Battle Bots - Team VOODOO

Senior Design Report submitted to the
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by

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Problem Statement

The sport of combat robotics is always evolving which provides new and unique challenges to overcome each year. Our task is to design and build a combat robot to compete in the Norwalk Havoc Robot League (NHRL) 12lb class on May 6th, 2023. The robot must conform to all competition rules, most importantly the weight and safety rules set by NHRL. The material and machining cost of the robot must also stay within the budget allocated to us via the University of Cincinnati BattleBots Club. This robot must be able to deal enough damage to disable an opponent while also being able to absorb or avoid impacts from other robot's weapons. We will use our knowledge of kinematics, material science, and innovation to improve on past years' robots, in order to build a robot of our own that is better suited for challenges listed above.

Research

Background of the Problem

A robot must be designed, manufactured, and tested in order to compete and win against other robots within the 12-lb weight class. Opposing robots will have varying designs so our robot must be effective against the maximum number of potential robot designs. This competition will test our design skills as well as our ability to work effectively on a team. We must also stay within a fixed budget as well as follow all the rules set in place by the tournament directors. Combat robots are complex mechanisms that take a lot of planning and time to successfully build. The components and materials needed to build a functional robot are also expensive and may be hard to acquire. One of the baselines for cost is to spend roughly $100 per pound of robot that you intend to construct. It will take many hours to complete this build as the design and planning as well as the build phases will pose challenges that must be overcome. While assembling the robot there could be bugs that have to be worked out for it to function properly. These robots can also be dangerous if the proper safety precautions aren't taken. Many injuries could occur during the fabrication process when operating the various machines at the Victory Parkway campus. Proper training on machines can help prevent such injuries. The testing of the robot can also present risks as rotating weapons pose serious risks to bystanders if the proper testing environment isn't used. We hope to build a more durable robot that can withstand our competition. Many robots are not durable and cannot take much damage from an opponent. We would like to implement sacrificial armor as well as a dampening system that would lessen the forces transferred to the electrical components during an impact. We think that the electrical components are the most susceptible to serious damage and would stop working as a result. This in turn would prevent us from continuing the fight with the other robot. Once the competition is over, we want to pass along the knowledge we have learned so that future teams can further improve their designs.

Applicable Standards

12lb Technical Regulations [4]:

- Compliance with all event rules is mandatory
- All bots must be at or below the specified weight for their weight class
- 12lb weight class multibots get a 3-pound weight bonus and non-wheeled bots get a 6-pound bonus
- The maximum weight of any single bot may not exceed 110% of the normal bot weight
- The bot(s) must fit into a 36 x 36 x 36-inch cube at the start of the fight
- All entrants must have an active weapon. Only the heaviest of the multi-bots must have an active weapon
- All weapons systems must have locks that stop their actuation. Weapons that move must have a lock that stops movement in all directions
- Flame and heat-based weapons are allowed. 12-pound bots are allowed up to 12 ounces of fuel
- Projectile weapons cannot exceed speeds of 150 mile per hour
- Weapons that primarily act by obstructing visibility are not permitted
- Electrical and shock weapons are not permitted, nor are electrical weapons that purposefully block radio signals
- Any weapon that results in arm to those outside the cage are not permitted
- Modular bots permitted as long as no more than 50% of the weight of a modular bot changes between configurations
- Entanglement devices are not permitted
- Liquids expelled from the bot are not permitted. Liquids used as a fuel source are permitted.
- Combustion powered bots are permitted
- Fabric, foam, and other ablative armor are permitted
- Electrical systems cannot exceed 72 volts
- Batteries that charge inside of the bot are permitted if the bot measures less than 11 x 8 x 6 inches
- All robots are guaranteed a minimum of 20 minutes between fights

State of the Art

The University of Cincinnati has designed and built robots to compete at the Xtreme Collegiate Clash event since 2017 and as of 2022, UC students will compete at Norwalk Havoc in the 12lb class. Each year, teams have found new and innovative ways to overcome the design challenges faced when entering Battle Bots. Some of these unique approaches found great success while others worked better in theory and need improving. As a team we will explore past robot designs done by UC students and robots that appeared on the show in order to learn from their mistakes and find ways to make our bot an improved version of those prior. Our analysis of past robots will be broken down into three sections, the weapon, the drive train, and the frame/armor.

Weapon:

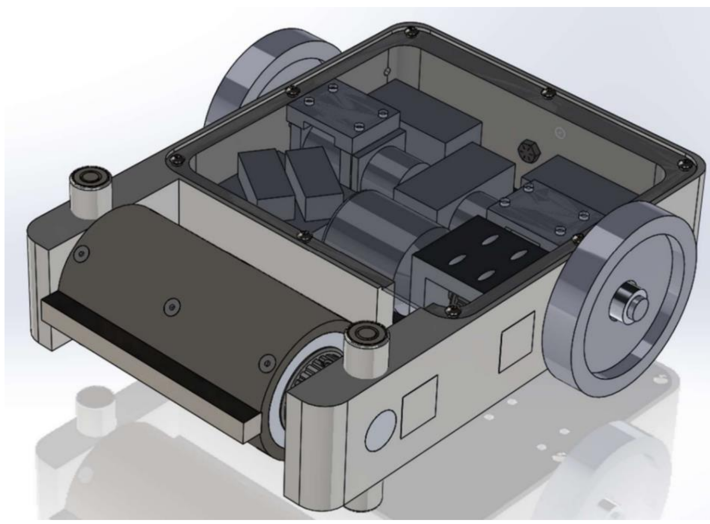


Figure 1.1: Drum Spinner - Splurt [17]

A drum spinner is a large cylindrical extrusion of steel equipped with one or more teeth, spinning at a high rate of speed in order to deal damage to other bots. Drum spinners typically span the entire front section of the robot giving the robot a large attack area. This makes the driver's job easy because very little precision driving is needed in order to make contact with opponents. When contact is made with another bot, the impact of the hit is even larger because the weapon bites with the entire length of the drum. Drum spinners also help the robot defensively because the entire front section of the robot is a danger zone for other bots. Drum spinners are typically heavy and spun with a tip speed of over 250 miles an hour which generates a massive moment of inertia. This inertia can be both a blessing and a curse. The inertia is good for inflicting major damage on opposing bots but this inertia can also make maneuvering the robot difficult. If a turn is made too sharp, drum spinner robots have a tendency to flip over which can leave them vulnerable to attack by another robot [20].

Some other drawbacks of drum spinners are that they are typically small in diameter, requiring the robot to get close to the opponent in order to deal damage [20]. This can be extremely dangerous because drum spinners tend to lose weapon on weapon fights due to their short reach. A robot with a larger diameter blade will almost always hit first making the drum spinner ineffective. The drum spinner is also very heavy, so other components' strength must be sacrificed.

The robot pictured above is Splurt, a drum spinner robot designed by UC seniors in 2020. Some of the unique approaches they took to counteract the weaknesses of the drum spinner was making the robot vertically symmetrical so even if they flipped over, the robot was still fully functional and able to continue battling [17]. The issues Splurt encountered were mainly weight related. Their drum spinner was so large, they were unable to use the stronger AR500 steel and instead opted for a hollowed-out cylinder of 1020 carbon steel. Even with the lighter drum weight still needed to be saved in other areas of the robot. The team had to sacrifice wheel guarding which left them vulnerable to wheel attacks which could quickly disable the bot [17].

Figure 1.2: Horizontal Spinner - Doomba [16]

Horizontal Spinners are flat bladed spinners that rotate on an axis perpendicular to the floor. They are very popular due to their simplicity of design and construction. Horizontal spinners are typically larger in diameter than drum and vertical spinners. Due to the blade's large diameter, it gives the robot a large attack area, making the robot simple to operate with the intention of dealing damage. This large attack area doubles as a defense mechanism because opposing robots will struggle to find a good angle of attack and struggle to get too close. The only good spot to attack a large blade horizontal spinner is from the rear but a simple 180-degree turn puts the opponent right back in the attack area.

When a horizontal spinner makes contact with an opponent, it sends both robots flying in opposing directions. In some cases, this can be good because it creates distance between your bot and the opponent, allowing the horizontal blade to get back up to speed. Though, over extended periods of time, these hits can cause the weapon to become unbalanced and the robot will begin violently vibrating itself apart. Due to the large diameter of most horizontal spinners, they can take a while to get up to speed. This means if an opponent is willing to get up close and personal, they may be able to suffocate the spinner so it never gets up to full speed. The large diameter also brings up weight issues where other components' strength must be sacrificed in order to have an effective horizontal spinner [19].

The robot pictured above is Doomba, a robot created by UC seniors in 2021. A way this team worked around the weight issues of the blade was by making the blade out of thinner material. This gave the weapon a much shorter spin up time of 2.92 seconds [16]. Although the blade could now spin up quicker, it was weaker, and after repeated hits the blade began bending. The bending became so severe that the blade began hitting the floor and the robot's frame [16]. Another issue that plagued Doomba was the weapons drive belt being exposed. The belt was frequently hit in matches which completely disabled the spinner [16]. Horizontal spinners are capable of outputting an extreme amount of damage to opponents, unfortunately this sometimes backfires, and the robot damages itself [19].

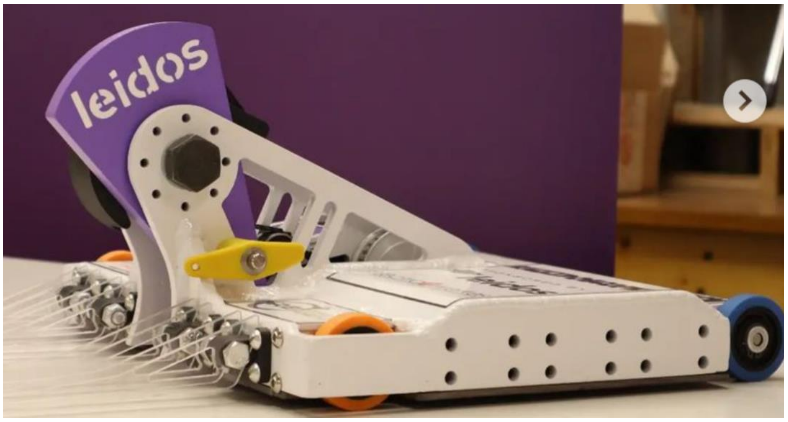


Figure 1.3: Vertical Spinner - Kaleidoscope [13]

Vertical spinners operate very similarly to horizontal spinners but they have a few notable differences. The major difference is in the blade orientation, on a vertical spinner, the blade rotates on an axis parallel to the floor. The blade can be spun upwards to get underneath opponents and flip them into the air, or spin downwards in order to better penetrate armor by pinching the opponent between the blade and the floor. Vertical spinners are typically smaller in diameter than horizontal spinners making them weigh much less allowing that weight to be used in making the robot's frame and armor more rigid [19]. This also enables the spinner to be made out of stronger, more dense materials like AR500 which is bullet proof. Small diameter vertical spinners made out of materials like AR500 tend to hold up over time because they are extremely resistant to impacts and deformation. This increases the reliability of the robot and increases the chances of the weapon assembly leaving the match in one piece.

Vertical spinners also come with their own set of disadvantages, the main one being the small attack area. The diameter of the weapon is small and the width of the blade only takes up a thin space at the front of the robot. This means the driver must be much more skilled at close range combat and maneuvering in order to deal damage while avoiding attacks from the opponent. Thin vertical spinners (ie. Any vertical spinner other than a drum spinner) are not very good defensively because of the large area they leave open to attacks, but in recent years they have proven themselves offensively as the best weapon to equip. The past 3 Battle Bots champions have all had vertical spinners similar to the design pictured above [1].

The robot pictured above is Kaleidoscope, a robot built by a 4th year MET student who mentors the UC Battle Bots Club. The robot had great success in competition but a few weak points on the weapon were showcased. Kaleidoscope’s weapon spun faster than any other robots in the 12lb class [13]. This was great for dealing out massive hits on opponents but due to the elevated speeds, any deformation or chipping of the blade would result in the blade being unbalanced. Another point for improvement on Kaleidoscope’s spinner is the force distribution after the blade impacts another robot. On a vertical spinner all of the reactionary forces from a collision translate straight down into the robot's frame. These forces caused Kaleidoscope’s frame to bow in the center underneath the weapon [13]. This issue can be counteracted by adding more compliant drive wheels to absorb the energy or by adding shock brackets that extend to the floor. This transfers the residual forces from the frame into the floor resulting in less damage to the robot.

Drive Train:

The drive train of the battle bot is the arrangement of components which allow the robot to be remotely controlled, providing movement, steering, power, and traction to the ground. These components are largely dictated by the rules and regulations for the competition in which the robot will partake in. In this category, for example, the rules dictate that radio systems must be Spektrum or Hobby King 2.4 GHz spread spectrum radio systems, and LiPo (Lithium Polymer) batteries are allowed. [4]

Transmitting power to the wheels is usually done in one of three ways: gear drive, chain drive, or belt drive. A belt drive is a frictional drive that transmits power between two or more shafts using pulleys and an elastic belt [2]. Belt drive systems are forgiving to use since they allow for slight misalignment. This is beneficial as it could reduce the tolerances needed to assemble and align the mounting holes of the drive motor with the wheel pulleys. Belts need to be properly tensioned to be able to gain enough friction to transfer power effectively. When the drive pulley spins, it creates a side of high tension on the belt between it and the load pulley, and a more slack side on the opposite half. If this is not taken into account in the design, premature belt wear can occur [2]. There are a couple of possible ways to lay out a belt drive system for a battlebot. Open belt drive has an open loop of belt wrapped around both pulleys rotating in the same direction. Cross belt drive can be used when the pulleys need to rotate in opposite directions. This is achieved by twisting or crossing the belt drive before installing it on the pulleys.

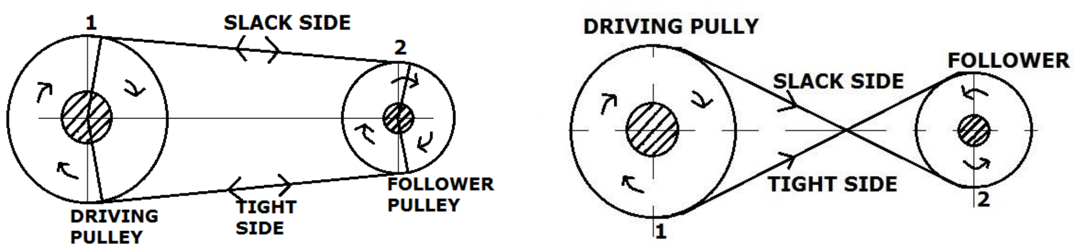


Figure 1.4: Open and crossed belt setups [15]

Chain drive is another option used in battlebots for the drivetrain. Chain drive consists of using a metal segmented chain to transmit power similar to that on a bicycle. Chain drive requires the use of sprockets instead of pulleys. These are toothed wheels which engage with the chain. All of these components must be made of steel since they experience substantial wear. Therefore, this option would increase the weight of the robot significantly compared to a belt drive. The advantage is that chains tend to be stronger than belts and can therefore transmit more torque in a smaller package. They have a very high working efficiency of about 96%, and do not have any stretch as compared to a belt. Sprockets do not wear out either so this system would be robust. Disadvantages include needing precise alignment for operation, as well as being loud and producing vibrations and needing lubrication [21]. The cost of chain drive is also a negative aspect since they tend to be costly compared to a belt [12].

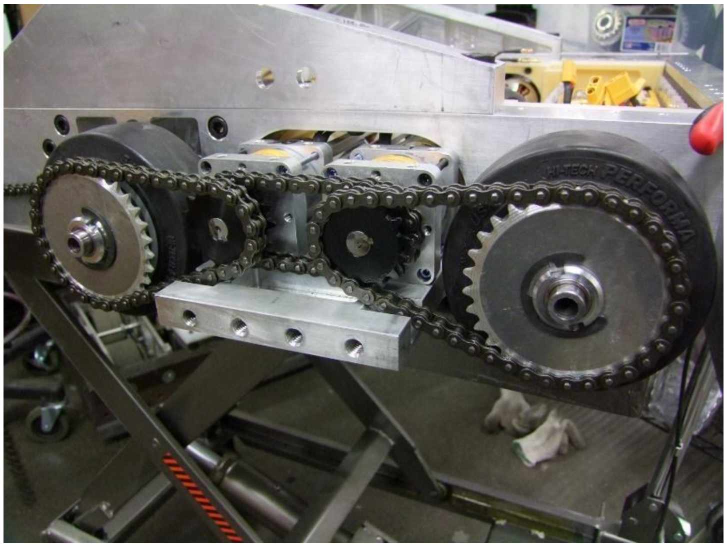


Figure 1.5: Chain drive mechanism [5]

The final drive train option considered for most battlebots is a gear train. Gear drive trains work by meshing toothed gear disks with each other. These disks can be made of different sizes to create a gearbox and alter the rotation. The advantages of gear drives are that there is no slippage between gears since they are solid disks meshed together. They can also be very compact, and are the best option to avoid wear compared to a belt or chain system. Gears require lubrication, and they can be difficult to use due to their lack of flexibility. Moreover, gears are the most expensive solution compared to chain and belt systems. They are also the heaviest, since they are solid disks of metal. Gearboxes are components that modify the rotational velocity of a drive motor, and these can be used along another drive mechanism to gear down or up the motor [3]. In researching this method, a standalone unit that contains a motor and gearbox was found. This is a simple solution for a four-wheel drivetrain that is easy to implement and control with minimal points of failure.

Figure 1.6: Gearbox drive mechanism [10]

Frame and Armor:

The frame and armor are very important to the design of a combat robot. The frame is what keeps the entire robot together and also helps to protect the electronics of the robot. The main component of the robot that protects the internals is the armor. The armor is mounted to the outside of the robot frame so that it can prevent opponents' weapons from hitting the electronics of the robot. Since the armor and frame take a lot of punishment from other robots, material selection and frame design are critical to ensure that your robot can survive in a fight. There is a wide selection of materials used for frame and armor components that each come with their advantages and disadvantages. These materials include aluminum, titanium, 4130 steel, AR500 steel, S7 tool steel, and ultra-high molecular weight polyethylene (UHMW) [7].

Aluminum is a commonly used metal that can be found in many commercial products. Aluminum is lightweight, strong, and easily machinable. Aluminum is typically used for the internal frame and fixtures of the robot rather than as an armor component due to how soft the material is. The softness of the metal allows competitors' weapons to easily bite into and gouge the metal. The only way this material can be used as armor is if it is thick enough to prevent competitors from breaking all the way through [7]. The most common alloys used for combat robotics are 2024, 5052, 6061, and 7075.

Titanium is another lightweight and strong metal that is used in combat robotics. Certain grades of titanium are half the weight of aluminum but can be three times as strong [7]. This can be a great alternative to steel armor if weight is an issue. However, titanium is more brittle than steel or aluminum so it won't bend as much before breaking if it takes a big impact. This material could be useful for areas of the robot that aren't expected to take large impacts. This would allow for extra armor or the inclusion of extra components due to the weight savings. While the weight savings are great there could be a tradeoff due to the increased brittleness of titanium.

4130 steel is another commonly used alloy [7]. This grade of steel is weldable, strong, and easy to machine. There are many different heat treatments that can be applied to this alloy which opens up the door to use it for a wide variety of applications. In combat robotics it is commonly used for shafts and axles. Steel alloys are generally cheaper than aluminum or titanium so you are able to get more material for the money spent which is great for teams on a budget.

AR500 steel is extremely strong and durable. It is routinely used in military vehicles as armor plating as well as target for recreation shooters. This material is about five to six times harder than mild steel while having the same density. This material is mostly used for rotating weapons due to the high impact resistance [7]. This material can also be used as armor, but this steel can be difficult to machine or shape due to the high hardness.

S7 tool steel is a type of steel used in machine tooling. This alloy can be oil hardened to increase its toughness. In combat robotics this material is used for small weapon teeth or inserts and is a good offensive weapon when dealing with AR500 armor [7]. This material can penetrate AR500 plating. If this material is heat treated improperly or is hardened too much it can become very brittle and shatter during competition.

Ultra-high molecular weight polyethylene is a popular polymer for combat robotics. Typically, polymers aren’t suited to the impacts that are experienced during a match. They are too soft and not strong enough to withstand the forces involved. This material is starting to be used as buffer material for armor plating [7]. When used as a buffer it can slow down and jam up other robots' weapons. UHMW is strong and abrasion resistant which gives it other uses besides a buffer. It is a low friction material which allows it to be used for bushings, balancers, or skid plates.

Figure 1.7: Witch Doctor and minibot from the TV show Battlebots[24]

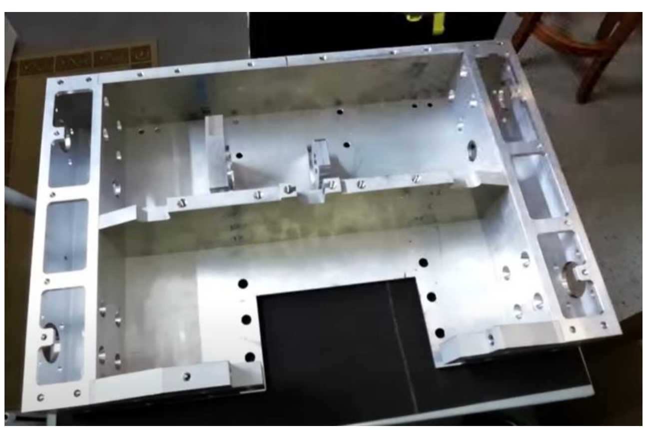


Figure 1.8: Frame construction for Witch Doctor [23]

Witch Doctor is a robot that has been featured on the TV show BattleBots. This robot was designed and built with a box frame. This style of frame is very versatile and can be built in a variety of shapes and sizes. Typically, this frame is built around the electrical components so that the robot is kept a compact size. This helps to reduce the overall weight of the robot. Despite the weight reduction certain parts of this frame won't be able to be as heavily armored as other parts. This is due to the large surface area that needs to be covered. The larger areas also provide more potential spots for a competitor to hit you. This robot utilizes different materials for different parts of their robot. The weapon of their robot is made from AR500 or AR550 so they can use the toughness of the material to damage other bots. The frame of the robot is made from 6061 aluminum and they have a steel plow at the front to protect themselves when they are trying to deal damage [22]. Overall, this robot was very successful during the 2021 fight season with a 78%-win percentage [22].

Figure 1.9: Gigabyte from the TV show Battlebots[11]

Gigabyte is another robot that has been featured on the show BattleBots. This style of frame is built within the weapon of the robot. This style of frame is very protective. Rather than having a single weapon at one end of the frame, the weapon surrounds the frame. This reduces the need for any armor plating on the frame since the weapon itself acts as a barrier to other robots. This allows for more weight to be distributed to other parts of the robot such as the weapon. A major downside to this style is that if the weapon shell is knocked off the robot, then the electronics and drive components are very susceptible to damage. Many precautions are needed to ensure a good connection with the frame. The shell of this robot is made from steel and it also has hardened fins for attacking other robots [11]. This robot had a 40%-win percentage during the 2021 fighting season [11].

Figure 1.10: Duck from the TV show Battlebots[9]

Duck is another robot featured on the BattleBots tv show. This style of frame is a wedge/plow robot. This frame is designed to ram into other competitors with the large plow at the front of the robot. The large plow is intended to absorb the impact and the competitor's weapon and direct forces back into the opponent. The frame of this robot is machined from a solid billet of 6061 aluminum and is designed to be rigid and durable since it will be taking a lot of punishment [9]. The plow at the front of the robot is made of a ¾" steel plate [9]. This design can handle impacts from other competitors really well since the frame and wedge are very thick. A major downside to this robot is that components can be frequently damaged since this style of robot acts as a battering ram. Since the frame is machined from a solid billet, repairs to it will be more difficult since frame panels can easily be swapped out. This robot did not record any wins during the 2021 fighting season [8].

End User

The end user of our robot is going to be all members of our senior design team. One member will be expected to be familiar enough with the robot to drive the robot during matches. This means the robot must be easy to control so the driver is able to maneuver around opponents to deal maximum damage while avoiding attacks. In the case where the robot takes a significant amount of damage, all of the team members need to be able to quickly repair and swap components in order to get the robot back for the next match. Components will be as simple and modular as possible in order to achieve this. As a team and as the end user of the robot, all members must follow the rules laid out in the NHRL rule book.

Summary of Research

Our goal is to build a combat robot that will comply with all the standards laid out by the Collegiate Class competition. We will be competing against other schools and people in the 12-pound weight division. We must stay under the fixed budget that is allotted to us. The general standard for robot building is to spend 100$ for each pound of robot [14] which would put us at roughly $1500. Many of these rules implemented are designed to protect competitors as well as spectators as combat robots can be very dangerous if used improperly. These safety precautions can be seen as the requirement for weapon locking bars as well as electrical disconnects. Other standards such as spill-proof batteries are essential to prevent people from being exposed to dangerous chemicals.

All weapon types researched for this project fall into the spinner category of weapons. Other weapons types are used, like hammers and flippers but these robots generally find little success in real match settings. The three main spinner types seen in battlebots competitions are drum spinners, horizontal spinners, and vertical spinners. All of these spinner types have their own set of advantages and disadvantages. Drum spinners deal damage over a wide area and act as armor for the robot, but they suffer the worst gyroscopic resultant forces out of the three and are very heavy. Horizontal spinners have a large attack area making it easy to hit opponents but horizontal spinners can be extremely unstable. When a hit is landed, both robots are flung in opposite directions causing damage to both. Vertical spinners come in the smallest, lightest weight package out of the three, and the resultant forces of weapon impacts go straight into the ground which better plants the robot to the floor. If not designed properly though, this resultant force can bend the robot's frame. No matter the spinner chosen, spinning weapons have a high success rate and they are able to store energy extremely efficiently. This is important in the 12lb class because there is very little weight to spare and every pound we take out of our weapon is another pound that can be used on the armor or drive train.

Regarding the drive train, all findings show that a compromise must be made. For our battlebot, a four-wheel design will be a favorable option. Choosing a lighter frame and weapon system will allow for the extra wheels, making the robot much more stable and maneuverable. For a power delivery method to the weapon, belts seem to be the best compromise in terms of low weight, simplicity, flexibility, and cost. The reduced durability is not as big of a concern for this application since belts are cheap and easy to replace in the event of wear. Another option would be to use individual motors directly driven at each wheel with a small gearbox. This makes all wheels independent of each other making it harder for an opponent to fully disable our drive train. Further, the use of the weapon is limited to the time of a fight, where damage is expected anyway, and therefore inspection and repairs are routine before each use. The drivetrain and frame are heavily correlated because a heavier frame requires a more powerful drive train. The key is to find a good balance between frame weight and strength in order to reduce the power requirements of the drivetrain.

Combat robots can be made of a variety of materials that each have their own advantages and disadvantages. The most common materials are aluminum, steel, titanium, and ultra-high molecular weight polyethylene. Aluminum is a common frame material while various grades of steel are used for the fabrication of weapon and armor components while titanium is versatile enough to be used as frame or armor. This can be seen in the combat robots from the show Battlebots. Many robots such as Witch Doctor use various materials as well as configurations to make their robot as effective as possible. They use an aluminum box frame to allow for easy mounting of components while the material choice helps to keep the frame light and strong. We would like to make a better version of Witch Doctor. The overall design of the robot could be improved with the addition of composite armor as well as more protection for electrical components.

Quality Function Deployment

Customer Features

As a team we deliberated and selected 10 customer features we found to be the most important in creating a successful combat robot. These features were then consolidated into a survey and presented to experienced individuals over multiple platforms. The survey was posted on Battle Bots subreddits and in the UC Battle Bots Club discord. The survey asked each individual their level of experience and knowledge of combat robotics and asked them to rank the importance of each customer feature below. The survey was taken by 35 individuals and this data was used in selecting our importance weights in the House of Quality.

- Ease of repair
- Modularity of components
- Overall weight
- Cost
- Drivetrain pushing power
- Drivetrain speed
- Driving while flipped
- Armor strength
- Weapon strength
- Weapon speed

Engineering Characteristics

- Disassembly/Reassembly time [min]
- Components are modular
- Pounds [lbs]
- Torque [N/m]
- Miles per hour [mph]
- Is invertible
- Armor Yield Strength [mpa]
- Weapon Yield Strength [mpa]
- Weapon Angular Velocity [rpm]
- Spin Up Time [s]

House of Quality

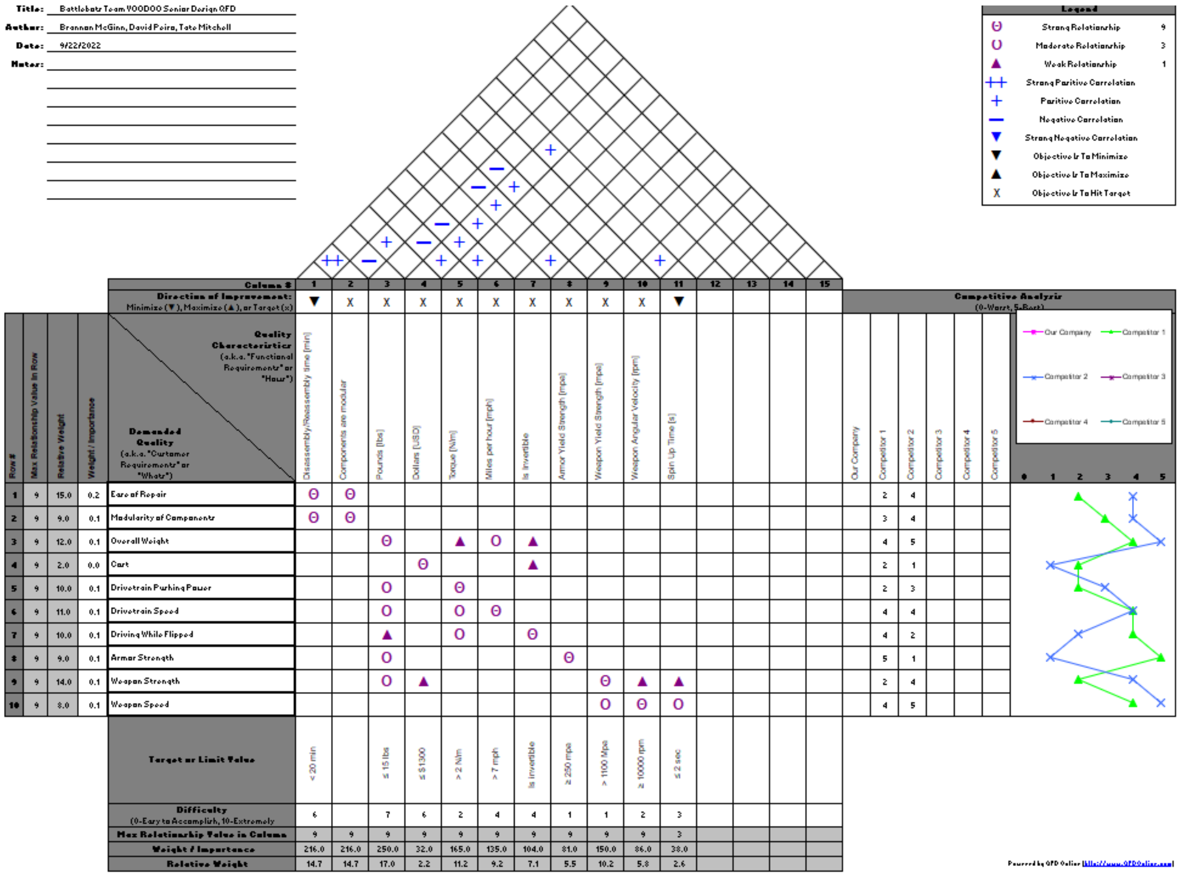


Figure 2.1 House of Quality

Product Objectives

Based on the combined results of the survey and the House of Quality, weighted importance ratings have been assigned to each engineering characteristic. The characteristics and their associated ratings are listed below in order of importance. As we move forward, this data will be used to drive the robot design and to justify design decisions.

1. **Weight (17.0)**
    a. Total weight must be under 12lbs.
2. **Disassembly Time (14.7)**
    a. Disassembly time should be under 20 minutes due to the short turnaround time between matches.
    b. Robot should utilize access panels to access electronics.
3. **Components are Modular (14.7)**
    a. Motors, wheels, and other components are simple to replace.
4. **Drivetrain Torque (11.2)**
    a. Motor torque is sufficient enough to push opponents without burning out motors.
    b. Motor torque is not too high that we begin sacrificing drive speed.
5. **Weapon Yield Strength (10.2)**
    a. Weapon must handle large impact loads over multiple fights.
6. **Drivetrain Speed (9.2)**
    a. Drivetrain speed must be high in order to maneuver around opponents.
    b. Speed must not be too high that torque and acceleration is sacrificed.
7. **Is Invertible (7.1)**
    a. Must be invertible so the robot is not counted out of the match.
8. **Weapon Angular Velocity (5.8)**
    a. Weapon must have a high speed to inflict maximum damage.
    b. Speed must not be so high that the weapon bite is sacrificed.
9. **Armor Yield Strength (5.5)**
    a. Material must be strong and cheap to replace when it is damaged.
10. **Spin Up Time (2.6)**
    a. Spin Up time must be short so high impact hits can be delivered regularly.
11. **Cost (2.2)**
    a. Robot cost must be within the budget allocated by the UC BattleBots Club.

Concepts Drawings

Weapon Concepts

Concept 1: Single Blade Vertical Spinner

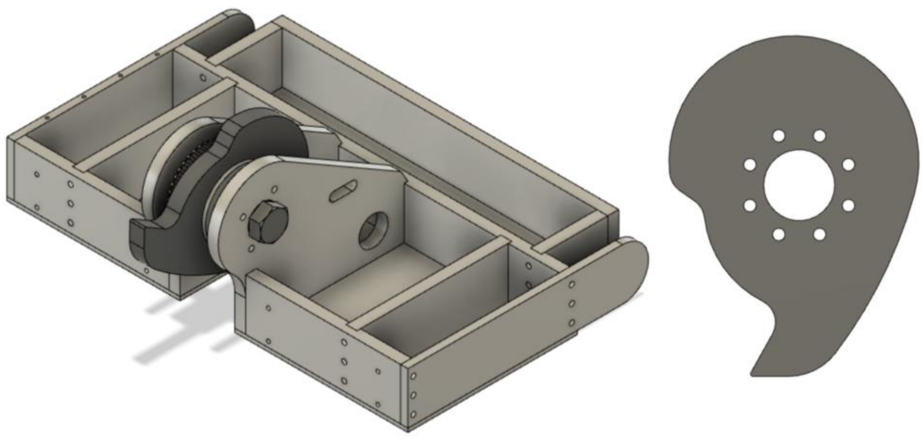


Figure 3.1: Single Blade Weapon on Frame, Single Blade Profile

This single blade spinner design above is based on the 250lb robot Witch Doctor. The weapon is made up of a 1/2in thick plate of AR500 water-jet-cut into the non-symmetric profile seen above. AR500 is extremely durable and 1/2in plate is a standard thickness making the material cheap and easy to source. A downside of using AR500 is that it is extremely difficult to machine and requires special cutters just to remove material.

The single blade weapon is beneficial because it allows you to get a bigger bite on your opponent. This is important because a bigger bite means a greater impact, which inflicts more damage to your opponent. The bite a weapon is able to achieve is based on two factors, weapon speed and the number of impactors / blades [6]. The faster a weapon spins and the more blades a weapon has, the lower the achievable bite. A single blade spinner only has the potential to hit an opponent once every rotation, but this works in the robot's favor. The low frequency of hits gives your weapon time to speed back up between each hit and it gives time for your opponent to move in closer before each hit. Both of these factors result in more impactful hits, so you hit opponents less frequently, but each hit is much more devastating.

