

2020 UC MET Battlebot Team

15lb Bot Senior Design II Report

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by

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ABSTRACT

This report details the research, design, proposed testing, and the predicted performance of our teams 15lb battlebot. Our team took on this challenge in order to compete our senior design project. This project was a major test of our work ethic, project management skills, and the theory knowledge we gained in the MET program. Due to covid-19 related shutdowns this bot was not able to compete or be built. The construction and performance of the bot will be theorized in this report. We hope that other teams can learn from our design.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

Our team must design a successful combat robot to compete in the Xtreme Collegiate Clash 15lb combat competition. This design must be in accordance with the rules, regulations, and safety standards adopted by the competition. A successful combat robot it must be able to disable other robots in competition, put on an entertaining show, last multiple rounds, and be an improvement upon past UC senior designed Battlebots. The key areas of design are Weapon design, Frame/Armor design, and the Drivetrain/Electronics design. Weapon design will be managed by Isabella long, Drivetrain/Electronics design will be managed by Mathew Itapson, and Fred Schroeder will manage the Frame/Armor design.

BACKGROUND

Battlebots is a worldwide engineering endeavor, centered around good ol' fashioned robot fighting. Most commonly, teams will gather around the engineering objective of designing a robot with offensive & defensive capabilities, that can last multiple fights. The Battlebots competitions are held by several different organizations worldwide. This year, the UC Battlebots team will be competing in Xtreme Collegiate Clash. Xtreme Collegiate Clash is a combat robotics showdown, for college students, hosted by Xtreme Stem, and their Non-profit parent company Ohio Robotics Inc. Xtreme Stem has a mission to “provide hands-on programs that engage students in Science, Technology, Engineering, and Mathematic (STEM) disciplines with a path to careers in manufacturing” (1).

According to the official Xtreme Collegiate Clash Technical Regulations, the bot must obey the following key rules. The bot must have an external deactivation switch and be able to be rendered fully deactivated once not in the combat arena. The entire bot must weigh 15lbs or less. The robot must be mobile and controlled via a remote radio controller. Efforts must be made to select and design a battery assembly, so the battery will not spray, if damaged. Pneumatic robots must meet PSI requirements. Hydraulic and combustion engine robots are not allowed. The robot weapon must not be on the “ban weapon list”, such as electrical arcs, flames, or RF jamming devices. These rules will be the UC 2020 Battlebot Team’s initial design constraints. For a detailed list of rules, see Appendix A.

RESEARCH

Frame Background

Battlebot frame and armor is the base upon which a great robot is built. The frame design will limit what weapon the robot can use, contribute the robot's weight, maneuverability capabilities, available internal space, and how force from combat blows is transferred throughout the robot. There are many different types of standard frame designs used in the Battlebot community. Some frame types are commonly paired with a specific weapon. Standard types of frames include the box frame, the spinning frame, and the tripod frame.

Box frame. A box frame is a simple squared design that allows for heavy armor and a large amount of internal storage space. This frame can be equipped with most weapon types and has commonly been paired with spinning weapons in UC's Battlebot history. Box frames can be paired with a wedge design, a triangular front plate designed to push and flip the opponent. The wedge addition can also be useful in deflecting blows, although it adds weight to the frame. Box frames, however, are vulnerable to being flipped. There are many creative solutions in Battlebot drivetrains, that neutralize the threat of inversion. (2)

Spinning frame. A spinning frame is a bold & entertaining design that can be quite effective. A spinning frame will score extra points with the judges, as it is a unique and difficult design that is superbly entertaining to watch. This frame is equipped with a spinning weapon, that circles the perimeter of the frame. Spinning frames save weight on armor, as much of their protection is incorporated into the all-encompassing spinner mounted on the robot. The internal components of a spinning frame are more complex to design, and they typically have less internal storage space for batteries, drivetrains, etc. Also, dealing with the gyroscopic force of a spinning robot can be a huge challenge for whomever is piloting the bot. (2) (3)

Tripod frame. A tripod frame is not commonly seen but offers several unique advantages. Tripod frames have two large legs in the front, and one in the rear which allows the weapon to be at a high profile. This allows the bot to handle a larger weapon, and strike the opponent on the top face, a common weak spot. They are typically equipped with spinning weapons. Tripod frames can be difficult to maneuver, and their legs are weak points that can cause the robot to fall over when attacked. (3)

Armor Background

Armor and the frame designs are intertwined as both determine how the bot absorbs force, and where the weak points are located. Choosing the correct armor materials is essential for a successful bot. Armor must protect from damage, while remaining light enough for the bot to remain in the 15lb weight class. For armor, a material with high toughness and moderately high hardness is optimal for protection. (3)

Weak points on a typical bot include the front, the sides, the wheels, and the areas that hold the drivetrain and the electronics of the bot. The most commonly used armor and frame materials are steel, aluminum, titanium, and Lexan. (4)

Armor Materials

Steel. Steel is likely the most commonly used material for frame & armor in the

Battlebot community. Certain Steels and steel alloys are the toughest material a builder can choose for armor. Steel also has a decent hardness, making it a perfect choice for protection. Steel is usually an easy material to mill and weld. Some steel alloys are more difficult and will require a plasma cutter or water jet. Steel is generally low cost, depending on the alloy purchased. Steel is also very dense, meaning it will add a lot of weight to the bot. (4)

Aluminum. Aluminum is also a commonly used armor and frame material. Because of aluminum's low density and low weight, thicker plates can be used which allow it to resist global deformation when hit. Aluminum is a great choice for saving weight and is still a tough material. Aluminum is more difficult to weld than steel and easy to machine. Aluminum, however, has significantly lower toughness and hardness, as compared to steel. Aluminum is also generally more expensive than steel. (4)

Titanium. Titanium is almost as strong as high-strength steels and over 40% less dense. This material will allow incredible protection, while saving weight. However, titanium is extremely expensive, difficult to machine, and difficult to weld. (4) (3)

Lexan. Lexan is a polycarbonate that has become increasingly popular with the UC Battlebot team. Lexan is the lightest of all materials which is of huge benefit in a light-weight class. Lexan is resistant to penetration, is a good shock absorber, and is extremely difficult to dent. Lexan is extremely easy to work with; making it ideal for machining extras in the event one part gets damaged. Lexan is expensive and vulnerable to being cut, such as by a saw robot, and will crack if stressed enough. (4)

UHMWPE. Ultra-High Molecular-Weight Polyethylene (UHMWPE) is most commonly used in the manufacturing world. This tough subset of polyethylene has a strength to weight ratio 8-15 times greater than steel. Like Lexan, it is an excellent shock absorber. It is easy to cut but has a high resistance to cracking. UHMWP has gained popularity, recently with the rise of low-weight Battlebot competitions. (5) (6)

Weapon Background

Weapon Types

There are a great variety of weapon types that can be used when designing a battlebot, but in general there are a few major types that show up frequently in competitions, both amateur and professional, light, and heavy weight.

Vertical Spinner. As the name suggests, a battlebot using a vertical spinner uses a vertically oriented spinning mass at the front of the bot. This weapon can be designed to spin upwards, which can help in tossing an opponent, or to spin towards the ground, in order to increase crushing power. This spinning arm can be designed in a variety of ways, but is typically a flat, shaped piece of metal.

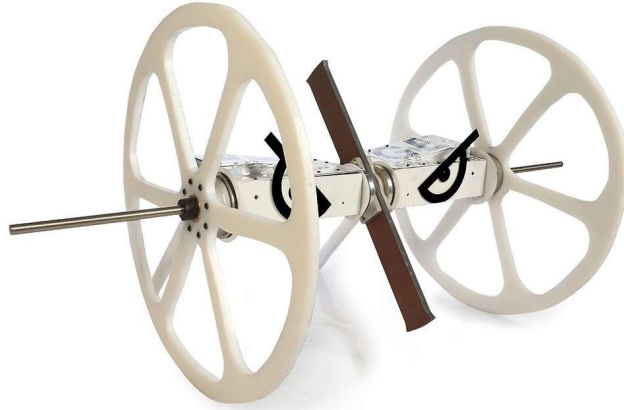


Figure 1. Huge, a battlebot known for its tall UHMWPE frame and large vertical spinner. (7)

Drum Spinner. While the drum spinner is technically another kind of vertical spinner, it differs by using a cylindrical drum design with teeth. These bots tend to have a huge moment of inertia in the front, creating a powerful weapon intended to deal heavy damage while launching opponents in the air to let gravity finish the job. The biggest downside to drum bots is that the high inertia at the front of the bot makes steering difficult and can even cause the bot to flip when making sharp turns. Creating a bot that can still operate upside-down can help counteract this weakness.



Figure 2. Minotaur, a bot whose powerful drum spinner has earned it 15 wins in only 3 years of combat. (8)

Horizontal Spinner. Horizontal spinners operate similarly to vertical spinners, with the obvious difference that the weapon spins horizontally instead of vertically. One of the biggest advantages of horizontal spinners is that their offense and defense is somewhat combined by the large area that the weapon operates in. This makes it difficult for an opponent to approach to make an attack without being hit. On the other hand, due to the nature of the weapon, the strong resultant forces generated by the weapon can cause the bot to tear itself apart over many hits. It also can take some time for the weapon to get up to speed, which an opponent may be able to take advantage of early in the fight.



Figure 3. Tombstone, one of the more famous horizontal spinner wielding battlebots. (9)

Wedge. Wedge battlebots have an inclined plane to lift, push, or flip the opponent, instead of having a moving weapon component. Because this weapon type is static, these bots tend to be very hardy since weight that would otherwise be allocated to a moving weapon can be used to increase defense or mobility. Unfortunately, wedge battlebots are not particularly exciting to watch, and they require a skilled driver to be effective. These bots are most effective when the arena they will be used in has traps that an opponent can be pushed into, or when an opponent can be deactivated by being flipped.



Figure 4. Maximus, a wedge bot. (10)

Drive Train Background

Wheel Configurations

2-wheel drive. The 2-wheel design is seen in multiple tiers of play in Battlebots. With a 2-wheel drive the bot can make very fast turns with little waste in energy (11). To achieve quick turns with this wheel orientation, most bots have each wheel independently powered or controlled. When a turn needs to be made, reversing 1 wheel, or stopping it completely while the other runs (12). In the past 4 years, the UC Battlebot team bot has been a 2-wheel drive bot (11) (13) (14) (15). Advantages to using the 2-wheel would be: high mobility, small turn radius, lighter weight, and less cost. Disadvantages to using the 2-wheel design would be:

can be harder to control with inexperienced driver, damage taken to 1 wheel can take the bot out of the fight and may need additional support either in the form of passive wheels or in the frame design.

Multi-wheel drive. Multi-wheel drive is meant to encompass bots that have 3 or more wheels to their design. While it is more common for these bots to have 4 wheels, some designers have built 6-wheel bots. Multi-wheel bots are generally larger than 2-wheel bots. They often look and function like a car. The 2014 UC Battlebots team used a 4-wheel drive bot (16). Advantages to using a multi-wheel bot are: if one wheel is damaged the bot can still move semi normally, can generate more momentum, moves faster in a straight line, can support a larger bot, more stability, and provides more traction. Disadvantages to using a multi-wheel bot; makes the bot heavier, slower turning, and more cost for materials.

Tread. Tread configuration has been around since the earliest iterations of robot wars. Tread or tracked bots do not use wheels but use metal or rubber tracks, these bots are configured much like a tank. By using the tread design, the competitor gains the option of running over the other bot. By using the differential drive, as in the 2-wheel configuration, the tread bot can accomplish a hybridization of the multi-wheel and the 2-wheel drives. Advantages of this configuration: faster turning than some multi-wheel bots, higher traction than wheels can provide, and can run over bots and field obstacles. Disadvantages of this configuration: susceptible to side attacks that would displace tread, if tread is interrupted could cause the bot to full stop, weak against flipping, and difficult to repair.

Drive types

Gear Drive. There are many types of gears which can be broken down by their position on axel like parallel shafts, intersecting shafts, and non-intersecting shafts (17). Parallel shaft is the simplest method to transmit angular speed with a rolling friction drive. They require contact force with limited slippage. To reduce slippage, more contact is necessary. Because of this more gears may be necessary. Intersecting shafts are very efficient at transmitting power at 90-degree angles. Their reduction ratio is dependent on the ratio of teeth between the gears in contact. Non-intersecting shafts configurations can have large reduction ratios because they can have large numbers of teeth in contact with a single gear (11) (17). In the previous 5 years, UC battlebots have used gear drive trains for movement (11) (18) (19) (15) (16).

Chain Drive. Chain drives are flexible means for transmitting large amounts of power. A chain drive requires a chain and 2-toothed wheels called sprockets. A power source is attached to one sprocket and the chain transmits the power to the second one. Because the chain and sprockets are interlinked almost all the power placed onto the primary sprocket gets transmitted into the second one. For the power to be adequately transmitted the chain must stay in tension while in contact with the sprockets or risk critical slippage (20).

Belt Drive. Belt drives operate similarly to chain drives, as they are flexible means for

transmitting power that use a belt instead of a chain and rotating shafts instead of sprockets. Because the belts are normally rubber, they can absorb impacts better than chain drive. Belt drives suffer from the same weakness as the chain drive in that they need to be held taut to be efficient and can be rendered useless if there is slippage (11).

CURRENT STATE OF THE ART

For the current state of the art the past five competition-years of UC senior designed Battlebots will be examined.

Frame State of the Art

UC 2014 Battlebot

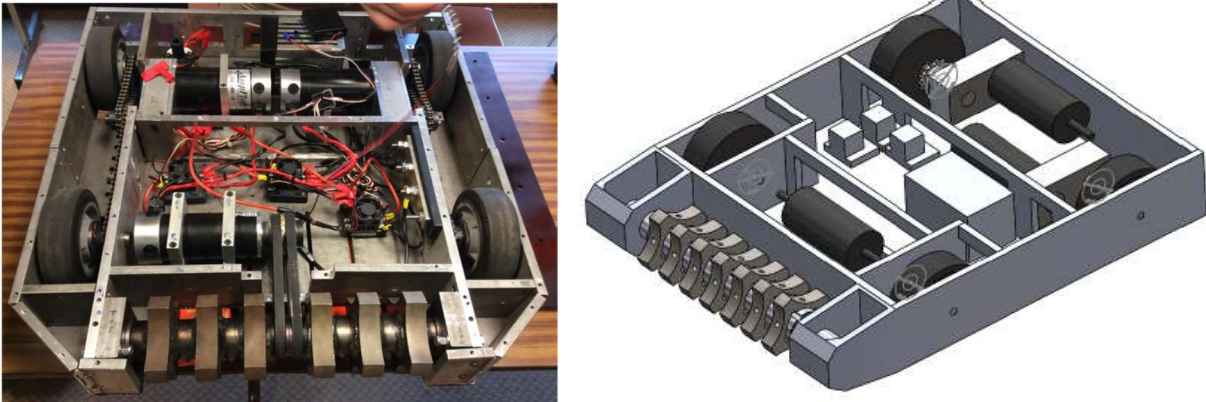


Figure 5. 2014 UC Battlebot

The 2014 UC senior designed 120lb Battlebot incorporates a square frame made of 2024 aluminum, with titanium honeycomb armor and reinforcements. Both the titanium honeycomb and the aluminum were 100% salvaged from previous projects. The dimensions of the box frame were based on the space needed for the drivetrain, batteries and motor. The fight results of this bot are unknown. Based on the stress test in the report, it is expected the frame held up well. (21)

In this design, the drivetrain, weapon, and electronics were first selected, and the frame was designed around it. This allows for optimal selection of the ladder components. This frame was picky in where it equipped armor. The design added titanium honeycomb armor on the front corners and the top to protect the most common areas of damage, and to protect the bot's internal components. The fact that all the frame and armor material was salvaged is a huge advantage to schedule and budget, as they were not burdened by the financial and schedule drain of ordering materials. (21)

The largest disadvantage of this frame design is its inability to shed weight after it has been machined. This frame has heavy, expensive pieces of armor, with minimal modular pieces. If weight has to be cut from the robot it would require re-machining and reconfiguration of internal components, as the frame was designed to be custom fit around

the selected batteries and motor. Also, choosing titanium armor would make it expensive and time consuming to re-machine a spare part, in case it is damaged during the competition. This design interestingly does not have excess armor in the back. The rear of the bot is vulnerable, as the aluminum frame is the only protection around the rear motor, and attacking the rear of a bot is a common battle strategy. In the report recommendations the team states that they recommend narrowing their frame design as it would assist in saving weight on the robot. (21) Designing the frame with looser tolerances for the internal components could also assist in dropping weight, as items can be dropped and rearranged. If the team was not at their max weight limit, they could have incorporated a wedge on their frame, which is useful for flipping other bots and deflecting blows. This bot has a low-profile heavily armored box frame, that allows the bot to drive when inverted; an extremely popular design that has been battle proven.

