129.85	$129.85	Castle Creations	Castle Creations	Electronics	Matthew, Hallagan	hallagmf@mail.uc.edu
BA-2814-1560	BadAss 2820-1820Kv Brushless Motor	https://innov8tive	2	$62.99	$125.98	Badass	Innovative Design	Electronics	Matthew, Hallagan	hallagmf@mail.uc.edu
	AR500 Blade - 0.50 thick	https://app.sendc	8	$12.28	$98.24	SendCutSend	SendCutSend	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
	AR500 Blade - 0.25 thick	https://app.sendc	4	$12.77	$51.08	SendCutSend	SendCutSend	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
6484K121	XL Series Timing Belt, Trade No. 110XL025	https://www.mcm	1	$5.50	$5.50	McMaster Carr	McMaster Carr	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
1277N56	Timing Belt Pulley, 3/8" Maximum Belt Width, Hub, 2.272" OD	https://www.mcm	1	$21.33	$21.33	McMaster Carr	McMaster Carr	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
1277N738	Timing Belt Pulley, NO Hub, 3/8" Maximum Belt Width, 1" OD, 3/16" Sha	https://www.mcm	1	$13.20	$13.20	McMaster Carr	McMaster Carr	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
	Entire Base Frame - TPU	https://www.ama:	1	$27.99	$27.99	Overture	Amazon	Frame	Matthew, Hallagan	hallagmf@mail.uc.edu
8975K217	Side Frame 6061 Aluminum - 1/2" Thick x 5" Wide - 2 Feet	https://www.mcm	1	$67.40	$67.40	McMaster Carr	McMaster Carr	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
89015K31	Multipurpose 6061 Aluminum Sheet - 0.25" Thick, 12" x 12"	https://www.mcm	1	$35.61	$35.61	McMaster Carr	McMaster Carr	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
85345K181	Top Frame - Garolite G-10/FR4 Sheet, 6" x 6", 3/32" Thick, Black	https://www.mcm	2	$7.35	$14.70	McMaster Carr	McMaster Carr	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
	BadAss 45C 2600mah 6S LiPo Battery	https://innov8tive	2	$63.99	$127.98	Badass	Innovative Design	Electronics	Matthew, Hallagan	hallagmf@mail.uc.edu
	Spektrum AR410 4-Channel RC	https://www.ama:	2	$34.99	$69.98	Spektrum	Amazon	Electronics	Matthew, Hallagan	hallagmf@mail.uc.edu
	Flycolor Francy BLHeli_32 3-6S Dshot ESC - 50 Amps	https://www.getfp	3	$19.99	$59.97	Flycolor	getfpv	Electronics	Matthew, Hallagan	hallagmf@mail.uc.edu
4634T38	Wheel Shaft - 6061 Aluminum 14 mm Diameter	https://www.mcm	1	$6.21	$6.21	McMaster Carr	McMaster Carr	Drivetrain	Matthew, Hallagan	hallagmf@mail.uc.edu
	Jake Wheels	Custom Made	6	$0.00	$0.00	N/A	N/A	Drivetrain	Matthew, Hallagan	hallagmf@mail.uc.edu
	Multipurpose 6061 Aluminum 1/4" Thick x 4" Wide	https://www.mcm	1	$10.58	$10.58	McMaster Carr	McMaster Carr	Drivetrain	Matthew, Hallagan	hallagmf@mail.uc.edu
BA-2820-780	BadAss 2820-780Kv Brushless Motor	https://innov8tive	2	$62.99	$125.98	Badass	Innovative Design	Electronics	Matthew, Hallagan	hallagmf@mail.uc.edu
	Pinion Gears: 11 Tooth, Mod 0.8, 5mm Bore, Hardened Steel	https://justcuzrob	2	$10.99	$21.98	JustCuzRobotics	JustCuzRobotics	Drivetrain	Matthew, Hallagan	hallagmf@mail.uc.edu
	Amass XT90 Male and Female Connector Plug for Battery, ESC	https://www.ama:	1	$11.99	$11.99	Venom Group	Amazon	Misc	Matthew, Hallagan	hallagmf@mail.uc.edu
91259A116	Shoulder Screw :1/2" Diameter, 5-1/2" Length, 3/8"-16 Thread	https://www.mcm	2	$23.58	$47.16	McMaster Carr	McMaster Carr	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
6338K424	Oil-Embedded Flanged Sleeve Bearing:1/2" Shaft Diameter and 3/4" Hc	https://www.mcm	3	$4.44	$13.32	McMaster Carr	McMaster Carr	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
94758A031	18-8 Stainless Steel Flange Nut: 3/8"-16 Thread Size	https://www.mcm	2	$7.66	$15.32	McMaster Carr	McMaster Carr	Weapon	Matthew, Hallagan	hallagmf@mail.uc.edu
91257A640	Hex Head Screw: Grade 8 Steel, 3/8"-16 Thread Size, 4" Long, Partially	https://www.mcm	2	$13.36	$26.72	McMaster Carr	McMaster Carr	Fasteners	Matthew, Hallagan	hallagmf@mail.uc.edu
94945A217	Locknut: Grade 8, Zinc Yellow-Chromate Plated, 3/8"-16 Thread Size	https://www.mcm	1	$17.76	$17.76	McMaster Carr	McMaster Carr	Fasteners	Matthew, Hallagan	hallagmf@mail.uc.edu
91251A555	Socket Head Screw 1/4"-20 Thread Size, 3-1/4" Long,	https://www.mcm	1	$12.61	$12.61	McMaster Carr	McMaster Carr	Fasteners	Matthew, Hallagan	hallagmf@mail.uc.edu
91251A548	Socket Head Screw 1/4"-20 Thread Size, 1-3/4" Long, Partially Threade	https://www.mcm	1	$17.53	$17.53	McMaster Carr	McMaster Carr	Fasteners	Matthew, Hallagan	hallagmf@mail.uc.edu
91290A119	Socket Head Screw Black-Oxide, M3 x 0.5 mm Thread, 14 mm Long	https://www.mcm	1	$14.38	$14.38	McMaster Carr	McMaster Carr	Fasteners	Matthew, Hallagan	hallagmf@mail.uc.edu
95462A029	Medium-Strength Steel Hex Nut Grade 5, Zinc-Plated, 1/4"-20 Thread S	https://www.mcm	1	$8.59	$8.59	McMaster Carr	McMaster Carr	Fasteners	Matthew, Hallagan	hallagmf@mail.uc.edu
91251A242	Socket Head Screw 10-24 Thread Size, 1/2" Long	https://www.mcm	1	$15.67	$15.67	McMaster Carr	McMaster Carr	Fasteners	Matthew, Hallagan	hallagmf@mail.uc.edu
98697A520	Low-Profile Narrow-Base Weld Nut with Projections, 10-24 Thread Size	https://www.mcm	1	$11.67	$11.67	McMaster Carr	McMaster Carr	Fasteners	Matthew, Hallagan	hallagmf@mail.uc.edu