A downside to the lower frequency of hits is if your opponent has a very fast weapon or a multi-blade weapon. They will likely get the first hit, causing you to lose the initial weapon on weapon exchange. Additionally, the non-symmetric shape can be difficult to balance on its center of mass. If this is done improperly, the weapon will vibrate at high speeds making it near impossible to operate. With all of the above considered single blade spinners have seen great success in the 12lb class, and due to the inverse relationship between the number of blades and achievable bite, the single blade design is able to produce the largest bite out of any spinner profile.

Concept 2: <u>Dual Blade Vertical Spinner</u>

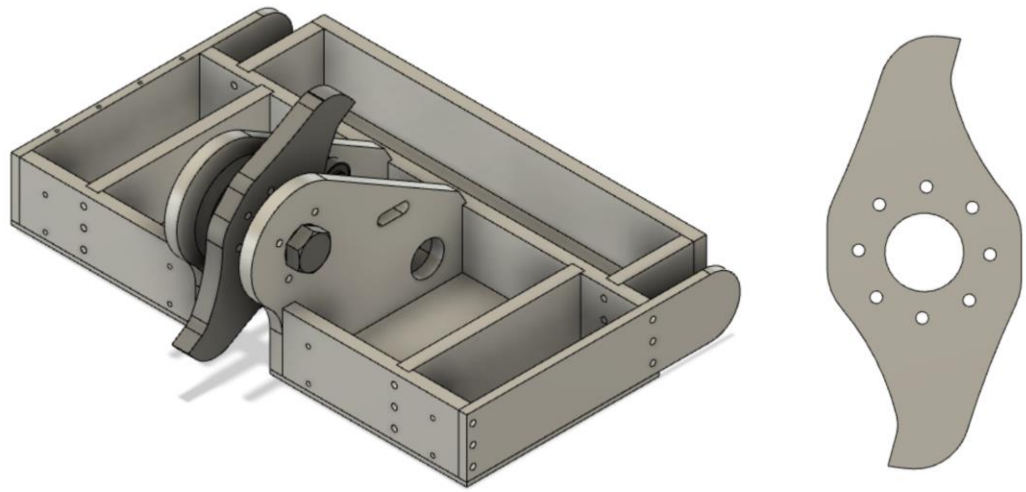


Figure 3.2: Dual Blade Weapon on Frame, Dual Blade Profile

The next design is a dual bladed vertical spinner based off of another 250lb robot called Hyper Shock. This weapon concept also utilizes 1/2in AR500 so all of the same benefits and drawbacks from the previous concept applies.

This design is very similar to the previous concept but it differs in key areas which changes the weapons performance. The most obvious difference is the weapon profile, this weapon is symmetrical and has two impactors / blades that deal damage to opponents. Because there are two blades, the frequency in which the weapon hits an opponent is double. This is beneficial for getting the first hit on an opponent or for getting in multiple hits before the opponent is able to react. Because of the high frequency, these impacts have less bite, but they are extremely effective at grinding and peeling away at the armor of opponents.

The drawbacks of using a double-bladed weapon are that it only gets a half rotation between each impact, meaning it gets half as much time to build up speed between hits. Because of this, dual bladed spinners are unable to produce extremely forceful hits like a single blade spinner can. In order to get the same bite as a single blade spinner, the dual blade weapon would have to be run at half speed but this lower speed reduces the overall effectiveness of the weapon.

This dual bladed design can be an effective weapon in its own right. It is less likely to give you a knockout punch, but rather win you a decision based on the damage it can inflict by chipping and grinding away at the opponent's exterior.

Concept 3: Drum Spinner

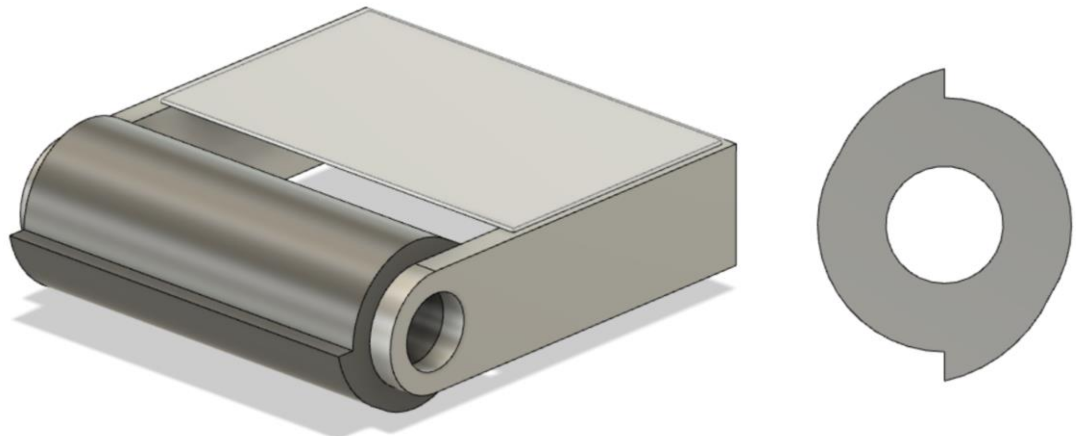


Figure 3.3: Drum Spinner Weapon on Frame, Drum Spinner Profile

The design above is a drum spinner based off of a robot built by a UC senior design team in 2020. The drum would be made from 1020 carbon steel due to its price, availability, and its high impact resistance. Carbon steel is not as strong as AR500 but a weapon this wide wouldn't be feasible to manufacture using AR500.

A drum spinner is a great option for a combat robot because the weapon doubles as a thick steel rotating armor bar that spans the entire front-side of the robot. Due to this width, the weapon is very heavy which increases its overall moment of inertia (MOI). This large moment of inertia gives the drum spinner a high potential to generate devastating hits on opponents. While very powerful, this high MOI has a drawback because it inhibits the robot's driving due to gyroscopic forces generated by the drum at high RPM.

Some additional shortcomings of the drum spinner design are that the robots drivetrain and armor suffers because so much weight is used on the weapon. A way to counteract this is by making the drum small in diameter. This reduces weight, but it also reduces the amount of energy the weapon can store and reduces the robots attack range. Another issue due to the drums weight is spin up time. If the motor driving the weapon does not have sufficient torque, the weapon make take a long time to reach top speed leaving you vulnerable for extended periods of time.

Drivetrain Concepts

One of the main decisions to be made when designing the battlebot is the number of wheels it will have. Battlebots tend to have as few as two wheels, or multi-wheel designs with more than three. Two wheeled designs have an advantage in weight since it requires fewer components. Wheels add substantial weight, as well as the necessary belts, pulleys, and hardware to mount them. On the other hand, four wheeled designs have superior handling as they do not need to drag, and can take advantage of four-wheel drive improving maneuverability. [18] Further, the design of the chassis can be made so that the wheels and drivetrain are internal and therefore protected, or have exposed wheels for a reduced frame size.

Concept 1: Two Wheel Drive

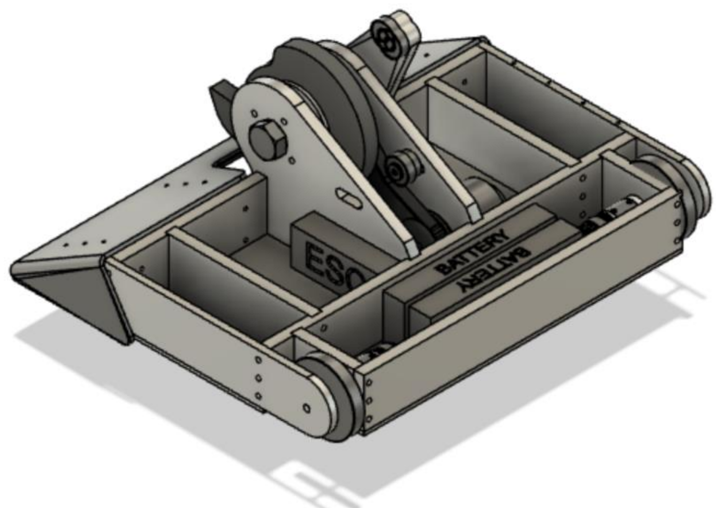


Figure 3.4: Two-Wheel Drive Train Design

Two-wheel drive bots have a number of advantages. Only needing two motors and no transmission between motors to the other wheels or additional motors to the extra wheels means there is a considerable weight reduction. This concept design would eliminate the need of two motors, gearboxes, and wheels. Moreover, there is an added amount of space in the cavity of the frame for other components such as batteries, ESC's, and wiring. Alternatively, the robot can be reduced in size since there are fewer components, further reducing the weight and improving acceleration and maneuverability; or the wall thickness can be increased to improve armor and rigidity. The main points against this design are the reductions in handling performance. Only having two wheels will hinder the ability of the robot to maneuver and evade attacks as well as perform offensive moves. Typical operation of two-wheel robots is to pivot mostly in place and wait for the opponent to attack and drive into the front facing weapon.

Concept 2: Shielded Four Wheel Drive

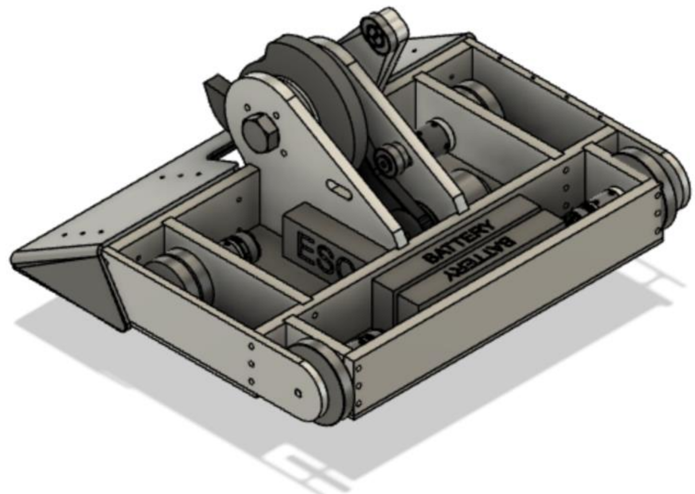


Figure 3.5: Four-Wheel Shielded Drive Train Design

Four wheeled designs are prevalent in battlebot competitions due to their increased handling and maneuverability. The additional components add weight and reduce interior space for electronics; however, the added mobility is usually worth the trade-off. Another advantage of four-wheel design with independent drive at each wheel is the added redundancy. The main system in the robot is the drive train, as long as the bot can move, it is still in the fight. Therefore, having two wheels on either side provides redundancy. In the event of an attack damaging any one of the four wheels, the bot will experience reduced handling characteristics, but will not be out of the fight and still be able to move defensively and offensively to some extent.

Shielded designs are those that contain all or some of the drive wheels and motors within the frame of the bot or otherwise protect them from direct impact. This is clearly advantageous for resilience, however at the expense of increased weight, complexity, and reduced interior space.

Concept 3: Exposed Four Wheel Drive

Exposed wheels provide more interior room for components since the space taken up by the wheels and motor is placed outside of the main frame members. The tradeoff is increased vulnerability to attacks to the drive train. In this design the rear wheel has some protection by the side plate of the frame extending over the wheel, however the back half of the wheel is still exposed. The front wheels are completely exposed, but have an internal, and therefore protected, gearbox and motor

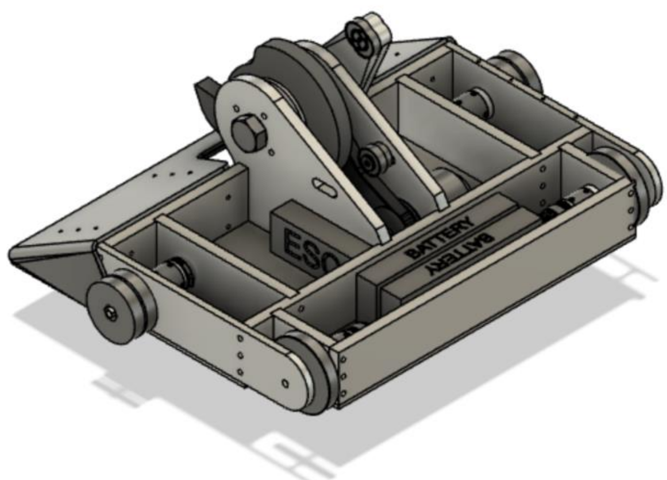


Figure 3.6: Four-Wheel Exposed Drive Train Design

For this bot's purpose a shielded drivetrain in the front will be the best approach given the likelihood of damage to the wheels and drivetrain. Keeping the robot mobile is the highest priority so protecting the wheels will be the best decision to provide the team the highest likelihood of success. A four wheeled designed with individual drives and gearboxes by using the motors outlined above, a simple solution is possible to achieve great mobility and reliability.

Therefore, considering the importance of the drivetrain components, a four-wheel drive design with internal components protected by the chassis will be the best option for our design.

Frame and Armor Concepts

Concept 1: Box Frame

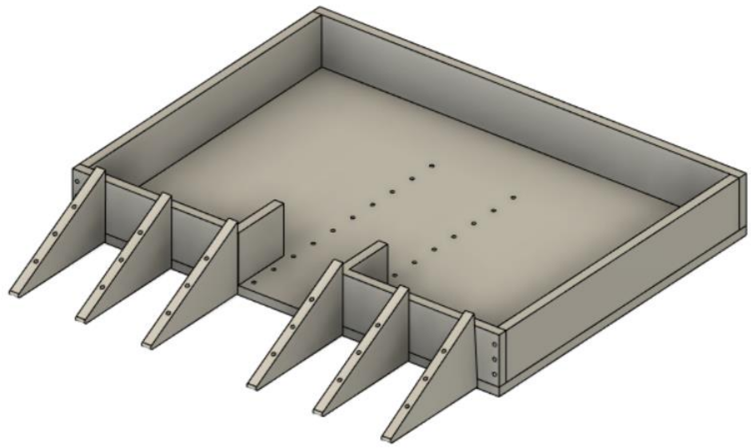


Figure 3.7: Box Frame

This concept utilizes a box frame. The frame itself would be constructed from 6061 aluminum which provides a good balance between strength and flexibility. The aluminum armor is ¼" thick and will provide good protection from opponent weapons. However, this thickness of aluminum does have the potential to deform from the impacts caused during competition. The front wedge lets(triangles) would be used to mount a plow device to the front of the robot which would lift opponents off the ground and feed them into the weapon. The front plow would be constructed from ⅛" titanium. The titanium would be more weight efficient than using steel and much stronger than aluminum so it would be durable enough to take impacts. This frame would be easy to machine since most of the parts could be cut with a water jet machine and then assembled together. The box shape does require more material than other frame designs which could make it more difficult to stay within the weight limit.

Concept 2: Internal Frame

Figure 3.8: Internal Frame

This concept is an internal frame that is built within the weapon. The frame would be constructed out of a material that is less dense than most metals. Polymers that are ⅜" thick could be a good frame material since they won't be taking any direct impacts from opponents. The main protection for this frame comes from the weapon surrounding it. The weapon would be made out of a hard and durable material such as AR500. With this design the frame would be very lightweight which would allow for more weight to be put into other components of the robot such as the weapon since that is where the main protection is coming from. However, if the weapon was to be disabled or separated from the frame, the electronics and drive train could easily be damaged or completely destroyed by an opponent.

Concept 3: Wedge Robot

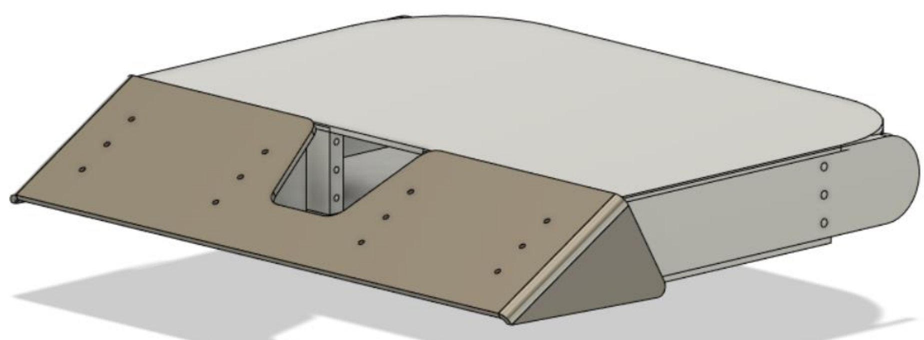


Figure 3.9: Wedge Robot

This concept is a wedge type frame. This frame style employs a wedge at the front that is used to ram into opponents and push them around. This robot would need to be very durable since it will be using itself as essentially a battering ram to try to break the opponent. This frame would be made from ⅜" thick aluminum to help provide strength and rigidity to withstand the repeated impacts. The front plow would be made out of ⅛" AR500 steel so that it would be very durable and impact resistant. Since there won't be an active weapon more weight can be dedicated to the frame of the robot which can add to the durability. Since there is no active weapon, inflicting damage with this frame style can be difficult.

Final Design Concepts

Concept 1: Two-wheel drum spinner

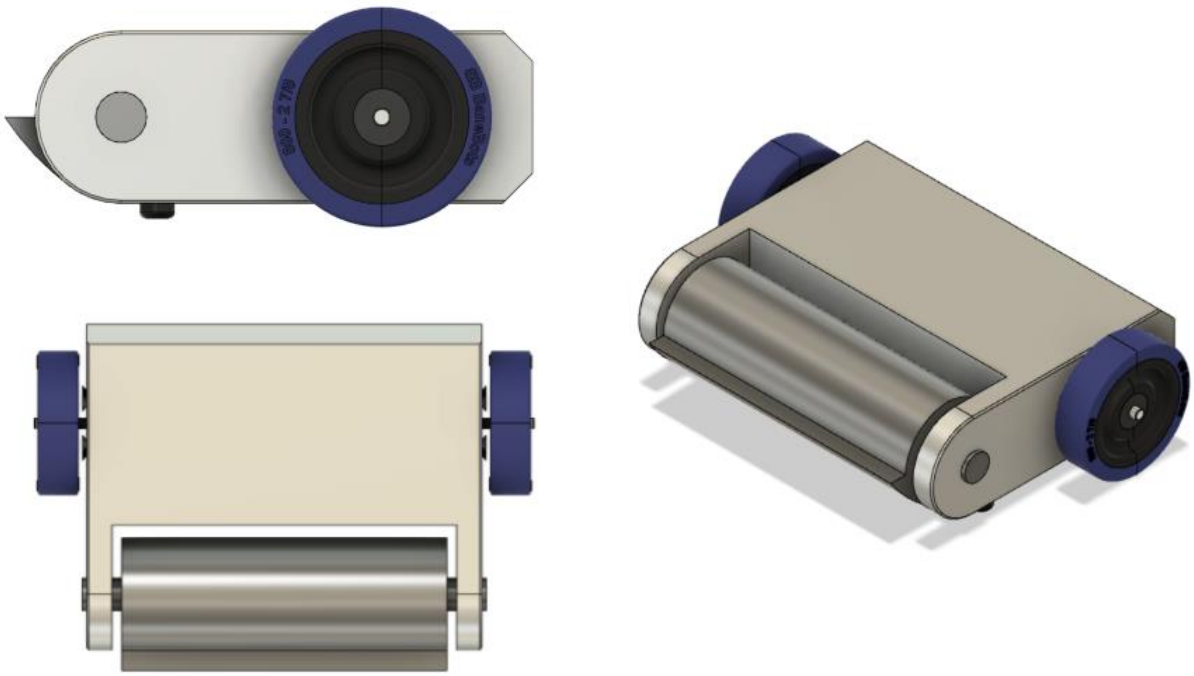


Figure 3.10: Drum Spinner Concept

The drum spinner design consists of a boxed aluminum frame with a large steel drum that spans the front of the robot. This design is vertically symmetrical so the robot can easily drive when inverted. The drum spinner acts as an offensive attribute while also acting defensively because it protects the entire front side of the robot. While being a bonus defensively, the strong and heavy drum requires a sacrifice in weight. Part of this sacrifice comes from the drive train, as this design only has two wheels. Only having two wheels makes it harder for the robot to navigate and makes it more vulnerable to attacks in the rear. This design also has little to no armor because weight could not be spared on it. Although these drawbacks exist, this design is simple and could be highly competitive if built properly.

Concept 2: Four-wheel single blade spinner

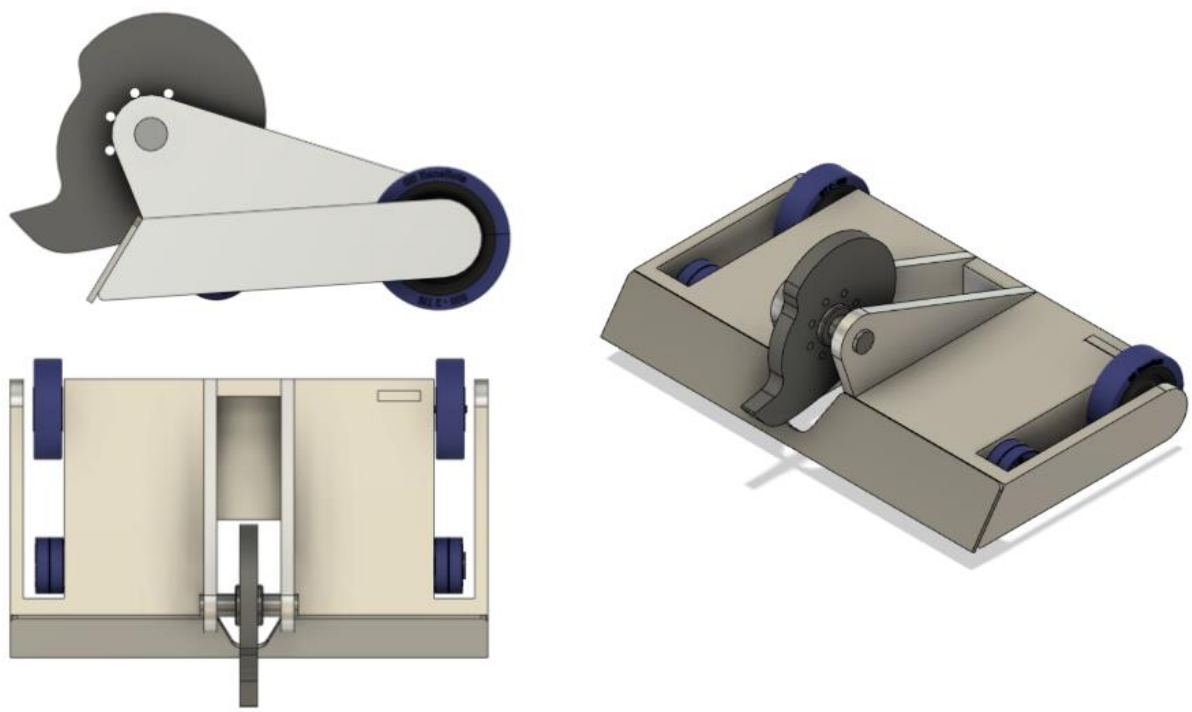


Figure 3.11: Single Blade Vertical Spinner Concept

This design is a single blade vertical spinner with an aluminum frame, titanium front wedge, and four internal / protected wheels. The single blade spinner is large, light weight, and simple to manufacture. This is important because spares will likely be needed so having an easy to produce part reduces the amount of time and money spent on machining. The weapon is also light weight which allows weight to be distributed elsewhere, making the frame and armor stronger. This design has a titanium wedge at the front of the robot which ties the aluminum frame together, making it overall stiffer. This wedge also rides close to the ground which prevents opposing robots from getting underneath our robot. The armor also extends past the wedge and around the wheels which protects them from side impacts that could potentially immobilize the robot. This design uses four wheels making it much more mobile than the previous concept. Double stacked small wheels are used up front in order to fit within the frame and in order to achieve a better grip to the floor. The larger wheels in the rear are exposed to impacts but, the large diameter allows the robot to drive while flipped over which gives us the opportunity to self-right.

Concept 3: Four-wheel dual blade spinner

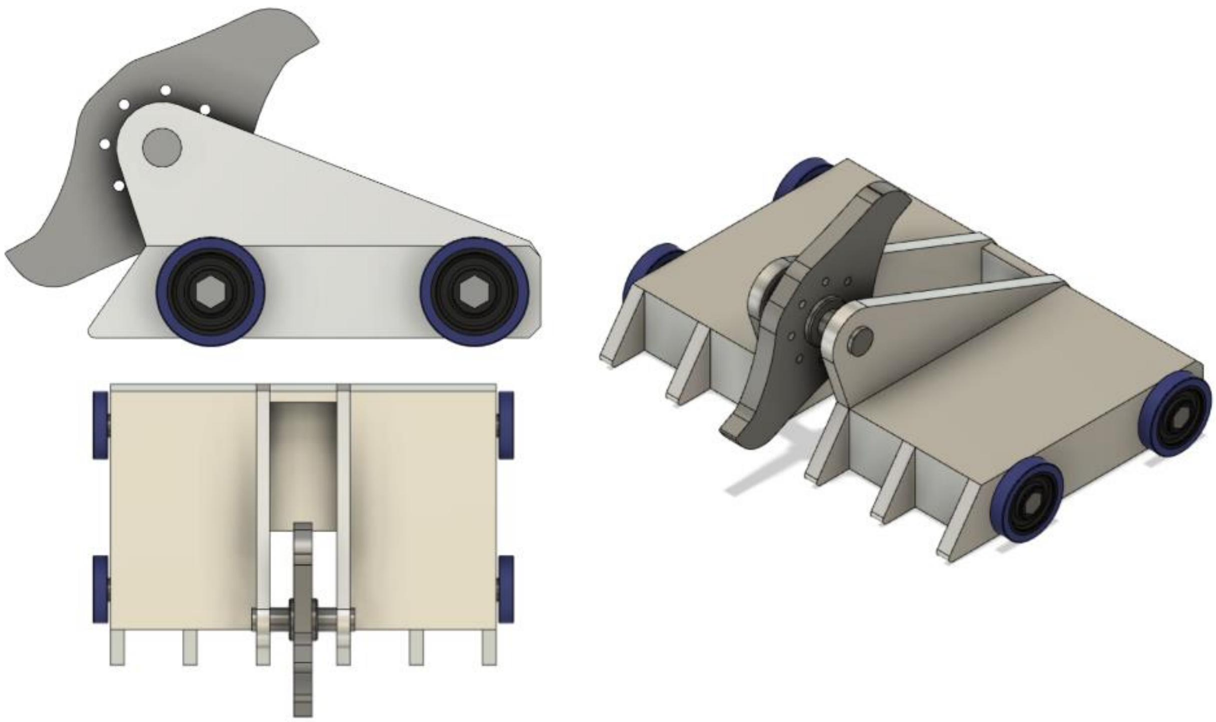


Figure 3.12: Dual Blade Vertical Spinner Concept

This design is a four wheeled, aluminum frame, vertical spinner that is similar to the previous design. The main differences of this design fall into the weapon and armor category. The weapon being used is a large diameter, lightweight vertical spinner with dual blades. This dual bladed spinner enables the weapon to hit an opponent twice as often as a single bladed spinner which is favorable in weapon-on-weapon exchanges because you are more likely to get the first hit. There is a tradeoff using a dual bladed spinner because the more blades, the less maximum bite you are able to achieve. In this case, this design has exactly half the bite of the single bladed weapon. The front of this robot uses bolt-on wedges which allows for mounting of different armor that better defends against certain opponents and weapon types. This design also uses four directly driven wheels but they are all the same size, which simplifies the programming of the electronic speed controllers. Differing wheel sizes require the wheels to run at different RPM in order to go the same speed. This design has no armor protecting the wheels which leaves the robot vulnerable to immobilizing hits from opponents.

Final Concept Weighted Matrix

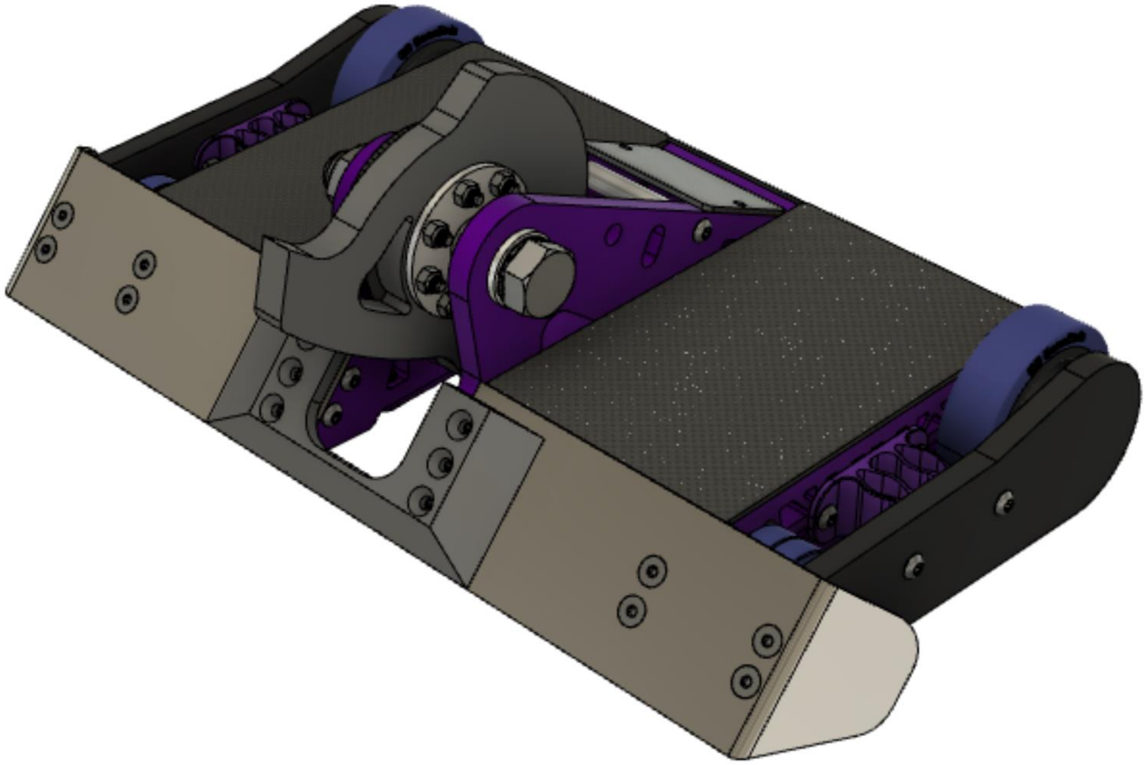
Concepts							
		Design 1		Design 2		Design 3	
Criteria	Importance Weight (%)	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Weight	25	1	0.25	3	0.75	3	0.75
Manufacturability	15	2	0.3	3	0.45	2	0.3
Component Modularity	15	3	0.45	4	0.6	4	0.6
Driving Inverted	5	4	0.2	1	0.05	1	0.05
Manuverability	10	1	0.1	4	0.4	4	0.4
Offensive Capabilities	10	3	0.3	4	0.4	3	0.3
Defensive Capabilities	10	3	0.3	4	0.4	1	0.1
Cost	10	4	0.4	2	0.2	3	0.3
	100	NA	2.3	NA	3.25	NA	2.8

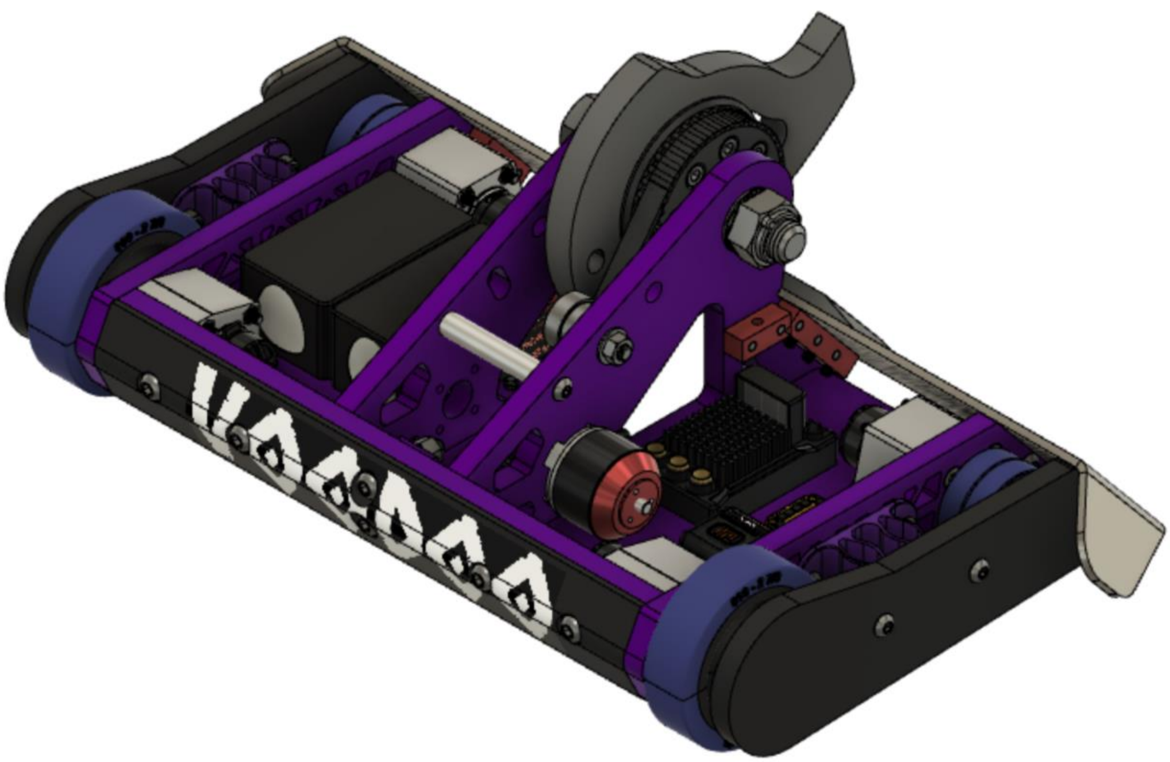
Unsatisfactory-0 Just Tolerable-1 Adequate-2 Good-3 Very Good-4

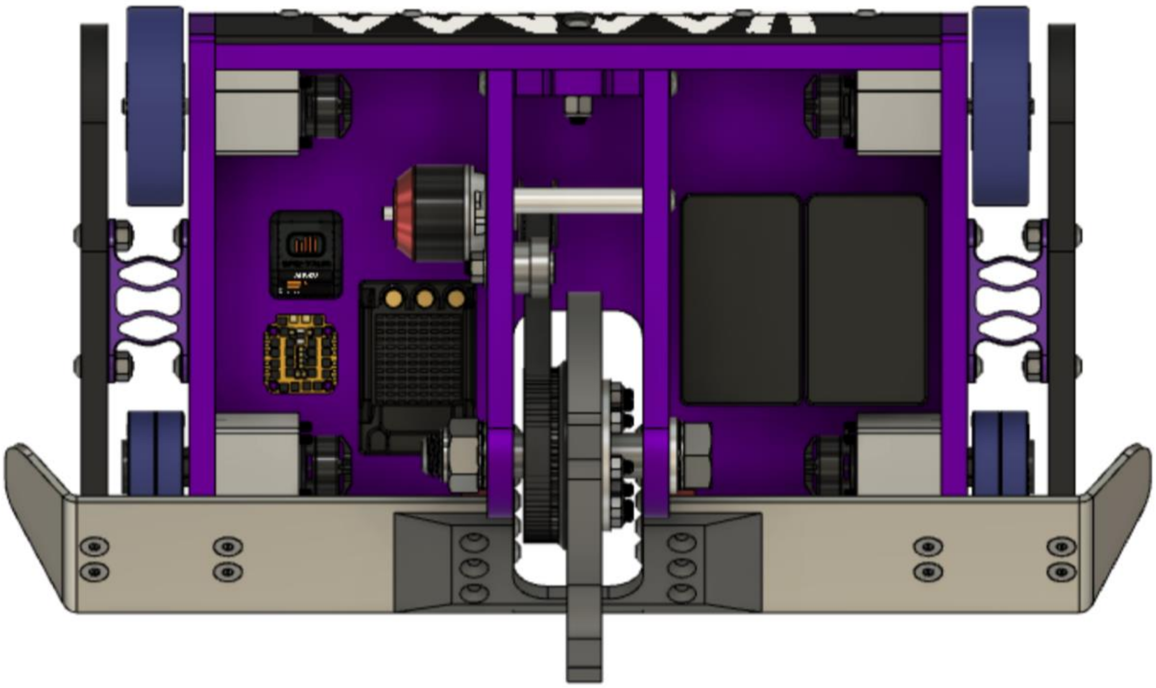
Figure 3.13: Final Concept Decision Matrix

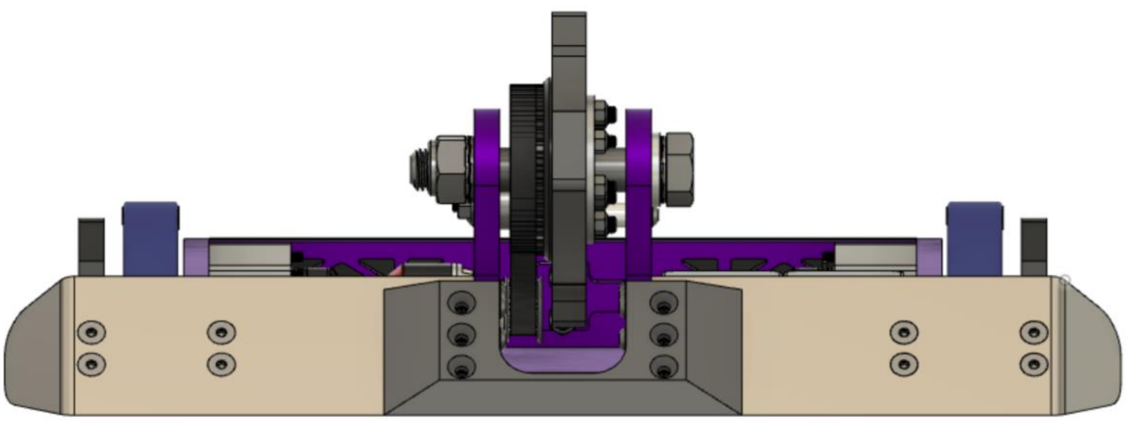
After conducting our survey, we were able to determine the criteria that were most important to consider when designing a combat robot. The top three criteria were the overall weight of the robot, the manufacturability, and the component modularity. Taking these factors into consideration, we used a decision matrix to reflect the overall importance of each criteria. Through this method, we were able to determine that design concept two would best fit the specified criteria.