For its weapon, this bot uses a unique modified drum/beater bar setup. Though this bot's fighting results are unknown, it appears that there is not much clearance around the front of the drum to allow the bot to hit opponents. However, due to the large length of the weapon, this may not be that much of an issue even if that is the case, since it is easier to catch corners and other parts of an opponent with a larger area of attack. This design puts the belt connections to the weapon in the center of the weapon, a good space saving method when trying to fit the motor near the center of the frame where it has the most protection. Because the small shaft is being used as the second pulley, the belts are also well protected by the weapon surrounding it.

The 2014 bot used a direct drive gearbox reduction system with two front support wheels. Direct drive gearbox is a great way to supply the power the bot needs for motion. The two support wheels were added for the sake of increasing traction and greater maneuverability. According to their report this wheel configuration and drive type worked well, accomplishing the speed and maneuverability that they were aiming for. Due to the additional weight caused by having four wheels it may not be viable for our bot. However their tank drive system is a great way to add additional maneuverability to our bot.

UC 2016 Battlebot 120lb



Figure 6. 2016 UC Battlebot

The 2016 UC senior designed 120lb Battlebot incorporates a square frame made of 6061-T6 aluminum, with thick extruded aluminum walls, AL-6XN stainless steel alloy wrapped around the walls of the bot, with aircraft grade aluminum in the corners to act as reinforcement. This is an extremely well armored box frame that reportedly suffered only minimal damage during their multiple battles (11). This design has many intelligent weight reduction choices. The walls of the frame were extruded to save weight, and then reinforced by T-brackets, to maintain the structural integrity of the frame. The walls were then reinforced by a stronger grade of aluminum, as to nerf the consequences of having thinner frame walls. The top cover of the bot is Lexan polycarbonate. The top of a box frame bot is not traditionally damaged and the selection of a lighter, weaker top cover allowed for strong reinforcements on perimeter of the robot. (11)

The largest blunder of this frame design is that it was too large. The front of the armor extended too far and the rotating drum weapon was not able to hit anything (11). This is mostly a flaw in the design process, rather than the nature of the frame design. Communication between all system designers is curtail for success. The choice of a Lexan top cover is also a risky design choice, as an attack from a high-profile weapon could easily damage the bots internal components and knock it out instantly. This frame could also benefit from incorporating a wedge to lift up any opponents and to deflect their blows. This frame, and the multiple materials used to construct it, exhibit intelligent weight saving choices, while reinforcing key areas.

Unfortunately, one of the most notable parts of the weapon design for this bot were the design errors that caused the weapon to be too short to reach past the frame of the bot. This made the weapon very ineffective and almost useless. Between matches the team had to cut the front edges off of their bot to enable it to properly attack, which in turn exposed the sensitive bearings and other support components. The bot did not last long after this point, showing the importance of clearance in this area, which we made sure to incorporate into our design.

The 2016 battlebot used a similar drive train set up as the 2014 with the exception of only having the drive wheels. While their report makes no mention of this effecting the overall functionality of their bot, reducing the weight of the bot is one of our design goals.

UC 2017 Battlebot 120lb

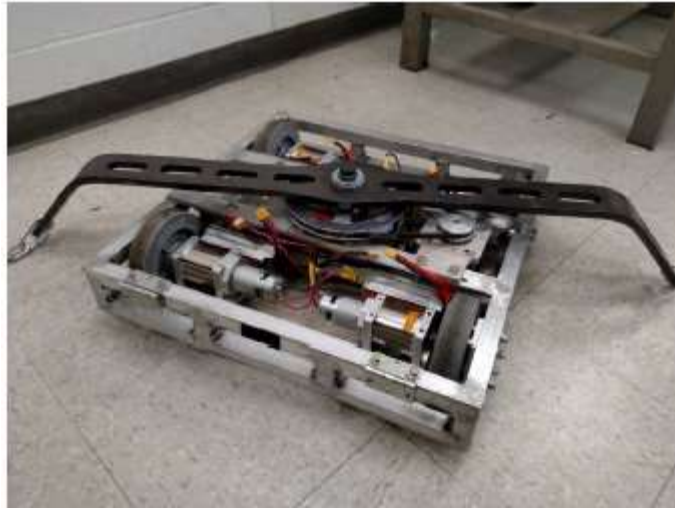


Figure 7. 2017 UC Battlebot

The 2017 UC senior designed 120lb Battlebot incorporates a unique spinning/box frame combination with acrylic sheet over the electronics, titanium honeycomb for protecting the drive motors and aluminum plate for the wedge (22). This bot was not able to compete due to complications with registration, so the results of the fight were not known. The greatest advantage of this frame is that it has the stable base, and increased internal storage space of a box frame, while being protected by a spinning weapon on top. This bot can focus less on heavy armor, as it is protected by the large spinning weapon. Aluminum is a safer material choice for the frame. Even if it is softer than steel, the weapon will theoretically cause the bot to take less blows. The square frame is also a strong and simple design and easy to machine and repair.

This main detractor from this frame is its large size. The large size will allow the frame to be a stable base for a rotating weapon, but the weight of the frame is difficult to manage over such a large area (22). If the frame was condensed it is possible the softer aluminum frame could be reinforced and more heavily armored. The spinning weapon gives the frame additional protection, so a smaller frame could give the weapon a larger relative striking distance, thus adding additional protection to the bot's internal components. Also, a robust square frame may have been overkill for a bot with an all-encompassing weapon. Another disadvantage is the threat of this bot being flipped. This threat is more the fault of the weapon and drive train design, but if this bot is inverted, it is basically rendered useless. The aluminum material they chose was reportedly difficult to weld (22). As an alternative, they could have chosen a different material, sent it to a professional welder, or bolted the parts together.

While the weapon on this bot provides excellent defense by nature of its design, it also had a few issues. Though not a significant issue, this bot only had two contacting segments of the weapon, making it easier for another bot to sneak in a blow to the frame, though they would likely still get hit in the process. It was also reported that the weapon actually spun with so much force that landing an attack would have caused serious damage to itself as well. Overall, a good design that needs a bit of refining.

UC 2018 Battlebot 220lb

Figure 8. 2018 UC Battlebot

The 2018 UC senior designed 220lb Battlebot incorporates a massive tube-steel box frame with two reinforced arms extending forward to hold the weapon. Results of this bot fight were not known, as the competition date was after the report due date. This team designed the frame to fit around the components (15). The vital components were wisely located as far to the rear as it could be. This frame was designed to be very strong with a safety factor of 15, meaning it could handle the massive blows from the opponents, and use lighter armor as the frame is unlikely to deform. This frame is well armored with thick steel plates located in heavy damage zones. (15)

The largest improvement to this frame would be the redistribution of armor. This team put a thick steel plate on the top, a low area of damage, and no armor on the wheels, creating an obvious weak point for the enemy to attack (15). Overall, this frame is extremely well reinforced and replicates a battle proven design.

The horizontal spinner design used in this bot had several potential variations, based on what type of material the team expected they may be sponsored to receive. In the end, 2024 aluminum was chosen, which is a strong type of aluminum, but an unusually weak material for a weapon in the 220lb weight class. It is unknown how well the bot performed despite this choice, as the competition the designer intended to compete was after the report was due.

UC 2018 Battlebot 60lb

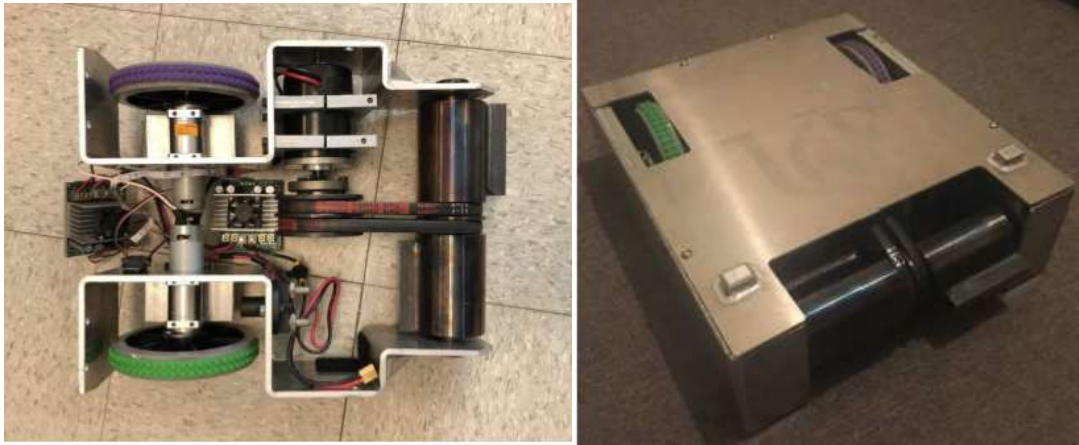


Figure 9. 2018 UC 60lb Battlebot

The 2018 UC senior designed 60lb Battlebot incorporates a box frame design made of 6061 Aluminum, with 1/8" thick aluminum plates covering the side walls. The box frame is a simple and battle proven design for reasons previously stated. This frame has added protection to the wheels and enables the bot to drive on both sides. The team chose their frame to be professionally fabricated, thus strengthening the frame and reducing personal shop time. (19)

This frame could benefit from better design planning. The weight of the frame could be redistributed to improve traction, as discussed in the report (19). Also, the team designed this bot with tight tolerances, and did not account for the bulk of weld beads, forcing them to grind down their welds and weaken the frame (19). To improve the strength to weight ratio, multiple materials could be used. Lighter materials, like Lexan, could have been used for low damage areas like the top cover, and heavier materials, like a high-grade aluminum, could be used for high damage areas, like the front of the bot.

The drum weapon design of this bot differs from most in that the weapon drivetrain is connected directly to the drum by using the drum itself as a pulley. This part of the design we decided to incorporate into our own weapon, but with more distance between the two belts to decrease the likelihood of a single hit severing both belts at once, one problem of this design. Another, more major problem of this design is the location of the teeth on the drum. Because the drum is not symmetric on all axis, the rotational moments on the drum can cause the bot to shake and damage itself under normal weapon operation.

UC 2019 Battlebot 15lb

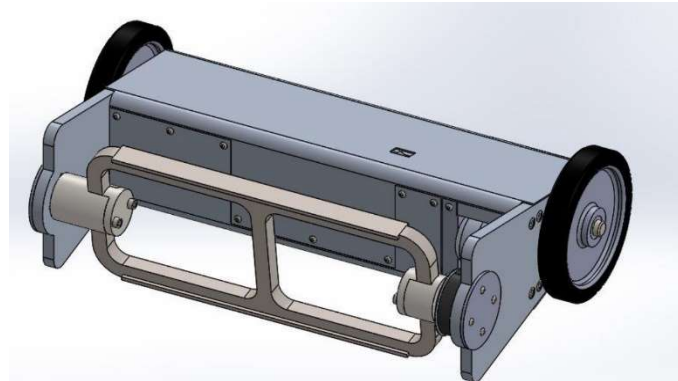


Figure 10. 2019 UC Battlebot

The 2019 UC senior Battlebot team designed 15lb bot that has a unique box frame, with aluminum frame and armor. It was not reported how well the frame withstood combat, but this bot did not do well in battle due to its weapon being too fragile. In this design, the frame is meant to protect from a majority of the blows while the thin armor will protect from superficial damage and shrapnel from harming the internal components. This is accomplished with thick aluminum frame side-walls and three thick interior aluminum cross bars (13). This frame design displays smart weight saving choices. The classic box frame has been shrunk to adapt to the 15lb weight class. With the frame designed to be the primary force absorber, less weight is attributed to armor. This frame is customized to accommodate their weapon and preferred control set-up (13). There is plenty of room, with this frame, for their weapon to be effective, and their wheels can operate from both sides if the bot is flipped.

This frame could be improved by further protecting weak points, such as the wheels, and the weapon bearings. Also, extra weight could be saved by replacing their aluminum armor with Lexan, as the frame is met to absorb most of the blows, so a lighter armor would be a wise choice. This frame could also benefit from the addition of a wedge to flip or push the opponent and to deflect blows.

As noted above, the weapon of this bot did not perform as desired during combat. Even with a spare weapon, the bot only lasted a few rounds due to the severe bending of the weapon each round. The beater bar design is a fairly simple, and generally effective design; however, due to some calculation errors in design this particular weapon was too thin, and could not stand up to the forces found in actual combat.

The 2019 bot is the closest in size for what we desire for our design. They as in previous years, they used a two-wheel direct gearbox drive train configuration. Their wheels were large enough for the bot to be able to recover if knocked over. The gear drive design allows for great power to be transmitted while keeping the area needed to be devoted relatively small. They had to add support brackets to protect the drive configuration in the event of taking a hit. There is no mention in their report for how well this bots drive system held up in competition.

END USER

The customer profile, for this project, is the Xtreme Collegiate Clash 15lb combat competition, and to an extent, the judges at that competition. The gender, age, and demographic of the judges is not likely applicable to designing battle bot customer features. The customer features will come from research, survey results from robo-combat veterans, and from the Xtreme Collegiate Clash rule book. The key points of the competition/rules are to design a bot that will put on an entertaining show, disable the other bots, last through multiple fights, and to incorporate safety into the design as to keep humans safe while handling the bot. Our need, as a team, is to design a bot in accordance with the competition rules and defeat all opponents who dare challenge the UC Battlebot team.

CONCLUSIONS AND SUMMARY OF RESEARCH

The goals of our 2020 battle bot are to meet the weight requirement, met regulation requirements, and to improve upon the designs of previous UC battlebots. After carefully studying the previous designs we have decided that the way to reach these goals is with a box frame, drum spinner bot, with a two-wheel direct gear drive. The box frame is a simple but effective design that keeps internal components safe while promoting symmetrical design for weight distribution. Drum spinners can deal great amounts of damage to enemy bots while acting as an extra level of defense for the bot. A two-wheel configuration with direct drive provides high maneuverability for the bot without sacrificing crucial weight and space for a 15 lbs bot.