Total: $1,226.28

Actual

Instructions	School Year*	Team Name*	Total Cost
This form Is to be filled out by a battlebot team to request the parts they need. All fields with a * next to them are required to be filled out.	2022-2023	Drumatic	$985.79

P/N*	Description*	Hyperlink*	Quantity*	Price Per Unit*	Total	Manufacturer	Vender*	What Sub Assembly and Other Comments*
	Easy-to-Weld 5052 Aluminum Sheet 1/4" Thick, Bent	https://sendcutse	1	$47.51	$47.51	SendCutSend	SendCutSend	Weapon - I order
-	AR500 Blade - 0.50 thick	https://app.sendc	8	$12.28	$98.24	SendCutSend	SendCutSend	Weapon - I order
-	AR500 Blade - 0.25 thick	https://app.sendc	4	$12.77	$51.08	SendCutSend	SendCutSend	Weapon - I order
91259A116	Shoulder Screw :1/2" Diameter, 5-1/2" Length, 3/8"-16 Thread	https://www.mcm	2	$23.58	$47.16	McMaster Carr	McMaster Carr	Weapon
6338K424	Oil-Embedded Flanged Sleeve Bearing:1/2" Shaft Diameter and 3/4" Hc	https://www.mcm	2	$4.44	$8.88	McMaster Carr	McMaster Carr	Weapon
94758A031	18-8 Stainless Steel Flange Nut: 3/8"-16 Thread Size	https://www.mcm	2	$7.66	$15.32	McMaster Carr	McMaster Carr	Weapon
6484K121	XL Series Timing Belt, Trade No. 110XL025	https://www.mcm	1	$5.50	$5.50	McMaster Carr	McMaster Carr	Weapon
1277N56	Timing Belt Pulley, 3/8" Maximum Belt Width, Hub, 2.272" OD	https://www.mcm	1	$21.33	$21.33	McMaster Carr	McMaster Carr	Weapon
1277N738	Timing Belt Pulley, NO Hub, 3/8" Maximum Belt Width, 1" OD, 3/16" Sh	https://www.mcm	1	$13.20	$13.20	McMaster Carr	McMaster Carr	Weapon
	Entire Base Frame - TPU	https://www.ama:	1	$27.99	$27.99	Overture	Amazon	Frame
91259A716	Alloy Steel Shoulder Screw	https://www.mcm	3	$3.40	$10.20	McMaster Carr	McMaster Carr	Fasteners
91251A551	Black-Oxide Alloy Steel Socket Head Screw	https://www.mcm	1	$12.80	$12.80	McMaster Carr	McMaster Carr	Fasteners
1688K15	Ultra-Low-Friction Oil-Embedded Sleeve Bearing	https://www.mcm	3	$1.26	$3.78	McMaster Carr	McMaster Carr	Fasteners
91294A134	Black-Oxide Alloy Steel Hex Drive Flat Head Screw	https://www.mcm	1	$10.84	$10.84	McMaster Carr	McMaster Carr	Fasteners
91294A132	Black-Oxide Alloy Steel Hex Drive Flat Head Screw	https://www.mcm	1	$7.34	$7.34	McMaster Carr	McMaster Carr	Fasteners
91094A114	Grade 8 High-Strength Steel Flange Nut	https://www.mcm	1	$9.39	$9.39	McMaster Carr	McMaster Carr	Fasteners
91257A640	Hex Head Screw: Grade 8 Steel, 3/8"-16 Thread Size, 4" Long, Partially	https://www.mcm	2	$13.36	$26.72	McMaster Carr	McMaster Carr	Fasteners
94945A217	Locknut: Grade 8, Zinc Yellow-Chromate Plated, 3/8"-16 Thread Size	https://www.mcm	1	$17.76	$17.76	McMaster Carr	McMaster Carr	Fasteners
-	Spektrum AR410 4-Channel RC	https://www.ama:	2	$34.99	$69.98	Spektrum	Amazon	Electronics
-	Flycolor Francy BLHeli_32 3-6S Dshot ESC - 50 Amps	https://www.getfp	3	$19.99	$59.97	Flycolor	getfpv	Electronics
BA-2820-780	BadAss 2820-780Kv Brushless Motor	https://innov8tive	3	$62.99	$188.97	Badass	Innovative Design	Electronics
010-0139-10	Sidewinder ESC	https://www.castl	1	$129.85	$129.85	Castle Creations	Castle Creations	Electronics
	Pinion Gears: 11 Tooth, Mod 0.8, 5mm Bore, Hardened Steel	https://justcuzrob	2	$10.99	$21.98	JustCuzRobotics	JustCuzRobotics	Drivetrain
	3D printed Nylon	https://braskem3	1	$80.00	$80.00	Braskem3D	Braskem3D	Drivetrain