Final Design









Component Selection
Weapon

Our team opted to use a single tooth vertical spinner with an attack diameter of 6-½”. The weapon will be made up of ½” thick AR500 steel to ensure it can deal out and withstand the immense forces it will undergo during combat. The weapon is mounted on a 17mm alloy steel shoulder bolt that acts as a dead shaft. This bolt is held on with a vibration resistant lock nut which prevents the assembly from loosening at high speeds. Three 69032RS high speed rated bearings are pressed into the AR500 so the weapon can smoothly rotate up to the high speeds required. The whole assembly is bolted together using M5 shoulder bolts; 8 shoulder bolts are used to distribute the stress of impacts and reduce the chance of a shearing failure. The weapon will be driven using a BadAss 2814 series brushless motor with 1560kv and 1440W. When using a 6 cell lipo battery, this motor spins at 34,632rpm. At this speed our weapon would likely be ineffective because it could achieve no bite, so the weapon is geared down using a 40 tooth nylon printed pulley and a 12 tooth aluminum pulley from McMaster-Carr. This gives a reduction of 0.3 resulting in a weapon rpm of 10,390rpm and a tip speed of 201 mph.

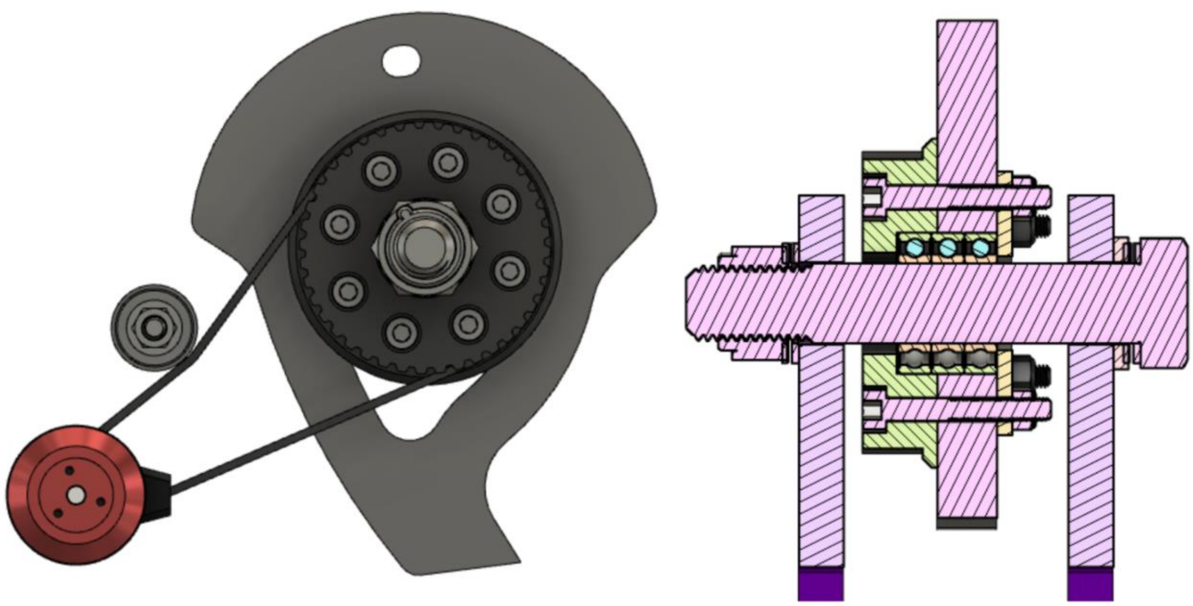


Figure 4.1: Weapon Sub-Assembly

Drive Train

A four-wheel design will be used for the drivetrain. The wheels will be 50A urethane, with a 2-⅞ inch in the rear and two 1- ⅝ inch double stacked for the front to improve grip. The motor selected is an all-in-one solution gearmotor by Fingertech. The 2300kv Mega Spark Motor with 21.5:1 reduction gearbox will be installed at each wheel. This configuration will provide the best maneuverability and stability for the vertical spinner weapon design. Having one motor at each wheel allows for a redundant drivetrain as if any one or more motors are damaged in combat, the other wheels can still operate at full capacity and prevent the robot from being out of the fight.

To mount the motors to the frame of the robot, a motor mount was designed to be 3-D printed out of TPU filament. This flexible filament provides a small amount of flex, so when the robot lands on its wheels, some of the force is absorbed and kept from damaging the motors. These mounts are the same exact part for the front and rear and provide the needed offset by mounting vertically or horizontally for either configuration. This way a few extra can be printed and they work for any side of the drivetrain that may need repair.

Figure 4.2: Drivetrain Sub-Assembly and Drive Motor

Frame and Armor

The frame of the robot is constructed using ⅜" aluminum plates for all of the frame rails and a 0.09" thick aluminum bottom plate that ties the entire frame together. The frame is made up of five fully symmetrical members which makes the frame extremely modular and easy to service. Aluminum was chosen because it has a good balance of weight and strength so it was a good material choice for the 12lb class. Adding to this strength, the frame rails key together as seen in figure 4.3. Mounted on the frame rails are aluminum nut strips which are used to hold on the titanium wedge and the carbon fiber top plates. The nut strips eliminate the need to tap threads into the aluminum frame which adds manufacturing time.

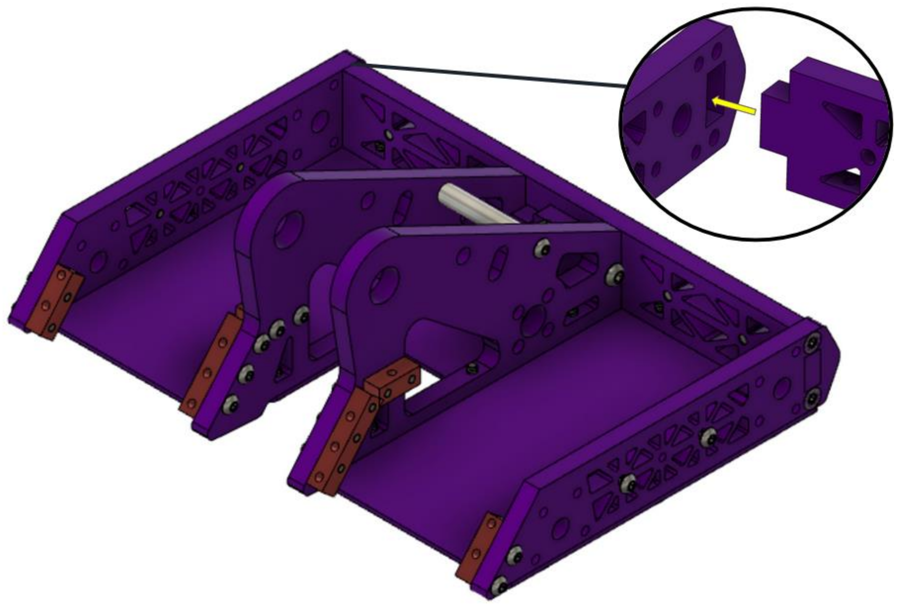


Figure 4.3: Frame Sub-Assembly

The armor consists of ⅛" titanium, ¼" AR500, ⅜" UHMW, ½" UHMW, and TPU. The titanium is used for the front wedge. This material is a great compromise between aluminum and steel since it has similar strength characteristics to steel and is lightweight like aluminum. The AR500 is mounted to the wedge and is used to deflect horizontal spinning weapons. The AR500 is very durable and impact resistant so it should hold up well for this task. The UHMW is used for the side panels as well as the for protection of the rear frame cross beam. This material is flexible and tough which can slow down or jam up opponents weapons when they hit it. The TPU shocks provide extra flexibility to the side panels as the TPU can flex and absorb impacts reducing energy transfer to the frame.

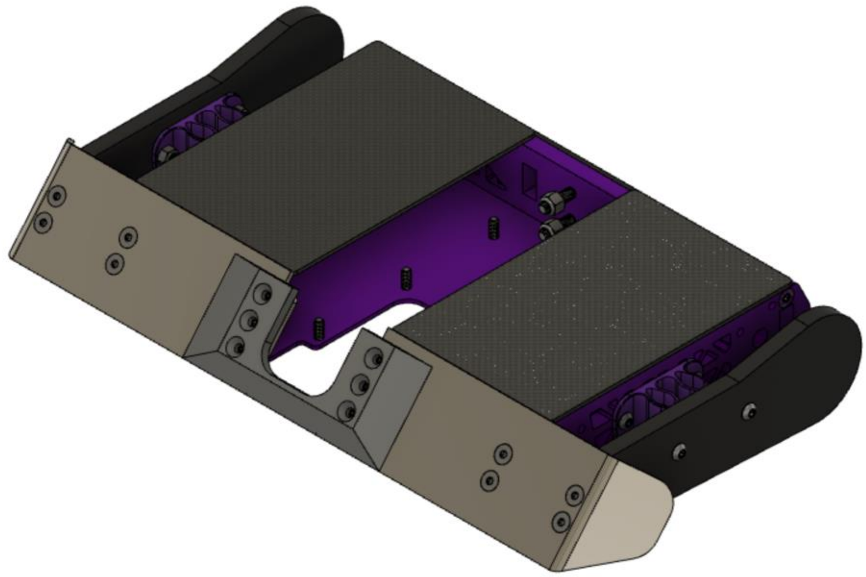


Figure 4.4: Front Armor Sub-Assembly

Figure 4.4: Rear Armor Sub-Assembly

Electronics

Three components are needed to control the robot drive and weapon. A battery, weapon electronic speed controller (ESC), and drivetrain ESC. For a battery after considering the form factor and space constraints, the Tattu R-Line Version 3.0 was selected. Using two of these in parallel we achieve a 2600mAh capacity. Our calculations are shown in the Appendix of this document, and they show this capacity will be sufficient for completing a 3 minute match. The calculations also outline the requirements for the ESC’s peak and continuous load we need to run the weapon and drivetrain. For the latter, a T-Motor Velox V2 4-in-1 ESC was chosen for the peak current of 55A and 45A continuous which is ample for the drive train, as well as being able to drive all four motors from the one ESC. For driving the weapon, the Sidewinder 8th Generation ESC is chosen with a 90A continuous current rating and a 125A peak.

Figure 4.5: Tattu R-Line V3 Battery

Figure 4.6: T-Motor Velox V2 ESC

Figure 4.7: Castle Sidewinder 8th Gen ESC

Weight Optimization

Frame members are constructed of three eights aluminum flat plate as it is lightweight and strong. Using the properties of this material we can incorporate geometry such as trussing in the frame to reduce the weight of each member considerably while maintaining most of the strength. After trussing the members, a stress analysis will be conducted to ensure the new frame is strong enough to withstand enemy blows from different robot weapon configurations as well as the solid frame can.

Below is a comparison of the weight savings achieved by trussing the back plate and side plates of the frame. The new geometry lightened the frame 48 grams on the back rail and 64 grams for both side members combined. For the weapon upright frame members, we performed a loading simulation to map the flow of stress through the part. The figure below demonstrates the outcome of our simulation with the colored area representing the path of the stress. Using this we could cut out material around it to lighten the frame while maintaining integrity where needed. This part of the frame optimization yielded the greatest weight savings at 300 grams for both uprights combined.

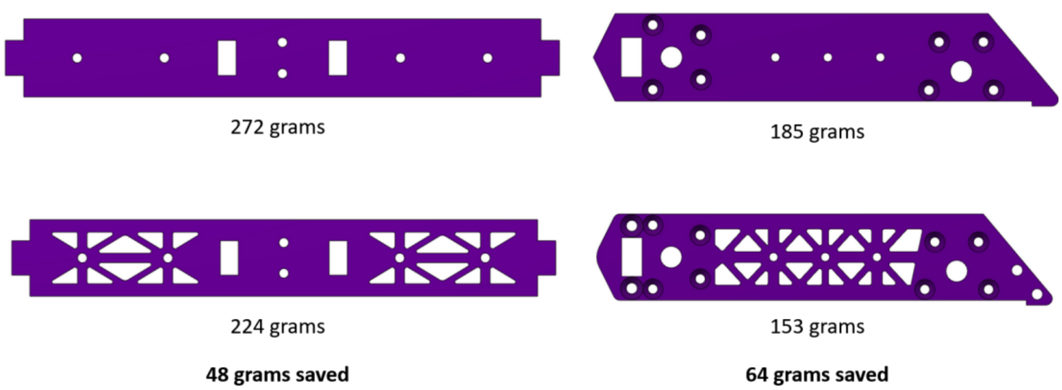


Figure 4.8: Frame Rail Weight Savings

Figure 4.9: Weapon Upright Weight Savings

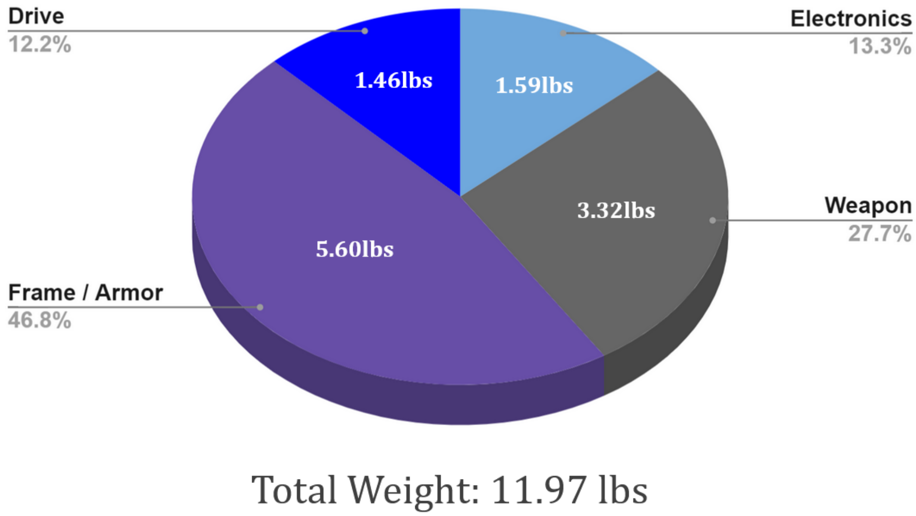


Figure 4.10: Pie Chart of Robot Weight Distribution

Stress Analysis and Safety Factor

The analysis of the weapon uprights simulates the force that would result from the weapon impacting an opponent. A 1000 newton load is applied to the lower portion of the weapon shaft hole. This force is angled slightly back into the weapon frame since an actual impact will have forces that move down and towards the rear of the robot. With these loading conditions the weapon uprights had a max displacement of 0.0072 millimeters and a max stress of 18 megapascals. This yields a safety factor of 15 for each weapon upright. The image on the left shows the overall displacement in the part and the image on the right shows the stress that occurs due to the load. lighter colors indicate lower levels of stress and strain.

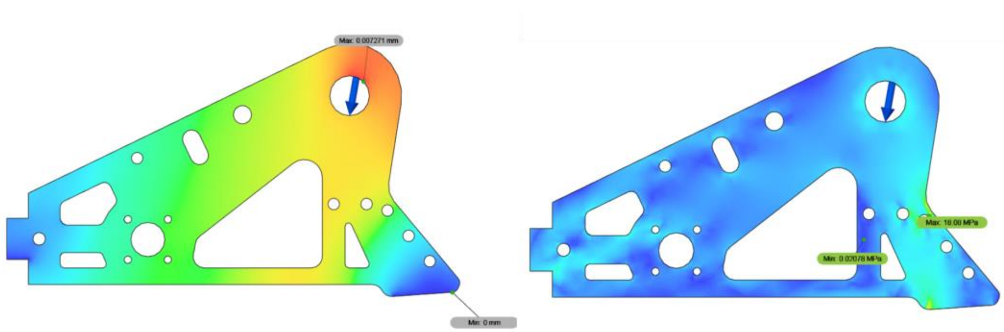


Figure 4.11: Weapon uprights displacement(left) and stress(right) analysis

There are two loading conditions that had to be considered for the rear frame crossbeam. The first loading condition simulates the forces that would occur from the impact of a horizontal spinning weapon on the side face of the part. The second loading condition simulates the forces involved from the impact of a vertical spinning weapon on the bottom of the frame member. A 1000 newton load is applied in both cases. The first loading condition produced a maximum displacement of 0.072 millimeters with a max stress of 57 megapascals. The second loading condition yielded a max displacement of 0.003 millimeters and a max stress of 7.6 megapascals. overall, loading conditions one and two had a safety factor of 4.75 and 35.8 respectively.

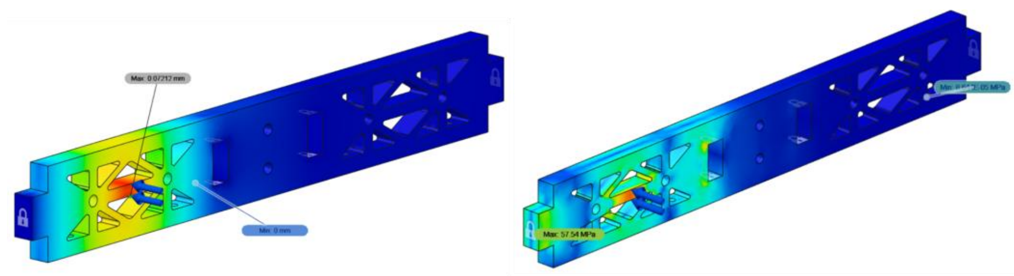


Figure 4.12: Rear crossbeam displacement(left) and stress(right) side load analysis

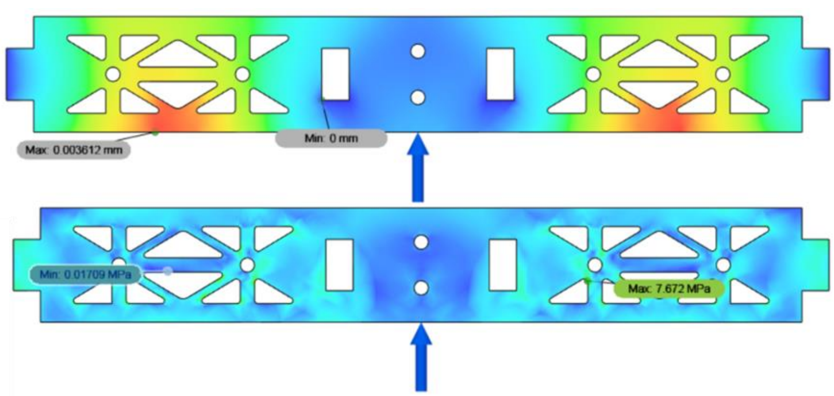


Figure 4.13: Rear crossbeam displacement(top) and stress(bottom) bottom load analysis

The armor wedge has two loading conditions which simulate a side impact as well as an impact to the bottom of the part. The load for each condition is 1000 newtons. The side impact produces a displacement of 1.769 millimeters and a max stress of 680 megapascals while the bottom impact has a displacement of 0.111 millimeters and a stress of 331 megapascals . This results in a safety factor of 1.3 and 2.66 respectively.

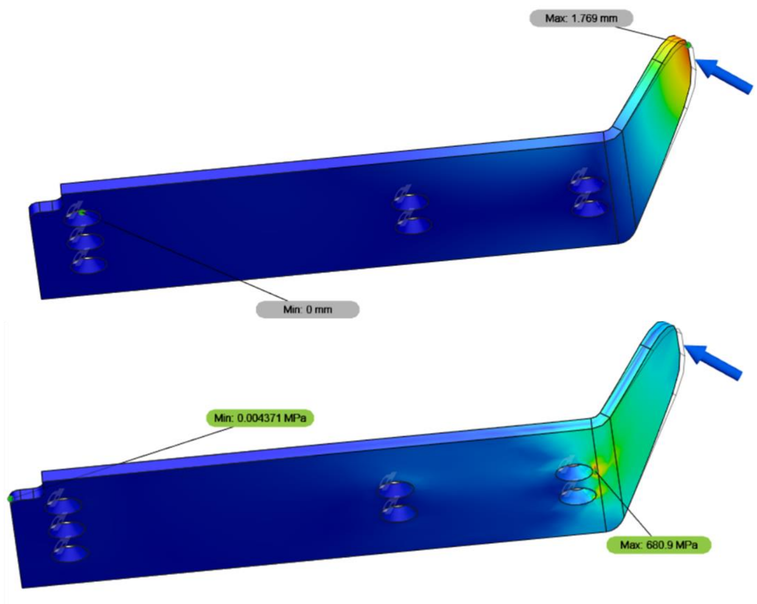


Figure 4.14: Wedge displacement(top) and stress(bottom) side load analysis

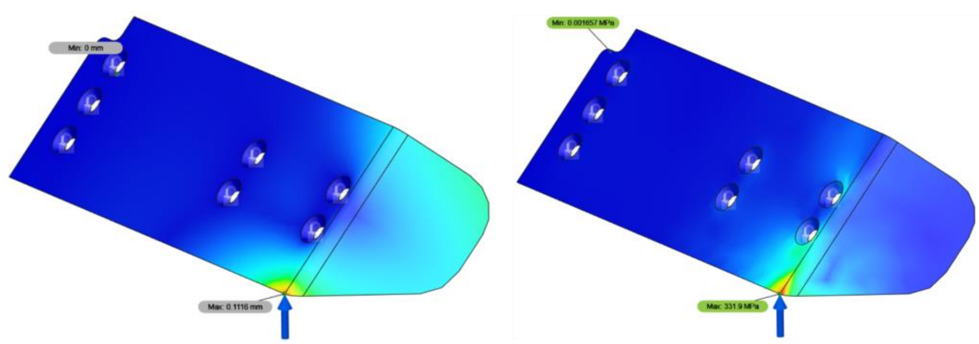


Figure 4.15: Wedge displacement(left) and stress(right) bottom load analysis

The weapon was loaded to determine the displacement that would occur from a side impact. If the weapon flexes too much or the stress is too high then this could permanently deform the weapon. If the weapon deforms then it could potentially damage components on our own robot such as hitting its own frame or the belt that drives the weapon. This test utilized a 1000 newton on the side of the impacting face. This results in a max displacement of 0.094 millimeters and a max stress of 511 megapascals. This yields a safety factor of 2.68.

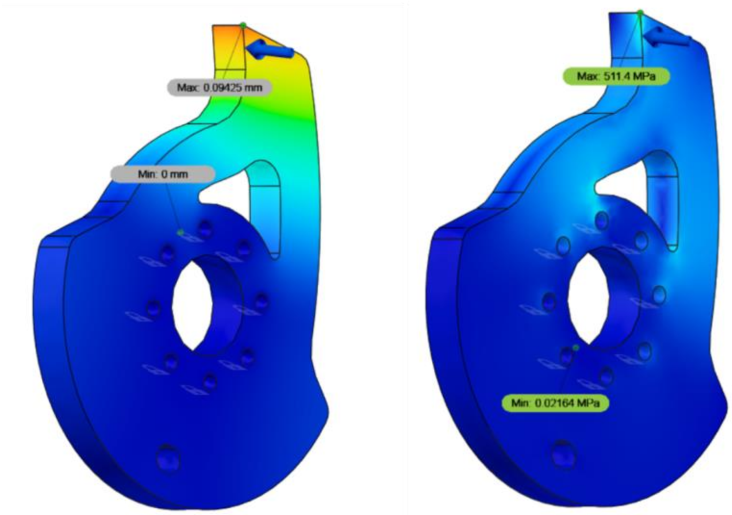


Figure 4.16: Weapon displacement(left) and stress(right) bottom load analysis

Weapon Impact Testing

The impact test simulates the weapon spinning at max revolutions and then impacting an aluminum block. The goal of this test is to keep the weapon stress below 1,200 megapascals or 12% strain. If the weapon exceeds these values then catastrophic failures can occur which would destroy the weapon and hinder the ability to effectively fight. The stress test produced a maximum stress of 36,663 megapascals and the maximum strain was 15.1%. These values occurred in the tip of the weapon disc. Stress and strain in the rest of the weapon remained relatively low.

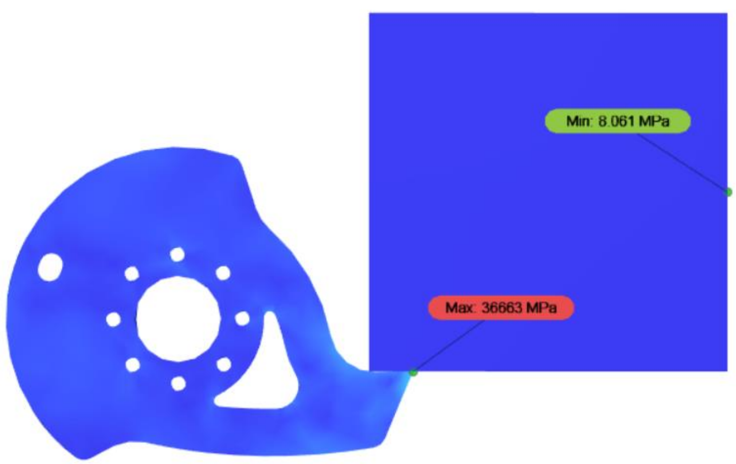


Figure 4.17: Weapon impact stress analysis

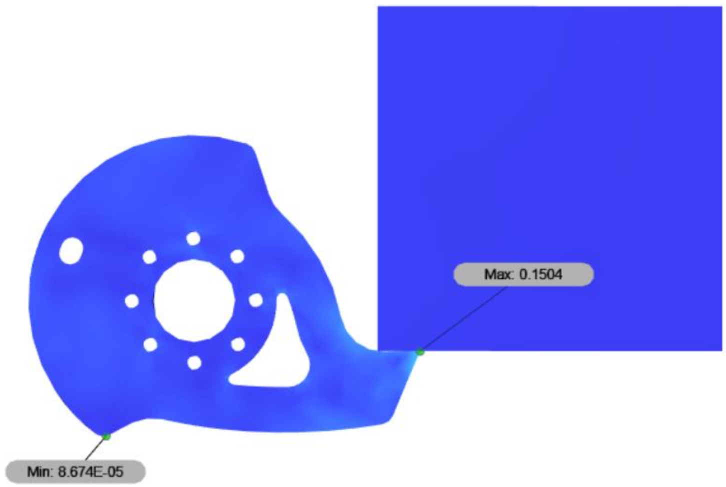


Figure 4.18: Weapon impact strain analysis

Factor of Safety Concerns

The minimum safety factor in the frame members is 4.75 so the frame should be able to handle the loads without failure. The wedge has a minimum safety factor of 1.3. This occurs when there is a load applied to the side of the wedge. There is a concern that this piece of armor could deform during combat due to a low safety factor. However, if this piece deforms under load then it will be absorbing energy to do so. When bent this wedge will act as a crumple zone that reduces force transfer to other parts of the robot similar to what happens to a car during a crash. The purpose of armor is to protect the internal frame and electrical components so if it becomes damaged, we can easily replace it. The weapon has a safety factor of 2.68 for side impacts. This causes slight concern due to the high stress that is present in the part. Failure is not expected though since the strain remains low at 0.3%.

Proof of Design

When the design was in the stage of fine tuning details and setting up the internal component arrangement, the team felt the need for a physical model to accomplish these goals: test robot frame assembly, setup layout of electronics within frame, find any issues with the design. For this, the internal components such as drive and weapon motors, ESC's, and weapon blades were 3D printed to scale using PLA. The TPU components were printed with the right filament to test their energy absorption properties. Batteries were made out of blocks of wood, cut precisely to the actual battery pack dimensions. Once the components were ready, frame members were made using a laser cutter at the 1819 shop. The cardboard used measured an eighth of an inch thick so three layers were cut and glued together to create three eight inch thick frame members.

The model was then assembled as it would if it was made of aluminum to test the robot frame assembly. In this process a flaw was found since installing the TPU shock mount proved to be very difficult as the nut could not be held easily inside the TPU shock as the bolt threads were started. This was fixed in a later revision of the shock mount. With a complete frame, the internal components were laid out, and an ideal setup was found, with both battery packs on one side compartment, making battery swaps easy and only requiring one top plate removal. For the final goal of this proof of design, we looked at any issues we could foresee with this design. Many improvements were made, such as altering the shape of the UHMW side pieces to cover more of the back wheels and make the gap with the ground smaller. The titanium wedge shape was modified to have the flaps on the sides rather than on top, as the angle on front already seemed enough to prevent enemy robots from climbing on top, and the side corner could use the extra protection. Finally, the rear corners were re-designed to have a captive key, rather than an open cutout. This retains the back piece and the fasteners are only holding the sides inward as opposed to being the load bearing connection.

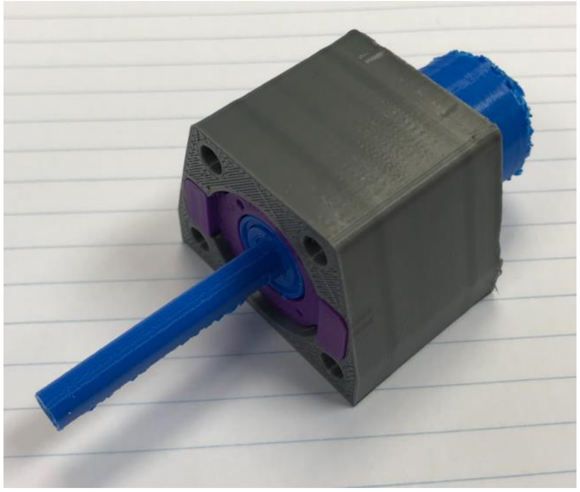


Figure 4.19: 3D Printed Motor and TPU Mount

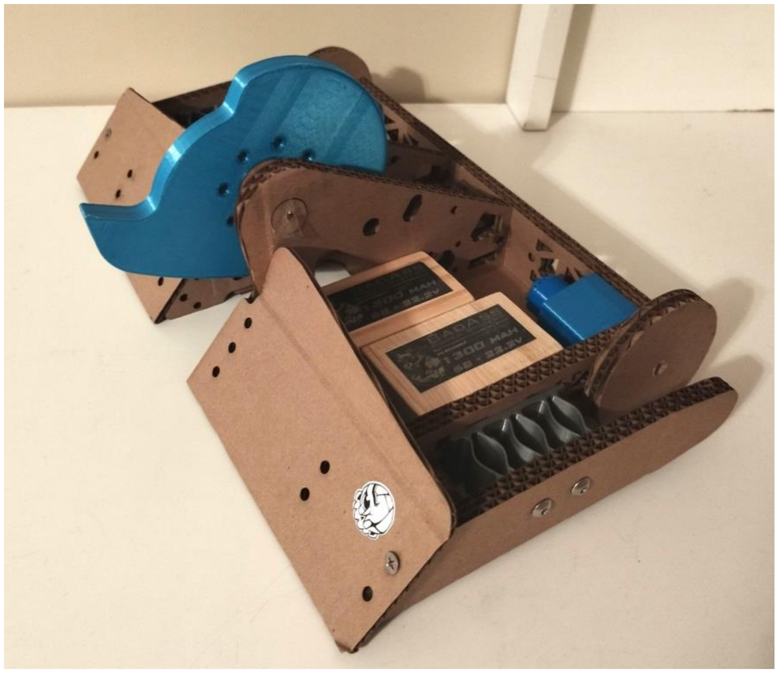


Figure 4.20: Robot Prototype Front View

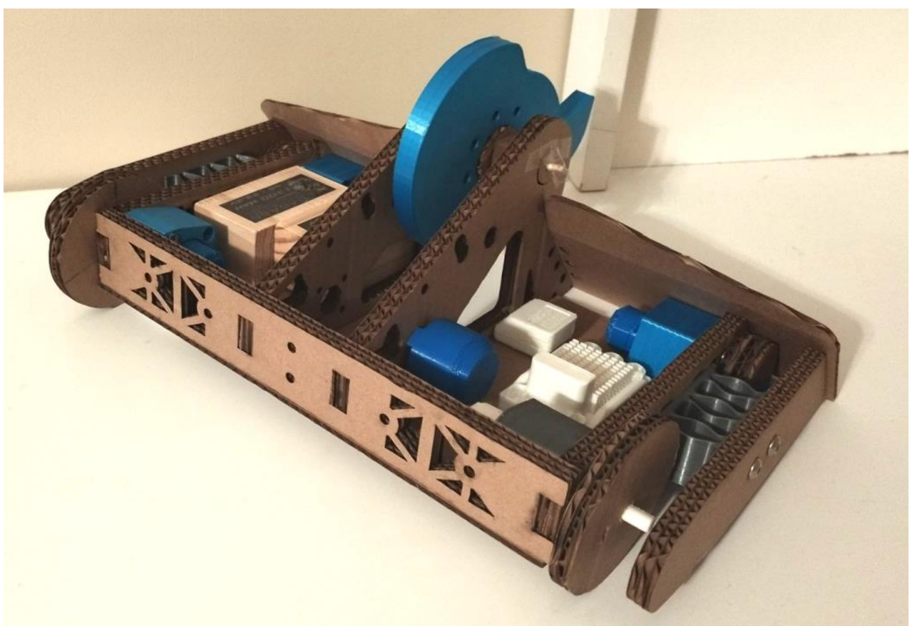


Figure 4.21: Robot Prototype Rear View

Fabrication
Planning

All of the aluminum frame components are 2-dimensional and are all made up of the same ⅜” thickness material. Because of this, the entire frame is able to be manufactured on a water jet cutter out of a ⅜” plate of aluminum. The photo below shows the layout for the water jet to follow. This layout is a 12” x 24” plate of 6061 aluminum that will be purchased from Mcmaster-Carr. This size plate enables the team to cut two entire frames and still have material left over for additional spare parts. Once the pieces have been cut, additional machining processes like grinding, tapping, countersinking, and anodizing will be done in the Victory Parkway machine shop.