CUSTOMER FEATURES

To develop the customer features for this product, team research was combined to accumulate a list of historically successful Battlebot features. These Battlebot design criteria's were then put into survey questionnaires, so they could be rated, and key customer features could be determined for our bot. The importance weighting of each customer feature is displayed numerically next to each feature. The higher the importance weighting, the higher it scored on the customer survey. Five is a perfect score.

Battlebot design criteria:

1. Must disable opponents
2. Must protect itself from attacks
3. Must be able to evade and maneuver around competitors
4. Must distribute weight to drivetrain, weapon, and frame & armor, to have optimal component weight, while remaining under the weight restriction
5. Must put on an entertaining fight
6. Must comply with competition safety standards
7. Must last multiple rounds
8. Must stay within project budget

Customer Features

1. Meets Weight Requirements (5.0)
2. Safety (5.0)
3. Optimized Weight Distribution (4.73)
4. Offensive Capability (4.333)
5. Maneuverability (4.29)
6. Mobility (4.04)
7. Ease of repair (3.92)
8. Defensive Capability (3.62)
9. Showmanship (3.2)
10. Meets Budget (2.55)

PRODUCT OBJECTIVES

To satisfy the customer features, the bot must have the following product objectives. The unit of measurement used to evaluate the characteristic is listed to its right. A brief expiation of what the characteristic addressed is listed below each characteristic.

1. Balance weight/center of gravity (CG (in))

Balancing the bot's weight, and choosing the optimal point for its center of gravity is a key feature in a well-designed battle bot. A well-placed center of gravity will allow for zero point turning, making the bot more agile and greatly increasing the bot's maneuverability, defensive, and offensive capabilities. A balanced center of gravity is also an important part in having optimized weight distribution. A well-balanced bot will also be more mobile than if it was unbalanced and has the ability to put on a more impressive show for the judges, thus increasing showmanship and mobility as well.
2. Diversity and optimize material selection (No. of materials)

In UC's history, the most successful bots have been built using a wide range of materials. For example, using a high strength material on heavily damaged areas and a low strength material on lightly damaged, will increase the bots defense and ability to make weight, but will also be more expensive than buying a bulk material and utilizing it for the whole bot. Diversifying the material selection will also greatly aid in the bots optimized weight distribution.
3. Bot safety factor (unitless)

Maximizing the bot safety factor will assist with the bot lasting multiple rounds. A durable design inherently has better offense and defense, is less likely to have a safety malfunction, and can put on a better show, for longer. The bot is also less likely to need repair, if the design is highly durable. However, increasing the safety factor is more taxing on the budget, and meeting the competition weight requirements.
4. Weapon speed (rpm)

Increasing the weapon speed will give the bot much better offensive, defensive, and showmanship capabilities, as the weapon will be used for protection, and vicious attacks. Increased weapon rpm will also make the bot more dangerous to handle, decreasing safety. A high weapon speed will also decrease maneuverability and mobility, as a high angular momentum in the front of the bot will make it more difficult to turn due to the gyroscopic effect (23). Increasing weapon rpm is also costlier to the budget and weight, as it will require more expensive, and heavier components to achieve a high rpm.

5. Spare part(s) have been made (no. of parts)

Producing spare parts for the bot will greatly increase the ease of repair, and the defensive capabilities. It will also increase the bot's mobility, as drivetrain components commonly need replaced after fights. Making spare parts will negatively affect the budget.

6. Battery life (minutes)

To last the entire match, it is essential the bot has a high battery life. Due to the weapon and drivetrain being battery powered, offensive capabilities, mobility, and maneuverability all benefit greatly from an increased battery life. However better batteries are more expensive, and have a negative correlation with budget.

7. Cost of materials (\$)

Minimizing the cost of materials will significantly reduce the budget, but may also result in lower bot performance metrics. The bot will have worse defense as the lightest, strongest materials are the most expensive. The bot will also have worse offense, as the best weapon motors are costly.

8. Traction (N)

High traction will allow the bot to be more mobile and maneuverable. This, in turn, will assist the bot in having better offensive/defensive capabilities. Better traction can be achieved through more expensive wheels and motors, thus detracting from meeting the bot's budget.

9. Torque distribution (J/rad)

Fine tuning the torque distribution of the drive train will greatly improve the bot's mobility and maneuverability. This will also translate to the bot being more offensive & defensive, as it has increased agility. Fine tuning the torque distribution is a fickle process and will make the bot slightly more difficult to repair.

10. Material Machinability (machinability index %)

Increasing the machinability, of the bot assembly materials will strongly benefit the ease of repair, and meeting budget, and moderately detract from defensive capability and meeting the weight requirements. Materials that are high on the machinability index require the smallest machining cost, this would be helpful to the budget, and repairing the bot. In general, easily machinable materials make worse armor, as they deform more easily than materials with a low machinability, this harms

defensive capability. Also, high machinability materials often have an increase density, which is harmful to meeting the weight requirements.

11. Part replacement time (s)

Decreasing the part replacement time will strongly relate to ease of repair, and moderately relate to showmanship, safety, and meeting the project budget. If parts can be replaced quickly, this will increase the bot's chances of lasting multiple fights, increasing its showmanship score. Newly replaces parts are less likely to fail and cause safety issues. A reduction in replacement time will also assist in meeting the project budget, as a design that can be replaced quickly should take less time, effort, and materials, thus reducing funds used for the replacement.

12. Wheel distance (in)

Having the optimal distance between wheels will allow for tight turning and directly relates to the bot's maneuverability. Increasing the bot's maneuverability will also make it more mobile, and both these factors will make the bot better at evading opponents, increasing the bot's defensive capabilities.

13. Bot weight is 15lbs or under (lbs)

Ensuring the bot is under 15lbs, the maximum competition weight, is directly related to meeting the weight requirements, and plays into an optimal weight distribution.

14. Bot has visually appealing design/accessories (No. of customizations)

The bot should be visually appealing in order to score better showmanship points with the judges. Accessories will be costly to the budget, meeting the weight requirements, and will be an extraneous element to fix between fights, hurting the budget, ease of repair, and weight requirements

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Column #																	
						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
						Part replacement time (s)	▲	▲	▲	▲	X	▲	X	X	▲	▼	▲	▲	X				
						Material machinability (machinability index %)		○															
						Bot safety factor (unitless)		○	○														
						Weapon speed (rpm)			○														
						Bot has visually appealing design/accessories (No. of customizations)				○													
						Torque distribution (J/rad)				○													
						Diversity and optimize material selection (No. of materials)				○	▲												
						Bot weight is 15lbs or under (lbs)					○												
						Balance weight/ center of gravity (CG) (in)					○												
						Spare parts have been made (no. of parts)						○	▲										
						Cost of materials (\$)							○										
						Battery life (minutes)								○	▲								
						Traction (N)									○								
						Wheel Distance (in)										○							
1	3	10.6	4.3	Offensive Capability																			
2	3	8.3	3.6	Defensive Capability			○																
3	3	10.5	4.3	Maneuverability																			
4	3	3.3	4.0	Mobility																			
5	3	12.3	5.0	Meets Weight Requirements			○	▲		▲													
6	3	11.6	4.7	Optimized Weight Distribution																			
7	3	7.9	3.2	Showmanship			○																
8	3	12.3	5.0	Safety			○																
9	3	3.6	3.9	Ease of repair			○																
10	3	6.3	2.6	Meets Budget			○																
Target or Limit Value						61.5	84.3	150.2	144.3	46.5	96.5	156	59.1	167.3	140.5	119.9	133	109.4	67.9				
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)						6	8	8	5	3	7	7	9	6	2	5	4	4	2				
Max Relationship Value in Column						3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		
Weight / Importance						166.0	206.7	370.1	355.6	111.5	238.2	383.5	145.5	413.1	346.1	294.7	327.9	269.6	167.2				
Relative Weight						4.4	5.4	9.8	9.4	2.9	6.3	10.1	3.8	10.9	9.1	7.8	8.6	7.1	4.4				

Figure 12. Rooms 1-4, 6, and 7 of the House of Quality

Title: _____
 Author: _____
 Date: _____
 Notes: _____

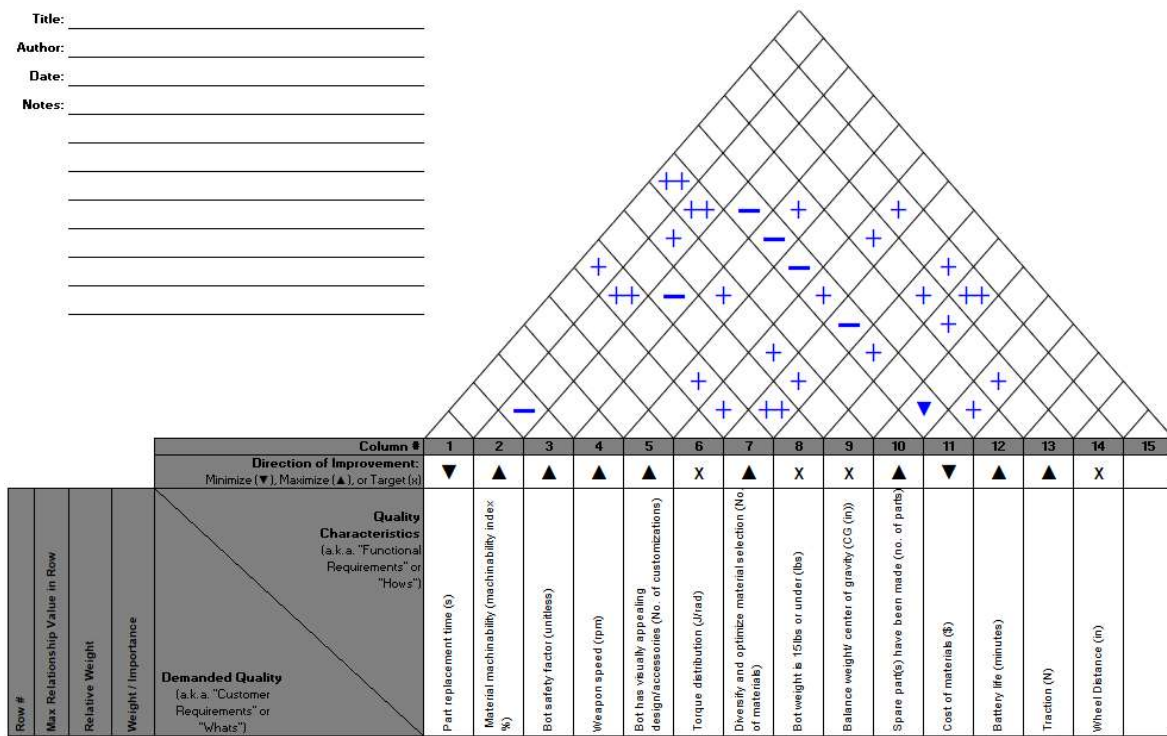


Figure 13. Room 8 in the House of Quality

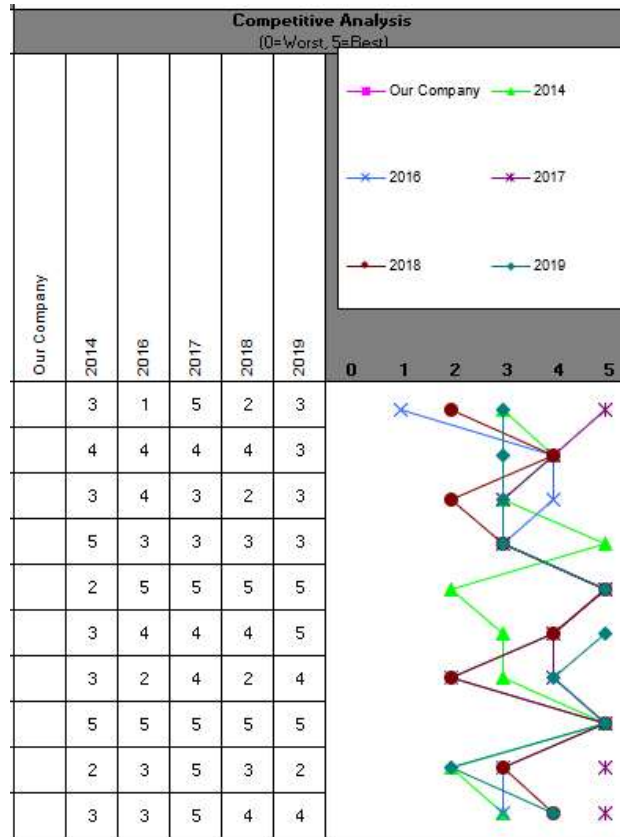


Figure 14. Room 5, Benchmark Satisfaction, in the House of Quality

Ranked Product Objectives

Rankings are displayed to the right of the product objective. Scores were derived directly from the house of quality.

1. Balance weight/ center of gravity (10.9)
2. Diversify and optimize material selection (10.1)
3. Bot safety factor (9.8)
4. Weapon speed (9.4)
5. Spare part(s) have been made (9.1)
6. Battery life (8.6)
7. Cost of materials (7.8)
8. Traction (7.1)
9. Torque distribution (6.3)
10. Material machinability (5.4)
11. Part replacement time (4.4)
12. Wheel distance (4.4)
13. Bot weight 15lbs or under (3.8)
14. Bot has visually appealing design/accessories (2.9)

DESIGN

Design Alternatives

Three initial designs were created based on our product objectives, derived from our house of quality. The below bots are our team's designs based on our state of the art and research and survey results. All three designs satisfy the product objectives and competition requirements, to various levels.