Total: $985.79

Closing Thoughts

Conclusion

Over the last 8 months, we have created a combat robot from scratch which has taught us a lot about where we are as engineers. Drumatic is planning to compete on May 6th at the NHRL tournament and we have high hopes for it to fight well and win fights throughout the weekend. There were three key factors that contributed to building the robot that we have today: understanding roles, effective communication and collaboration.

The roles for senior design projects are not explained very clearly as the roles truly depend on what your project is about. Defining roles is the first and most important part of creating a good team. In order to define roles, you have to understand the people you are working with and that means hanging out and creating a team like atmosphere within your senior design group. Once everyone understands the roles that they believe they will succeed at, each student should receive one or two aspects of the combat robot that fits what they excel at. The reason why roles are important is that it creates a clear division of responsibilities between each of the team members which will lead to better utilization of time and communication. One of the best examples of how we used roles to be a better team was during Senior Design II while we were redesigning the majority of our robot. Instead of creating three new combat robots from scratch, we were able to give each one of us a role and base the design off of each other's new designs. Ethan created a new frame which Ben then based the overall size and diameter of the weapon he was designing around, this allowed us to utilize our time better and create the best combat robot we could without wasting resources. Defining roles early and sticking to your area of focus will help you to be a better team in the long run.

Effective communication is a deal breaker for being a successful team. It is one of the major reasons we were able to manufacture and refine our parts during Senior Design III. During the semester, we created excel charts that detailed what, when and how each of our parts was going to be machined. This was only able to be done because we communicated with each other on a daily basis, whether it was at class, over the phone or at one of our weekly meetings, and this led to an understanding that each of us was here for each other. One major misunderstanding, which was caused by bad communication, was when we had to machine the holes in our pulley. As I talked about earlier, we had an excel sheet with all the machining operations needed and one of our teammates forgot to mark down that he had already made the pulley holes as needed so a duplicate was created which was a waste of important time and money. This shows that communication is key and to always talk to your teammates if you have any doubt or questions about a task or design. We had good communication, but it is always something you can improve upon, which we talk about in the lessons learned section.

The last aspect that allowed us to build Drumatic was collaboration which may seem as weird as we just focused on roles in the previous paragraph. Roles and collaboration can work together especially during brainstorming such as during the design phase when you are presented with thousands of different ideas that could be perfect. We mainly used collaboration during the Senior Design I when we had to narrow down so many options such as which weapon to use where we created dozens of prototypes before we settled on the drum design. Collaboration can also be used when problems arise as not everything is going to go as planned. The teammates can work together to fix the problem efficiently. This one was especially important to us as during the last couple weeks of the second semester, we found out that one of our motors was not going to work with a new battery we had to use which was as crisis, but we were able to create a plan to use our extra drive motor to work as a weapon motor. We had to order new pulleys and do quick manufacturing, but the plan worked and that was thanks to collaboration.