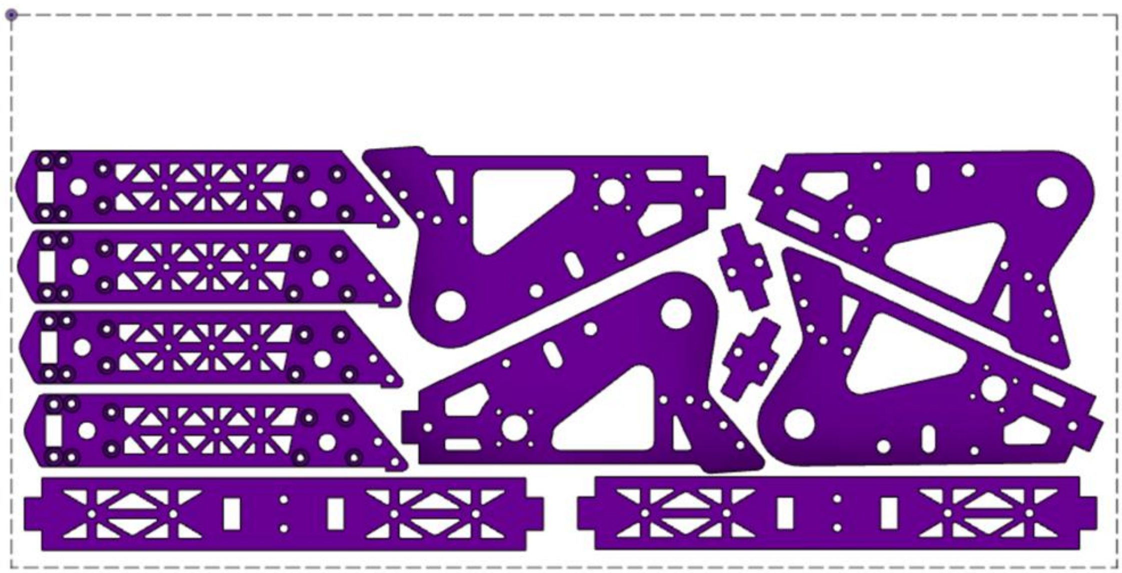


Figure 4.22: 12” x 24” Aluminum Frame Layout for Laser Cutter

The front wedges are both constructed out of a ⅛” titanium plate. The flat profile of the wedge will be laser cut by Send Cut Send; a manufacturer of customized laser-cut metal parts. These parts will then be shipped to the team for further machining. Titanium is a difficult metal to bend due to its low uniform elongation so a torch must be utilized to heat up the titanium to make it more pliable. The flat wedge will be mounted in a vice and heated at the joint, the end of the wedge will then be clamped and torqued down.

Figure 4.23: Complete Wedge Model and Torch Bending Titanium Wedge

This robot design utilizes a lot of thermoplastic polyurethane (TPU) because of its high flexibility and durability. It is a perfect material for combat robotics because it absorbs impacts which helps protect other components and it is strong enough to withstand those impacts itself. The two components using TPU are the armor shocks and the motor mounts. All of these parts will be printed on the team's personal 3D printers using 1.75mm Overture TPU Filament.

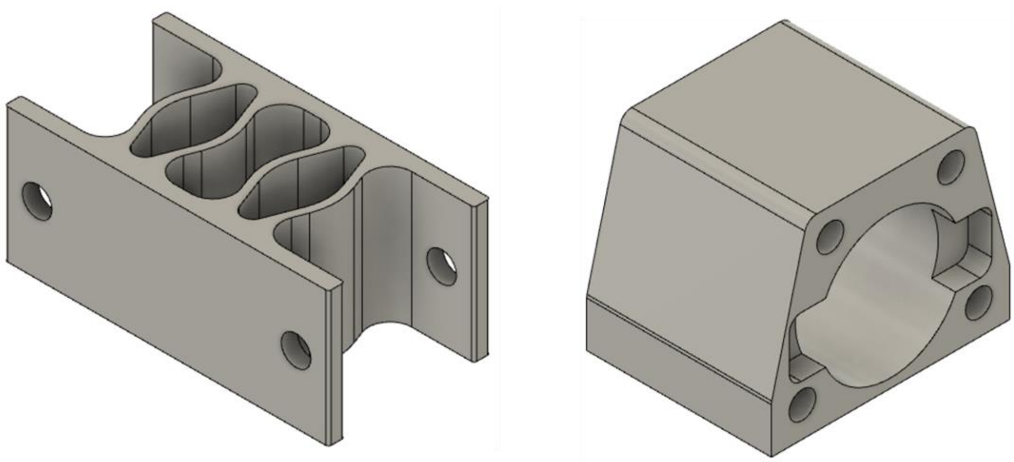


Figure 4.24: TPU Armor Shock and Motor Mount

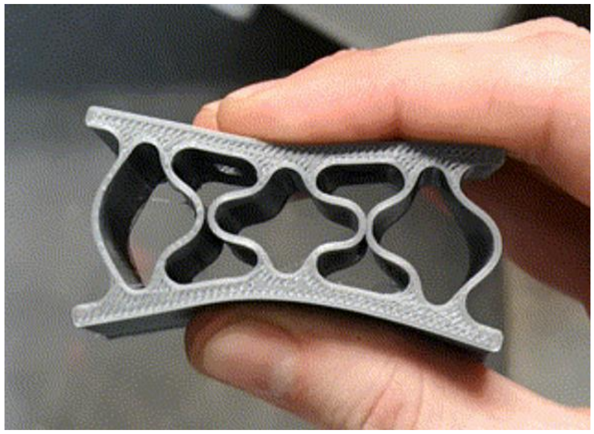


Figure 4.25: TPU Armor Shock Flexibility Demonstration

During the manufacturing planning phase the team created a machining spreadsheet that tracked the progress of the build. This spreadsheet was an adaptation of a previous seniors manufacturing schedule and it proved to be critical in keeping the team on schedule and organized. Every machining task required to build Voodoo was written down along with the equipment needed, the part number to reference the drawing, and the estimated time to complete the task. Each item was then given a color based on its progress. An important part in making this strategy effective was allocating work properly to each team member. At every meeting, each team member would choose a task to be responsible for. The team would then split up and work on their machining task individually. This enabled us to complete the robot build at an accelerated pace. Then with the task completed, it would be marked green on the sheet.

Machining					
Process	Component	Tools	Part Number	Qty	Time Est. (hr)
Drill / Tap	Rear Crossmember	#25 Bit (5/32) 10-24 Tap	101	1	1
Drill / Tap	Side Plates	#25 Bit (5/32) 10-24 Tap	102	2	1
Counter Sink	Side Plates	82 Degree Countersink Bit	102	2	0.5
Bending	Wedge R	Torch and Vice	103	1	1
Bending	Wedge L	Torch and Vice	104	1	1
Grinding Sharp	Bowtie	Hand Grinder	105	1	0.5
Cut to Length	Nutstrip	Bandsaw and Debur	106	4	1
Counter Bore	Rear Armor	12mm Dia Counterbore	107	1	1
Chamfer	Rear Armor	Manual Mill	107	1	1
Drill	Side Armor	1.5mm Bit	108	2	0.5
Cut to Length	Nutstrip	Bandsaw and Debur	110	2	0.5
Bore	Weapon Blade	Owens CNC	300	1	1
Drill / Tap	Weapon Upright	#25 Bit (5/32) 10-24 Tap	301	2	1
Counter Bore	Weapon Upright	1/4in Dia Counterbore	301	2	0.5
Cut to Length	Weapon Standoff	Bandsaw and Debur	303	2	0.5
Drill / Tap	Weapon Standoff	#25 Bit (5/32) 10-24 Tap	303	2	1
Drill / Tap	Nut Plate	#25 Bit (5/32) 10-24 Tap	307	1	1

Laser Cutting / Water Jetting					
Process	Component	Tools	Part Number	Qty	Time Est. (hr)
Laser Cutting	Bottom Plate	SCS Laser	100	2	N/A
Water Jetting	Rear Crossmember	1819 Water Jet	101	1	1
Water Jetting	Side Plates	1819 Water Jet	102	2	1
Laser Cutting	Wedge R	SCS Laser	103	1	N/A
Laser Cutting	Wedge L	SCS Laser	104	1	N/A
Laser Cutting	Bowtie	SCS Laser	105	2	N/A
CNC	Rear Armor	RA Jones CNC Table	107	1	2
CNC	Side Armor	RA Jones CNC Table	108	2	2
CNC	R/L Top Plate	Owen CNC	109	2	1
Laser Cutting	Weapon Blade	SCS Laser	300	2	N/A
Water Jetting	Weapon Upright	1819 Water Jet	301	2	1
Laser Cutting	Bearing Plate	SCS Laser	302	2	N/A
CNC	Wire Plate	Owen CNC	304	1	0.5
Laser Cutting	Bolt Spacer	SCS Laser	305	2	N/A
Water Jetting	Nut Plate	1819 Water Jet	307	1	1

Printed					
Process	Component	Tools	Part Number	Qty	Time Est. (hr)
3D Printing	Armor Shocks	TPU Filament Davids Printer	112	2	2
Silicone Molding	Grommet	Silicone and Mold	113	1	2
3D Printing	Motor Mount	TPU Filament Davids Printer	200	4	4
3D Printing	40T Pulley	Nylon Filament 3D Printer	306	1	2
3D Printing	Motor Flag	Nylon Filament 3D Printer	201	4	1

Figure 4.26: Manufacturing Tracking Spreadsheet

Frame

The frame members all consist of simple geometry so there is no need for any three dimensional machining to cut out the profiles of each piece. In order to manufacture the frame, we bought a 0.375 x 12 x 24 inch piece of plate stock from McMaster-Carr. One full frame can fit within a single square foot so we bought extra stock material with the intention to make multiple frames so we would have replacement parts in the case that we took damage at competition. We utilized the waterjet fabrication capabilities at the 1819 Innovation Hub where the stock material was able to be cut into two separate frames. There was very minimal clean up work required after the waterjet process. The only area that needed to be cleaned up were the keyways and the edges of all the parts. When we designed the keyways, we designed them with zero tolerance. So, we had to file the inside and outside of the keyways to remove the slight kerf and rounded corners that were left from the waterjet. This allowed us to achieve an extremely close fit where each piece keyed together which improves the strength and rigidity of our frame. The only portion left to get the frame members competition ready was to drill and tap the holes to mount the top and bottom plates as well as some for mounting the shock armor.

Figure 4.27: Full Frame Assembly 3D Model

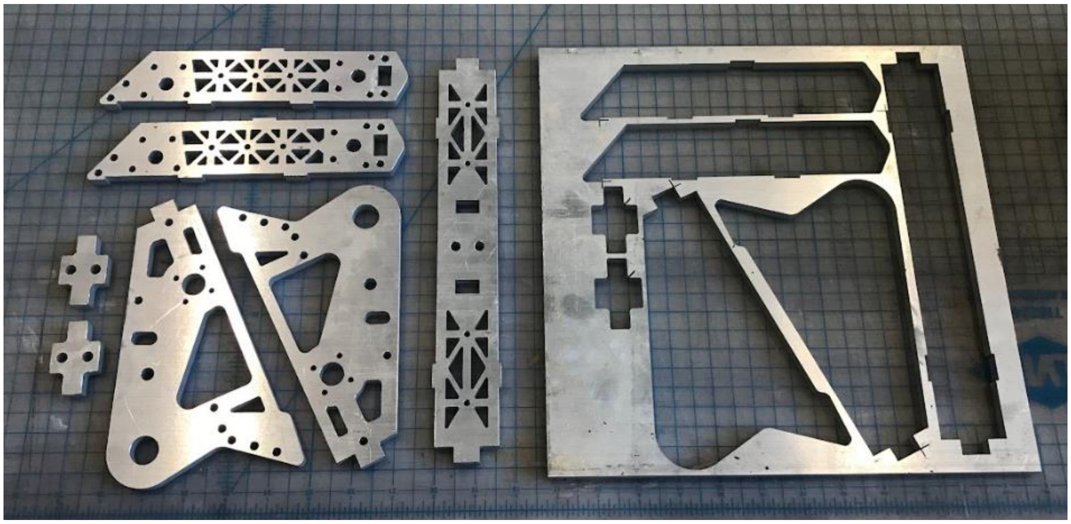


Figure 4.28: Post waterjet cutting of the frame with the leftover stock material

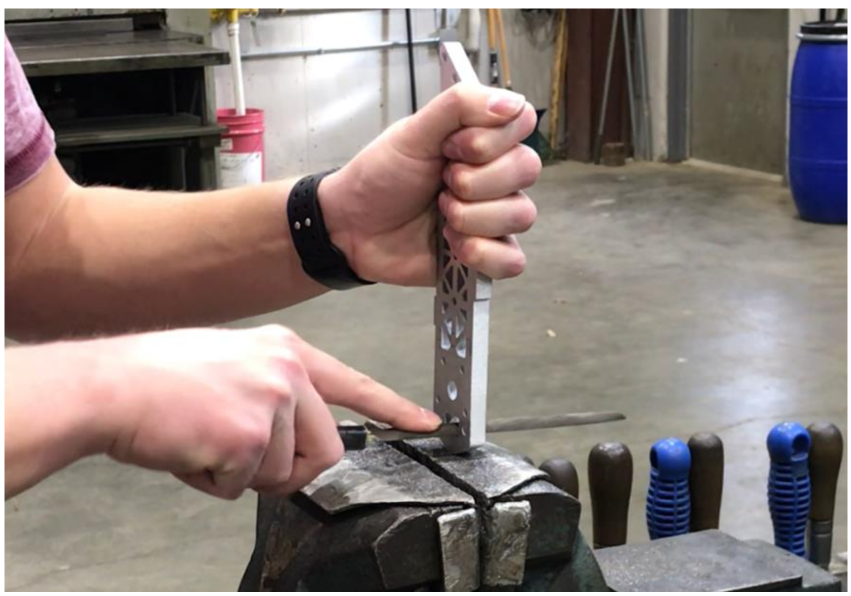


Figure 4.29: Filing the keyways of the frame to provide clearance for them to fit together

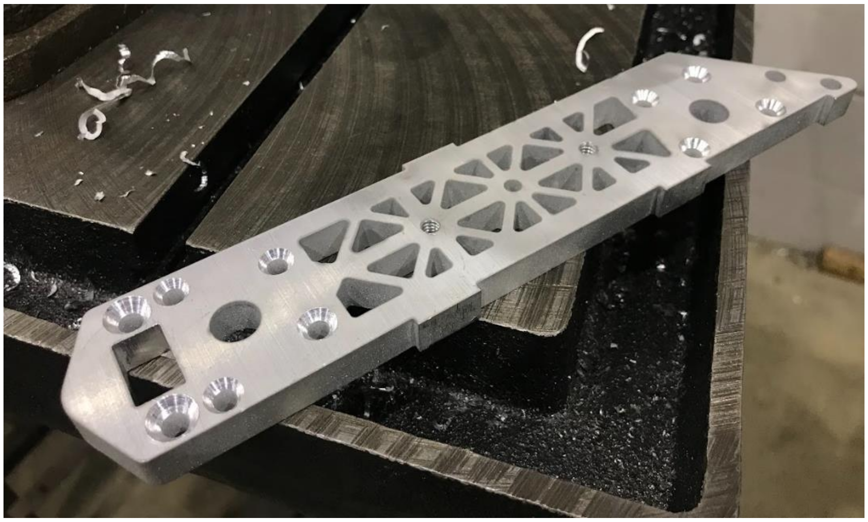


Figure 4.30: Side rail after tapping and countersinking

Figure 4.31: Weapon supports in a vise to have holes drilled

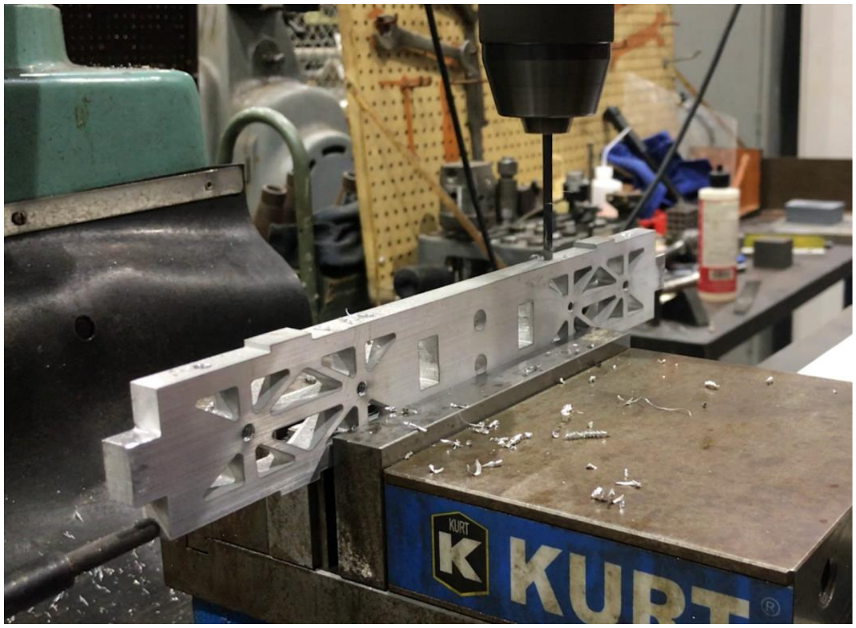


Figure 4.32: Drilling holes into the top of the rear frame member

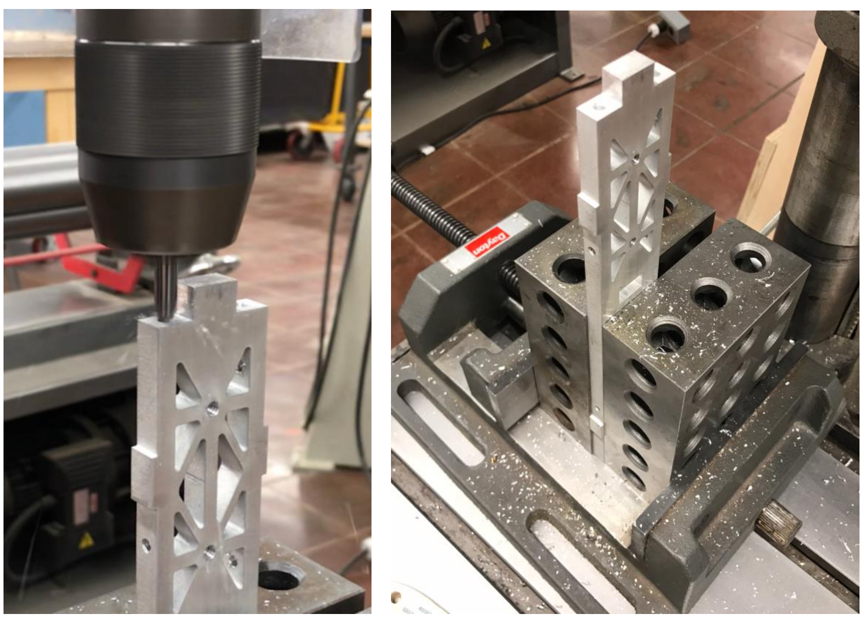


Figure 4.33: Drilling holes in the ends of the rear frame member

Figure 4.34: Drilling the hole for the weapon support brace using a lathe

Armor

There are four materials used for the armor on the robot: Ultra High Molecular Weight Polyethylene (UHMW), Thermoplastic urethane (TPU), titanium, and AR500 steel.

Figure 4.35: Full Armor Assembly 3D Model (Frame not shown)

The back and sides of the robot are protected by using sacrificial UHMW pieces. This material is lightweight, and dense enough to withstand some impacts. Damage is expected to these pieces of armor, so they are considered consumable and spares are easy to swap out, as well as being low cost. The purpose of these components are to take the brunt of side and rear impacts and protect the main frame and internal components and electronics. These parts were made in a CNC router using the cad files to give accurate parts that match the profile of the bot.

Figure 4.36: CNC Routered UHMW Guards

The side pieces are mounted using TPU "shock-mounts". They are made using an Ender 3 Pro FDM printer and a soft TPU filament. These compliant parts allow the side armor pieces to flex in and out, providing space to dissipate energy from opponent blows, as well as to soften a landing from the side if airborne. The shock mounts were printed with one hundred percent infill to make them as rigid as they were needed. This flexible filament needed slow printing speeds such as forty milliliters per minute to obtain adequate layer adhesion and extrusion.

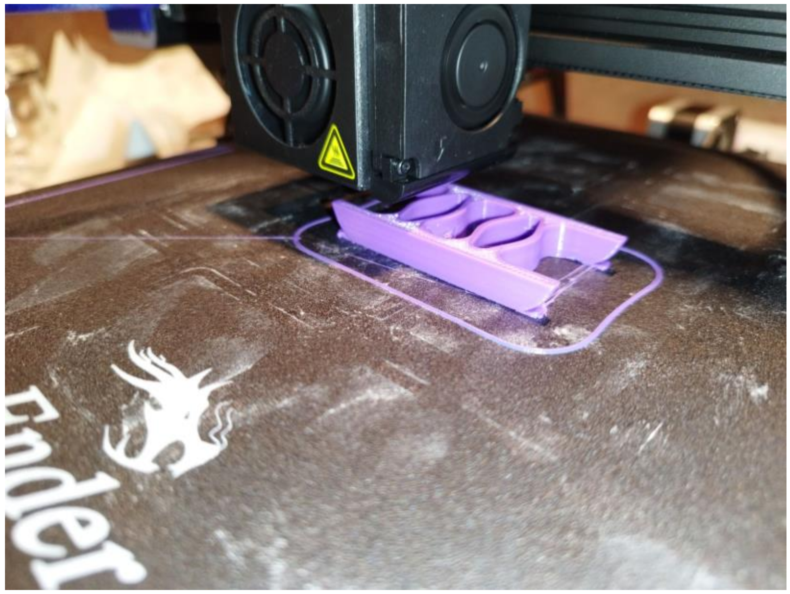


Figure 4.37: TPU Shock-Mount being printed on Ender 3 Pro

Figure 4.38: TPU Shock-Mount

The front of the robot is expected to see the most impacts and damage, as well as being a structural part of the frame. For this reason stronger materials were chosen such as titanium and AR500 steel. A full front wedge could have been made out of steel, but due to weight constraints the team decided to opt for a titanium plow. Titanium is a third of the weight of steel, while providing similar strength and protection from impacts. This component was laser cut using the company SendCutSend. The bend on the ends of the wedge were made in a vice with a butane torch and clamps to bend the appropriate 50 degree angle.

Figure 4.39: 50 Degree Torch Bent Titanium Wedges

Finally, AR500 was used for the connecting piece in the front that straddles the weapon. This piece is intended to provide additional protection from horizontal spinner opponents. It was ordered from SendCutSend who water-jet cut the profile and holes. The bevels were made using a belt sander to remove the edge and deflect horizontal impacts.

Figure 4.40: Grinding AR500 Horizontal Blade Deflectors

Figure 4.41: Sharpened AR500 Horizontal Blade Deflectors

Weapon

Once the frame and armor completed production, the team moved onto the fabrication of the robot's weapon assembly. The weapon assembly contains an aluminum 40T XL timing pulley, two 1/8in aluminum spacer plates, one 1/2in AR500 blade, three press fit bearings, and socket head cap screws that sandwich all of the components together.

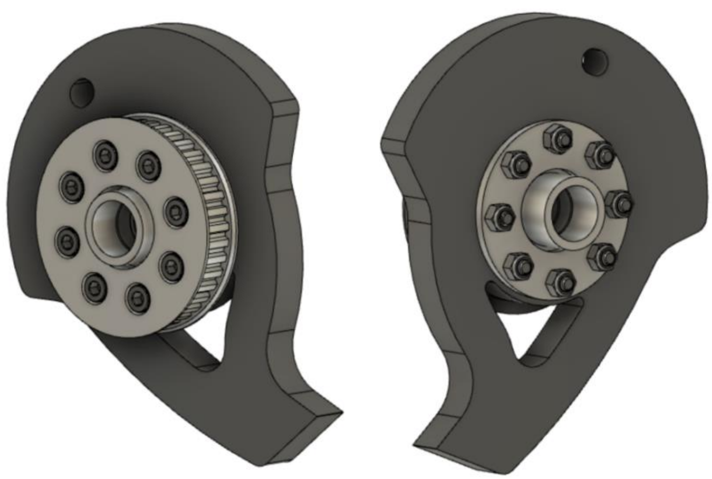


Figure 4.42: Weapon Stack up Assembly 3D Model

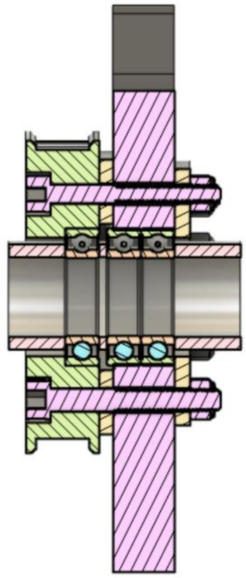


Figure 4.43: Weapon Assembly Section View

The weapon blade was purchased from SendCutSend who lasercut the blade profile from a DXF file. The blade was then clamped into a mill and the bearing hole was bored to the proper dimension to press fit a bearing. Both 1/8in aluminum spacer plates were also purchased from SendCutSend and did not require any further machining.

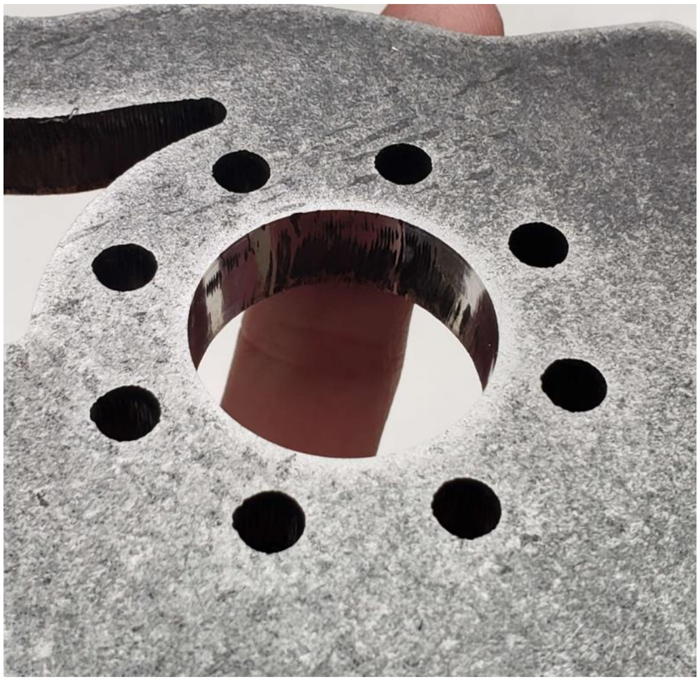


Figure 4.44: Milling AR500 Blade for Bearing Press Fit

Next, the 40T XL timing pulley was chucked in a lathe and bored to press fit a bearing. The bearing was pressed in using an arbor press. The pulley was then moved to a horizontal mill where the circular bolt pattern and counterbores were machined into the pulley.

Figure 4.45: Boring Bearing Hole and Counter bores into Pulley

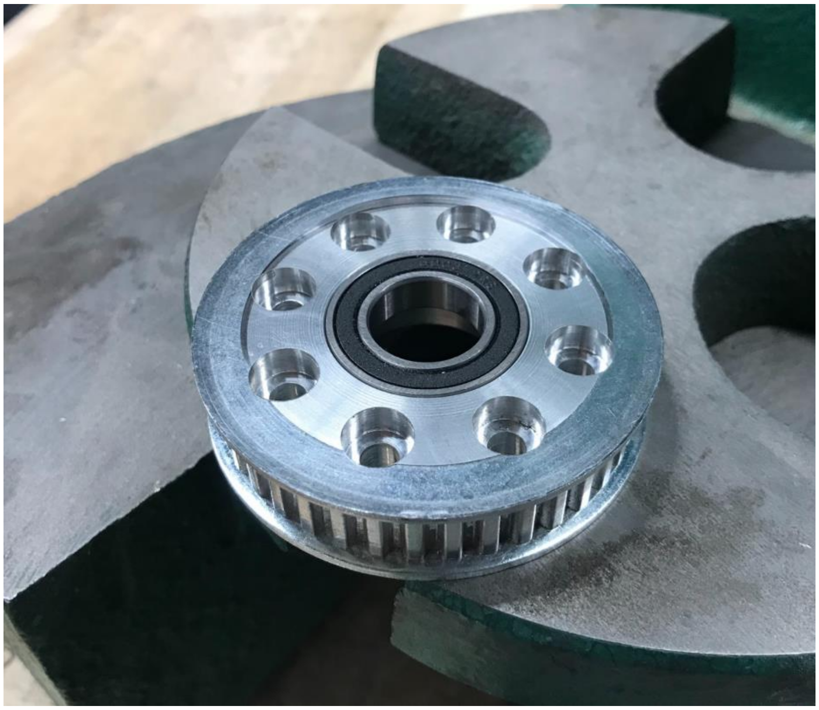


Figure 4.46: Pressing Bearing into Pulley on Arbor Press

Lastly, spacers were turned on the lathe at 1819 in order to keep the weapon centered along its mounting shaft.

Figure 4.47: Turning Down and Boring Weapon Spacers on Lathe

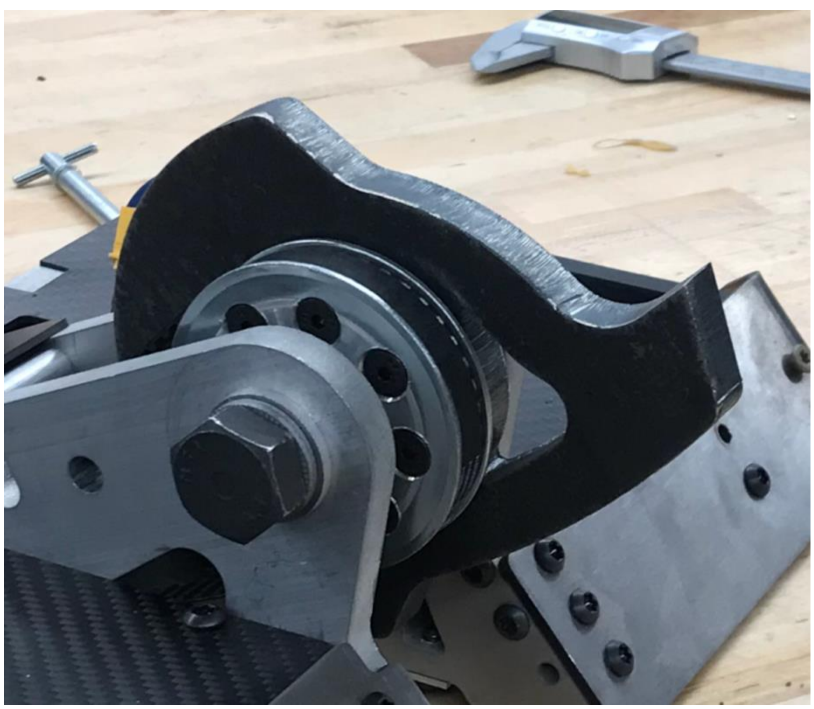


Figure 4.48: Complete Weapon Assembly

Electronics

With all of the mechanical components manufactured and completed, the next step was to solder the robot's wiring harness. The goal for the wiring harness is to provide power and signal to the robot's weapon and drive motors. In order to do this, the electrical system needed two 6 cell Lipo batteries, a Sidewinder 8th weapon electronic speed controller (ESC), a 4in1 drive ESC, and an AR620 receiver. A wiring diagram as seen in Figure X.X was created in order to simplify the process of wiring all of the components.