Design 1 – Wedge Bot

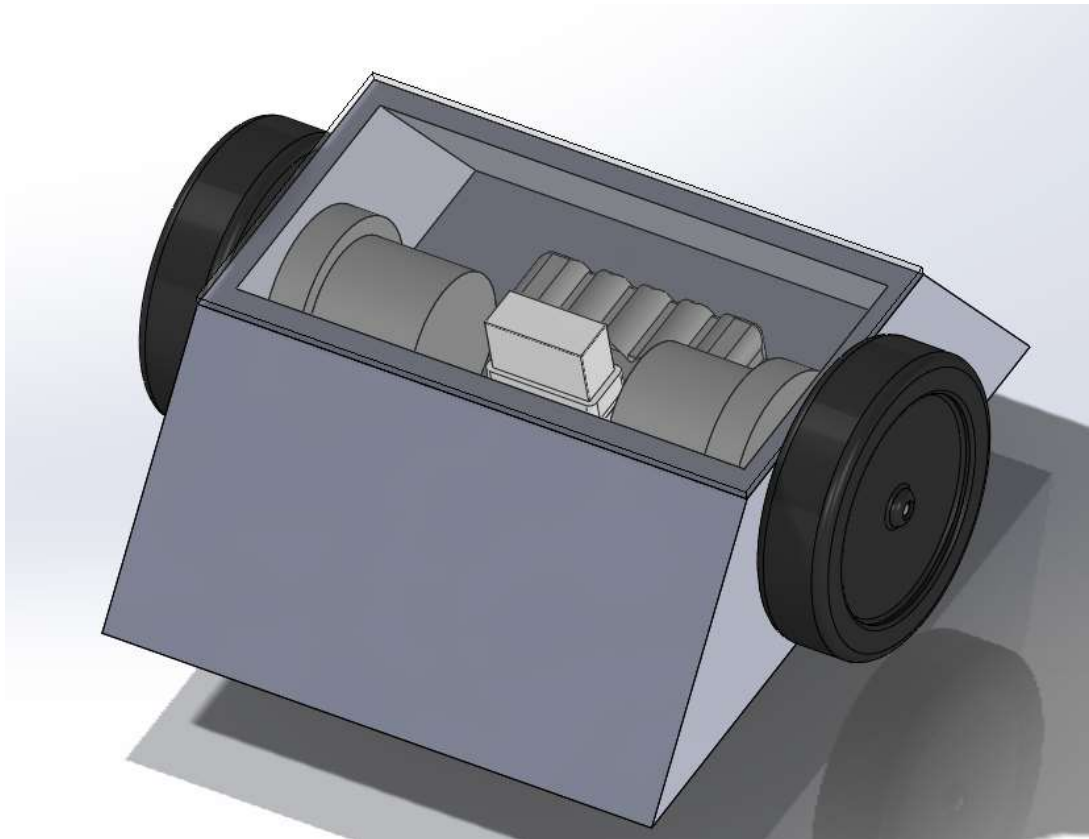


Figure 15. Wedge Bot Concept

The bot in Figure 15. Wedge Bot Concept is of a wedge bot design. This design was chosen for its ability to flip opponents in and out of the ring, as well as the durable design. The weapon on this bot, is the 45-degree wedge. This design scores low in the showmanship category, due to its low offensive capabilities, but has high durability and can easily sustain multiple fights. The wedge weapon also has high attack surface area, making it easier for the driver to use. Due to the weapon being simplistic it requires minimal materials to manufacture, and be of low weight. This bot has few internal components, allowing its overall 9"x8" frame to be smaller than other designs. This bot also has long battery life, as only the drive train is using power. Much of this bot's weight is attributed to speed and defense. This bot is heavily armored and equipped with high-speed motors. Two wheels have

been selected so the bot can make tight turns during a fight. This bot's low profile and stable base make it difficult to flip, but the design is not reversible. In the event this bot gets flipped, it is out of the fight. This bot is low-cost, simple to manufacture, and requires little battery power to operate. This agile bot adopts the strategy of lasting multiple fights through high durability and evasiveness.

Design 2 - Drum Spinner One Piece Frame

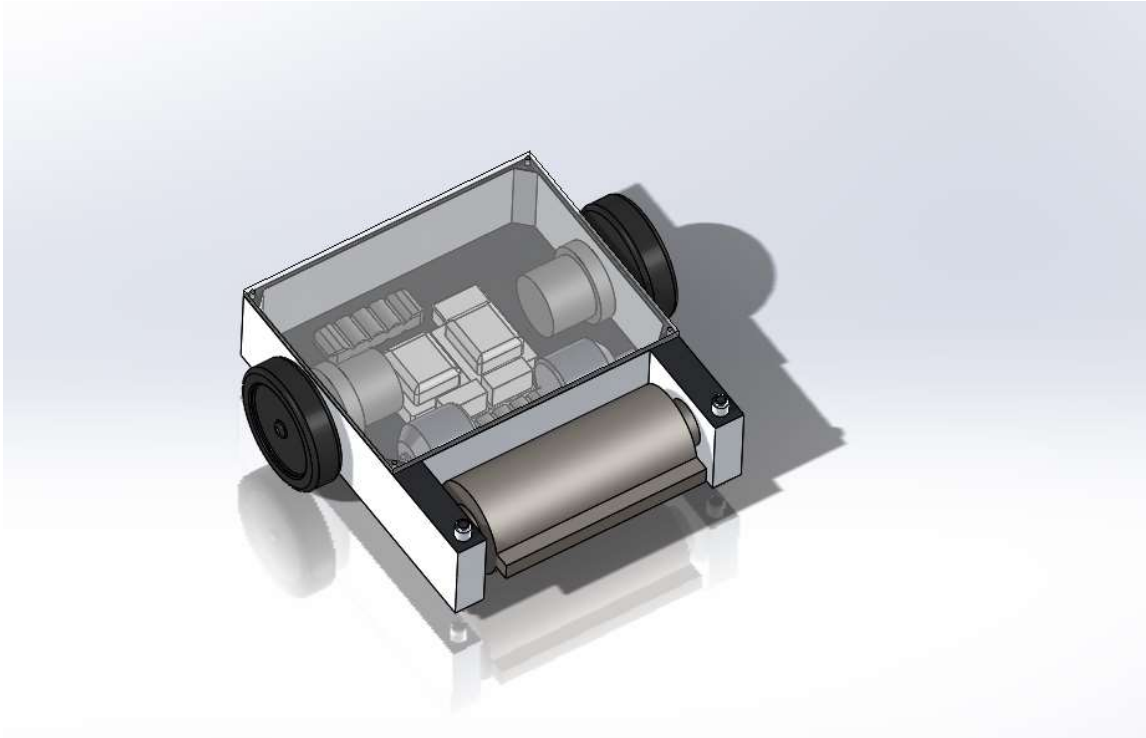


Figure 16. Drum Spinner, One-Piece Concept

The bot in Figure 17. Drum Spinner, Multi-Piece Concept **Error! Reference source not found.** is a drum-spinner, box frame design. The bot is equipped with two independently driven and controlled wheels, giving the bot a tight turning radius and reducing drivetrain weight, as opposed a four-wheel design. The large 4" wheel radius and wheel placement allow the bot to drive upside down in the event it gets flipped. Wheel armor was decided against, to save weight, as direct wheel attacks are rare, although deadly. An aluminum frame was initially chosen. The large aluminum box frame measures 8"x10"x3", with 1/4" thick walls, and a 1/4" Lexan top cover. This increased frame size allows internal components to be placed away from the walls, and out of harm's way. The oversized frame, however, will add additional weight to the bot. The unique feature of this bot is the once piece machined aluminum frame. Although this once piece frame would be difficult to make spare parts for, the increased strength reduces the need for a replacement frame. The frame benefits from the fact it needs no welds or bolts for assembly, reducing the risk it will fall apart during a fight. For this bot, the armor and the frame are one, trading armor weight in exchange for larger frame dimensions.

This bot's battle strategy is agility and aggressiveness. Along with the bot's tight turning radius, front sliders have been added to assist with maneuverability and to transfer the force from a direct hit into the ground. A high RPM belt-driven drum spinner would be installed to transfer a massive amount of force to opponents. The main advantage of this bot is the large drum spinner. The high weapon-contact-area makes this bot deadly anytime it is facing forward, and reduces the need for the driver to be accurate. The need for armor is reduced as the drum spinner protects the entire front face of the bot.

Design 3 - Drum Spinner Multi Piece Frame

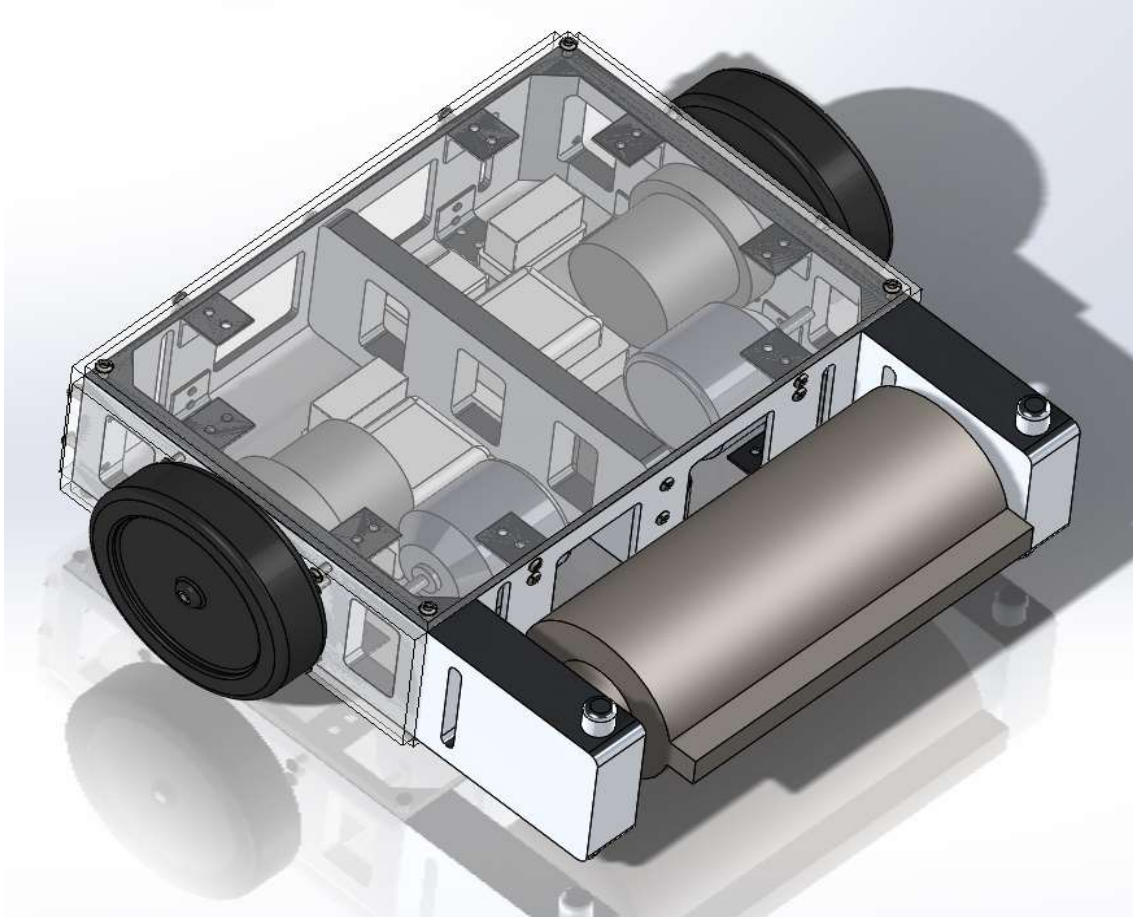


Figure 17. Drum Spinner, Multi-Piece Concept

The bot in Figure 17. Drum Spinner, Multi-Piece Concept is similar to the bot in, and has the same drive train and weapon design/benefits. The bot can make tight turns, and drive upside-down. The wheels have been left unprotected, to save weight. The drum spinner is able to do heavy damage to the bot, and requires little diving skill to make a successful attack with. The drum spinner also protects the bot's front face, reducing the need for armor. The key feature for this bot is the multi-piece frame and armor. The bot was initially chosen to have an aluminum skeleton frame with Lexan armor, and a Lexan top/bottom. In 15lb competitions, the top and bottom faces are low damage areas, so they were equipped with light armor. However, the top and bottom would be vulnerable to a direct hit, if the bot gets

oriented in an unexpected way, during a fight. To reduce weight, the frame has been hollowed out, and the frame size has been shrunk to 7"x10"x3". Aluminum L-brackets have been placed on each side of the frame, for increased structural strength. The Lexan armor is the bots main form of defense. This armor is light weight, and can be easily replaced, although it does not withstand repeated hits well. This bot is more aggressive, and will put on a better show than the wedge bot (**Error! Reference source not found.**), and can be more easily repaired, and would be less expensive than the Figure 16. Drum Spinner, One-Piece Concept drum spinner bot. This bot has more weak points and lighter armor than the one-piece frame bot (Figure 16. Drum Spinner, One-Piece Concept), meaning the driver would have to be more attentive at keeping the drum facing forward, and on the attack, as the drum is the strongest line of defense.

Design Selection

Decision Factor	Weighted Importance	Wedge Bot		One Piece Drum		Multi Piece Drum	
		Rating	Score	Rating	Score	Rating	Score
Offensive Capability	4.3	2.75	11.825	4.25	18.275	4.25	18.275
Deffensive Capability	3.6	3.75	13.5	3.75	13.5	3.5	12.6
Manuverability	4.3	4.75	20.425	4	17.2	3.67	15.781
Mobility	4	4.75	19	3.75	15	3.75	15
Ease of Meeting Weight	5	3.67	18.35	2.5	12.5	2.5	12.5
Ease of Manufacturing	3.5	3	10.5	4	14	3	10.5
Ease of Repair	3.9	3.75	14.625	3	11.7	4	15.6
Balanced Weight Distribution	4.7	4	18.8	3	14.1	3	14.1
Showmanship Capabilities	3.2	3	9.6	3.75	12	3.25	10.4
Saftey	5	5	25	5	25	5	25
Ease of Meeting Budget	5	3.67	18.35	2.5	12.5	3	15
Total	-	-	179.98	-	165.78	-	164.76

Table 1. Weighted Matrix

Offensive Capability	Wedge Bot	One Piece Drum	Multi Piece Drum
Weapon Speed	1	5	5
Weapon Surface Area	4	4	4
Damage Delivered	1	5	5
Weapon Durability	5	3	3
Total	11	17	17
Average	2.75	4.25	4.25

Table 2. Weighted Matrix Sub-Table

To select one of the three designs, a weighted matrix was made. Each variable in the Decision Factor column in Table 1. Weighted Matrix was broken down into its own sub-table. For example, in the Offensive Capability sub-table, the offensive capability was broken down into weapon speed, weapon surface area, damage delivered, and weapon durability, see Table 2. Weighted Matrix Sub-Table. The bots were rated on these sub factors with a scale of 1-5, one being unfavorable and five being favorable. The average of those sub-factor ratings were imported to Table 2. Weighted Matrix Sub-Table. They were then multiplied with a weighted importance, to calculate how the bot scored on that variable. For example, the wedge bot scored a 2.75 on offensive capability, this score was multiplied by a weighted importance of 4.3 to give the bot an overall offensive score of 11.825. The weighted

importance was calculated based on survey results, and the opinions of other Battle Bots team members.

In the results of the weighted decision matrix, the wedge bot scored the highest with a score of 179.98, the one-piece drum spinner followed with a score of 165.78, and the multi-piece drum spinner was a close third with a score of 165.76. The final bot scores were had a total difference of 8.8%, with the wedge scoring 12pts higher than the multi-piece drum spinner. The wedge bots final score makes since, as these bots have been historically successful in competitions. The wedge bot has advantages in maneuverability, ease of meeting the weight requirements, balanced weight distribution, and ease of meeting the budget. However, the wedge bot was decided against due to their inability to put on an exciting fight, and their susceptibility to being flipped.

The team wanted to take on the challenge of building a complex weapon system, and was in favor of a drum spinner that would put on a more aggressive show. The two drum spinner designs had a negligible score difference of 0.6%. The multi-piece frame only needs half the frame material, as compared to the one-piece frame, making it almost half the cost. Having multiple frame parts, secured together with bolts, also makes damaged parts much easier to replace. The multi-piece frame is slightly heavier, due to the weight of the additional bolts and screws. After running strength calculations, the multi-piece frame was found to be significantly weaker than the one-piece frame. Due to this the one-piece bot design was chosen. This design scored higher in defensive capability, and ease of manufacturing. The one-piece frame adds strength, and only one major center-cut is needed to manufacture the frame. The same frame scored lower in its ability to meet the budget, and its ease of repair. This frame has a lot of material waste in the process, and to repair damage the entire frame must be replaced. To negate this, the team will have an additional frame prepped, and loaded with spare parts, if replacement is needed.