Drumatic was a success and that was due to a great team that we made through teamwork and collaboration. This senior design was an amazing learning experience and it taught all of us so much about engineering while still using the five years' experience we learned here at the University of Cincinnati.

Future Work

When looking back at our design we have definitely thought about altering some components as we went along with the project. When first designing our combat robot we had a lot of trouble with weight. We initially were set to be in the 15 lb. weight class but got moved to the 12 lb. weight class mid-way through the first semester. We were already overweight in the 15 lb. class, so we had to do an entire re-design of our original design, which mainly required shrinking the robot entirely to get underweight. We eventually got the robot's weight down to 10.5 lbs., which is a lot lower than we intended. If we could go back and do some redesigns, we would consider making the robot a little bigger because we had some trouble getting all of our electronics to fit inside the robot. Having extra space would ensure nothing is getting squished and avoid wires from getting tangled up in the motors. Our battery is also very delicate, so it is very important that we keep the battery safe and out of reach of any things that could damage it.

Another aspect of the robot that we would consider changing is the drivetrain. We currently are using a planetary gear system for our drivetrain instead of a gearbox. Our gear system is our own design that is custom made using a nylon print to make internal gear teeth in our wheel that are rotated by an 11-tooth pinion that is connected to our drivetrain motor. The wheel has a dead shaft going through it and spins on a brass bearing. It is a very unique design that allows our robot to be easy to control and makes it very quick when it comes to reaction time. It is incredibly fast with a gear ratio of 96:11. We have not had the opportunity to fight any other bots yet, so we don't really know how well it will hold together when being struck by our opponent.

This is something we won't know until after the competition, but since we are slightly underweighting, we could potentially see us switching to a normal gearbox system for our drive train if our custom drive system doesn't work at the competition in Norwalk.

When designing our weapon, we had to ensure that the weapon assembly would be capable of holding our weapon and to withstand the impact it will have to take when striking opponents and when getting hit by our opponents. We did this by creating slots in our side aluminum pieces that allowed the middle frame of the weapon assembly to slide right on. Then we welded the pieces together to ensure none of the parts would come apart. Doing this allows us to interchange our drum weapon out of the weapon assembly easily, but the design of our weapon assembly doesn't do a very good job of protecting the pulley belt on the weapon drum. There is nothing there to cover the belt, so it could be hit by our opponent and ultimately disable our weapon. The good thing is that just because our weapon gets disabled doesn't mean we lose. As long as our robot is capable of driving around then we can still compete. If we could go back, we would find a way to design our weapon assembly to be able to cover our weapon pulley, so it gets hit by our opponent. We could also add an attachment to our TPU frame that could hangover the pulley to give it some protection.

While designing our combat robot we really wanted to ensure that we did something unique from other combat robots that have been made before. Our drum design was one of the big aspects of our robot that was different to previous designs. We staked multiple blades together and held them all together using hex bolts. Our frame was also unique compared to other robots because we use such a light material. Most teams make their combat robots frame out of aluminum or some kind of light metal. The majority of our frame is made up of thermoplastic polyurethane (TPU), which is known for being light and strong. We haven't had the opportunity to test it in combat, but based on our FEA simulations it should be strong enough to take damage from our opponents and keep our electronics safe. If the TPU doesn't work well at the competition in Norwalk we could definitely explore some other plastics or metals for our frame of the robot in the future.

Lessons Learned

One of the biggest things that can be taken away upon completion of this project is the importance of teamwork and communication. Initially in the first semester, it was difficult to blend all of the different design ideas that each member of our team had in mind. Our group had spent time making individual concepts when it would have been beneficial to work together to create one working idea. There were also lapses in communication between changes that were either required or had been made that made it difficult to ensure that no group member felt overwhelmed with the amount of work that needed to be performed. This was corrected in the second semester where it was obvious that our group had found a better sense of balance in the distribution of tasks and ideas.

Another valuable lesson that was learned is the importance of sticking with what our group wanted to do. Throughout the design process it was difficult to take into account all of the suggestions that our team leaders would provide. There would be a list of changes that our group was given to make, those changes were made, and then the following week our team leader would ask why we had made the changes that were just discussed in the previous week and then come up with another list of suggestions afterwards. This made the design phase of our robot grueling at times, and we would have been better off leaving some of these suggestions just as that and not necessarily taking them all into account as required to make a functional bot. In some cases, team leaders would make contradictory statements as to whether a design change would be permissible or not and we would have to decipher which one was actually relevant to our design. It would have been beneficial to our group to stay true to our own ideas and concepts and provide a reasoning behind why we believed in those proposed design decisions while also considering the given suggestions but not necessarily taking them to heart as all being necessary.