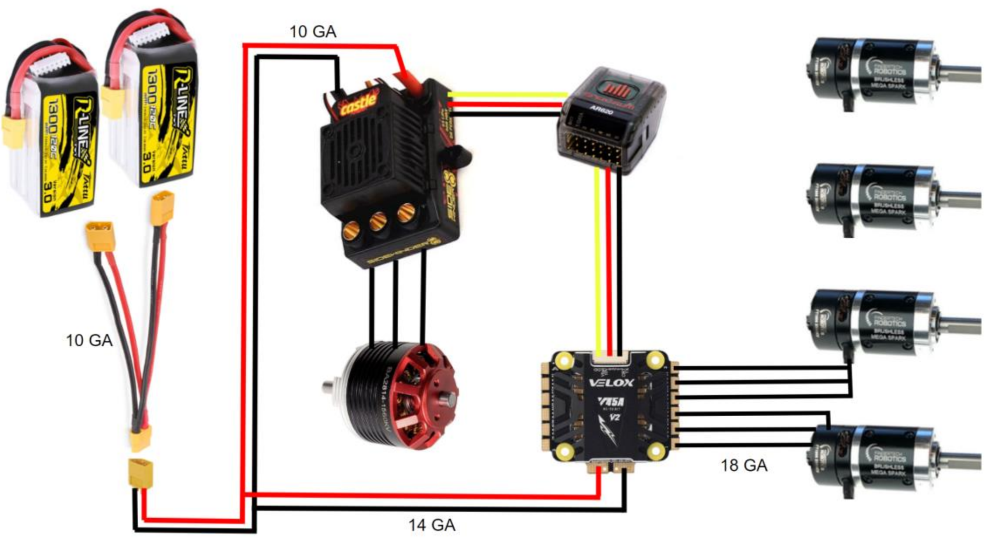


Figure 4.49: Wiring Diagram

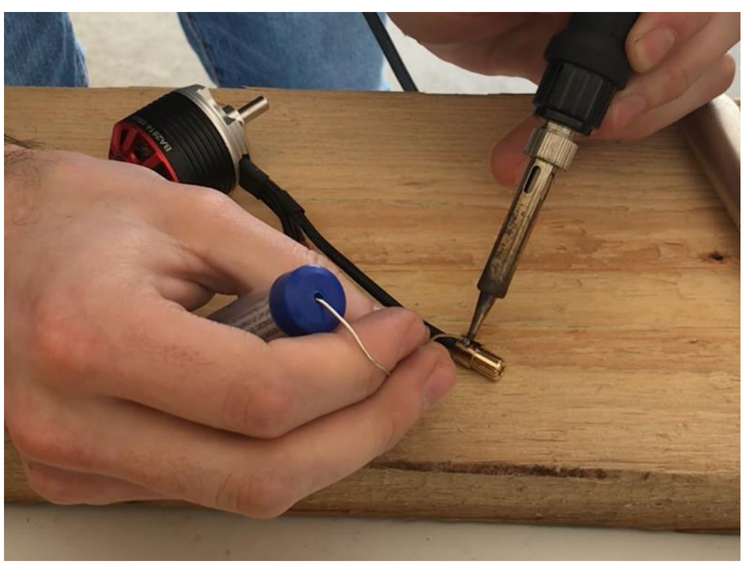


Figure 4.50: Soldering 6.5mm Bullet Connector to Weapon Motor

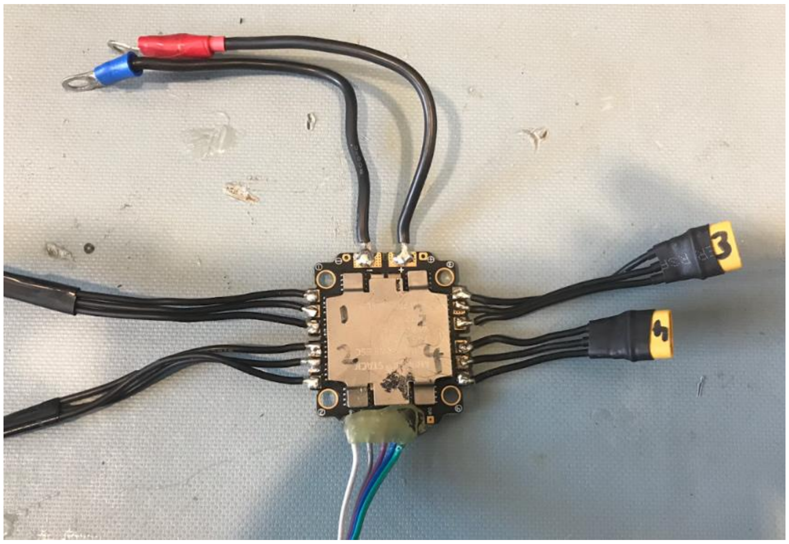


Figure 4.51: Fully Wired 4-in-1 ESC

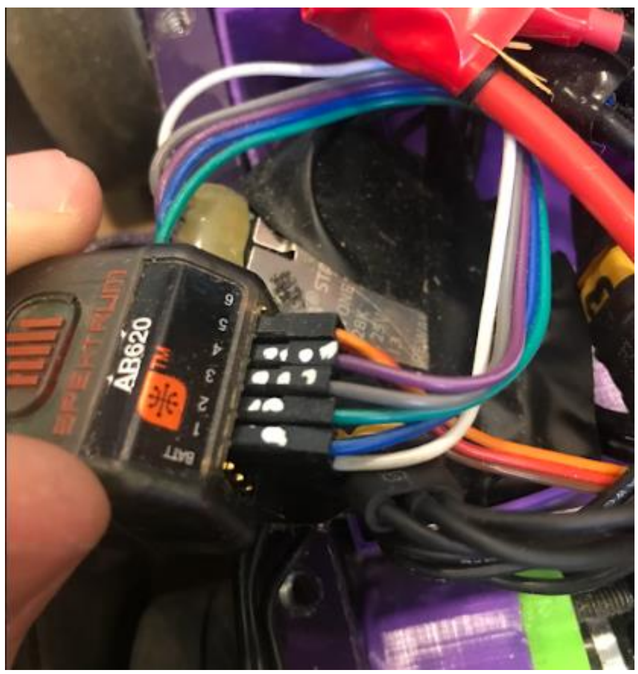


Figure 4.52: Labeled Signal Wires Plugged into AR620 Receiver

With the robot taking large hits, it’s a possibility that the energy from those hits transfer into the electrical components which could disable the robot. To avoid this from happening, all of the electronic components were housed in a shock absorbent TPU wireway as well as surrounded by foam. This reduced the stress on the robot’s internal components and helped with wire management. It is also important that the electrical connectors do not become disconnected so once the wiring was complete and confirmed to be correct, all of the connections were wrapped with electrical tape.

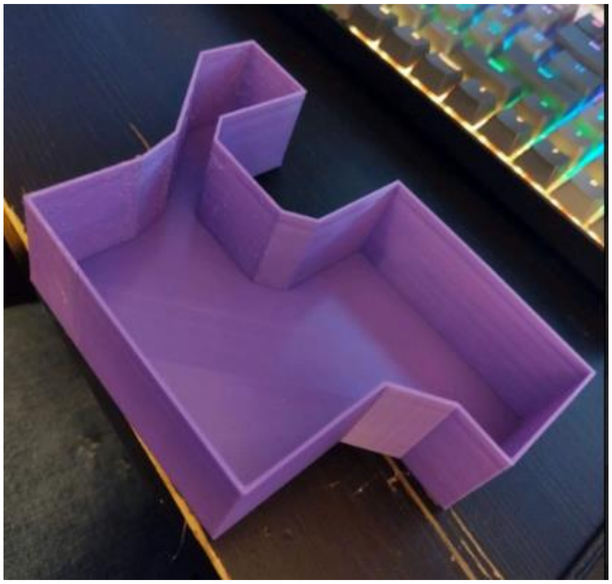


Figure 4.53: Shock Absorbent TPU Wire Way

Figure 4.54: Complete Wiring Harness Installed in the Robot

Now that the wiring harness was complete, the robot could be plugged into a power source to ensure all the connections were soldered and insulated properly. If this step is not taken, a loose connection could affect the robot's performance as well as short out and cause the robot to catch fire. Upon first power up, all components worked as they should and no sparking occurred. This confirmed the robot was properly wired. In addition to powering up the bot, we also bound the AR620 receiver to the transmitter / controller. More specifically, we "safe bound" the robot which ensures that if the robot loses signal from the transmitter, the robot will set all motors to their zero position. This ensures that if the transmitter loses communication with the robot, the weapon and drivetrain will completely stop.

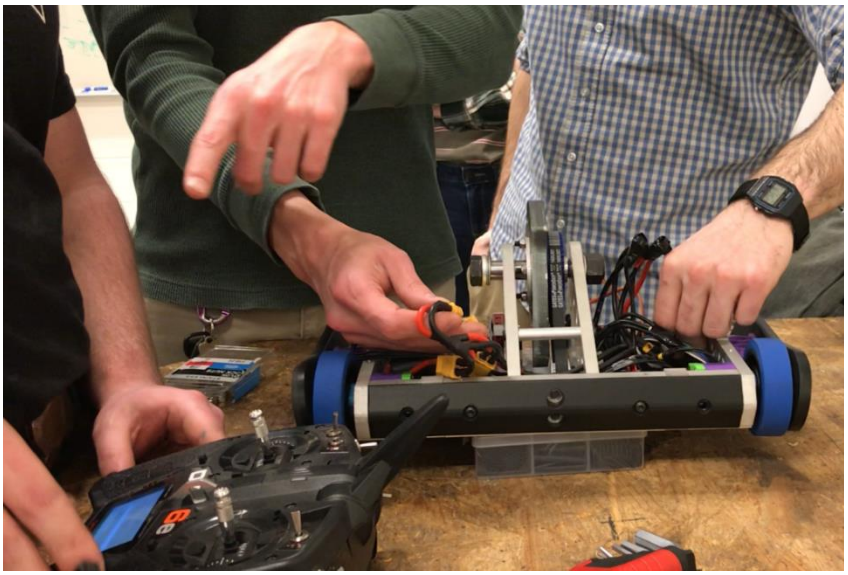


Figure 4.55: First Power Up and Safe Bind

Modifications

Any modifications listed here are improvements we made to the design during the fabrication and testing stage. These changes were made either because the initial design did not work, or we saw room for improvement. The models built before fabricating the aluminum frame helped find these areas for improvement.

Side-Shock TPU Armor Mount

The TPU Side-Shock mount for the UHMW armor was an area that needed improvement. When assembling the cardboard prototype, installing the TPU mount proved to be somewhat challenging. The three-baffle design had nuts placed in between baffles, which made access with a closed end wrench difficult. To hold the nut while starting the screw would often push the nut off of the wrench, and the flexible baffles would push on the wrench making it difficult to hold it in place and straight. The modified design utilized two baffles with nuts on the outside. This greatly simplified installation as the wrench could be held from the side, and there is more access to hold the nut in the wrench while starting the screw.

Another modification needed to be made to the side-shock mount since when installed in the prototype, the amount of flex offered to the UHMW was excessive. Reducing the number of baffles to two exacerbated the issue. The solution was simple, by increasing the thickness of the baffle walls the stiffness could be adjusted. Using a thickness with a multiple of 0.4mm, the nozzle bore size, made 3D printing work well for this part. With these two modifications the shock-mount was greatly improved and working exactly as intended, ready to be mounted on the final robot.

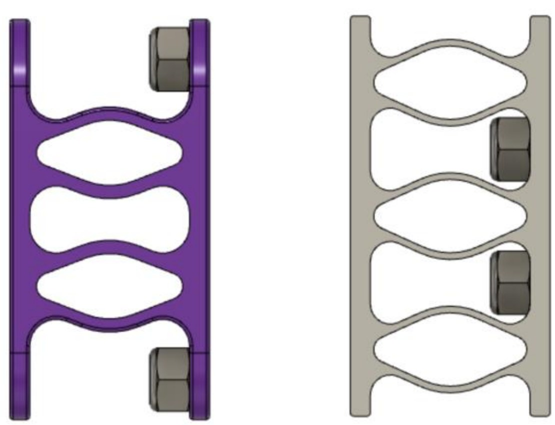


Figure 4.56: Updated Side Shock (Left) vs Original Side Shock (Right)

Weapon Uprights

Another modification we made to Voodoo was involving the weapon uprights, specifically where the weapon motor mounts to the upright. The original design allowed the motor to mount to the upright but due to the short length of the motor's output shaft. The 12T weapon pulley had little engagement with the shaft. This was an issue because that pulley is going to be subjected to a lot of force after every weapon impact and with such little engagement, the pulley was liable to fall off. The fix for this was adding a 3mm deep bore in the upright where the motor mounted. This recessed the motor into the upright on one side, and on the other side, the shaft stuck out 3mm further than the original. This additional 3mm of engagement solved our issue and the weapon pulley never came off its shaft again.

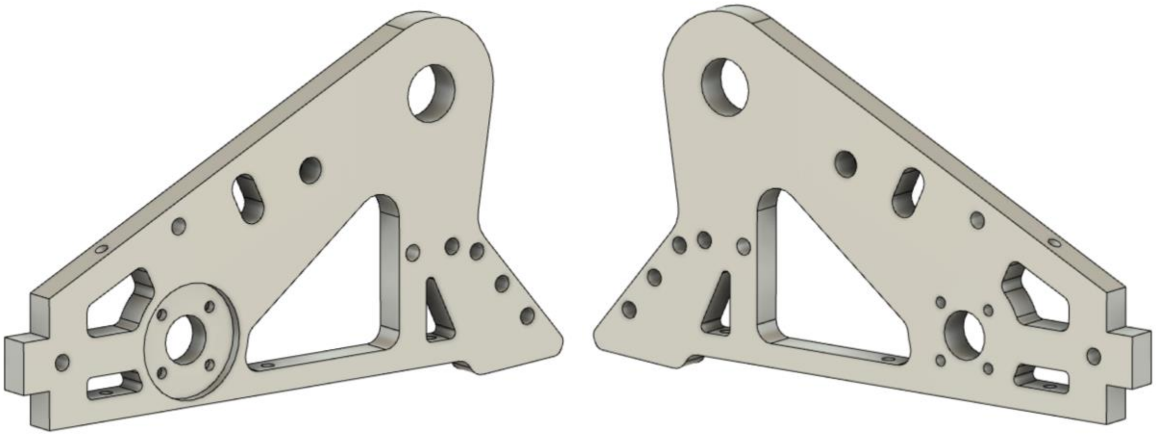


Figure 4.57: New Bored Upright (Left) vs Original Upright (Right)

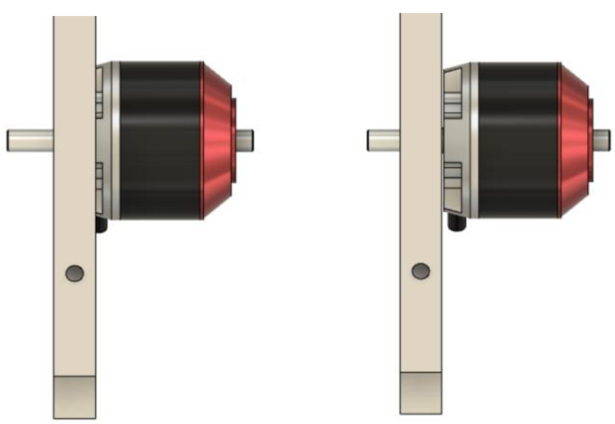


Figure 4.58: New Mounting Location (Left) vs Original Mounting Location (Right)

Final Assembly

With all of the parts manufactured and the wiring harness soldered, the fabrication process ended, and the assembly process began. Voodoo was designed to be modular and easy to repair. This is because broken parts will need to be swapped out often and in a timely manner. This is accomplished by having the robot broken down into 4 main subassemblies that can be easily swapped in and out as a whole unit. These subassemblies are the weapon stack up, the frame, the side/front armor, and the drive modules. This modular design makes Voodoo easy to service and assemble. The assembly can be broken down into 9 steps:

1. Frame Assembly

The first step is assembling the aluminum frame of the robot. The frame consists of the weapon uprights, side rails, rear cross member, bottom plate, and nut strips. All of the members key together, strengthening the frame and making it difficult to assemble incorrectly. The side plates attach at each end of the rear cross member, and the uprights key into that face of the rear cross member. All of the frame members are fixed together using the same 10-24 thread button head screws with the same drive type, a T25 torx. This means the entire frame can be constructed using a single tool.

2. Weapon Motor Installation

Next, while there is still ample working space inside the robot, the weapon and drive motors should be bolted to the frame. The weapon motor bolts to the left upright using M3 socket head screws. Once the weapon motor is fixed to the upright, the 12 tooth XL pulley can be installed onto the weapon motor shaft. A flat is ground on the shaft in order to better engage with the set screw on the pulley.

3. Drive Module Installation

Then two identical drive modules are bolted to each side plate, so four drive modules total. Each drive module is held on the frame using four M4 countersunk bolts. These bolts thread into nuts that are captured by a 3D printed nut retainer. This enables us to install and remove the drive modules without having to reach a wrench or socket in tight areas. With the motors fixed to the frame, the front and rear wheels can be installed on their respective shafts. T81 Banebots hubs are slid onto the rear drive shafts and held down by a set screw. The wheel is then pressed onto the hub and held in place by a snap ring. The same process is followed for the front wheels except that T40 Banebots hubs are used.

4. Mount Side Shocks

Before installing the armor, the soft, shock absorbing TPU must be mounted to the side rails. If the TPU shocks are mounted to the armor first, it makes installing the TPU on the frame much more difficult. The side shocks are held in with two 10-24 screws that tap into the frame side rails.

5. Armor Installation

The armor is made up of two 1/8in titanium wedges, two 3/8in UHMW side guards, and one 1/2in UHMW rear guard. The titanium wedges are fastened to the side guards using two wood screws. The wood screws bite into the gummy UHMW material creating an extremely strong joint. Now with the front wedge and side guard fixed together, that subassembly is fastened to the main frame. The titanium wedge bolts to the nutstrips at the front of the robot's frame and the side guards are mounted to the TPU shocks using a 10-24 nut and bolt. With both wedge and side guard assemblies installed, the only area left unprotected is the rear cross member. To protect it, the 1/2in UHMW rear guard bolts directly to the rear cross member using tapped holes in the frame.

6. Weapon Stack Up Assembly

The weapon stack up consists of the weapon blade, two spacer plates, three ball bearings, and a 40 tooth Xl timing pulley. The three bearings are pressed into the blade and the pulley (two in the blade and one in the pulley). The blade is sandwiched between the two spacer plates and the pulley is mounted to the outside of the left spacer plate. This stack up is held together using eight M5 socket head screws and eight M5 nylon insert lock nuts.

7. Weapon Installation

Once the weapon stack up is assembled, the weapon can be installed onto the weapon shaft. The weapon shaft is a 17 mm shoulder bolt that runs through a hole from one upright to the other. To install the weapon stack up, first wrap the timing belt around the 40T pulley on the stack up, then wrap the belt around the 12T pulley on the weapon motor. Once this is done, the weapon stack up can be slid in between the uprights and the weapon shaft can be inserted through the first upright, into the weapon bearings, and out through the other upright. Then to hold the weapon shaft in place, a vibration resistant nut is tightened down on the 17 mm shoulder bolt.

8. Electronics Installation

To install the electronics, the TPU wire way with the wiring harness inside is placed in the left compartment of the robot's frame. The weapon motor bullet connectors are then plugged into the Sidewinder 8th weapon ESC. Then the four MR30 connectors on the 4in1 drive ESC are plugged into their corresponding motor. Two of the drive motor plugs are in the left compartment and the other two are in the right compartment. Due to this, two of the wires from the 4in1 must be routed through an access hole in the uprights, over to the right compartment. The battery is then placed in the right compartment, and it is surrounded by a layer of foam.

9. Top Cover Installation

The final and simplest step of the assembly process is fastening the top plates onto the robot's frame. Two carbon fiber top plates key into place and are held down using 10-24 screws that thread into tapped holes in the top of the frame. With this step complete the robot is ready to compete.

Assembly Notes

An important note to add is that during this assembly process, every piece of hardware receives a dab of blue thread locker in order to prevent screws from backing out and coming loose. This is especially a concern around the weapon where the high rotational speeds may cause a vibration strong enough to loosen screws. The thread locker is also coated on our drive motor shafts prior to installing the wheel hubs. This prevents the hub from sliding off its shaft.

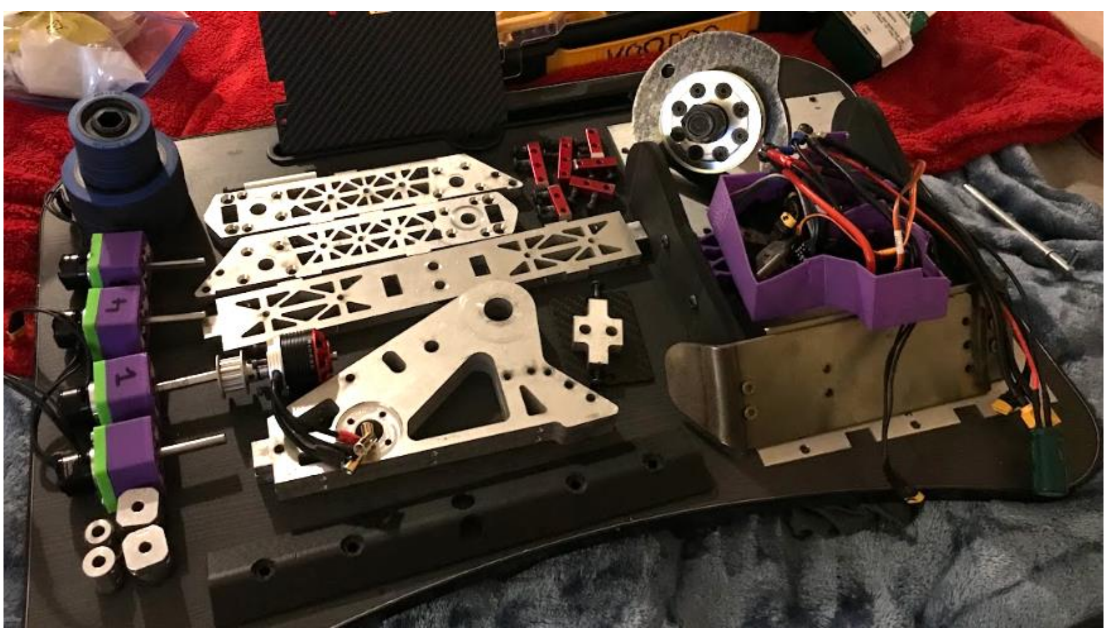


Figure 4.59: Fully Disassembled Robot

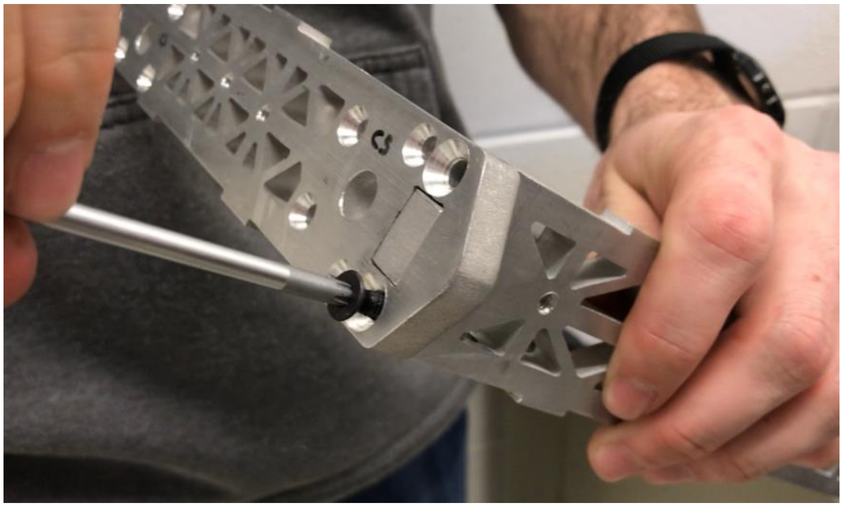


Figure 4.60: Side Plate Being Fastened to Rear Cross Member

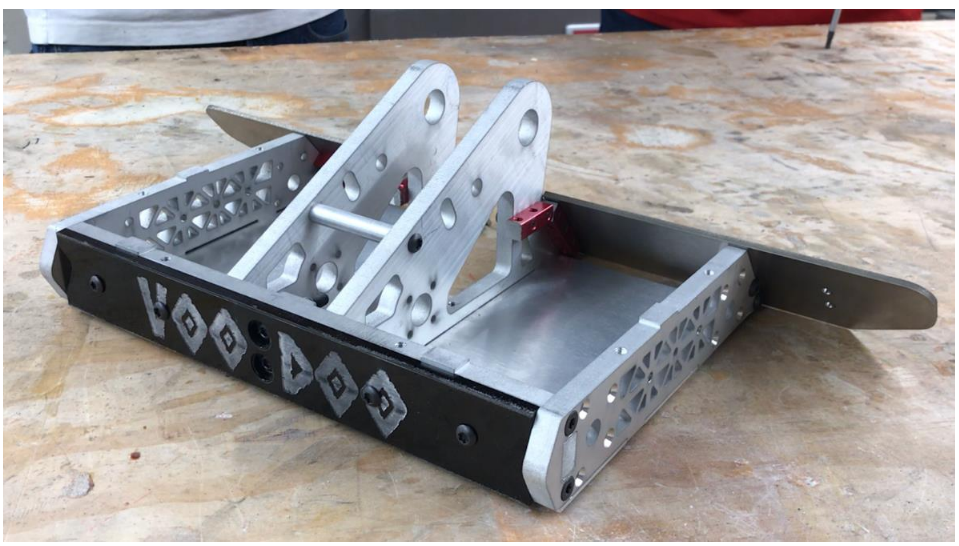


Figure 4.61: Fully Assembled Frame with Wedges

Figure 4.62: Weapon Motor Fastened to Upright

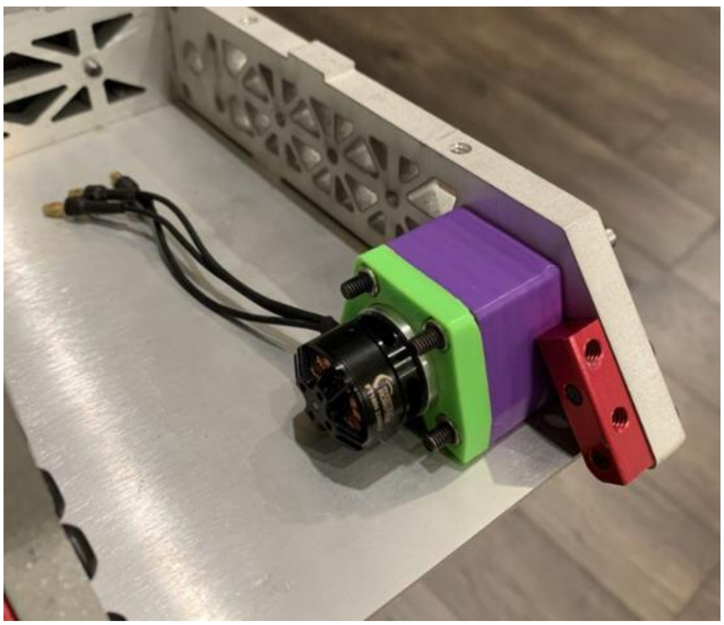


Figure 4.63: Drive Module Fastened to Side Plate

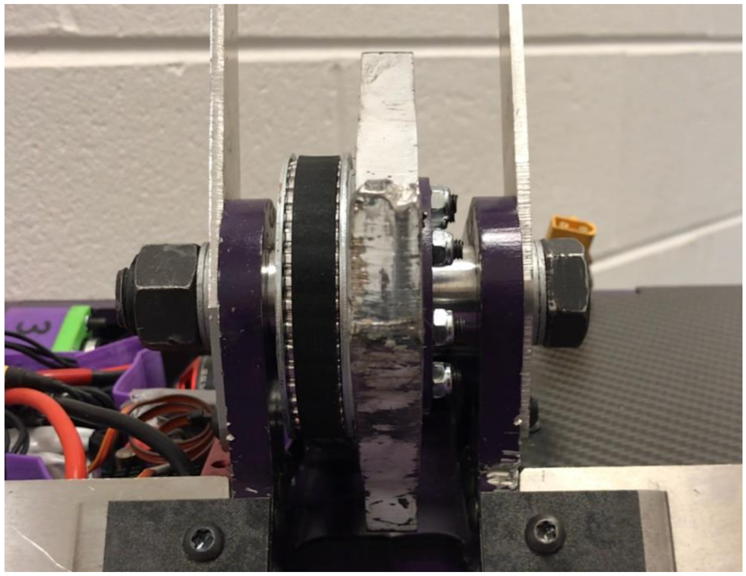


Figure 4.64: Weapon Stack Up Installed on Weapon Shaft

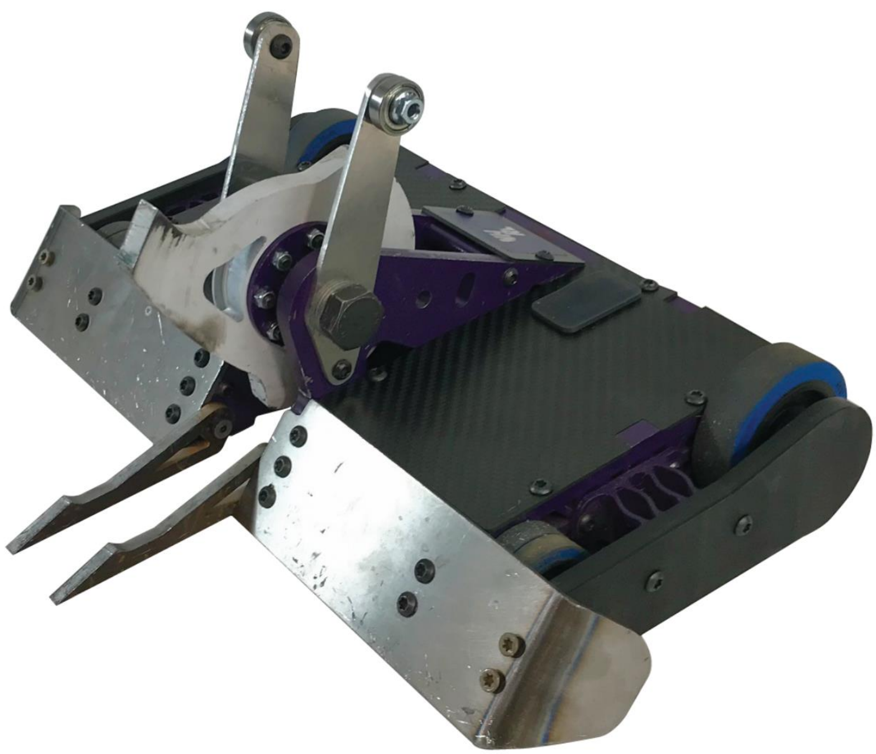


Figure 4.65: Fully Assembled Robot

Testing

Safety Inspection

In order to compete, the robot must first pass a safety inspection and be in accordance with all of NHRL's safety standards. Typically, NHRL does not hold a competition until after graduation, so the safety inspection is simulated by a battle bots club member. This was not the case for our team, rather than waiting till May 6th to compete, we worked on an accelerated schedule in order to compete at the March 18th NHRL event. Due to this we were able to get our robot inspected by NHRL officials. The four basic tests for passing safety inspection are, being within the 12-pound weight limit, having a sufficient weapon locking system, showing you are able to safely power on the robot, and demonstrating that the robot shuts off if the transmitter signal is lost.

Voodoo's final weight came to 11.27 lbs which was well within the 12-pound weight restriction. Next, the weapon lock was inspected to determine if it would truly prevent an accidental weapon spin up. Voodoo uses an 8mm diameter steel quick release pin that runs through a hole in the weapon blade and both uprights. When the pin is installed, the weapon is mechanically locked in place and the weapon motor simply doesn't have enough startup torque to shear through the steel pin. With this being said, our weapon lock was considered more than sufficient by the NHRL safety crew.

Next, are the safety checks that involve the robot's functionality and the operator's ability to safely handle the robot. These tests take place inside a steel test cage so the robot can be safely powered on. The proper procedure must be followed when putting your robot in the cage. First the robot should be placed in the cage with the door open, then the transmitter should be powered on. Once the transmitter is powered on, the robot can be powered on. Then the weapon lock can be removed, and the cage door can be closed. We were able to follow this procedure and had no issues with that part of the inspection.

Now that the robot is powered on and in the cage, our functionality test could be performed. The NHRL official requested us to spin up the weapon and drive the robot around in the cage. During this part of the inspection, the safety official is looking to see if the robot catches fire or if anything malfunctions that could cause a safety issue. As expected, we did not experience any fires or malfunctions during the inspection. The final test and the most important test was to ensure the robot was "safe bound" to the transmitter. The official asked us to turn the transmitter off while the weapon was spun up. When this was done, the weapon lost power and the blade began to slow to a stop. With this step completed, Voodoo successfully made it through NHRL's safety inspection. Once safety was passed, we received a sticker that shows Voodoo is eligible to compete.

Figure 4.66: Robot's Final Weight on NHRL's Scale

Figure 4.67: Weapon Spun Up in NHRL Test Cage

Figure 4.68: NHRL Safety Passing Sticker

Weapon Testing

In order to test the weapon, there are a few safety concerns that must be addressed. The wiring of the electronics was inspected to ensure there would be no shorts in the system which could result in overheating and potential fires in the bot. The next thing to address is the hardware holding the bot together. Any hardware that isn't self-locking (like using a locknut) must have Loctite applied to it. When the weapon is spun up, there will be small vibrations that can cause hardware to loosen and back out. This can then be hit by the weapon and produce a projectile, or it can be sucked into the bot and cause damage. Now the weapon can be safely spun up in a test box. When first testing the weapon, it is important to make sure that there isn't too much load on the motor. The most load on the motor occurs when first starting it. A lot of current will be dumped into the motor in order to overcome the inertia of the weapon. It is important to listen to how the motor sounds when first turning it on. We started by doing a slow ramp up at low speeds to make sure that the motor was functioning correctly. We then returned the motor to a resting state where we then did a slow ramp up to full speed. Once we verified that everything was working as expected we punched the throttle like what would occur in a match. We throttle the motor from 0 to 100 as fast as we could move the throttle knob. The motor sounded great and didn't have any issues starting or reaching top speed. During this testing we used an electronic speed controller that had a data logging feature which allowed us to see how many volts and amps were flowing to the motor during the different testing phases. The data showed us that we had a peak of 72 amps during the last test with a continuous draw of 9 amps. This low amp draw also indicates that our system was very efficient with the power that it was using which allows us to reduce our overall battery capacity and save weight. Another factor that the data showed was the voltage drop during the high amp draw. The voltage drop is hard on the speed controllers which like to have relatively constant voltage flow. To counteract this drop in voltage, we included a capacitor in the system which can discharge to make up for the lack of voltage the speed controllers are receiving. After ensuring that all the electronics would perform as expected, we next moved onto the mechanical and drive portion of the weapon testing.

Testing Data	
Max tip speed	180mph
Max bite	2 inches
Max amp draw	72
Continuous amp draw	9

Spin-up time (seconds)	
0%-30%	2.08
30%-100%	0.73
100%-0%	10.18

Figure 4.69: Mamba X Data

For the mechanical testing of the weapon, we needed to impact something to assess the amount of bite we would get out of our weapon as well as test the strength and durability of the weapon and the weapon support structures. In order to do this, we took a large piece of 1-inch-thick wood and hit it with our weapon at full speed. This test yielded almost 2 inches of bite into the wood. This test demonstrated the large amount of bite that we would get out of our weapon. The last test we performed was the driving test. This test was intended to show us the controllability of our bot with the weapon at full speed. When the weapon is spinning there is a lot of angular momentum in the weapon disc which will resist a change in its axis of rotation. This change occurs when the bot turns while driving. Subsequently, this gyroscopic force can lift one side of the robot off of the ground and reduces the traction and handling ability. While testing we found that there was minimal gyroscopic force present when attempting to turn, only lifting the side of the bot about 5 degrees. This is due to our wide frame, which helps maintain contact with the ground and also our lower tip speed on our weapon. Overall, the controllability of the bot was excellent.

Figure 4.70: Weapon Impacting Wood

Figure 4.71: Weapon Blade Bite with Hand for Scale

Figure 4.72: Maximum Lift off Ground

Drivetrain Testing

The manufacturing stage for the electronics consisted of laying out components, soldering connections, plugging components together, and laying them out in the robot. During these steps faulty connections could happen, or defective or damaged components could exist. After manufacturing the wiring harness, programming the receiver and ESC was needed, to do this, an Arduino was used. Testing the drive train consisted of two stages. The first one was to test the components. To do this, a transmitter needs to be connected to the receiver, and a battery hooked up to the electronics. Once the transmitter is connected and the electronics have power, each motor can be individually triggered. Ensuring each component works and communicates with its corresponding electronic components completes the first round of testing.

The next step is to test the drivetrain performance. To do this, mixing needs to be done with the transmitter. This step determines the interaction between the controls on the transmitter and what the ESC outputs to each motor. For example, to turn right, the left side wheels must spin forward, and the right-side wheels must spin backwards. At the same time, the front wheels are smaller than the rear, so the rear wheels must spin slower than the front ones to keep them spinning in sync. After this step is completed, testing is done by driving the robot and observing its response. Adjustments can be made through the transmitter as needed. Further, pushing power tests were performed to determine if Voodoos drivetrain had enough power to push and control opponents. This test involved driving full throttle head-to-head against other robots from the UC Battle Bots Club, which gave an analog to other robots that may be seen at competition. These tests revealed that our drivetrain was strong enough to move the weight of our own bot as well as the weight of an opponent pushing full throttle back at us.

The last drivetrain test performed was testing the inverted driving and the self-righting ears that Voodoo was equipped with. The ears stick up past the weapon and have ball bearings mounted on the end of them. This allows the robot to drive upside down using only the rear wheels. This means if Voodoo is flipped over, it still has controlled movement and cannot be counted out of the fight. Being able to drive inverted also opens the opportunity for self-righting the robot. The battle cage has wooden ledges that line the bottom of the walls, and these ledges are commonly used as leverage for self-righting. Our plan, if inverted, was to run into the ledge at full speed and use the force of the weapon hitting the ledge to un-invert the robot. We simulated the ledge and cage floor and were successfully able to self-right the robot even with the weapon turned off.