Selected Design

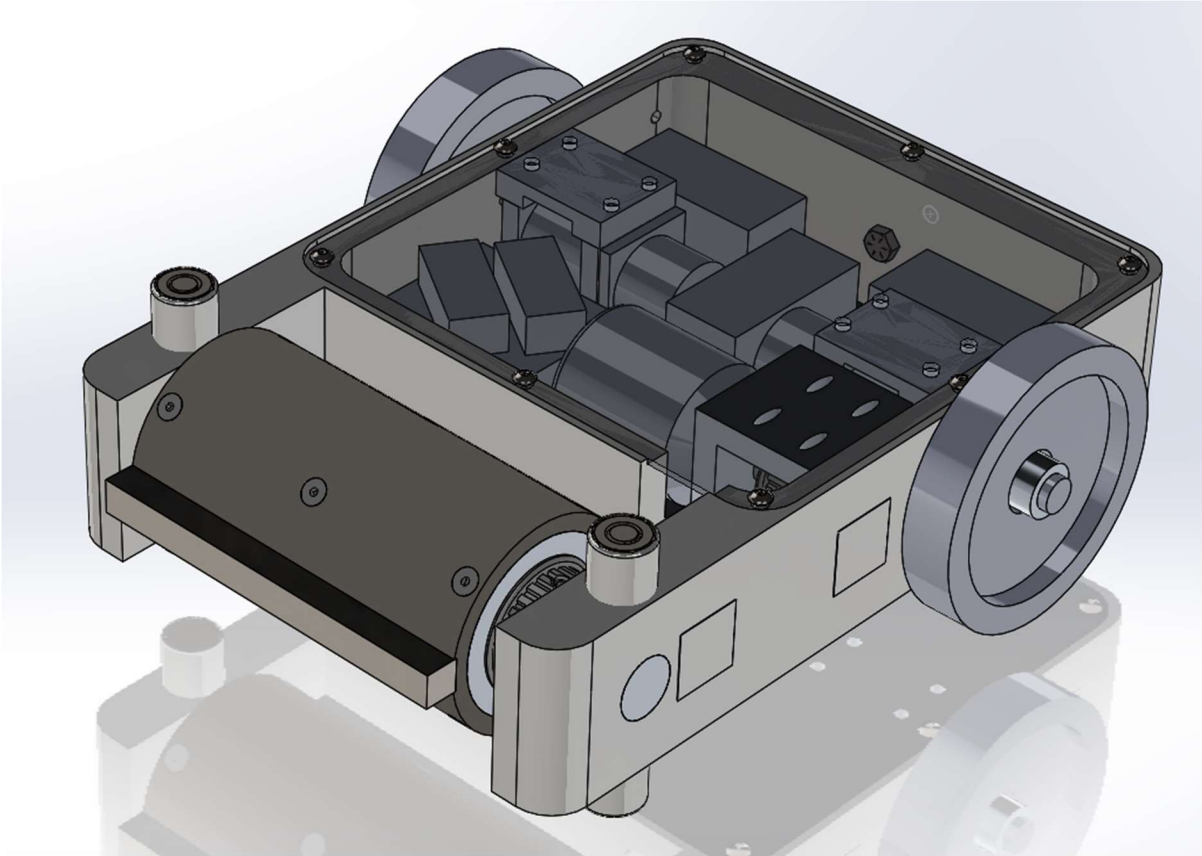


Figure 18. Final Concept Design

The selected one-piece bot design, in Figure 18. Final Concept Design has been further refined to incorporate a smaller, thicker frame made of UHMW Polyethylene. The frame and drum dimensions have been reduced to save weight. The drum design has been further refined to be stronger, well balanced, and simpler. This design is equipped with two-wheel drive, allowing for tight turns. The high rpm drum spinner will deal damage to opponents and protect the bot's front face. The bot is moved by two independently controlled direct-drive wheels. The estimated final weight is 13.94lbs, including all components, fastening materials, and electronics. This leaves about 11lb for insulation and wiring weight. For more on the design, please see the respective frame, weapon, and drivetrain design sections.

Frame Design

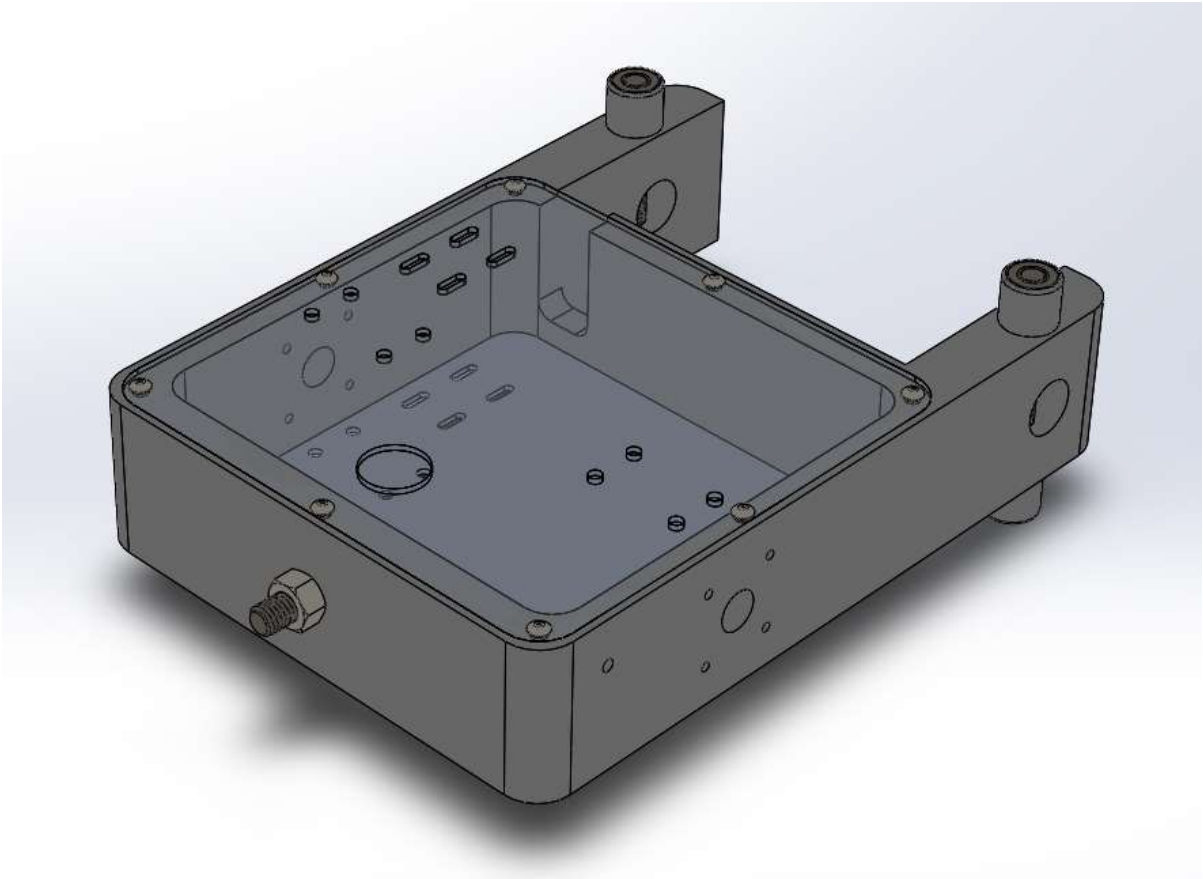


Figure 19. Final Frame Design

The final frame design,

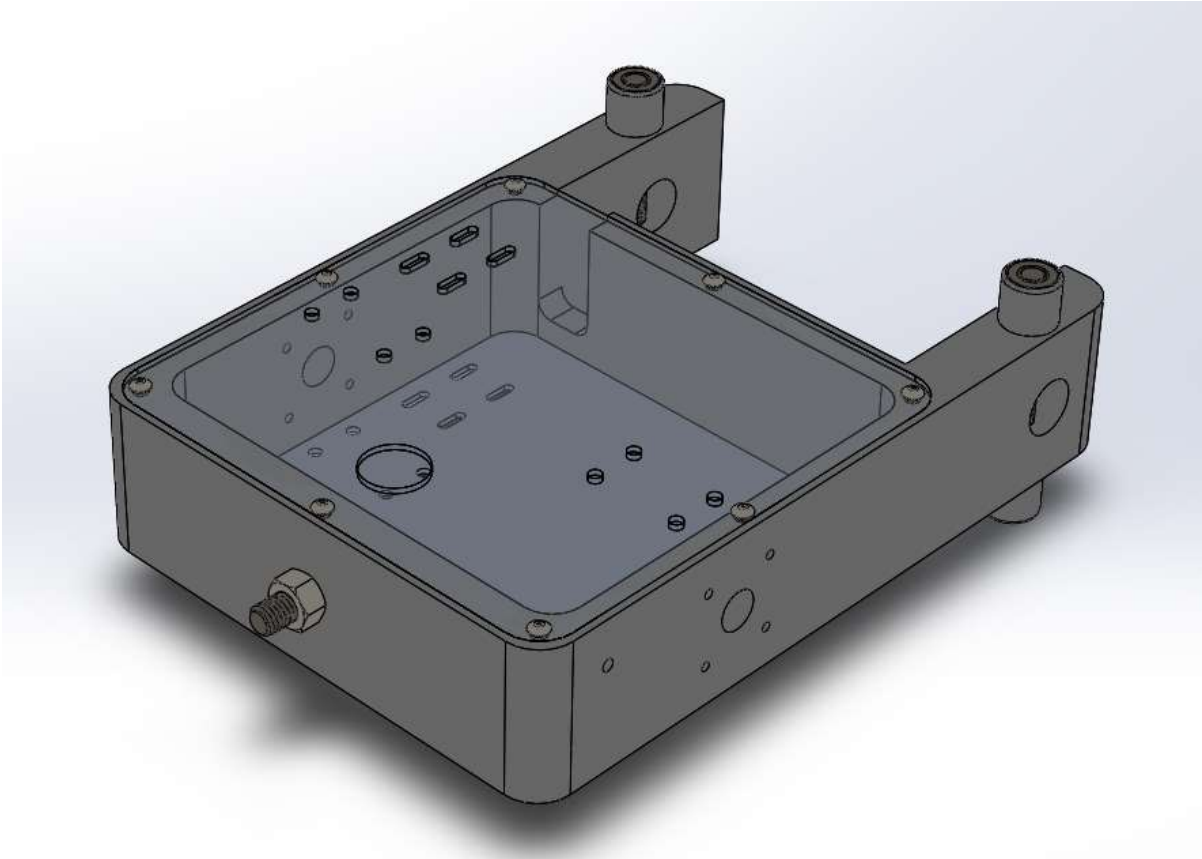


Figure 19. Final Frame *Design*, consists of a once-piece UHMWPE, a high-density polyethylene, body measuring 12 by 8 ½ inches, and two 6061 aluminum, recessed top and bottom covers. The front and side walls are ½ inches thick, and the rear wall is ¾ inches thick. The top and bottom covers are 0.09 inches thick, and recessed 0.09 inches to prevent them from being stripped in competition. The front arms are 1 inch thick. The internal and external corners are filleted to decrease the fragility, and avoid sharp 90degree angles, where stress would be highly concentrated. The front skids will allow the bot to remain level with the 4-inch wheels, even if the bot is flipped. The skids have a 7/16ths, 4-inch bolt and nut running through them, to secure the weapon to the frame. A 2 inch long, 7/16ths rear orientation bolt has been installed on the rear plate, to prevent the bot from being permanently stuck on its back plate, if flipped. UHMWPE was chosen for its high elasticity, durability, and low weight. This material is similar to Lexan in its sock absorption qualities, but is less likely to shatter. UHMWPE has gained popularity in the low-weight battle bot competitions, and has even been used in high weight competitions, most notably by the bot “HUGE”. This material has given us the ability to have a large 7 inch by 7 ½ inch cavity where our internal components will be secured. This material is relatively inexpensive and easy to machine, allowing spares to be fabricated with simple machinery. The one-piece frame design was chosen for its much higher strength to weight ratio. The frame allows impact forces to be transferred over a large area, and eliminates high-stress points, such as bolt holes, where a frame is likely to crack. A multi-piece frame, of the same dimensions, was designed alongside this frame, but it failed stress analysis. This frame has a safety factor of over 5.26, with a weight of only 3.64lbs. See the stress analysis section for details.

Weapon Design

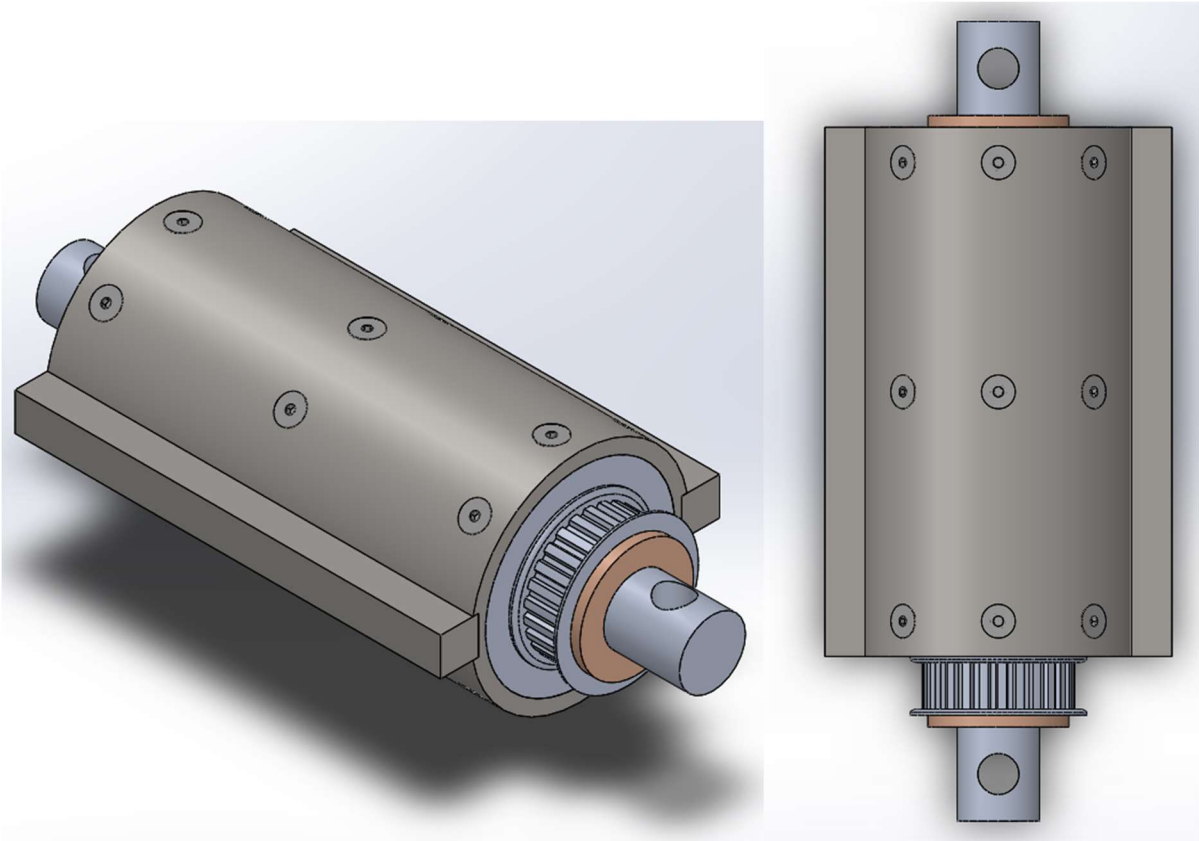


Figure 20. Isometric and top view of drum spinner weapon.