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Appendices

Norwalk Havoc Robot League Regulations

Here is the Aggression Judging Matrix right off NHRL website (4),

5-0:

   - This bot used its active weapon to attack its opponent with intent for almost the entire match. The opponent spent almost all of the match not actively attacking with an active weapon using intent.
   - The opponent spent almost the entire match actively avoiding engagement.
- **4-1**:
   - This bot frequently used its active weapon to attack its opponent with intent. The opponent occasionally used its active weapon to attack its opponent with intent.
   - This bot often used its active weapon to attack its opponent with intent, but only for part of the match. The other bot never used its active weapon to attack its opponent.
   - The opponent spent a significant portion of the match actively avoiding engagement.
- **3-2**:
   - This bot used its active weapon to attack with intent slightly more than its opponent.
   - Both bots' active weapons were at least partially disabled, but this bot tried to attack more with its disabled weapon than its opponent.
   - This bot attacked consistently throughout the match with its active weapon. Its opponent bunched its attacks over a shorter period of the match but spent long portions of the match not attacking.

Here is the Control Judging Matrix right of NHRL website,

- **6-0:**
   - This bot pushed the other bot around the cage at will, repeatedly putting them into bad situations while never itself being put in a bad situation.
   - The other bot got stuck far more often.

- **5-1:**
   - This bot was able to get the other bot in bad positions in the cage several times, while it got put in bad positions occasionally, but less frequently.
   - The other bot got stuck somewhat more often.

- **4-2:**
  - This bot got the other bot in bad positions slightly more often than it was put in bad positions.
  - The other bot got stuck slightly more often.
  - Both bots were stuck in bad positions about the same amount, but the other bot stuck itself in bad positions more.

- **3-3:**
  - Both bots seemed to control the match equally.
  - Neither bot seemed to take control of the match.

Here is a level chart that helps with scoring for damage off the NHRL website (4),

- **Level 1:** Destroying or disabling the drive system and all weapon systems on its opponent will score maximum damage points. In this case the opponent was likely saved from a knockout by the fight timer running out.
- **Level 2:** Destroying or disabling some of an opponent's drive or all its weapon systems. This includes removing a spinner's weapon belt, so it no longer spins. An articulated weapon, like a hammer saw, must be completely disabled to count here; that is, both the saw and the arm must be disabled. It also means disabling an opponent's drive to the point where they can translate around the arena just enough to avoid being counted out, but not so much that they can move anywhere at will.
- **Level 3:** Reducing the effectiveness of an opponent's drive or weapon systems. This includes removing at least one wheel, doing enough damage to at least one wheel to make it inoperable in a way that significantly affects the bot's driving, partially disabling an articulated weapon (disabling either the saw or the arm, but not both), and cutting a flamethrower line so that the other bot sprays fire on itself. It also includes compromising an opponent's ability to drive somewhat, but not enough to initiate a count-out.
- **Level 4:** Doing structural damage to an opponent, like damaging its frame, doing significant damage to non-ablative armor, or damaging a wheel in a way that doesn't significantly change a bot's mobility.
- **Level 5:** Most ablative armor removed from at least one side of the opponent, or small gouges/holes in an opponent's non-ablative armor.
- **Level 6:** Cosmetic damage to a bot, like scratches against paint. Or some ablative armor removed.

Here is the Damage Judging Matrix right off NHRL website (4),

- **6-0:**
  - There are at least 4 levels separating the two bots. For example, one bot is at Level 6, and the other bot is at Level 2.

- **5-1:**
  - There are 3 levels separating the two bots. For example, one bot is at Level 4, and the other bot is at Level 1.