Figure 4.73: Pushing UC 12lb Robot (BAKA)

Figure 4.74: Self Inverting Test

Testing Against Other Robots

In order to gain an understanding of how our bot would do against other robots, we sparred with other robots in the club as well as competed at the March 18th NHRL event in Connecticut. Inside the club we frequently sparred with another member's bot called Maximizer which was built by Jake Hoffman. During this testing we did not test weapons against each other as it was not safe to do so. Weapon locks were installed during the fighting. This sparring was meant to test the different configuration of our robot as well as the power and maneuverability of our drivetrain. Our fork configuration was successful in getting underneath Maximizer which allowed us to control his robot. Our drivetrain was powerful enough that when we got under his bot, we were able to push it around. The next thing about our drive train was testing the speed. In these tests our bot was able to use its speed to outmaneuver the opponent which would allow us to get to the sides of his bot.

Figure 4.75: Pushing UC 12lb Robot (Maximizer)

At the competition in Connecticut, we put our bot up to the true test. We had our first fight against Milktank which is a horizontal spinner. For this fight, we changed our configuration to use the AR500 steel bowtie armor rather than our forks. In this fight we were able to easily outmaneuver our opponent with our increased speed and controllability due to our 4-wheel drive setup. We delivered numerous hard hits to the opponent, and they eventually lost power in their robot resulting in a knockout and our first ever win. After the fight we did an inspection so we could see what was damaged so we could prepare for our next fight. Our armor held up very well and took minimal damage during the fight. The weapon tip was still sharp and deformed very little from all the impacts it delivered. The frame did not bend, and the weapon uprights maintained their shape after all of the impacts.

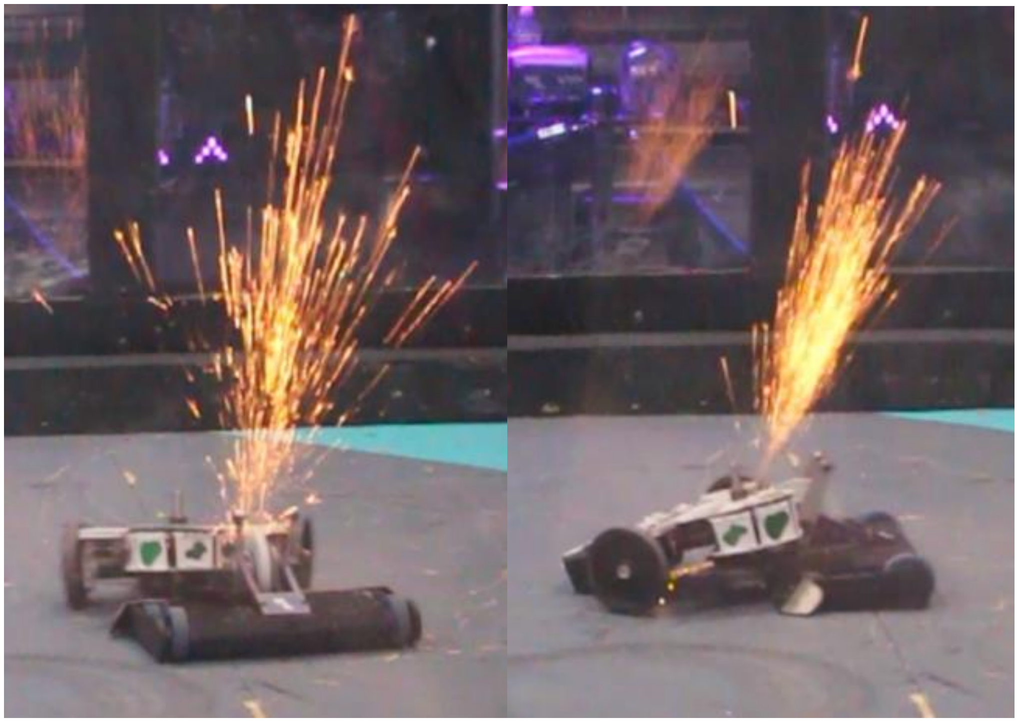


Figure 4.76: Voodoo Cutting Milktank's Armor

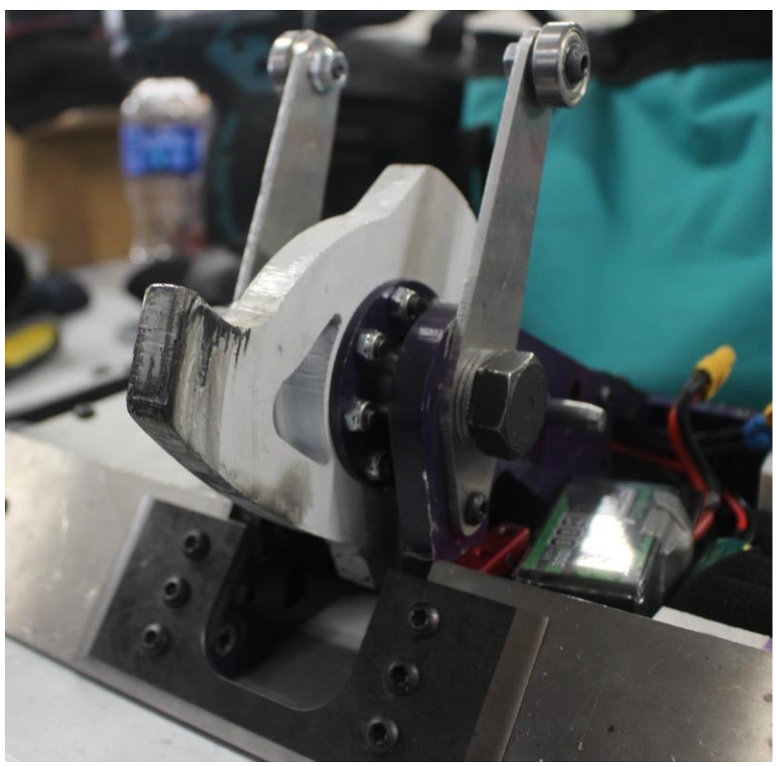


Figure 4.77: Weapon and Robot Condition Post Milktank Fight

Our last fight was against a bot named Saiko!. This fight, we went with our fork configuration because Saiko! is a vertical spinner so forks would allow us to get under him and control the fight. At the start of the fight, we got the first hit, and it was a big one. We launched Saiko! about 5 feet up into the air. From there, the next couple of exchanges caused us to lose our forks and our weapon. We took quite a few big hits from our opponent which ultimately ended up with us stuck on our nose and unable to drive with the win going to Saiko!. After the fight we did another damage inspection. Our armor on the front and sides was thoroughly chewed up from all of the big hits we had taken but it had ultimately done its job and prevented our opponent from reaching the aluminum frame. Our titanium armor had a few dents and cuts in it on the front from the impacts we took and the UHMW on the sides had some deep gouges in it. The UHMW successfully protected the wheels as they didn't take any damage from that fight, and we were still able to drive normally after. The frame members were strong enough and rigid enough that it did not deform from any of the forces during the fight. The only major damage to the frame were a few stripped nut strips and bolts that were holding the titanium wedge on. Overall, the bot performed very well even though the result wasn't in our favor. The repairs we had to make were minimal as the majority of the bot could still be used for other fights which attests to the robust design.

Figure 4.78: Voodoo gets Massive Hit on Sakio!

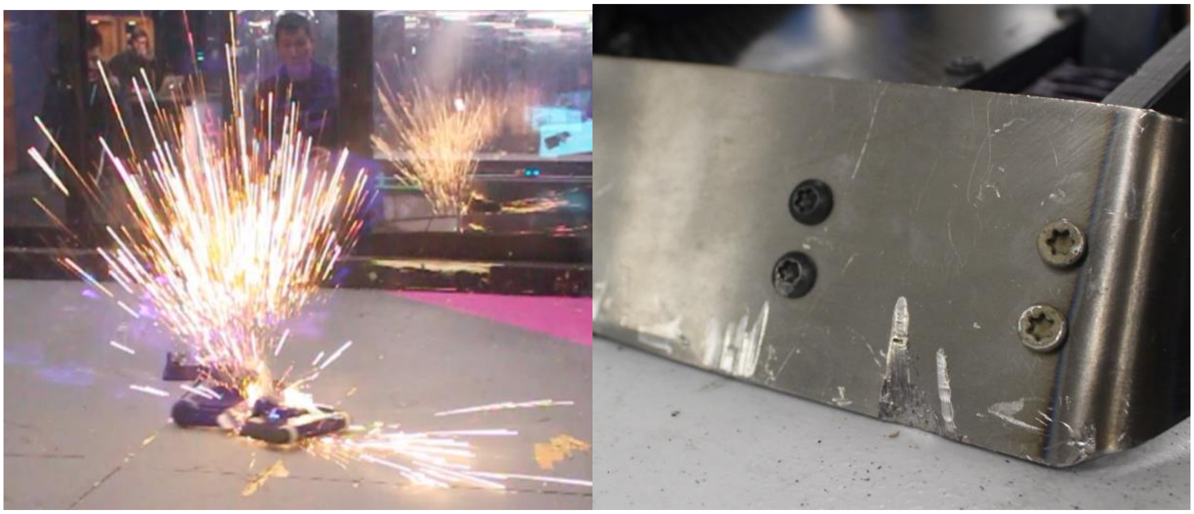


Figure 4.79: Saiko!'s Hit on Voodoos Titanium Wedge and Resulting Damage

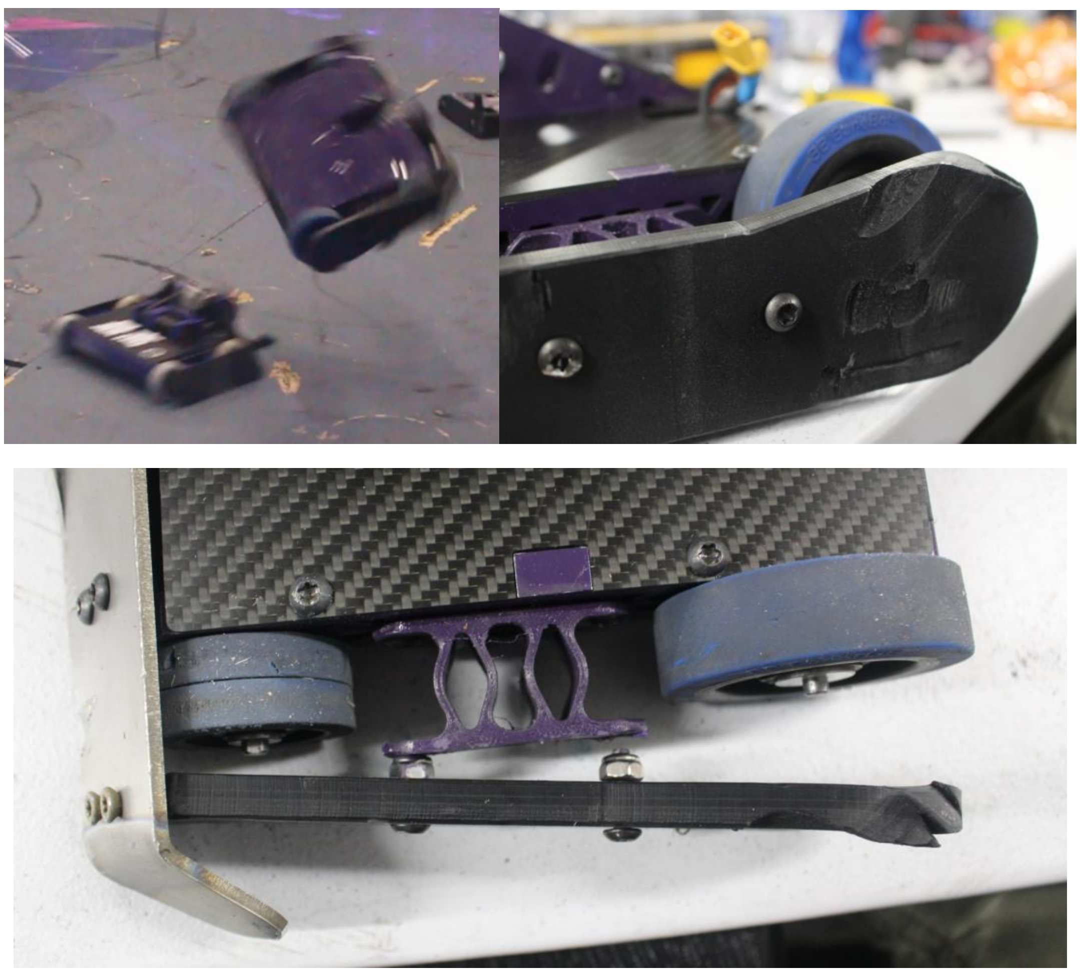


Figure 4.80: Saiko!'s Hit on Voodoos UHMW Side Armor and Resulting Damage

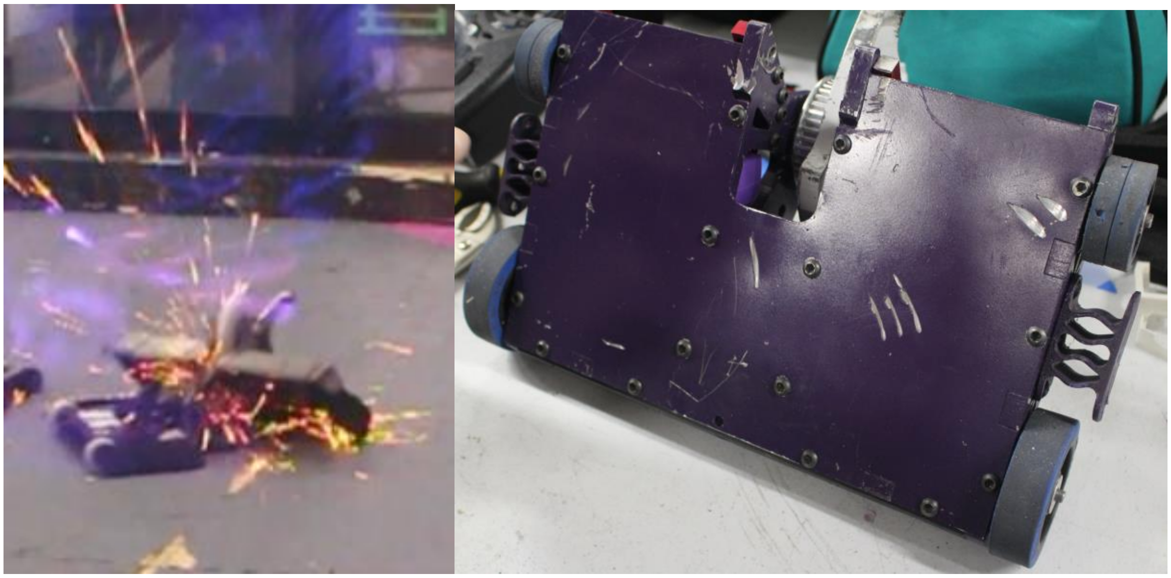


Figure 4.81: Saiko!'s Hit on Voodoos Aluminum Bottom Plate and Resulting Damage

Figure 4.82: Parts Replaced Post Saiko! Fight

Project Management

Project Budget

Proposed Budget

After a meeting with Professor Janet Dong and UC Battle Bots Club President Cole Pownell, we have been allocated a total of $1,650 to build our robot. This money will cover the cost of materials, machining, and off-the-shelf parts we purchase throughout the robot building process. If the budget is exceeded, each team member has agreed to put up $250 of their own money in order to cover the additional costs. This brings the total budget limit to $2,400.

Based on our bill of materials which can be seen in the appendix, our total material cost is $1,533 which is $117 under the UC Battle Bots Club budget. We estimate this money will be used up by additional manufacturing costs.

Subsystem	Expenses
Weapon	$450
Drivetrain	$341
Frame	$127
Armor	$235
Electronics	$210
Hardware	$125
Manufacturing	$45
Total	**$1,533**

Figure 5.1: Estimated Budget Breakdown by Subsystem

Actual Budget

With the build completed, the total cost of the robot and spare parts came out to be $1,817, which exceeded our initial budget by $167. This was mainly due to unforeseen hardware and manufacturing costs such as the cost of the water jet at 1819 and the prices of specialized hardware on McMaster-Carr. Another reason for exceeding the budget was the cost of purchasing and manufacturing spare parts. The team manufactured an entire second frame as a spare in case the original frame was damaged during combat. This also meant purchasing a second set of frame hardware which drove up the overall cost. Without spare parts, the total cost of the robot is closer to $1300 but due to the destructive nature of combat robotics, spares are necessary.

Subsystem	Expenses
Weapon	$425
Drivetrain	$390
Frame	$168
Armor	$163
Electronics	$210
Hardware	$228
Manufacturing	$233
Total	**$1,817**

Figure 5.2: Actual Budget Breakdown by Subsystem

Schedule

The milestones below have been set based on the requirements of the UC Battlebots Club, NHRL Competition, and the UC Senior Design schedule. A more detailed schedule can be seen in Figure 5.3 where the upcoming milestones are highlighted yellow.

Date	Milestone
9/30/2022	Final Proposal Due
10/11/2022	Start Senior Design II
11/15/2022	Final Prototype Due for Printing
12/5/2022	Presentation I
1/9/2023	Start Senior Design III
4/6/2023	Tech Expo
5/6/2023	Norwalk Havoc Robot Competition

Figure 5.3: Milestone List

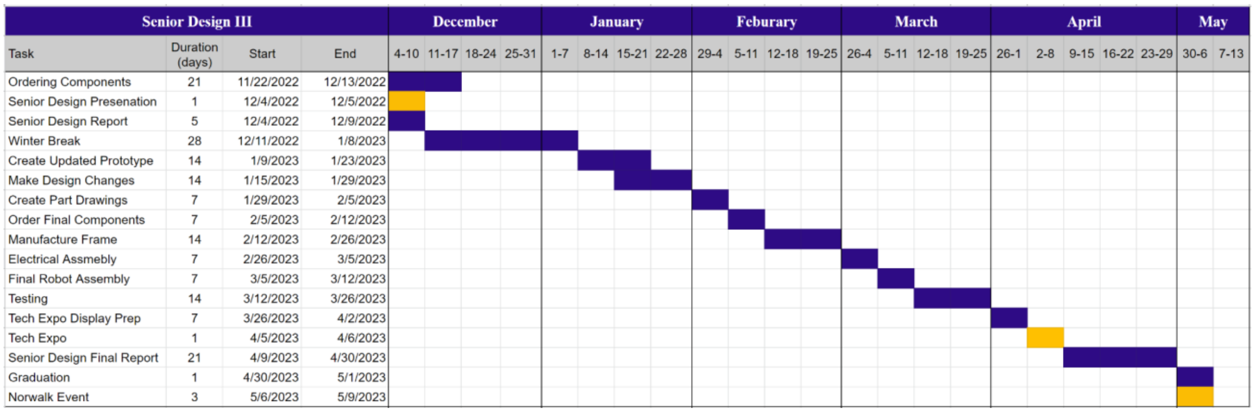


Figure 5.4: Gantt Chart

Recommendations

1. Better fork mounting

Through our real-world testing at the NHRL competition we realized that there was an issue with the way that we mount our forks to the robot. In its current state, we use shoulder bolts with the shoulder turned down slightly to mount the forks on the inside of the weapon uprights. This has proved to be a bad location to mount the forks as well as not strong enough to handle the forces present during combat. During one of our fights, both of our forks were ripped off by the opponent because the shoulder bolts broke under the stress. Not only did we lose the forks but, one of the forks got sucked in by our weapon after breaking off which damaged our weapon motor pulley and disabled our weapon for the rest of the fight. In order to improve our design, we need a better location for mounting the forks as well as a more robust design for the fork mounting hardware. The forks should be moved away from the weapon uprights to prevent them from damaging the weapon assembly if they are to be ripped off again. Larger hardware would improve the strength of the mounting assembly and reduce the changes of them coming off of the bot again.

2. Improve drive motors

There were two issues found with the motor and gearbox selection during our real-world testing at NHRL. The first one was that with the rear wheels being as large as they are, the motors seemed to be undersized for the torque needed. They had to work hard to keep the robot moving and were susceptible to damage from strong impacts and landings. The other issue was with synchronization of the front and back wheels. Despite efforts mixing the transmitter to account for the front and rear wheel size difference, the driving performance suffered from unequal drive speeds. Driving in a straight line proved difficult as wheels spin at slightly different rates with each motor performing slightly differently. The recommendation for an improved drive train would be to increase the size of the motors and use a belt or chain system with different sized pulleys to drive the robot. This larger motor could provide the torque needed for larger rear wheels, and the belt system would perfectly time the rotations of the front and rear wheels with appropriate pulleys supplying the right ratios. This would solve the drive performance issues.

3. **Reduce size of the robot**

   The final recommendation for improving this combat robot would be to reduce the overall size and footprint of the bot. The current design presents ample room for electronics inside the frame. The left side even requires foam to fill the space and keep the battery in place and not bouncing around. Having a compact robot has multiple advantages. A small footprint means the robot is more difficult to hit by an opponent. A smaller robot also means the weight can be dedicated to thicker armor, weapon, and stronger drive, rather than being wasted on making the frame larger. The interior of the robot should be just big enough to tightly fit all of the electronic components. Allowing just enough space for electronics and allocating weight to critical components is an improvement that could be made to Voodoo.

Conclusion

With 9 months of hard work behind us, we had our final product, Voodoo. A robot that went to the Norwalk Havoc Robot League competition on March 18th and proved itself to be a viable opponent against the best of the best in the sport. Voodoo went 2-1 overall at the event and left its last match fully functional, only needing small repairs. During the event, Voodoo did not suffer any electrical issues, or require any of the spare frame pieces, this was due to the shock absorbent armor and TPU wire way we designed. As a team, we considered the March 18th Norwalk Havoc event to be a complete success. This success was due entirely to the good research done, the rigorous design process followed, the time management strategy, and the team's relentless commitment to the project and improvement.

Investing the time in doing good research was critical to the success of our robot because it enabled us to see patterns and similarities that a majority of successful 12lb robots shared. These similarities being using vertical spinners, having multiple fighting configurations, and using four wheeled drive. This extended research period also helped us learn from other senior design teams' mistakes, so we did not replicate them.

Another major contributor to this robot's success was the design process followed during Senior Design I and II. When a design concept was initially proposed, the team would break down the concept based on its manufacturability, durability, and its repairability. All of this was determining the design's practicality for combat robots' application and these determinations were made on the research done, seeing what had been successful for other robots. Once a concept was considered feasible for our application, it was designed and then revised multiple times. These revisions for example would make the design simpler to manufacture, easier to service, and just overall more durable. Going through this iterative design process, we found that it took our team about a week longer to finalize our robot design than the other two senior design teams. When on a tight schedule as we were, this week felt significant, but we quickly realized how critical that extra design time was to our success. As other teams began to run into manufacturing issues or clearance issues on their physical robots, our manufacturing and assembly process went smoothly with little to no bumps in the road. This was because of the team's diligence in the design stage, looking over every hole with a fine-tooth comb. We were able to catch issues in the model rather than on the physical robot. This saved us an exponential amount of time, enabling us to complete our robot a month ahead of schedule. This gave us more time to troubleshoot and improve our robot before competition.

Although having a solid final design helped accelerate the manufacturing and assembly of Voodoo, having good time management proved to be the real reason we finished ahead of schedule. By looking at the recommendations from past senior design projects, a consistent recommendation was to meet frequently, so as a team we were all meeting a minimum of twice per week outside of our scheduled Battle Bots Club meeting time. This was feasible for us because we all shared an identical class schedule, so we are easily able to meet before or after class. When deadlines approached these meetings became even more frequent, up to 3 or 4 times a week including the weekends. Some of the tools we used to manage our time was the manufacturing spreadsheet, and the Gantt chart created at the beginning of the semester. We overestimated the manufacturing time, and we treated our preset deadlines as if they were real deadlines. We also machined certain parts based on what was necessary to continue making progress on the robot rather than just machining parts in order of part number. This combination of actions led to Voodoo being finished an entire month ahead of schedule and enabled us to compete in Norwalk on March 18th. Our time management directly affected the success of our project because it allowed us to get combat experience and real testing data against other robots.

The most important aspect for the success of our project was every team member's dedication to the project. Each member put every ounce of effort they had into designing and building this robot and each member brought a specific set of skills that meshed perfectly with the others. There were countless late nights revising the design, long days in the machine shop, and multiple weekends spent wiring and troubleshooting to perfectly dial in the robot. As a team we enjoyed the project and working with one another so much, we decided to design and build an improved version of Voodoo out of our own pockets to compete alongside this robot on May 6th. This is the kind of team culture and attitude that led to such success on this project.

Over the months spent on this project, our team found great success by consistently improving the design, staying organized, staying committed, and doing good research. By staying consistent, our team was able to design and build a competitive, robust, and sleek combat robot that both ourselves and the University of Cincinnati can be proud of. We believe Voodoo is a perfect representation of the skills we acquired through the College of Engineering and Applied Science, and we hope to further represent the college well at NHRL on May 6th.

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Appendices

House of Quality

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	X	X	X	X	X	X	X	X	X	▼				
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Disassembly/Reassembly time [min]	Components are modular	Pounds [lbs]	Dollars [USD]	Torque [N/m]	Miles per hour [mph]	Is Invertible	Armor Yield Strength [mpa]	Weapon Yield Strength [mpa]	Weapon Angular Velocity [rpm]	Spin Up Time [s]				
1	9	15.0	0.2	Ease of Repair	Θ	Θ													
2	9	9.0	0.1	Modularity of Components	Θ	Θ													
3	9	12.0	0.1	Overall Weight			Θ		▲	O	▲								
4	9	2.0	0.0	Cost				Θ			▲								
5	9	10.0	0.1	Drivetrain Pushing Power			O		Θ										
6	9	11.0	0.1	Drivetrain Speed			O		O	Θ									
7	9	10.0	0.1	Driving While Flipped			▲		O		Θ								
8	9	9.0	0.1	Armor Strength			O					Θ							
9	9	14.0	0.1	Weapon Strength			O	▲					Θ	▲	▲				
10	9	8.0	0.1	Weapon Speed									O	Θ	O				
				Target or Limit Value	< 20 min		≤ 15 lbs	≤ $1300	> 2 N/m	> 7 mph	Is invertible	≥ 250 mpa	> 1100 Mpa	≥ 10000 rpm	≤ 2 sec				
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	6		7	6	2	4	4	1	1	2	3				
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	3				
				Weight / Importance	216.0	216.0	250.0	32.0	165.0	135.0	104.0	81.0	150.0	86.0	38.0				
				Relative Weight	14.7	14.7	17.0	2.2	11.2	9.2	7.1	5.5	10.2	5.8	2.6				

Figure 2.2: HOQ Rooms 1, 2, 3, 4, 6, and 7

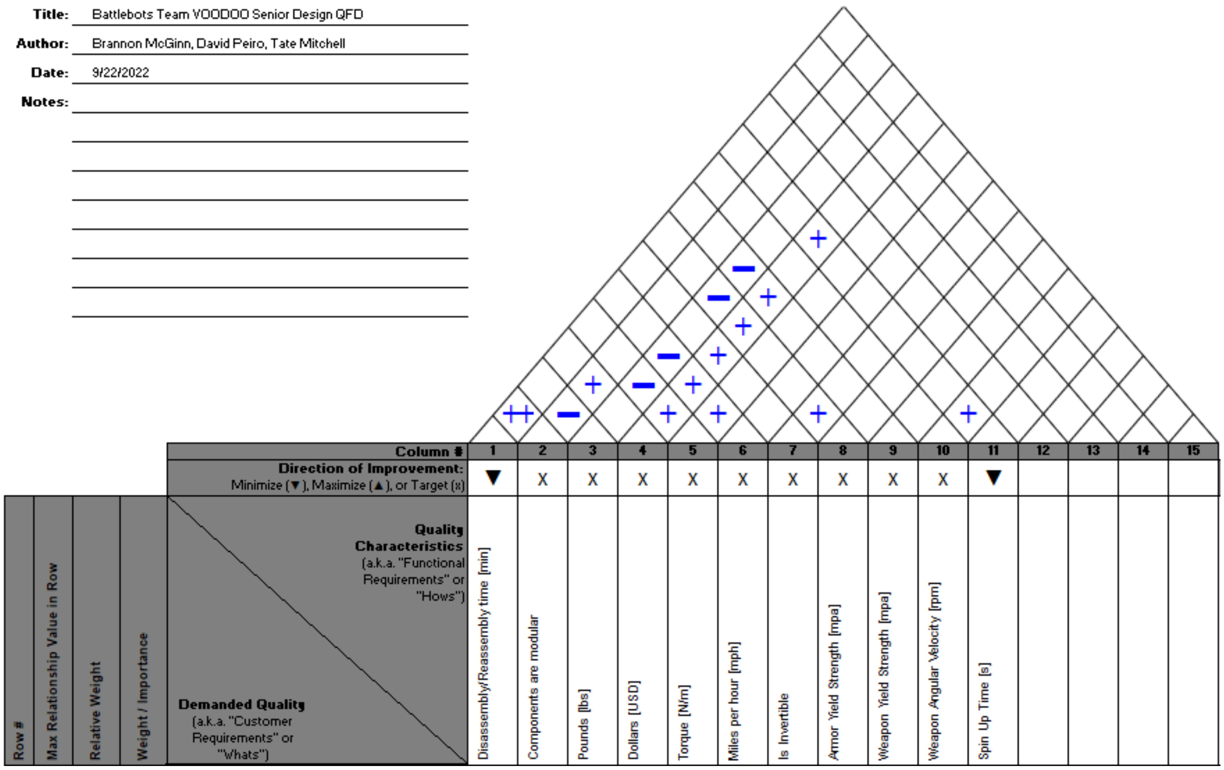


Figure 2.3: HOQ Room 8

Competitive Analysis
(0=Worst, 5=Best)

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

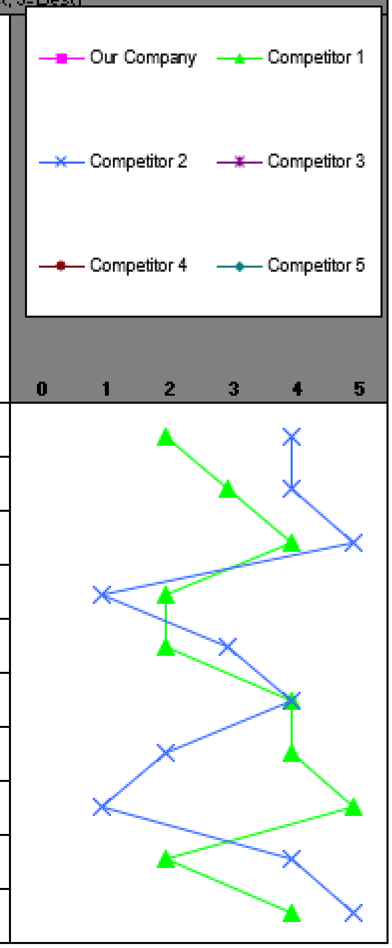


Figure 2.4: HOQ Room 5, Benchmark Satisfaction

Survey Questions

1. Have you ever seen or participated in a combat robotics event / match?

(Y/N)

2. Rate the importance of the following feature in Combat Robotics: **Ease of Repair**

(1-10)

3. Rate the importance of the following feature in Combat Robotics: **Component Modularity**

(1-10)

4. Rate the importance of the following feature in Combat Robotics: **Cost of Robot**

(1-10)

5. Rate the importance of the following feature in Combat Robotics: **Drive-train Reliability**

(1-10)

6. Rate the importance of the following feature in Combat Robotics: **Drive-train Push Power**

(1-10)

7. Rate the importance of the following feature in Combat Robotics: **Drive-train Speed**

(1-10)

8. Rate the importance of the following feature in Combat Robotics: **Self Righting Capabilities**

(1-10)

9. Rate the importance of the following feature in Combat Robotics: **Armor Strength**

(1-10)

10. Rate the importance of the following feature in Combat Robotics: **Weapon Speed**

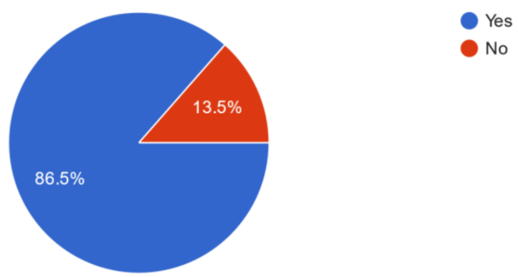
(1-10)

11. Rate the importance of the following feature in Combat Robotics: **Weapon Reliability**

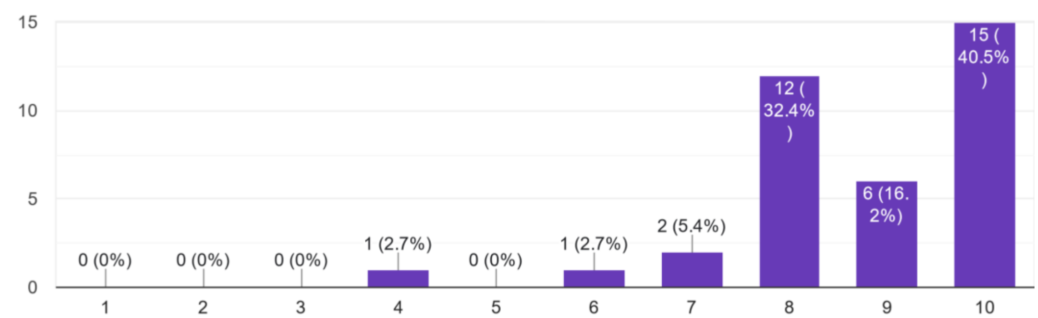
(1-10)

Survey Results

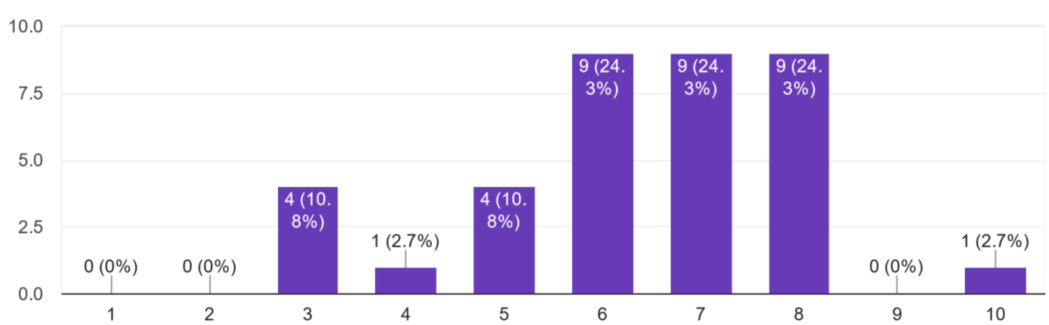
1. Have you ever seen or participated in a Battle Bots event / match?
37 responses



2. Rate the importance of the following feature in Combat Robotics: Ease of Repair
37 responses

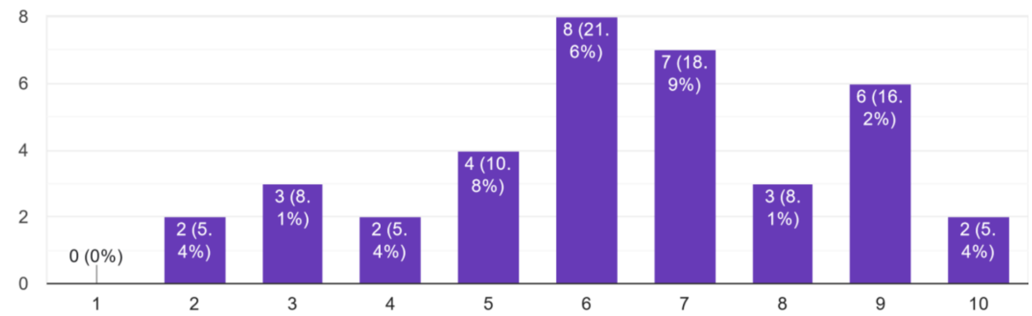


3. Rate the importance of the following feature in Combat Robotics: Component Modularity
37 responses



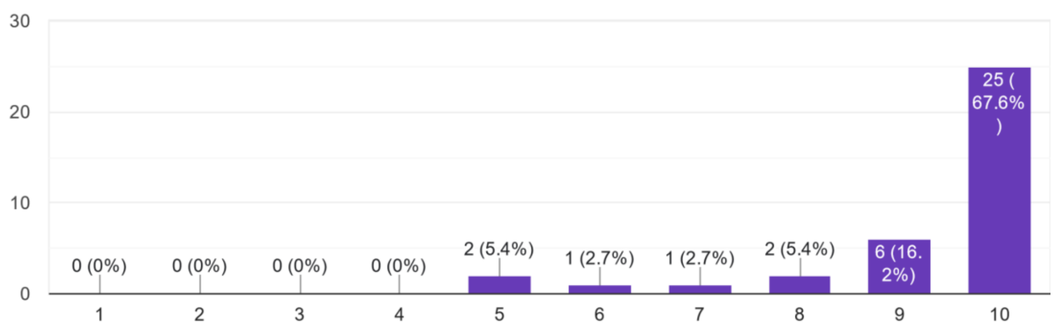
5. Rate the importance of the following feature in Combat Robotics: Cost of Robot