The final weapon design decided upon was a drum spinner, due to its powerful offensive capability alongside its high affinity against most matchups. One of the greatest strengths of the drum weapon is its wide area of attack as well as its inherent defensive capabilities, as the entire front of the battlebot is defended by the weapon. Because of this, less weight has to be devoted to the armor, which in turn means that more weight can be devoted to the overall offensive capabilities of the bot. This drum is bolted into the frame via the holes in the shaft shown above, holding the shaft in place so that the drum can spin around it via the belt and pulley system which drives the weapon. Three internal aluminum plates support the inside of the drum and are held in place by 6 vibration-resistant screws each.

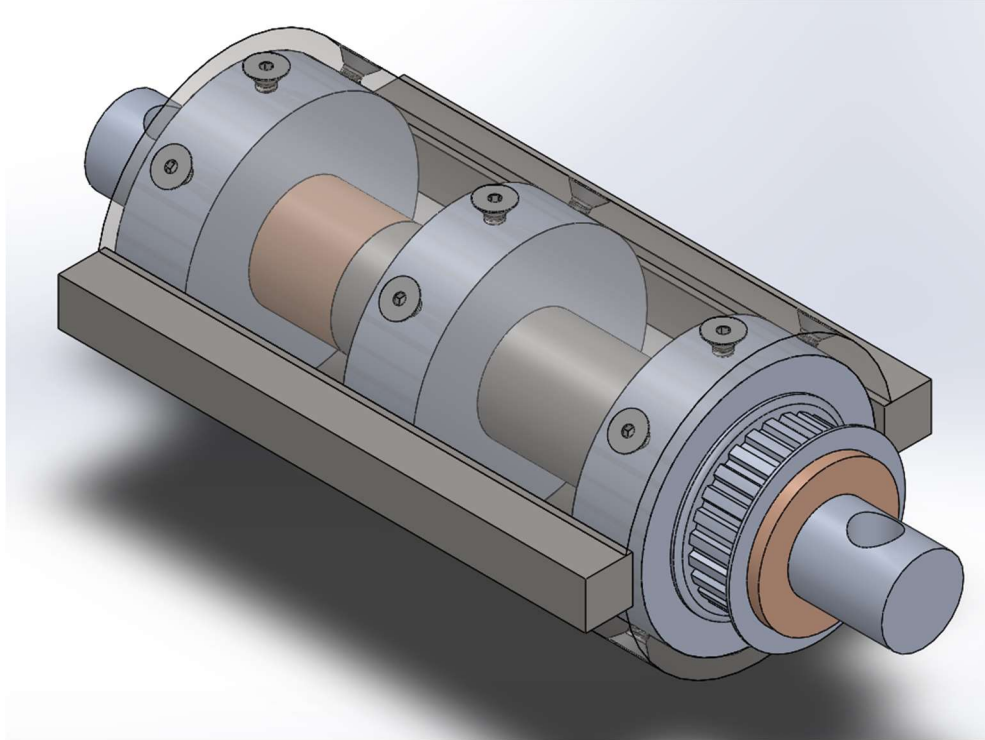


Figure 21. Transparent weapon showing internal aluminum support plates and bushings

In this design, the heavier steel outside of the weapon is supported by lightweight aluminum supports, increasing the functionality of the weight needed for the stronger contacting points. The greater the weight towards the outside of the arc created by the spinning weapon, the greater the inertia, and in turn force delivered, will be. However, because the majority of the weight of the drum is towards the outside generating inertia, the inside of the drum pipe is a natural weak spot. To ensure a strong defense, the three aluminum supports inside the pipe prevent collapsing or warping of the drum when attacked.

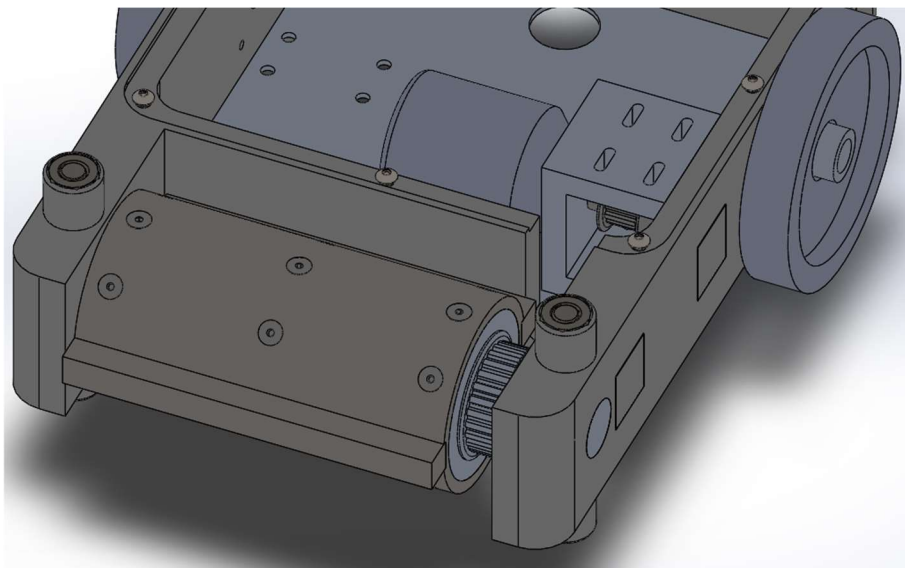


Figure 22. Weapon with internal support block/tensioning system

Inside the bot, the drum is driven by a Turnigy Aerodrive SK3 - 5055-320KV Brushless Outrunner Motor, which spins a small 12 tooth pulley. This pulley connects to the outside driven 26 tooth drum pulley via a 13" long 3/8" wide timing belt. The machined "C" shaped support block, as the name suggests, supports the motor by providing a stable base. It also doubles as a tensioning system due to the slots in the block, which allows the driving pulley to slide forward and back as needed to achieve proper belt tightness, before being screwed down with nuts and bolts (not shown). Because of the lower weight class, the weapon does not need additional supports on its other side, though it is worth noting that a larger motor than the one used in this design would likely need an additional support structure in the back.

Using a timing belt instead of a V-belt for the weapon helps it weapon achieve its maximum running speed faster. This is important, as the first few seconds of a fight are critical, and having the opportunity to get the first hit in can often make or break a match. Having a fast spin-up speed is also especially important for drum spinners in general, as the drum also doubles as armor for the front of the bot when up to speed.

Drivetrain Design

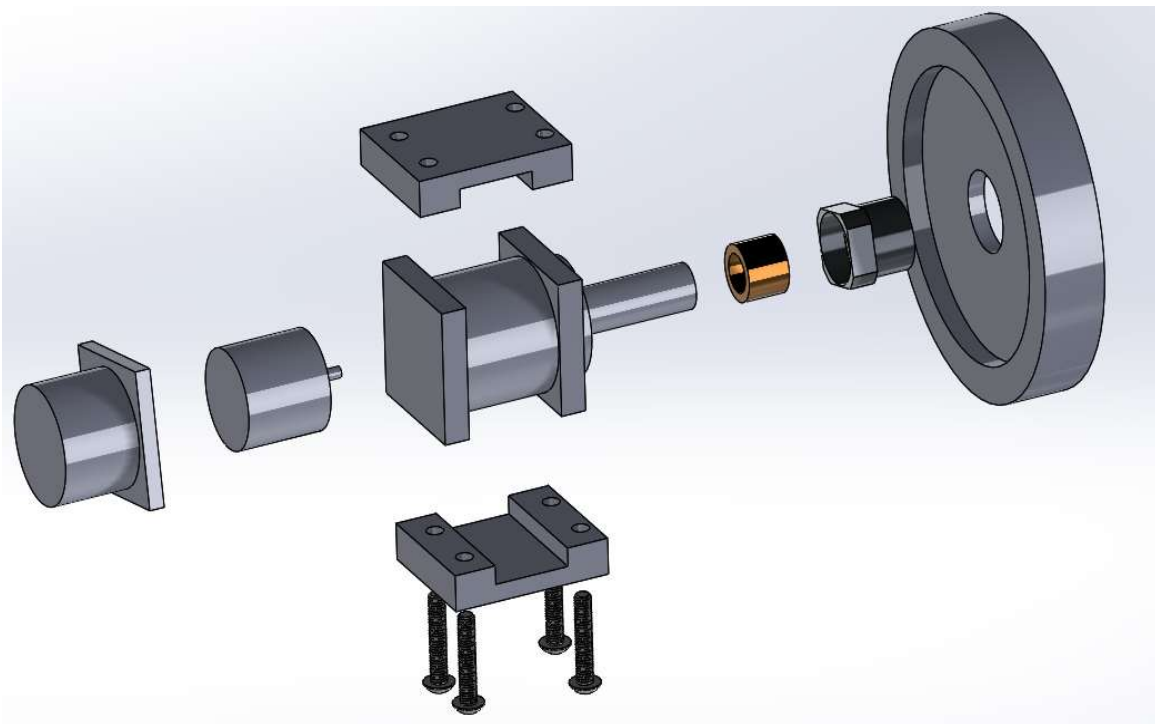


Figure 23. Final Drivetrain Design

For the drive train design, it was decided that the bot would have a direct gear drive. A direct gear drive would provide the speed and maneuverability that would be necessary for the bot while also staying within the space and weight restrictions. The drive train consists of a 4" diameter wheel, a wheel hub, gearbox, motor, 4x 10-32 screws, a motor guard, a bronze bushing, and two support structures. The wheel was decided on to be large enough for the bot to still be able to move if it was knocked over. For the gearbox and motor, we decided that go

with a combination of a Turnigy D2826/10 and a P61 20:1 gearbox. The hub piece is standard for the wheel and gearbox that was selected. We added 10-32 screws to secure the motor in its spot during combat. The motor guard is used to protect the motor from dust as well as secure the motor to keep it from getting jostled during combat. The bronze bushing was added to protect the shaft of the gearbox from the frame of the bot and support the bot during impact landings. The support blocks are cut from the same material as the frame of the bot. The support blocks keep the drive system in place while also keeping it elevated at the correct distance or the wheels. The left and right drive trains are symmetrical with a total weight of 2.14lbs.

Stress Analysis

Frame

All of the stress analyses were done using FEA in SolidWorks. The method of force application was learned from senior Battle Bots Club members, and accurately replicates a competition blow. The kinetic energy generated by an existing club bot was calculated based on the bot's 1500rpm, 4.9lb spinning weapon. It was then assumed 100% of this force was transferred to the bot. This force was then divided by the weapons small contact area to generate a force per square inch. See the calculation section for details.

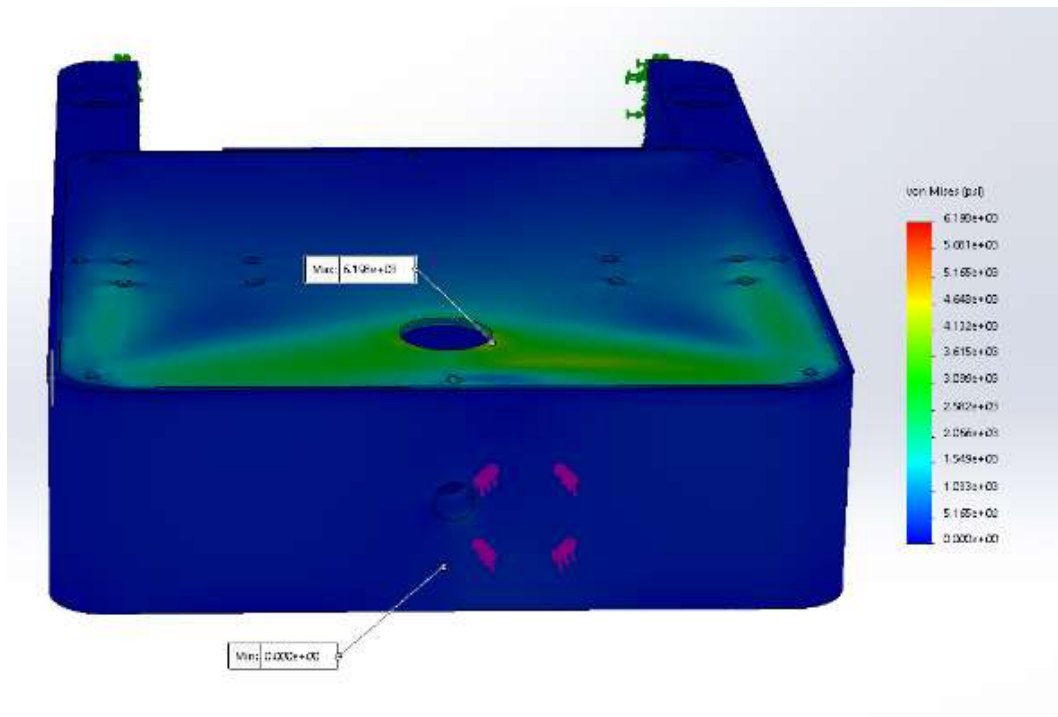


Figure 24. Rear Plate Stress Test

For all of the stress test a 160lb force was applied to a 1in² area, to mimic a weapon collision. In the analysis, the frame was locked in place, replicating a worse-case scenario of

our bot being hit while immobilized and against a wall. The sides, front corner, and rear plate yielded a safety factor of 9.81, 8.55, and 5.26, respectively. Figure 24. Rear Plate Stress Test shows the rear plate stress test, which yielded the highest stresses on the bot. This test shows 6,190 psi transferred to the top plate and 1,103psi transferred at the impact point, to the frame. The aluminum top plate retained a safety factor of 6.46, and the frame, one of 5.26. The resilient one-piece design was key to designing a UHMWPE frame, as all multi-piece frame designs failed to meet proper safety factors, under testing.

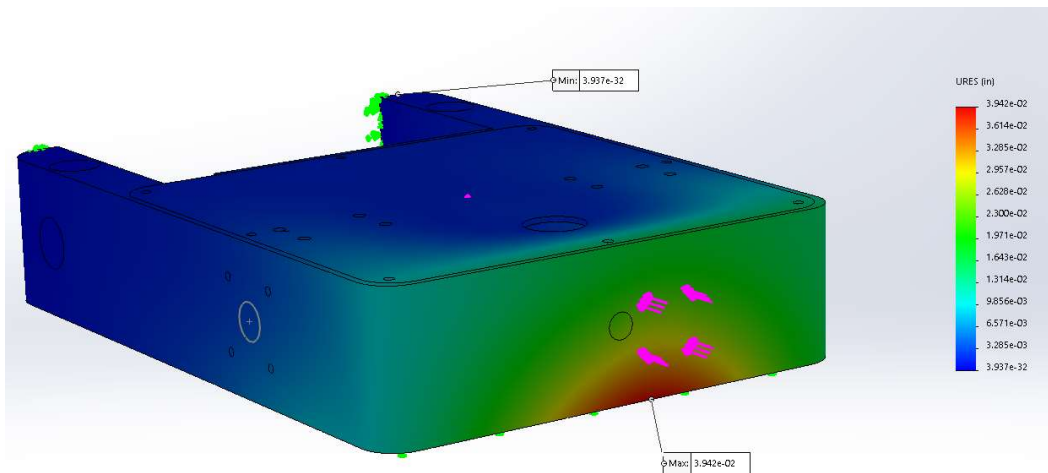


Figure 25. Rear Plate Displacement Test

Displacement was also found using FEA in SolidWorks. The largest displacement resulted from the force analysis at the rear-center, the same test as Figure 24. Rear Plate Stress Test. Figure 25. Rear Plate Displacement Test shows a maximum displacement of 0.03942" at the bottom lip of the bot. Maximum displacement is expected at this spot, as the bottom lip (and the top lip) is only 0.125 inches thick, due to the recessed plate. The results reflect UHMWPE's excellent shock absorption qualities. For the remaining displacement test, please see Appendix B.