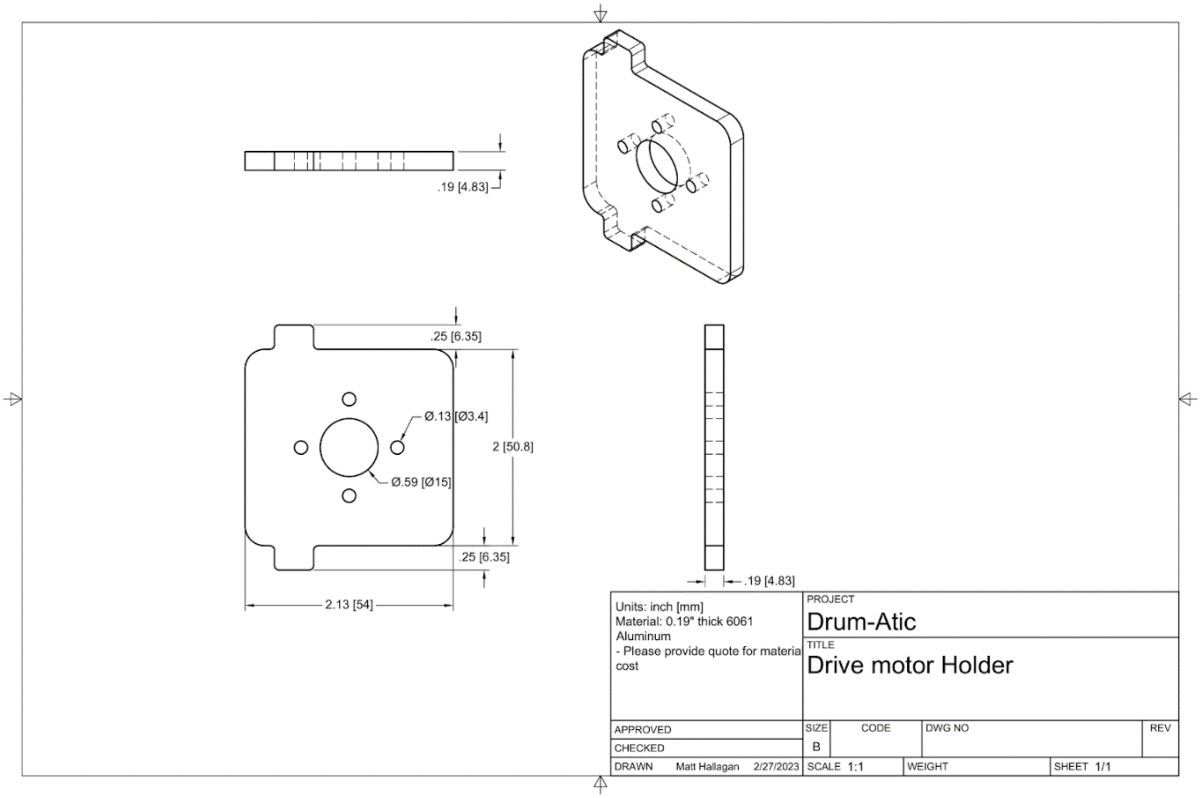
- **4-2:**
  - There are no more than 2 levels separating the two bots. For example, one bot is at Level 5, and the other bot is at Level 6.

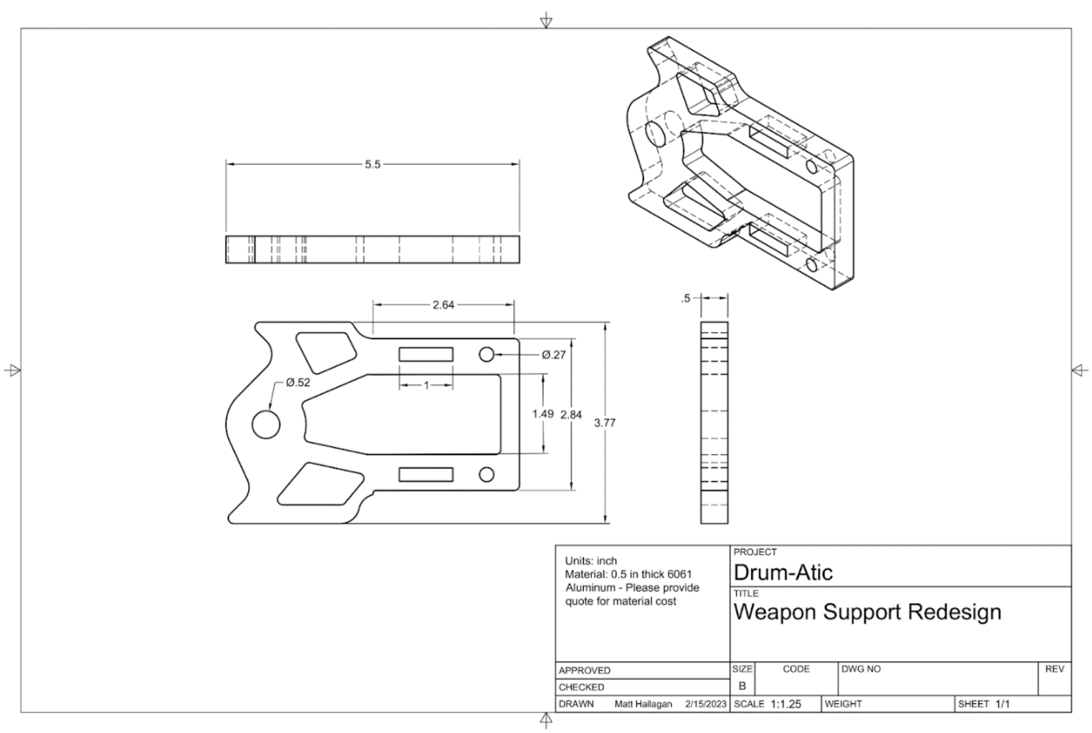
- **3-3:**
  - Both bots did an equal amount of damage to each other.
  - Neither bot did any damage to the other.