37 responses



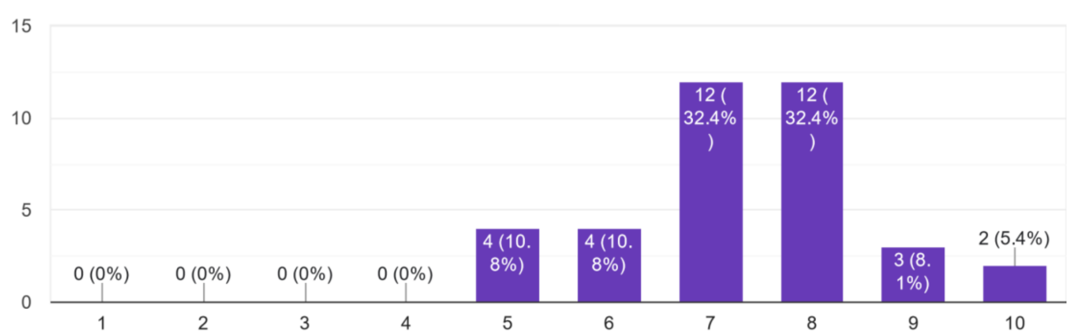
6. Rate the importance of the following feature in Combat Robotics: Drive-train Reliability

37 responses

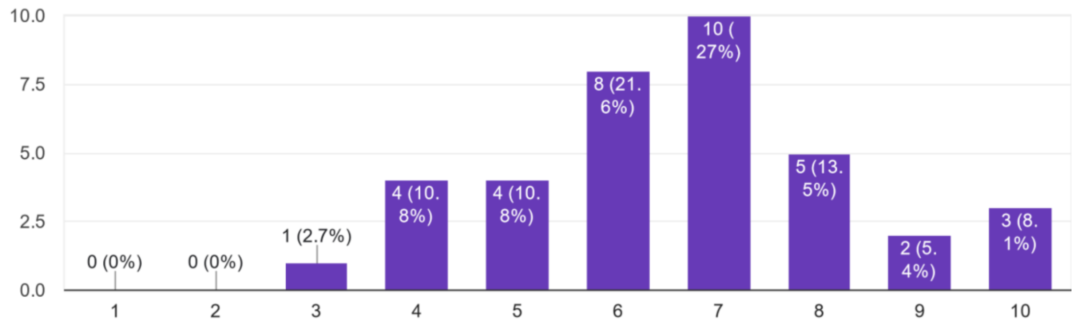


7. Rate the importance of the following feature in Combat Robotics: Drive-train Pushing Power

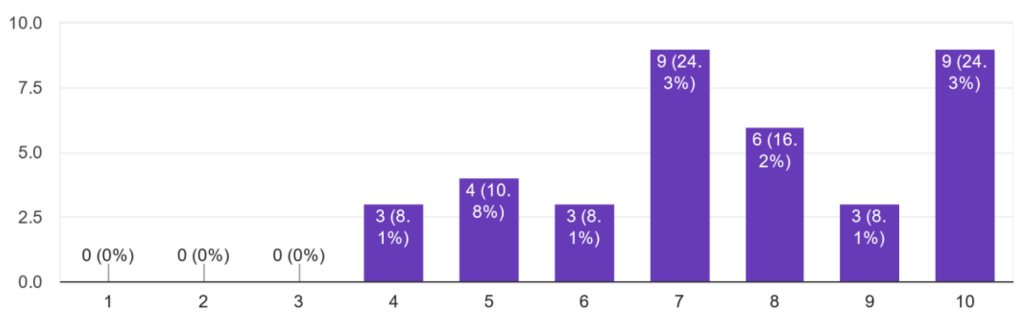
37 responses



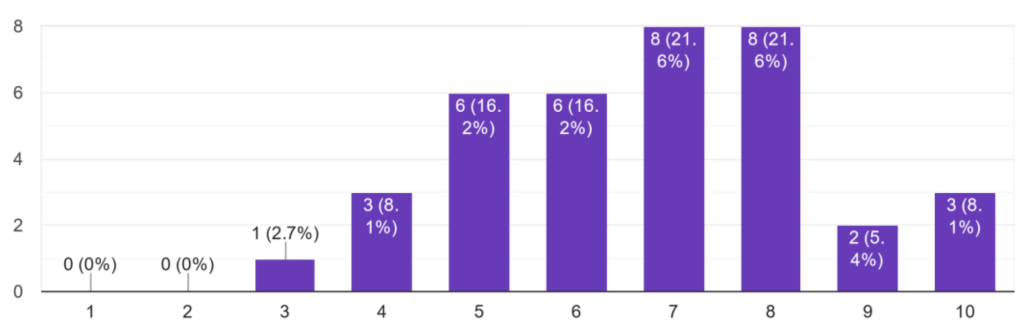
8. Rate the importance of the following feature in Combat Robotics: Drive-train Speed
37 responses



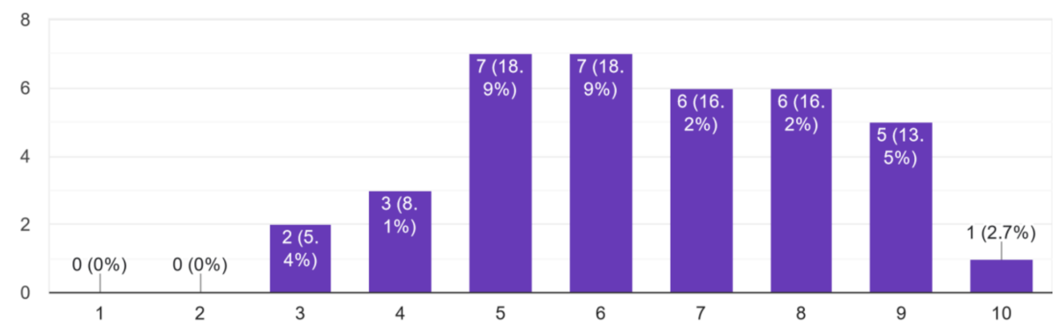
9. Rate the importance of the following feature in Combat Robotics: Self Righting Capabilities
37 responses



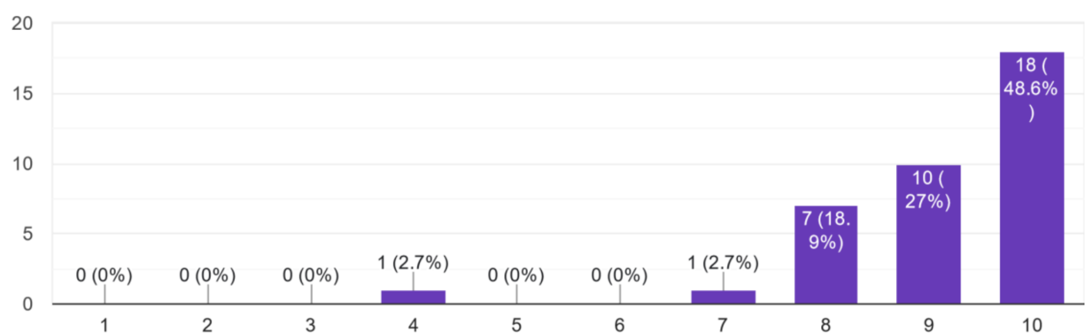
10. Rate the importance of the following feature in Combat Robotics: Armor Strength
37 responses



11. Rate the importance of the following feature in Combat Robotics: Weapon Speed
37 responses



12. Rate the importance of the following feature in Combat Robotics: Weapon Reliability
37 responses



Calculations

Weapon Performance Calculations

Target Values:

$$Weapon\ tip\ speed: 175mph$$
$$Weapon\ spin\ up\ time: < 1\ second$$

Inputs:

$$6s\ Lipo\ Battery\ Voltage = 22.2V$$
$$Weapon\ Dia = 6.5in$$
$$Weapon\ MOI = 1853000gmm^2 = 0.001853kgm^2$$

$$Weapon\ RPM\ for\ desired\ tip\ speed = \frac{Tip\ speed\ (mph) \cdot (5280ft/mi)}{(Weapon\ dia\ (in)\ /12in/ft) \cdot (60min/hr) \cdot \pi}$$

$$= \frac{(175\ mph) \cdot (5280ft/mi)}{(6.5in\ /12in/ft) \cdot (60min/hr) \cdot \pi}$$
$$= \frac{924{,}000ft/hr}{(0.5417ft) \cdot (60min/hr) \cdot \pi}$$

$$Weapon\ RPM\ for\ desired\ tip\ speed = 9{,}054\ RPM$$

$$Motor\ RPM = Weapon\ RPM \cdot \left(\frac{Driven\ Pulley\ T}{Driver\ Pulley\ T}\right)$$
$$= 9{,}054\ RPM \cdot \left(\frac{40\ T}{12\ T}\right)$$

$$Motor\ RPM = 30{,}180\ RPM$$

$$Minimum\ Motor\ kv = \frac{Motor\ RPM}{Battery\ Voltage} = \frac{30{,}180\ RPM}{22.2\ V} = 1360kv$$

$$Minimum\ Motor\ kv = 1360kv$$

$$Weapon\ Deg/s = Weapon\ RPM \cdot 6 = 9{,}054RPM \cdot 6$$

$$Weapon\ Deg/s = 54{,}324\ deg/s$$

$$Weapon\ Rad/s = Weapon\ deg/s \cdot \left(\frac{\pi}{180deg}\right) = 54{,}324\ deg/s \cdot \left(\frac{\pi}{180deg}\right)$$

$$Weapon\ Rad/s = 948\ rad/s$$

$$Weapon\ Energy = (0.5) \cdot (Weapon\ MOI) \cdot (Weapon\ Rad/s)^2$$

$$Weapon\ Energy = (0.5) \cdot (0.001853kgm^2) \cdot (948\ rad/s)^2$$

$$Weapon\ Energy = 833J$$

$$Minimum\ Motor\ Wattage = \frac{Weapon\ Energy}{Spin\ up\ time} = \frac{833J}{0.9s} = 925W$$

$$Minimum\ Motor\ Wattage = 925W$$

Outputs:

$$Weapon\ RPM\ for\ desired\ tip\ speed = 9{,}054\ RPM$$
$$Weapon\ Energy = 833J$$

$$Minimum\ Motor\ kv\ =\ \mathbf{1360kv}$$

$$Minimum\ Motor\ Wattage\ =\ \mathbf{925W}$$

Drivetrain Performance Calculations

Target Values:

$$Travel\ the\ length\ of\ the\ arena\ in\ 1.5\ seconds$$

Inputs:

$$4s\ Lipo\ Battery\ Voltage\ =\ 14.8V$$

$$Arena\ Size\ =\ 16ft\ x\ 16ft$$

$Front\ Wheel\ Dia\ =\ 1.625in$

$Rear\ Wheel\ Dia\ =\ 2.875in$

$$Fingertech\ Gearbox\ Ratio\ =\ 1:21.5$$

$$Required\ Drivetrain\ Speed\ =\ \left(\frac{Arena\ Length}{Travel\ Time}\right) = \left(\frac{16ft}{1.5s}\right) = 10.67\ ft/s\ = 7.3mph$$

$$Required\ Wheel\ RPM = \left(\frac{Drivetrain\ Speed}{Front\ Wheel\ Dia\ \cdot\ \pi}\right) \cdot \left(\frac{63360in/mi}{60min/hr}\right)$$

$$Required\ Wheel\ RPM = \left(\frac{7.3mph}{1.625in\ \cdot\ \pi}\right) \cdot \left(\frac{63360in/mi}{60min/hr}\right) = 1{,}510\ RPM$$

$$Required\ Motor\ RPM = \ Wheel\ RPM\ \cdot\ Gearbox\ Ratio$$

$$Required\ Motor\ RPM =\ (1{,}510RPM) \cdot (21.5) = 32{,}465RPM$$

$$Minimum\ Motor\ kv\ = \frac{Req\ Motor\ RPM}{Battery\ Voltage} = \frac{32{,}465\ RPM}{14.8\ V} = 2194kv$$

Outputs:

$$Required\ Drive\ Train\ Speed\ =\ 7.3\ mph$$

$$Required\ Wheel\ RPM\ =\ 1{,}510\ RPM$$

$$Minimum\ Motor\ kv\ =\ \mathbf{2194}\boldsymbol{kv}$$

Electronic Components Calculations

Target Values:

$$Batteries\ lasts\ for\ full\ match{:}\ 3\ min$$

$$ESCs\ rating\ exceed\ burst\ amperage\ of\ motors$$

Inputs:

$$6s\ Lipo\ Battery\ Voltage\ =\ 22.2V$$

$$Weapon\ Motor\ Wattage\ =\ 1440W$$

$$Drive\ Motor\ Continuous\ Amp\ draw\ =\ 7A$$

$$Weapon\ Motor\ Burst\ Amperage\ =\ \left(\frac{Motor\ Wattage}{Battery\ Voltage}\right) = \left(\frac{1440W}{22.2V}\right) = 65A$$

$$Weapon\ Motor\ Continuous\ Amperage\ = 45A$$

$$Milliampere\ hour\ required\ =$$

$$=\ Total\ Continuous\ Amperage \cdot \left(Match\ Time\ \cdot \left(\frac{1min}{60s}\right)\right) \cdot \left(\frac{1000mA}{1A}\right)$$

$$=\ (45A + 7A) \cdot \left(3min\ \cdot \left(\frac{1min}{60s}\right)\right) \cdot \left(\frac{1000mA}{1A}\right)$$

$$= (52A) \cdot (0.05s) \cdot \left(\frac{1000mA}{1A}\right)$$

$$Milliampere\ hour\ required\ =\ 2600mAh$$

Outputs:

$$Required\ Battery\ Capacity\ =\ 2600mAh$$

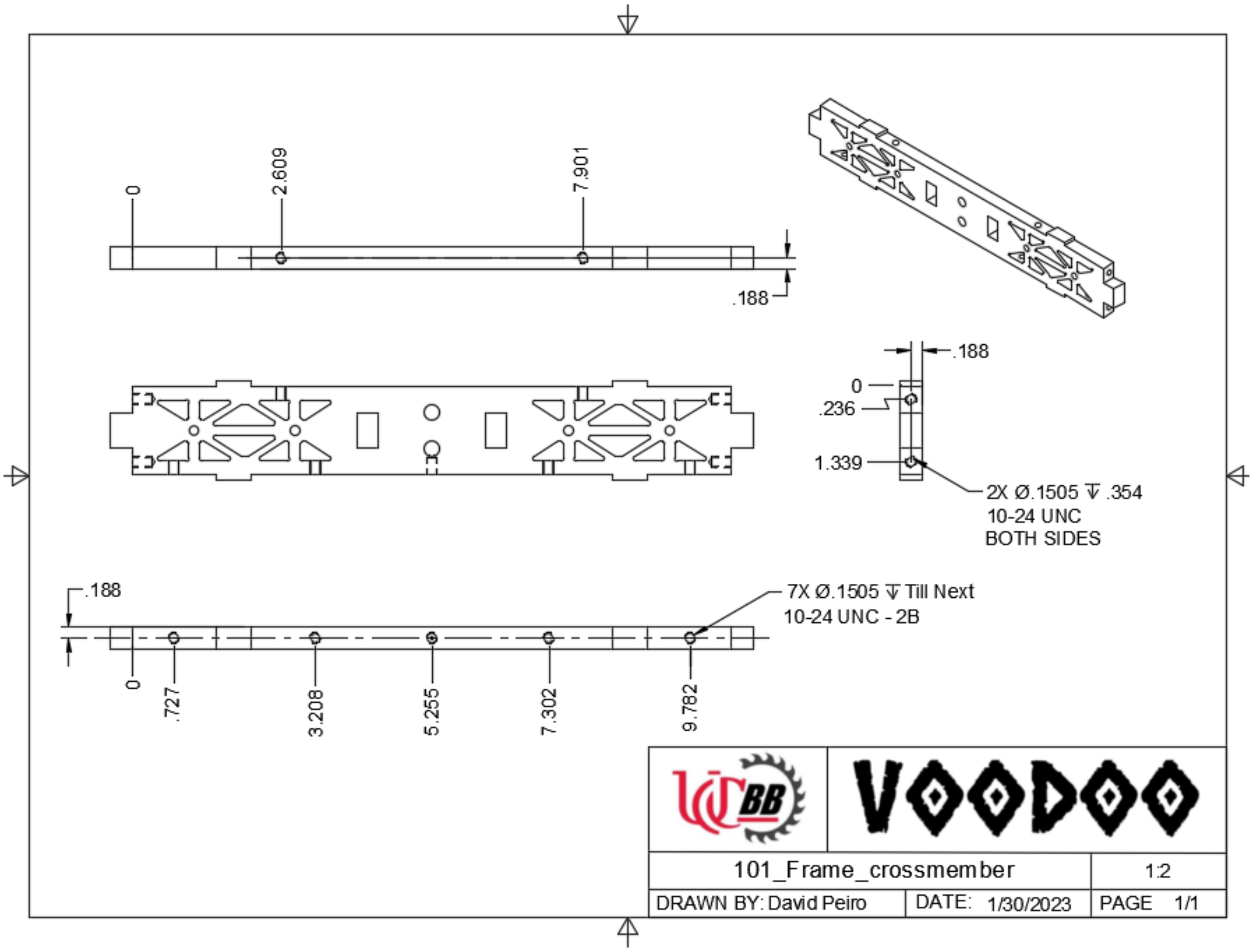
$$Weapon\ ESC\ Burst\ Rating\ >\ 65A$$

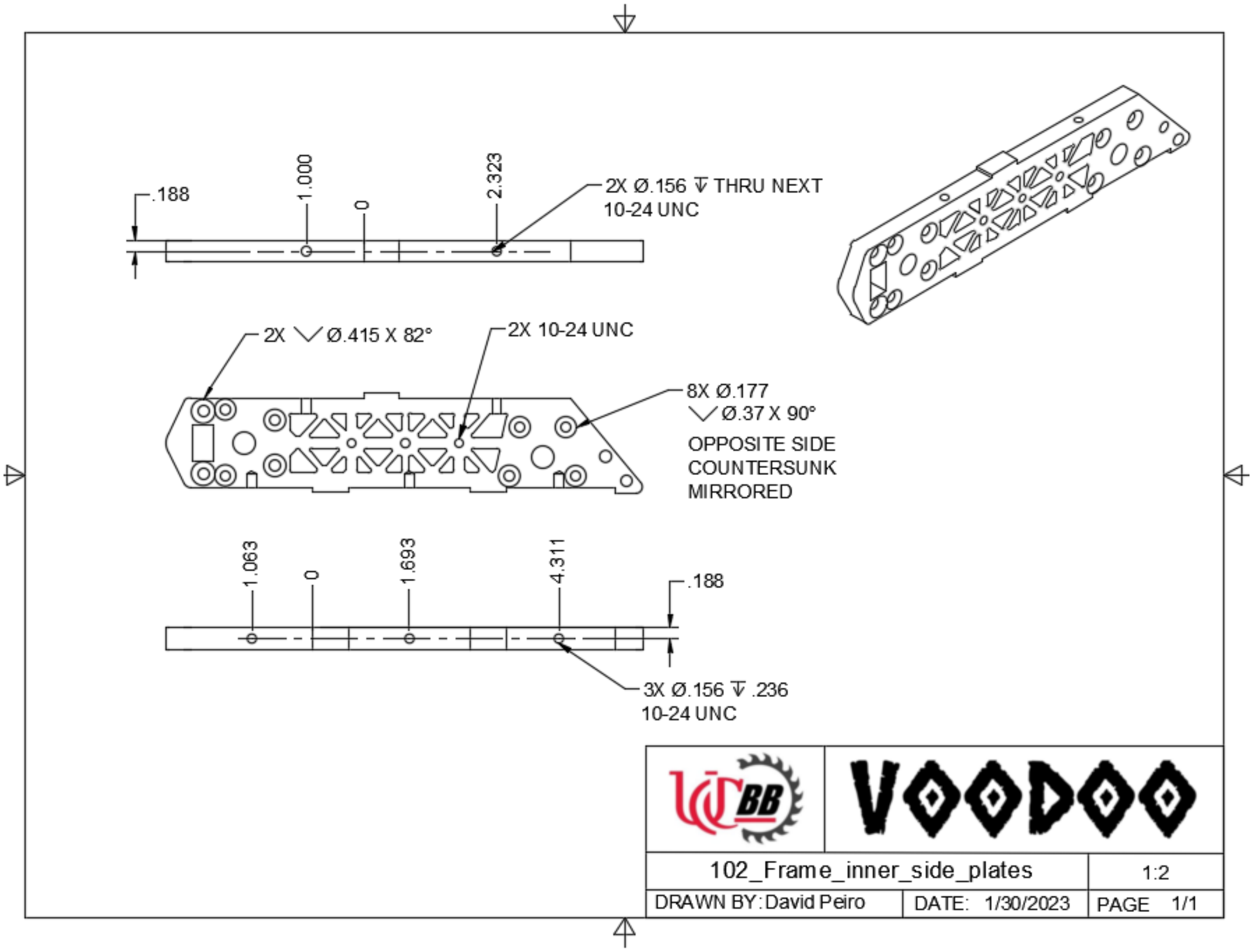
$$Drive\ ESC\ Burst\ Rating\ \geq\ 20A$$

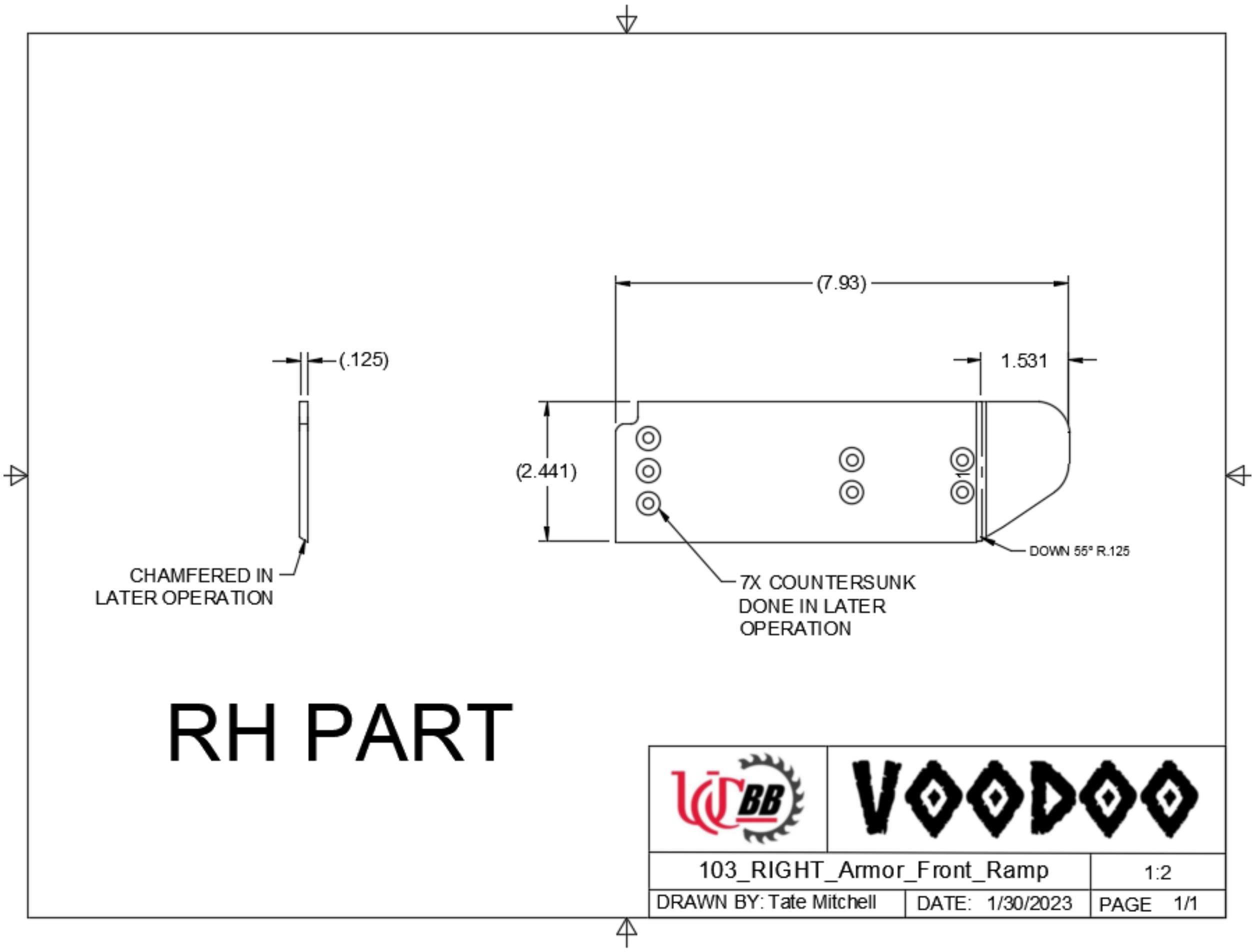
Bill of Materials

Description*	Quant	Price/Ur	Total	Manufacturer
Grade 5 Titanium 1/8in Right Wedge	1	$71.34	$71.34	SendCutSend
Grade 5 Titanium 1/8in Left Wedge	1	$71.34	$71.34	SendCutSend
BaneBots Wheel, 1-5/8" x 0.4", 1/2" Hex Mount, 50A, Black/Blue	6	$2.50	$15.00	BaneBots
BaneBots Wheel, 2-7/8" x 0.8", Hub Mount, 50A, Blue	4	$3.50	$14.00	BaneBots
FingerTech Brushless Mega Spark - Premium Planetary Gearmotor	4	$49.94	$199.76	Fingertech Robotics
T-Motor Velox V2 V45A 3-6S BLHeli_32 4-in-1 ESC	2	$55.99	$111.98	Tiger Motors
Tattu R-Line Version 4.0 1300mAh 6S1P 130C Lipo Battery	4	$39.99	$159.96	BadAss
AR620 DSMX 6-Channel Sport Receiver	1	$49.99	$49.99	Spektrum
0.375in Medium NutStrip 15x15, 10-24 thread	2	$13.22	$26.44	Fingertech Robotics
Bottom Plate	1	$21.10	$21.10	SendCutSend
6061 Aluminum Round Stock 3/8" Diameter (1ft)	1	$1.84	$1.84	McMaster-Carr
Black Oxide Alloy Steel Torx Flat Hd 10-24, 5/8" Lg (pack of 50)	1	$13.65	$13.65	McMaster-Carr
Black-Oxide Alloy Steel Torx But Hd 10-24 Thread, 3/4" Lg (pk 50)	1	$13.57	$13.57	McMaster-Carr
Button Head Hex Drive Screw Black-Oxide Alloy Steel, M6 x 1.00 m	1	$14.41	$14.41	McMaster-Carr
Button Head Hex Drive Screw Black-Oxide Alloy Steel, M6 x 1.00 m	1	$9.69	$9.69	McMaster-Carr
Low-Profile Shoulder Screw 8 mm Shoulder Diameter, 20 mm Shou	2	$8.56	$17.12	McMaster-Carr
Alloy Steel Socket Head Screw Black-Oxide, M5 x 0.8mm Thread, 3	1	$13.75	$13.75	McMaster-Carr
Black-Oxide Alloy Steel Hex Drive Flat Head Screw M4 x 0.70 mm T	1	$16.75	$16.75	McMaster-Carr
Alloy Steel Socket Head Screw Black-Oxide, M3 x 0.5 mm Thread,	1	$9.54	$9.54	McMaster-Carr
Alloy Steel Socket Head Screw Black-Oxide, M2 x 0.4 mm Thread,	1	$15.08	$15.08	McMaster-Carr
Overture TPU Filament 1.75mm PURPLE	1	$26.99	$26.99	Overture
Uncoated High-Speed Steel Countersink for Screws, 82 Degree, 3	1	$11.33	$11.33	McMaster-Carr
Uncoated High-Speed Steel General Purpose Tap Bottoming Cham	1	$5.74	$5.74	McMaster-Carr
Multipurpose 6061 Aluminum 3/8" Thick x 12" Wide x 24" Long	1	$80.00	$80.00	McMaster-Carr
UHMW Polyethylene Plastic Sheet 3/8" Thick x 12" Wide x 24" Lon	1	$24.00	$24.00	BuyPlastic
UHMW Polyethylene Plastic Sheet 1/2" Thick x 6" Wide x 12" Long	1	$8.00	$8.00	BuyPlastic
BadAss 2814-1560Kv Brushless Motor	2	$56.99	$113.98	BadAss
SIDEWINDER 8TH ESC, 25.2V ESC, 8A PEAK BEC, WP	1	$129.95	$129.95	Castle
6903 2RS, 17mm Bore Diam, 30mm OD, Double Seal Deep Groove	6	$7.29	$43.74	Koyo
Weapon Blade	2	$30.72	$61.44	SendCutSend
Bearing Plate	2	$5.58	$11.16	SendCutSend
Timing Belt Pulley XL Series, 3/8" Maximum Belt Width, with Hub, 2	2	$10.33	$20.66	McMaster-Carr
XL Series Timing Belt, Trade No. 140XL037	1	$8.05	$8.05	McMaster-Carr
Steel Hex Head Shoulder Screw 17mm M16 x 2mm Thread	2	$13.14	$26.28	McMaster-Carr
Steel-Insert Locknut for Extreme Vibration Class 8, M16 x 2 mm Th	2	$6.26	$12.52	McMaster-Carr
Steel Wedge Lock Washer for M16 Screw Size (Pack of 8)	1	$12.70	$12.70	McMaster-Carr
Bearing 608ZZ Shielded 8x22x7 Ball Bearings (Pack of 10)	1	$9.99	$9.99	VXB
12x24 g10 sheet 1/8"	1	$60.00	$60.00	

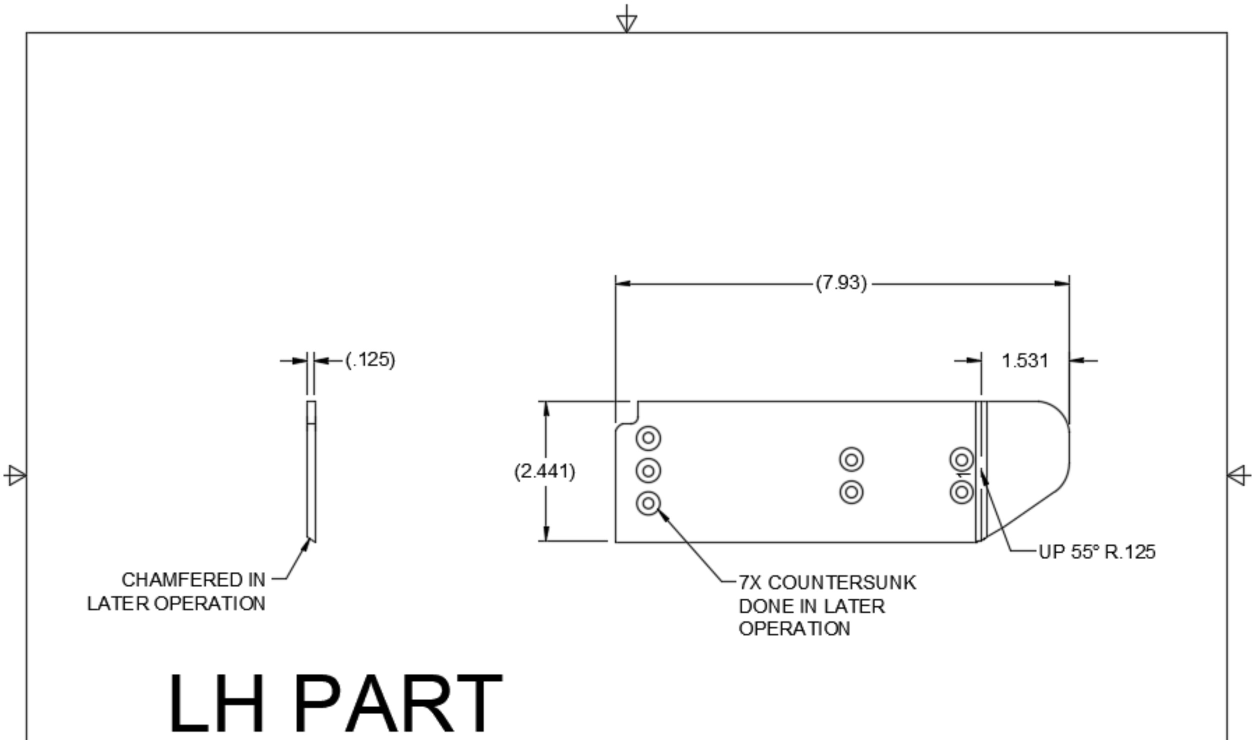
Manufacturing Prints



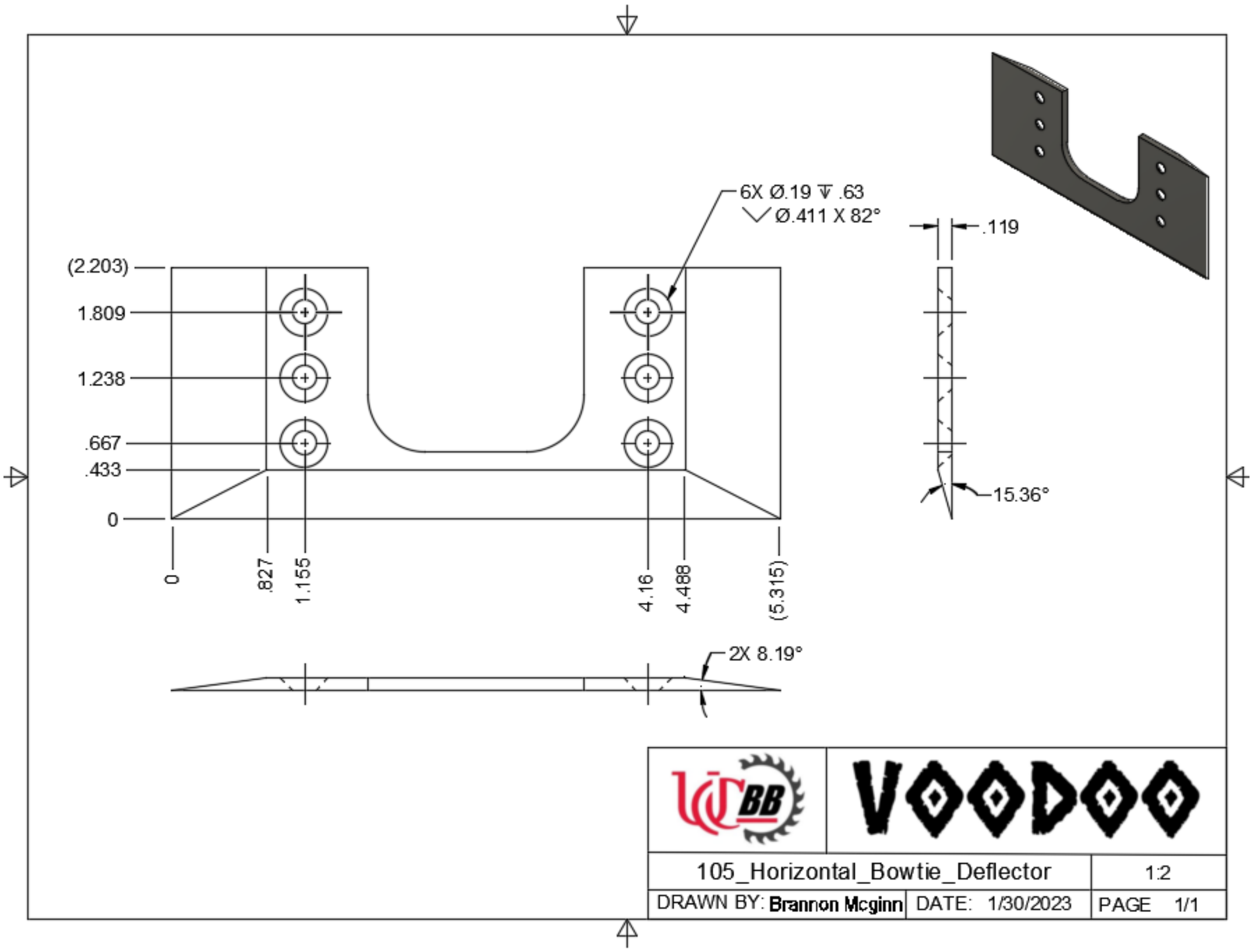

.188
1.000
0
2.323
2X Ø.156 ↧ THRU NEXT
10-24 UNC
2X ⌵ Ø.415 X 82°
2X 10-24 UNC
8X Ø.177
⌵ Ø.37 X 90°
OPPOSITE SIDE
COUNTERSUNK
MIRRORED
1.063
0
1.693
4.311
.188
3X Ø.156 ↧ .236
10-24 UNC
VOODOO
102_Frame_inner_side_plates
1:2
DRAWN BY: David Peiro
DATE: 1/30/2023
PAGE 1/1