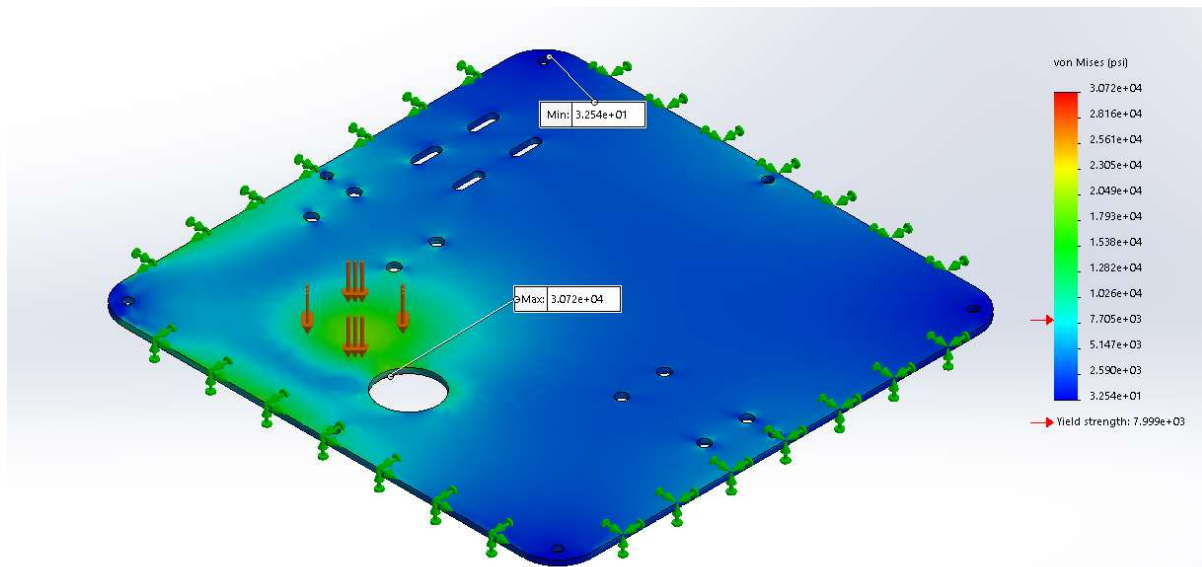


Figure 26. Top Plate Stress Test

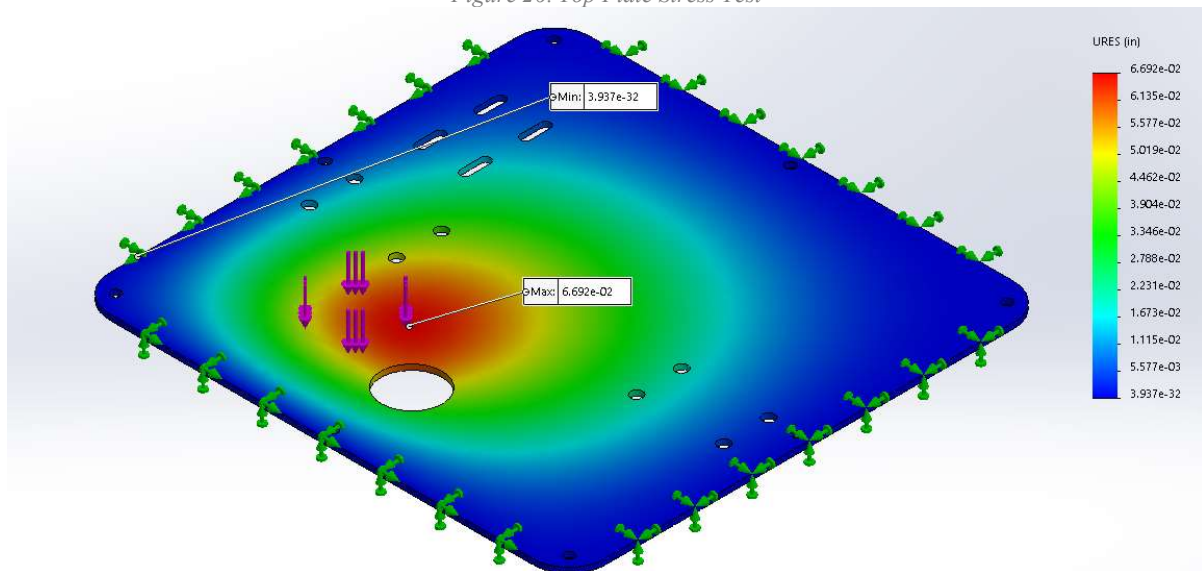


Figure 27. Top Plate Displacement

The safety factor for an opponent’s bot landing on top of our bot, was also calculated. Less than 300psi was experienced, and a safety factor of over 20 was calculated. This is the thinnest piece of armor, and the weakest. While it can withstand the weight of another bot, it cannot withstand a weapon blow well. Figure 26. Top Plate Stress Test, shows the 30,720psi experienced at the kill switch access hole. Figure 27. Top Plate Displacement shows the displacement of .067in experienced. A safety factor of 1.3 was calculated. Our bot would be in danger from a hammer bot, which are rare in small weight competitions, and this bot was not designed to face. This bot is also vulnerable if it gets oriented in a way in which the top plate could receive a weapon blow. The orientation bolt, at the rear of the frame is in place to prevent an unideal orientation. For images of the remaining stress test, please see Appendix B. For the safety factor calculations, please see the Calculations section.

Weapon

The material for the drum is 1020 carbon steel. Steel was chosen as the material for the weapon for its high yield strength and relatively low cost. Though steel is one of the heavier possible metals, this can be something of a benefit in a weapon due to the increased inertia and in turn, force at the contacting points of the weapon. Steel, in general, tends to be relatively easy to machine when compared to other high-strength metals. Steel is also known for its great impact resistance due to its generally high shear modulus values, an irreplaceable benefit in a weapon that will almost exclusively experience impact loads.

Through a series of calculations (detailed in the weapon calculations section, below), it was found that the approximate force that the drum will deliver is about 302 lbs force. To confirm the durability of the drum, drop tests to simulate impacts were done at 6ft, the equivalent of about 861 lbs force, around 2.87 times the expected force delivered/received. To simulate impact loads, the drop test function of SolidWorks was used. While SolidWorks does have a paid shock/impact simulation program, we did not have the budget to purchase this premium program. For the default version of SolidWorks, the drop test was the best way to imitate potential hits, even with limited angles.

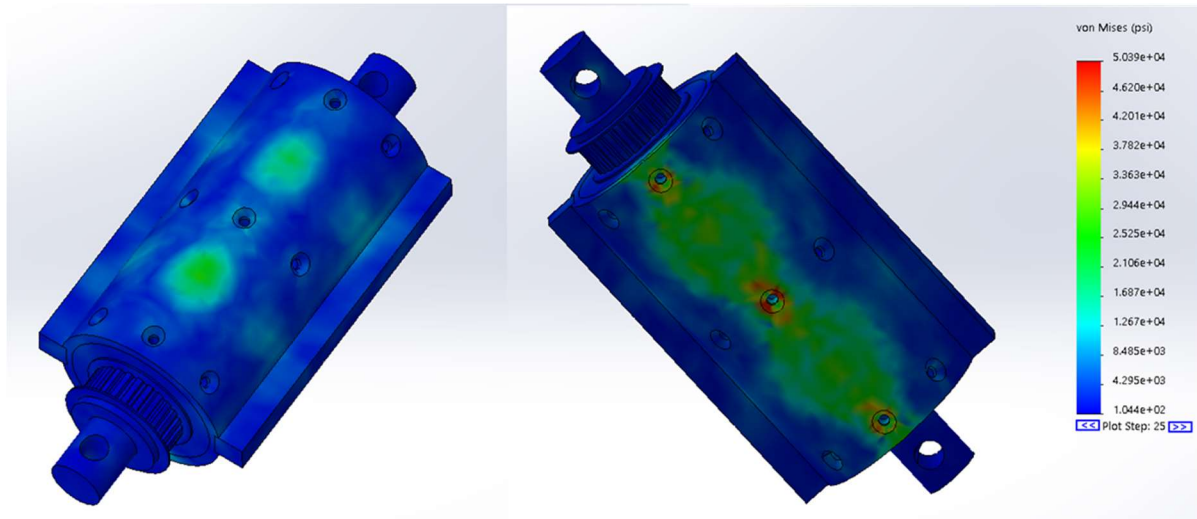


Figure 28. Results of 6 foot drop test, with the top of the drum shown at left, and the bottom impacting site at right. Note the stress concentrations between the internal support plate locations.

As the flat drop test in Figure 28 shows, the most significant forces in the drum were felt in the areas between the major internal supports. In these areas, (shown in green) the safety factor was only 2.04 under the increased load tested, which equates to a 5.85 safety factor when considering the actual expected ~ 300 lbf impact loads. The red concentrations around the milled screw holes are technically the largest forces felt by the drum according to this test, however once the screws are properly in place they are expected to absorb some of this shock. The screws were only omitted from this test due to the limitations of the SolidWorks testing program.

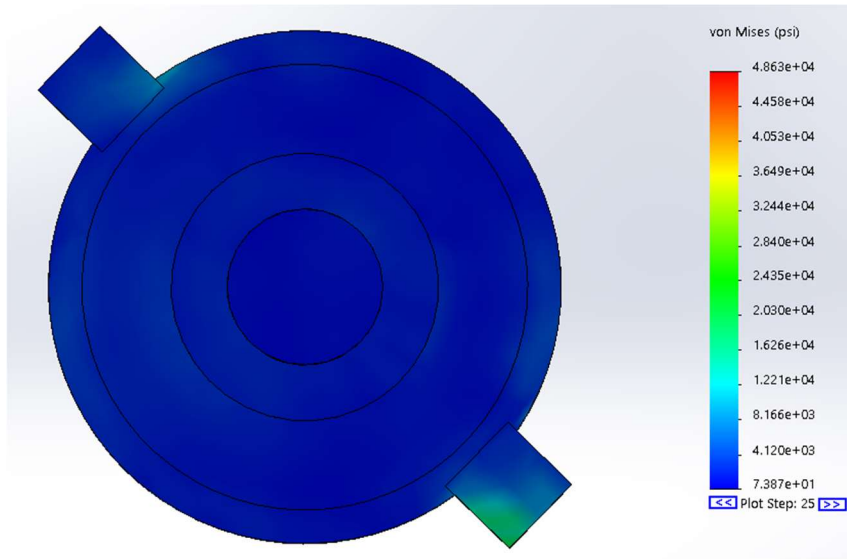


Figure 29. Side view showing angle of second 6 foot drop test. Gravity was exerted in the downward facing direction.

A further 6-foot drop test was conducted at a 45° angle, to simulate some of the impact effects that the drum's teeth might feel when giving or receiving blows. Figure 29. Side view showing angle of second 6 foot drop test. Gravity was exerted in the downward facing direction. shows the minor deflection that the teeth are expected to experience under a significant blow. It is worth noting, however, that the strength of the welds holding the teeth in place were not able to be properly simulated, and because of this the actual deformation may vary from that of the simulation.

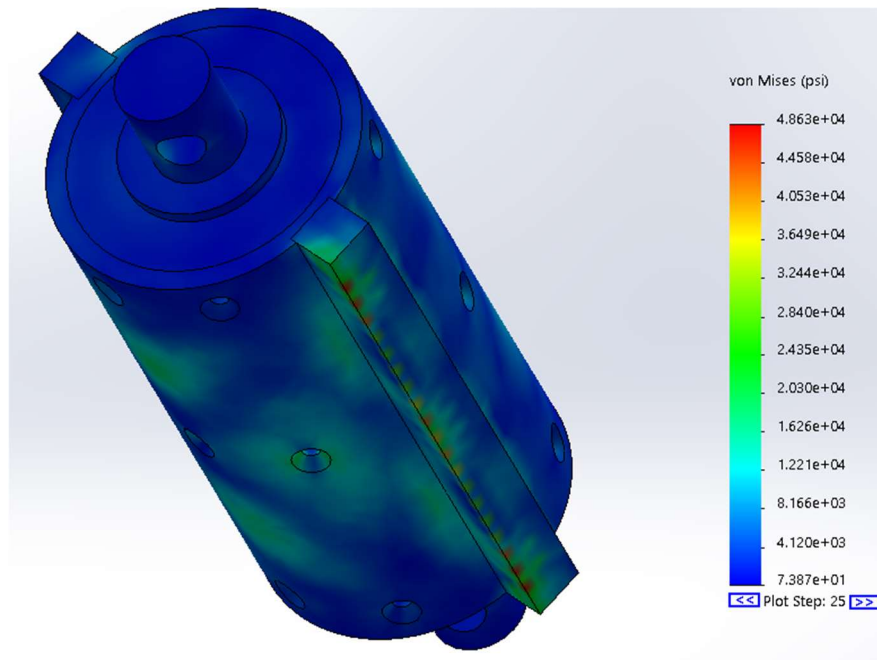


Figure 30. Alternate view of 45 degree angled drop test, 6 foot height, impacted side

The factor of safety in the areas where the most damage was taken (shown in red, at the corner of the contacting tooth) was about 1.23, which is generally an unacceptably low number. However, when considering that this is the max force, at the weakest corner edge of the teeth, at around 2.87 times the expected force, this number is not as bad as it first seems. Interpolating, the safety factor of this extreme edge is actually closer to 3.53 under expected force.

Calculations

Frame Calculations

The below calculations are for the force applied to the frame in the stress analysis, and the safety factor.