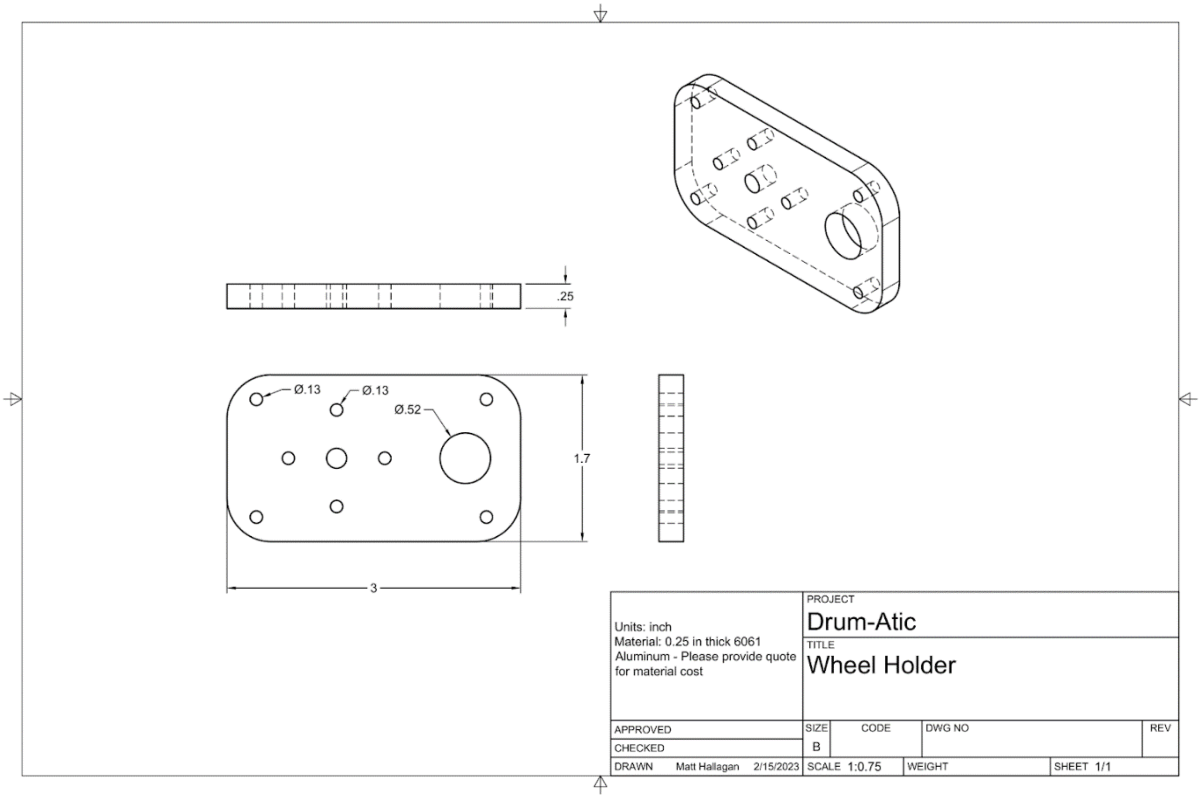
Survey Questions

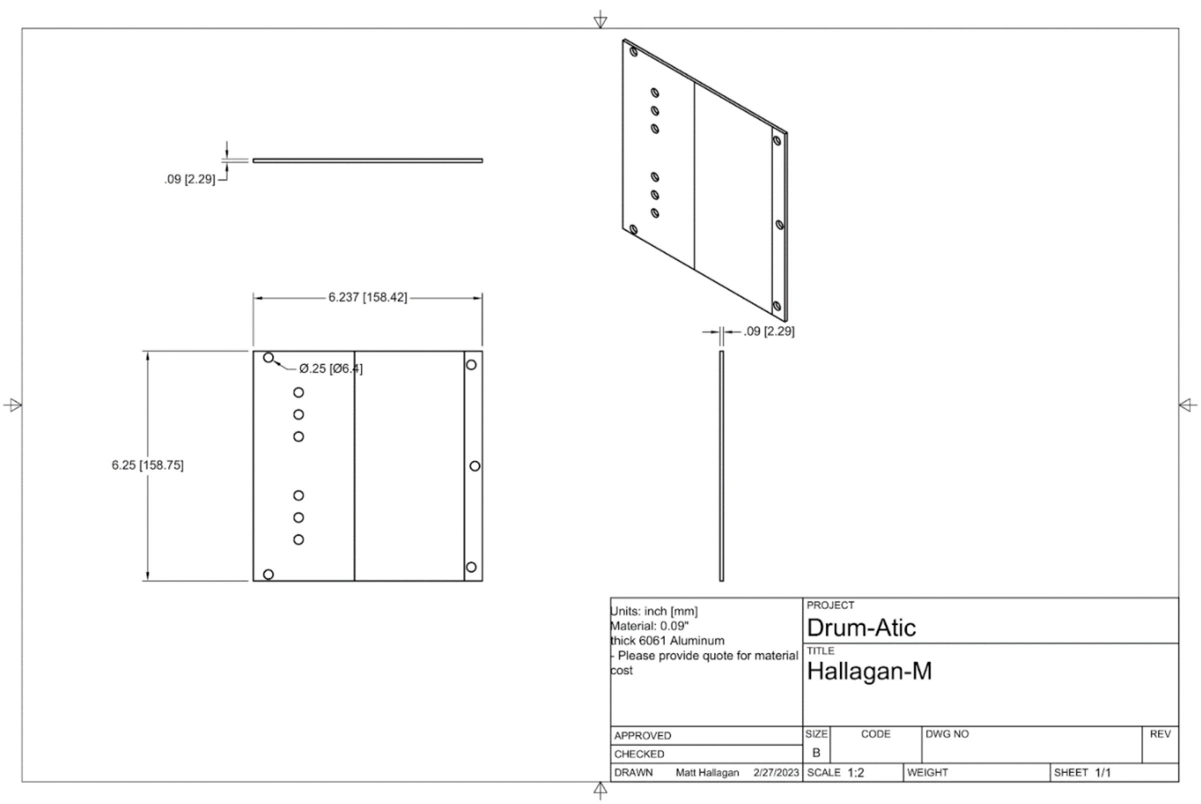
- Rank the following feature in relation to building a Combat Robot: Safety
    - What is your opinion of the current Safety features in the combat robot landscape?
- Rank the following feature in relation to building a Combat Robot: Offensive Capabilities
    - What is your opinion of the current Offensive Capabilities in the combat robot landscape?
- Rank the following feature in relation to building a Combat Robot: Defense
    - What is your opinion of the current Defense in the combat robot landscape?
- Rank the following feature in relation to building a Combat Robot: Weight
    - What is your opinion of the current Weights in the combat robot landscape?
- Rank the following feature in relation to building a Combat Robot: Ease of Repair
    - What is your opinion of the current Ease of Repair ability in modern combat robots?
- Rank the following feature in relation to building a Combat Robot: Driving Control
    - What is your opinion of the current Driving Control seen in modern combat robots?
- Rank the following feature in relation to building a Combat Robot: Weight Distribution across Robot
    - What is your opinion of the current Weight Distribution of Combat Robots?
- Rank the following feature in relation to building a Combat Robot: Budget Limit
    - What is your opinion of the current Budget Limit for combat robots?