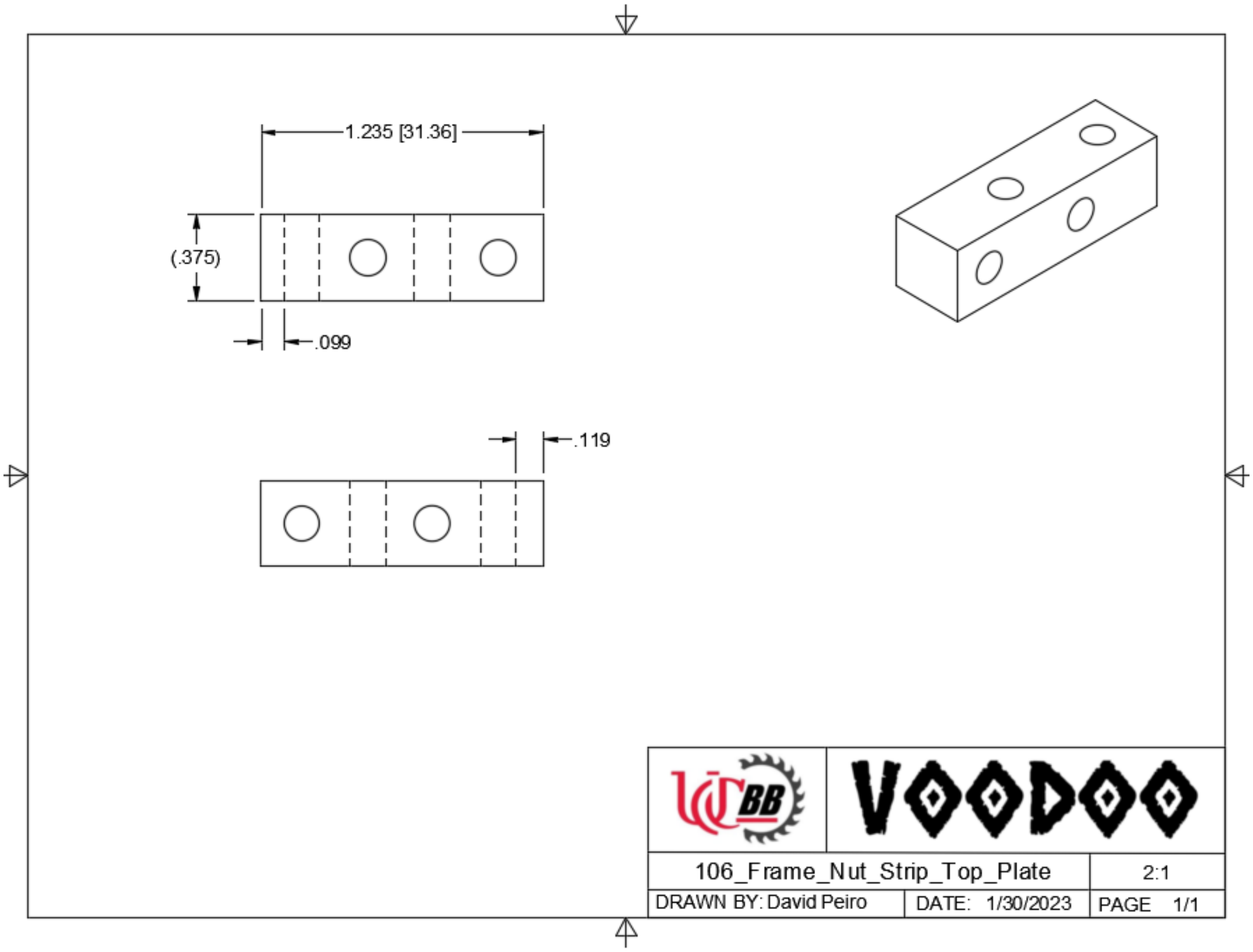


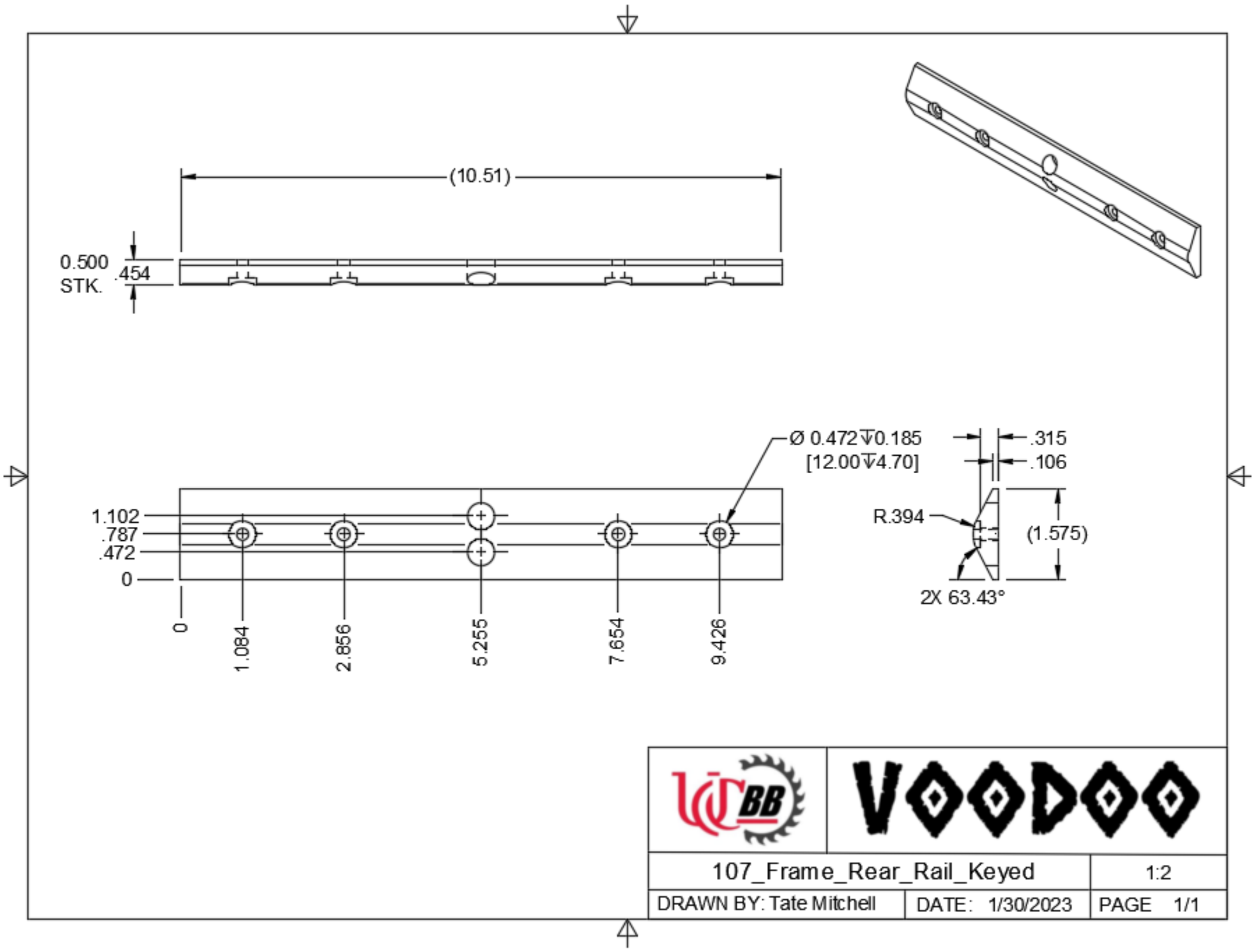
(.125)
(7.93)
1.531
(2.441)
CHAMFERED IN LATER OPERATION
7X COUNTERSUNK DONE IN LATER OPERATION
DOWN 55° R.125
RH PART
VOODOO
103_RIGHT_Armor_Front_Ramp
1:2
DRAWN BY: Tate Mitchell
DATE: 1/30/2023
PAGE 1/1



VOODOO		
104_LEFT_Armor_Front_Ramp		1:2
DRAWN BY: Tate Mitchell	DATE: 1/30/2023	PAGE 1/1


6X Ø.19 ⏷ .63
⌵ Ø.411 X 82°
.119
(2.203)
1.809
1.238
.667
.433
0
15.36°
0
.827
1.155
4.16
4.488
(5.315)
2X 8.19°
VOODOO
105_Horizontal_Bowtie_Deflector
1:2
DRAWN BY: Brannon Mcginn
DATE: 1/30/2023
PAGE 1/1


1.235 [31.36]
(.375)
.099
.119
VOODOO
106_Frame_Nut_Strip_Top_Plate
2:1
DRAWN BY: David Peiro
DATE: 1/30/2023
PAGE 1/1



(10.51)
0.500
STK.
.454
Ø 0.472↧0.185
[12.00↧4.70]
.315
.106
1.102
.787
.472
0
R.394
(1.575)
2X 63.43°
0
1.084
2.856
5.255
7.654
9.426
VOODOO
107_Frame_Rear_Rail_Keyed
1:2
DRAWN BY: Tate Mitchell
DATE: 1/30/2023
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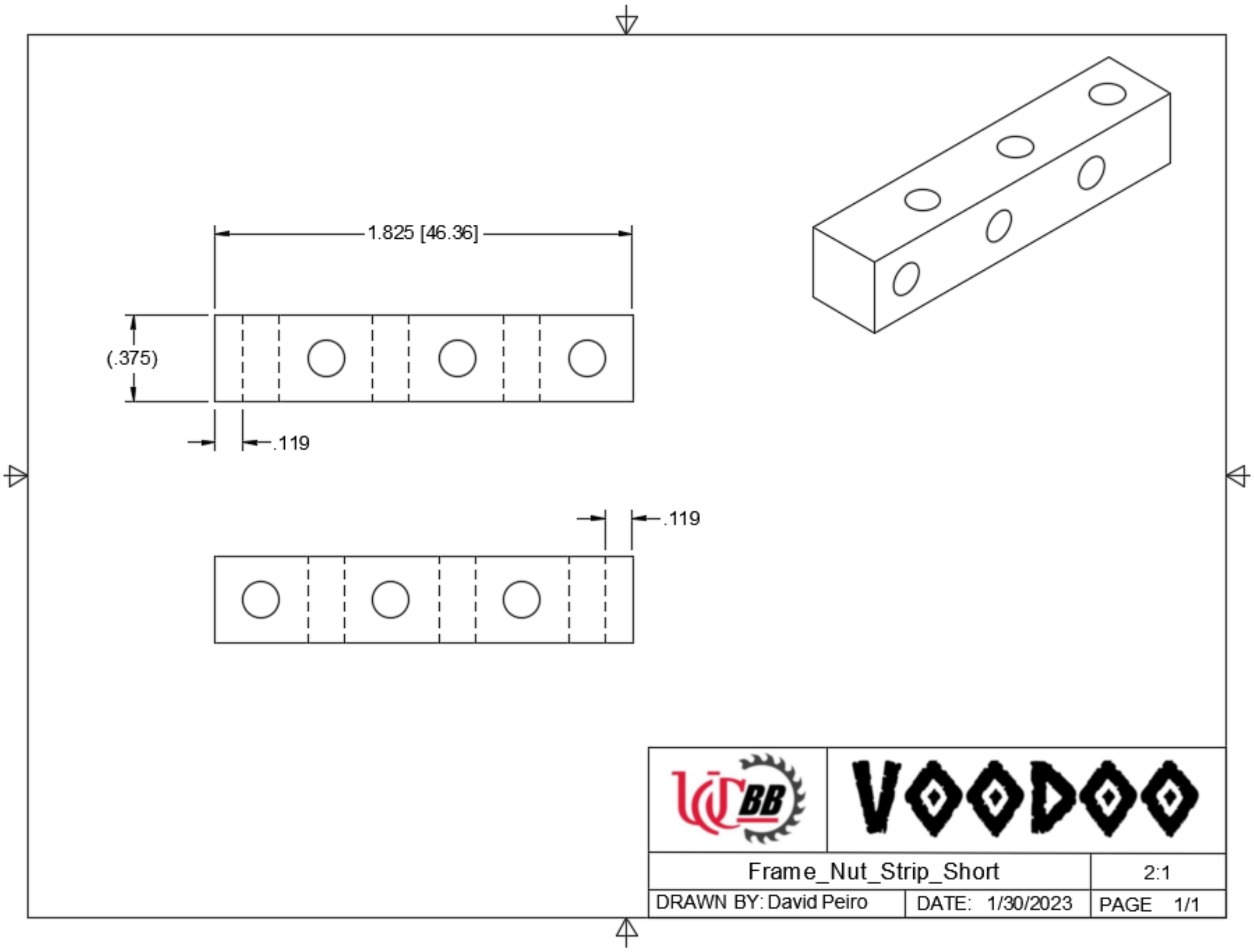
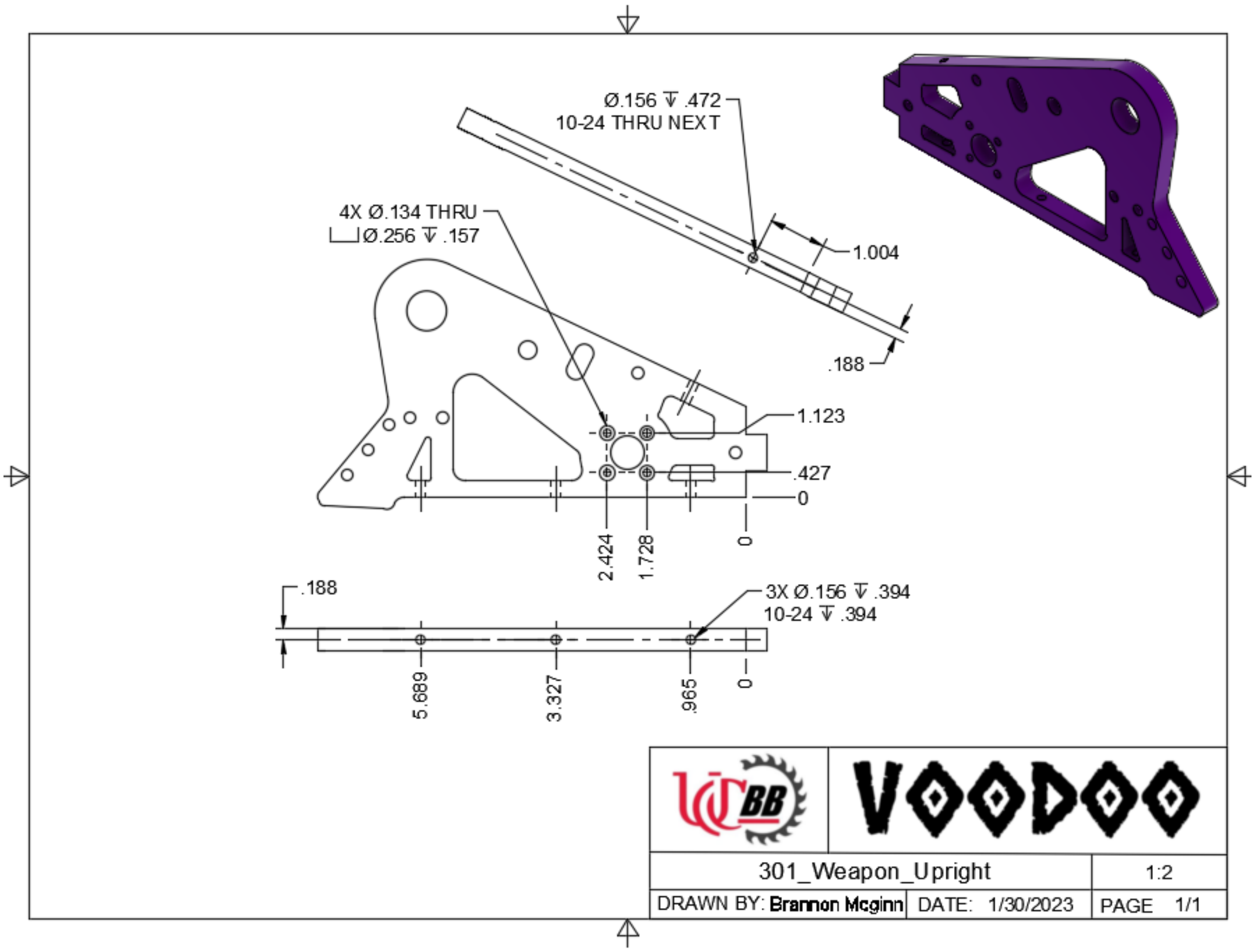
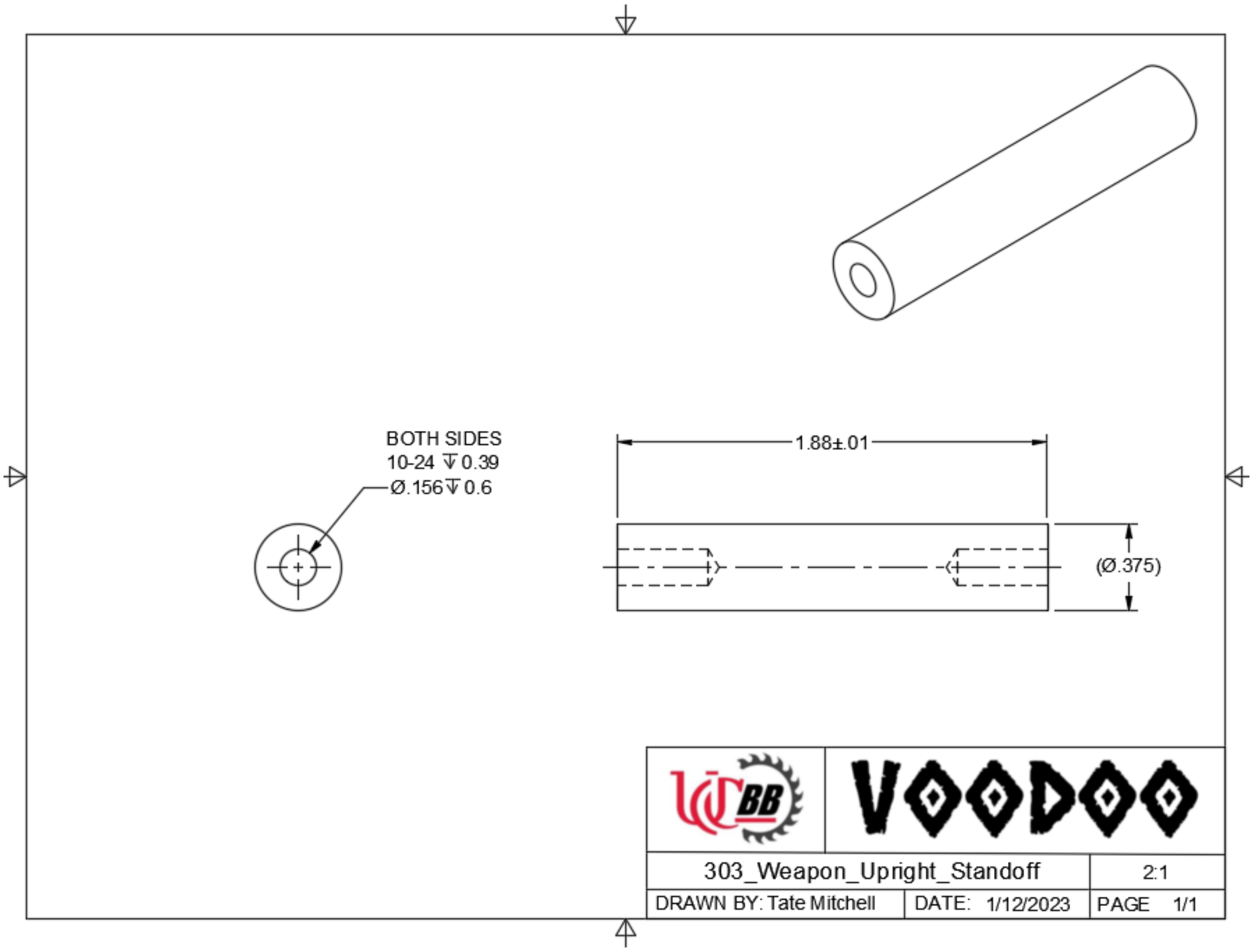
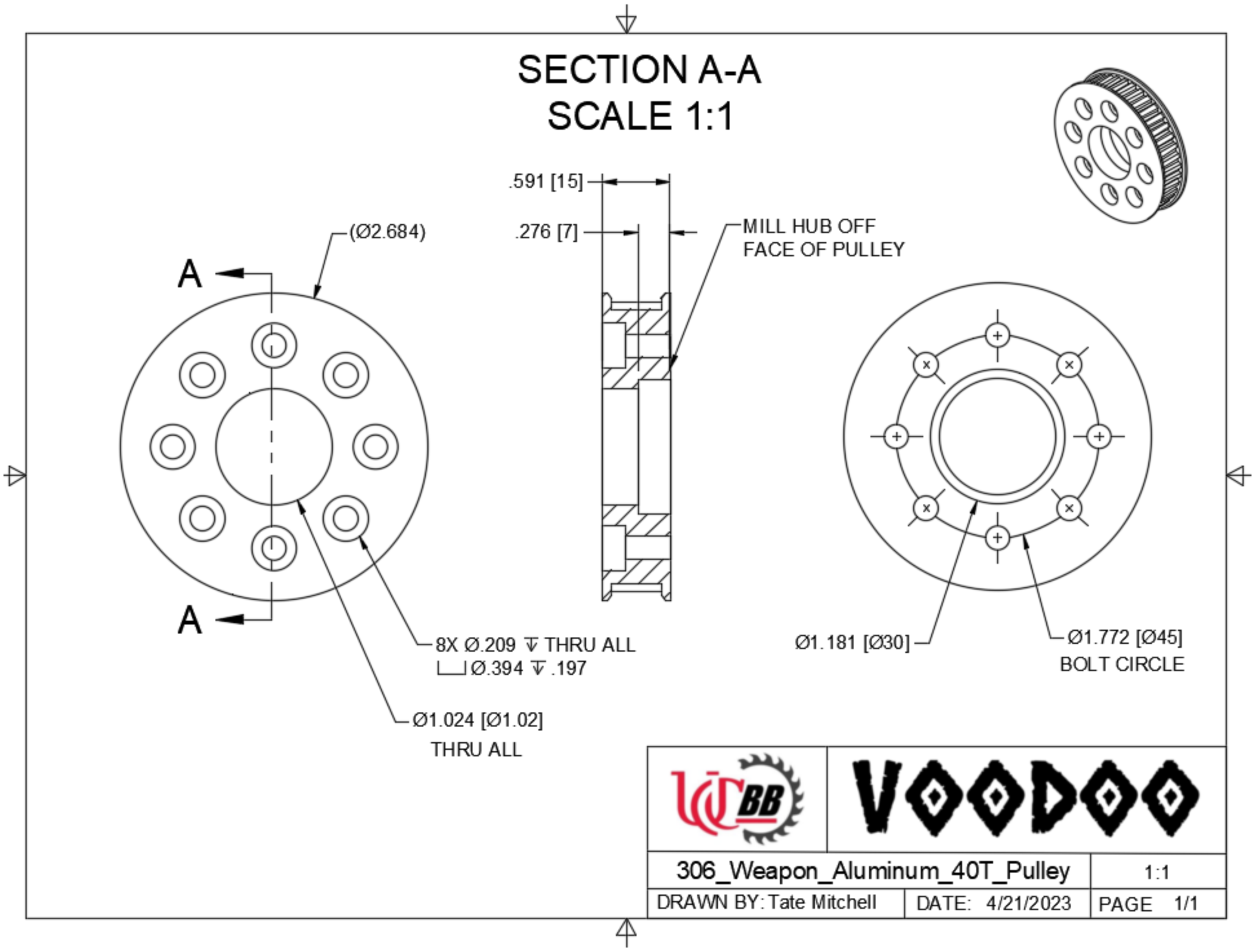
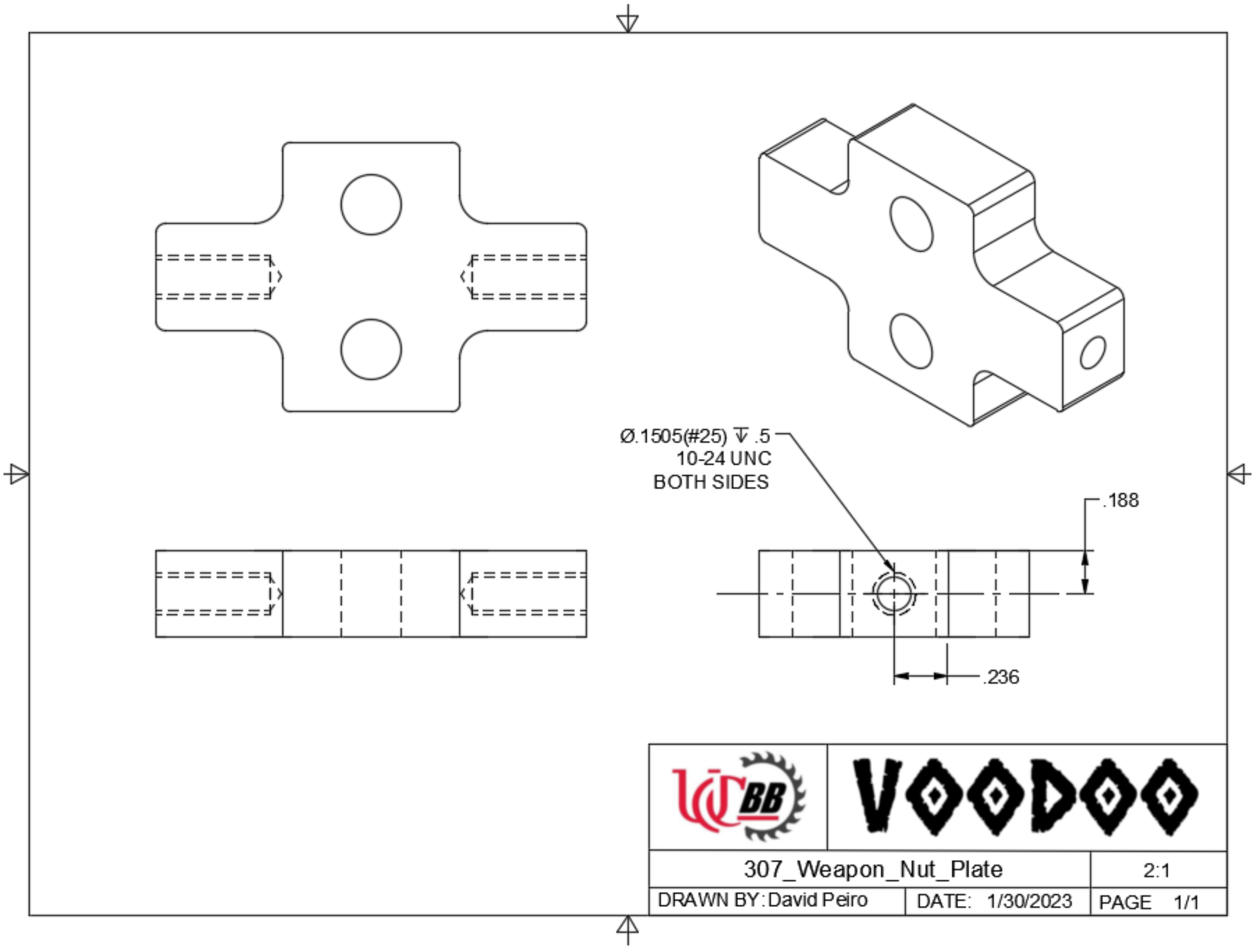
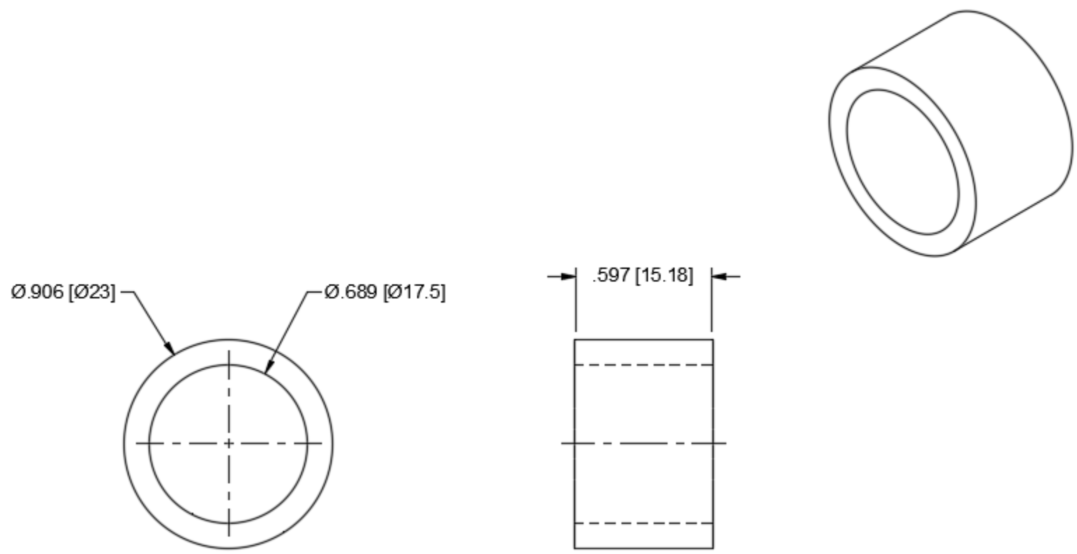

1.825 [46.36]
(.375)
.119
.119
Frame_Nut_Strip_Short
2:1
DRAWN BY: David Peiro
DATE: 1/30/2023
PAGE 1/1


Ø.156 ↧ .472
10-24 THRU NEXT
4X Ø.134 THRU
⌴ Ø.256 ↧ .157
1.004
.188
1.123
.427
0
2.424
1.728
0
.188
3X Ø.156 ↧ .394
10-24 ↧ .394
5.689
3.327
.965
0
VOODOO
301_Weapon_Upright
1:2
DRAWN BY: Brannon Mcginn
DATE: 1/30/2023
PAGE 1/1

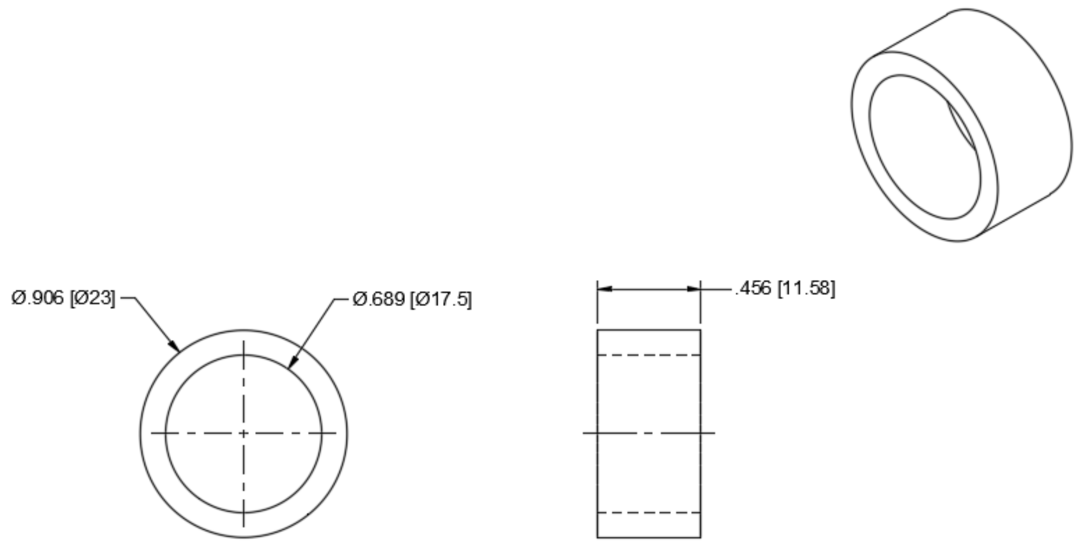

BOTH SIDES
10-24 ⊽ 0.39
Ø.156 ⊽ 0.6
1.88±.01
(Ø.375)
VOODOO
303_Weapon_Upright_Standoff
2:1
DRAWN BY: Tate Mitchell
DATE: 1/12/2023
PAGE 1/1


SECTION A-A
SCALE 1:1
.591 [15]
.276 [7]
MILL HUB OFF FACE OF PULLEY
(Ø2.684)
A
A
8X Ø.209 ↧ THRU ALL
⌴ Ø.394 ↧ .197
Ø1.024 [Ø1.02] THRU ALL
Ø1.181 [Ø30]
Ø1.772 [Ø45] BOLT CIRCLE
VOODOO
306_Weapon_Aluminum_40T_Pulley
1:1
DRAWN BY: Tate Mitchell
DATE: 4/21/2023
PAGE 1/1


Ø.1505(#25) ↧ .5
10-24 UNC
BOTH SIDES
.188
.236
VOODOO
307_Weapon_Nut_Plate
2:1
DRAWN BY: David Peiro
DATE: 1/30/2023
PAGE 1/1



309_Right_Weapon_Centering_Spacer		2:1
DRAWN BY: Tate Mitchell	DATE: 1/30/2023	PAGE 1/1



310_Left_Weapon_Centering_Spacer		2:1
DRAWN BY: Tate Mitchell	DATE: 1/30/2023	PAGE 1/1