- Rank the following feature in relation to building a Combat Robot: Appearance
    - What is your opinion of the current Appearance of combat robots?
- Rank the following feature in relation to building a Combat Robot: Driving Mobility
    - What is your opinion of the current Driving Mobility of combat robots?

Drawings


.19 [4.83]
.25 [6.35]
Ø.13 [Ø3.4]
2 [50.8]
Ø.59 [Ø15]
.25 [6.35]
2.13 [54]
.19 [4.83]
Units: inch [mm]
Material: 0.19" thick 6061
Aluminum
- Please provide quote for materia
cost
PROJECT
Drum-Atic
TITLE
Drive motor Holder
APPROVED
CHECKED
DRAWN Matt Hallagan 2/27/2023
SIZE B
CODE
DWG NO
REV
SCALE 1:1
WEIGHT
SHEET 1/1


5.5
2.64
.5
Ø.27
Ø.52
1
1.49
2.84
3.77
Units: inch
Material: 0.5 in thick 6061
Aluminum - Please provide
quote for material cost
PROJECT
Drum-Atic
TITLE
Weapon Support Redesign
APPROVED
CHECKED
DRAWN Matt Hallagan 2/15/2023
SIZE B
CODE
DWG NO
REV
SCALE 1:1.25
WEIGHT
SHEET 1/1


.25
Ø.13
Ø.13
Ø.52
1.7
3
Units: inch
Material: 0.25 in thick 6061 Aluminum - Please provide quote for material cost
PROJECT
Drum-Atic
TITLE
Wheel Holder
APPROVED
CHECKED
DRAWN Matt Hallagan 2/15/2023
SIZE B
CODE
DWG NO
REV
SCALE 1:0.75
WEIGHT
SHEET 1/1


.09 [2.29]
6.237 [158.42]
Ø.25 [Ø6.4]
6.25 [158.75]
.09 [2.29]
Units: inch [mm]
Material: 0.09" thick 6061 Aluminum - Please provide quote for material cost
PROJECT
Drum-Atic
TITLE
Hallagan-M
APPROVED
CHECKED
DRAWN Matt Hallagan 2/27/2023
SIZE B
CODE
DWG NO
REV
SCALE 1:2
WEIGHT
SHEET 1/1