Kinetic Energy of a Weapon Strike

r = radius of weapon = 1.75in = 0.04445m

m = mass of weapon = 4.89lbs = 2.22kg

w = rotational velocity

Bot weapon speed = 1500rpm

$$\omega = (1500rpm) \left(\frac{2\pi}{60} \right) = 157.07 \frac{rad}{sec}$$

I = rotational moment of inertia = mr^2

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}I\omega^2 = \frac{1}{2}(mr^2)\omega^2$$

$$KE = \frac{1}{2}((2.22kg)(0.04445m)^2)(157.07 \frac{rad}{sec})^2 = 54.11J = 40lbf$$

Force per in²

A = weapon contact area = 0.25in²

$$P = \frac{F}{A} = \frac{40lbf}{0.25in^2} = 160psi$$

Bot Landing on the Top Plate Calculation

Weight = 15lbs

Acceleration due to gravity = 32.2 ft/s²

$$m = \frac{weight}{gravity}$$

$$F = ma = \left(\frac{15lb}{32.2m/s^2} \right) \left(\frac{32.2m}{s^2} \right) = 15lbf$$

Safety Factor Calculation

The below calculation is for Figure 24. Rear Plate Stress Test, the lowest calculated safety factor

Tensile strength of UHMWPE = 5800psi

Highest load on frame = 900psi

$$Safety\ factor(\eta) = \frac{breaking\ load}{effective\ load} = \frac{Tensile\ Strength}{Applied\ Force}$$

$$\eta = \frac{5800psi}{1,103psi} = 5.26$$

Tensile strength of 6061 Aluminum = 40,000psi

Highest load on aluminum top and bottom plate = 30,720psi

$$\eta = \frac{40,000psi}{30,720psi} = 1.3$$

Battery Calculations

$$estimated\ battery\ usage = 3 * 20A * 3\ minutes * 1000\ mAmps * 60 \frac{min}{hr} = 3000mAh$$

Wheel calculations

Motor RPM range: 20720-23520 RPM

Rated RPM: 22120 RPM

Wheel Diameter: 4in

Gearbox ratio: 20:1

Gear safety factor = .9

$$RPM_{wheel} = \frac{Rated\ RPM}{Gear\ ratio} * gear\ safety\ factor = \frac{22120}{20} * .9 = 995.4\ RPM$$

$$Linear\ Speed = Circumference * \frac{RPM_{wheel}}{60} = 12.57 \left(\frac{995.4}{60} \right) = 17.37\ mph$$

$$Input\ Torque = \frac{Wheel\ load * F_f * (wheel\ radius)}{gear\ ratio} = \frac{7.5lbs * .9 * 2in}{20} = 0.675in - lbs$$

Weapon Calculations

Pulley Ratio:

$$Pulley\ Ratio = \frac{Driven\ dia.\ D1}{Drive\ dia.\ D2} = \frac{1.5625}{1.0625} = 1.4706 \left(or\ \frac{25}{17} \right)$$

Weapon RPM:

$$Weapon\ RPM = \frac{Motor\ RPM}{Pulley\ ratio} = \frac{7303.8}{1.4706} = 4966.584\ RPM$$

Weapon Angular Velocity:

$$\omega = \frac{\text{Weapon RPM} * 2\pi}{60} = \frac{4966.584 * 2\pi}{60} = 520.1 \frac{\text{rad}}{\text{sec}}$$

Weapon Linear Velocity:

$$\begin{aligned} v &= \text{Weapon RPM} * \text{Weapon Dia.} * \pi * \frac{60\text{min}}{1\text{hr}} * \frac{1\text{ft}}{12\text{in}} * \frac{1\text{mile}}{5280\text{ft}} \\ &= 4966.584 * 3\text{in} * \pi * \frac{60\text{min}}{1\text{hr}} * \frac{1\text{ft}}{12\text{in}} * \frac{1\text{mile}}{5280\text{ft}} = 44.33\text{mph} \end{aligned}$$

Weapon Mass:

$$m = \frac{\text{weight}}{\text{gravity}} = \frac{4.26}{32.2} = 0.132 \text{ slugs}$$

Inertia:

Hollow cylinder:

$$m = 3.82 \text{ lbs}$$

$$I_{\text{cylinder}} = \frac{1}{2} m (ID^2 + OD^2) = \frac{1}{2} * 03.82 * (1.0625^2 + 2^2) = 9.796 \text{ lb} * \text{in}^2$$

Teeth, where r = distance from center of rotation to outer edge of teeth:

$$m = 0.44 \text{ lbs}$$

$$I_{\text{teeth}} = \frac{1}{2} * m * 3^2 = \frac{1}{2} * 0.44 * 3^2 = 1.98 \text{ lb} * \text{in}^2$$

Total:

$$I_{\text{total}} = I_{\text{cylinder}} + I_{\text{teeth}} = 9.796 + 1.98 = 11.776 \text{ lb} * \text{in}^2$$

Kinetic Energy:

$$KE = \frac{I\omega^2}{2} = \frac{0.00254 * 520.1^2}{2} = 343.5 \frac{\text{lb} * \text{ft}}{\text{sec}^2}$$

Weapon Force, where = impact time, estimated at 0.1 sec:

$$F = ma = m * \frac{v}{t_i}$$

$$F = \frac{W}{g} * \frac{v}{t_i} = \frac{15}{32.2} * \frac{65.01}{0.1} = 302.84 \text{ lbf}$$

Weapon Torque

$$\text{Weapon torque} = \text{pulley ratio} * \text{avg motor torque} = 1.4706 * 16.69 = 24.54 \text{ in} - \text{lbs}$$

Weapon Motor Calculations

Motor: E-flite Power 60, 470KV motor

Rated kV = 470 rpm/volt

Rated amperage (continuous) = 65A

Rated amperage (max) = 80A

Rated voltage = 22.2V

RPM:

$$\begin{aligned} \text{Motor RPM} &= \text{Rated kV} * \text{Rated voltage} * 0.7 \\ &= 470 * 22.2 * 0.7 = \mathbf{7303.8 \text{ rpm}} \end{aligned}$$

Wattage:

$$\text{Motor Wattage} = \text{Amperage} * \text{Rated voltage}$$

For average:

$$\text{Motor Wattage} = 65A * 22.2V = \mathbf{1443 \text{ Watts}}$$

For max:

$$\text{Motor Wattage} = 80A * 22.2V = \mathbf{1776 \text{ Watts}}$$

In horsepower (average to max):

$$\text{Motor Horsepower} = \frac{W}{746} = \mathbf{1.934 \text{ to } 2.381 \text{ hp}}$$

Motor Torque (average to max):

$$\text{Motor Torque} = \frac{HP * 5252 * 12}{RPM} = \frac{HP * 5252 * 12}{7303.8} = \mathbf{16.69 \text{ to } 20.55 \text{ in} - \text{lbs}}$$

Weapon Battery Calculations

$$\text{Est. battery usage (amp} = 65\text{avg, } 80\text{max)} = \frac{\text{amp} * 3\text{mins} * 1000\text{mA}}{60\text{min}} = \mathbf{3250 \text{ to } 4000\text{mAh}}$$

Selected battery: Adafruit Industries LLC 353, which is rated to provide 6270mAh. This is the same battery used for the wheel drive system, making it easier for us to buy extras since they can be used to replace the batteries in either system.

Weapon Belt Calculations

For the belt, a v-belt was chosen over the timing belt design, due to its better impact resistance. Unlike a timing belt, a v belt is more likely to slide in the pulley during an impact, instead of skipping or outright snapping. As for size, we needed to select a belt with a large enough cross section to provide the strength and support needed to drive the weapon, without becoming too large of a target. For this reason, the 3L (3/8-inch width by 7/32 height) belt was chosen based on its size/shape and historical success in 15-pound bots of previous years.

To determine the required length of the belt, the pitch diameters (the diameter between the lowest points where the belt touches the pulley) of the two pulleys and the distance between their centers was required. For the larger, driven, 2-inch pulley built into the drum, the pitch diameter was:

$$D1 = 2in - \left(2 * \frac{7}{32} in\right) = \mathbf{1.5625 inches}$$

and for the smaller, driving, 1.5-inch pulley:

$$D2 = 1.5in - \left(2 * \frac{7}{32} in\right) = \mathbf{1.0625 inches}$$

Using these two diameters and an approximate desired centerline distance (C) of 4.5 inches, the belt length required was found to be 13.137 inches using the following formula:

$$\begin{aligned} \mathbf{Belt\ length} &= \left((D1 + D2) * \frac{\pi}{2} \right) + (2 * C) + \left(\frac{(D1 - D2)^2}{4 * C} \right) \\ &= \left((1.5625 + 1.0625) * \frac{\pi}{2} \right) + (2 * 4.5) + \left(\frac{(1.5625 - 1.0625)^2}{4 * 4.5} \right) = \mathbf{13.137 inches} \end{aligned}$$

Since belts have standardized lengths by the inch, this was shortened to the existing length of 13 inches. Calculations were then re-done using a belt length of 13 inches to find the required centerline distance of 4.4375 inches. Despite being a shorter distance than the originally estimated 4.5 inches, this still gave us plenty of room for the tensioning system while also maximizing space in the back of the bot for the other components.

Belt velocity:

The velocity of the belt was calculated using the following formula, where the pulley pitch diameter used was that of the driving pulley D2, and the motor RPM was 7303.8 rpm.

$$v_{belt} = \frac{\pi * D2 * Motor\ RPM}{12} = \frac{\pi * 1.0625 * 7303.8}{12} = \mathbf{2031.6\ ft/s}$$

Bill of Materials & Budget

The bill of materials gives a full list of all the components needed to build SPLURT. The parts highlighted in yellow were already purchased, and would not need to be ordered if a future year wanted to build our bot. This bill of materials covers one bot with a spare frame and weapon. Because the electronics of the bot were expensive, with a smaller likelihood of breaking than other parts, the decision was made to not double up on the electronics.

Some components were purchased outside of the BOM below, using personal funds. Three D2826-10s Turnigy Motors (two for the drivetrain, one spare) were purchased for \$22 each, or \$66 altogether. These motors were purchased ahead to prevent issues stemming from major components being out of stock as the dates got closer to the competition, an issue that other teams ended up facing. The 2.875 in OD pipe used for the drum and scrap aluminum plate to be used for the supports were purchased together at David Hirschberg & Co. for \$18.76. For a more detailed list of the parts in the below chart, please see Appendix E.

Part	Description	Quantity	Price Per Unit	Total
FRAME				
One Piece Frame	12" x 12" x 2-1/2" UHMW Sheet, Black	2	\$98.63	\$197.26
Top and Bottom Cover for Frame	0.09" Thick, 18" x 18" 6061 Aluminum Sheet	1	\$38.36	\$38.36
Frame Cover Screws	Stainless Steel Hex drive screw, 8-32 Thread Size, 3/8" Long	1	\$4.79	\$4.79
Frame Cover Screws	Brass Screw Inserts, 8-32	1	\$12.60	\$12.60
WEAPON				
Flanged Weapon End Bushing	FF-1102 Oil Impregnated Bronze Flanged	4	\$5.78	\$23.12
Center Internal Weapon Bushing	Multipurpose SAE 660 Leaded Bronze Sleeve Bearing	2	\$11.89	\$23.78
Pulley motor 12 teeth (bore out ID for 6mm (0.236in))	XL Series Corrosion-Resistant Belt Pulley, 1"OD	1	\$8.98	\$8.98
Pulley drum 26 teeth (bore out full step ID (1 1/8in) for shaft+bushing)	XL Series Corrosion-Resistant Timing Belt Pulley, 1.88" OD	2	\$13.22	\$26.44
Weapon Motor	Turnigy Aerodrive SK3 - 5055-320KV Brushless Outrunner Motor	1	\$52.71	\$52.71
Drum assembly screws (x25 per pack)	Thread-Locking Hex Drive Flat Head Screws (vibr-resist)	2	\$7.76	\$15.52
7/16 threaded rod for Frame+Weapon connection & Rear Orientation Bolt	Steel All Thread Rod, 7/16"-14 Thread Size, 3'0" Long	1	\$4.46	\$4.46
Skid to Weapon Connection Bolts (7/16 Nut)	High-Strength Steel Hex Nut	1	\$8.03	\$8.03
7/8" Aluminum Shaft	7/8 inch Dia. 6061-T6511 Aluminum Round - 2ft Length	1	\$13.00	\$13.00
Weapon Belt- Pickup at Branch #154	XL, 130XL037, 3/8" Width - Timing Belts	4	\$5.57	\$22.28
DRIVETRAIN				
Drive Gearbox	P61 Gearbox: Standard, 26:1 with Blank Motor Block	2	\$54.90	\$109.80
Wheel Hub	T81 Hub, 1/2in Shaft	2	\$3.15	\$6.30
Bronze Bushings (for drive shaft (5/8 bushing))	Multipurpose SAE 660 Leaded Bronze Sleeve Bearing for 1/2" Shaft Diameter and 5/8" Housing ID, 1/2" Long	2	\$1.68	\$3.36
Drive Gearbox Support Screws	18-8 Stainless Steel Button Head Hex Drive Screw 10-32 Thread Size, 1" Long	1	\$6.16	\$6.16
ELECTRONICS				
Bot Batteries (price is estimated)	BATTERIES - 3 CELL (x2pcs in series)	4	\$35.00	\$140.00
ESC x3pcs (Weapon + Drive)	SIDEWINDER 8TH ESC, 25.2V ESC, 8A PEAK BEC, WP	3	\$102.55	\$307.65
RC Receiver	Spektrum AR410 4-Channel RC Sport Receiver, Black	2	\$27.81	\$55.62
Power (Kill) Switch	FingerTech Mini Power Switch	1	\$7.20	\$7.20
Connectors for electronics with heat shrink	Finware 10 Pair XT60 XT-60 Male Female Bullet Connectors	2	\$8.99	\$17.98
SHIPPING				
Ordered Shipping Price		1	\$14.00	\$14.00
Remaining Shipping Price		1	\$58.47	\$58.47
Machining Cost Estimation		1	\$0.00	\$0.00

School Year	Team Name	Total Cost
2019-2020	The SPLURTTettes	\$1,177.87

PROJECT MANAGEMENT

BUDGET, PROPOSED/ PROJECTED

Proposed Budget

The project budget was approved for \$1,200, funded by the UC Battlebots club. This initial budget is based off of total component costs. A more extensive budget was calculated detailing the cost of each component. This budget includes components for a spare frame, spare weapon without electronics, and spare general materials such as screws and wiring. Table 3. Condensed Budget, UC 2020 Battlebot shows the condensed budget.

Subsystem	Total Cost
Frame	\$253.01
Weapon	\$198.32
Drivetrain	\$125.62
Electronics	\$528.45
Shipping	\$72.47
Total	\$1,177.87

Table 3. Condensed Budget, UC 2020 Battlebot

Actual Budget

Due to the COVID-19 outbreak and subsequent shutdowns, the decision was made to halt all part orders with the exception of the larger McMaster Carr order which contained the majority of initial machining components. The costs of these components are outlined in Table 4. Actual Budget, UC 2020 Battlebot, below

Subsystem	Total Cost
Frame	\$253.01
Weapon	\$87.21
Drivetrain	\$9.52
Electronics	\$0.00
Shipping	\$14.00
Total	\$363.74

Table 4. Actual Budget, UC 2020 Battlebot

For a more detailed list of cost, please see Appendix E.

SCHEDULE

Projected Schedule

Below are the planned key milestones for building and testing the bot, along with the competition date and academic obligations. The purchase of materials, and testing have been placed on this timeline, as previous senior design reports emphasize allotting time for these activities. See Table 5. Key Milestones, Expected, UC 2020 Battlebot.

Milestone	Date	Duration
Submit Budget to Battlebots Club	7-Dec	
Fall Semester Ends	13-Dec	
Spring Semester Starts	13-Jan	
Senior Design II Presentaion	20-Jan	
Redesigning	28-Jan	11-Feb
Budget Approved	10-Mar	
Order Materials	16-Mar	
Spring Break	16-Mar	
Material Orders approved	20-Mar	
Machining	30-Mar	7-Apr
Assembly	7-Apr	10-Apr
Tech Expo	9-Apr	
Testing	9-Apr	15-Apr
Final Presentation	16-Apr	
Safety inspection	17-Apr	
Competition	18-Apr	
Final Report	25-Apr	
Spring Semester Ends	1-May	

Table 5. Key Milestones, Expected, UC 2020 Battlebot

With some complications near the end of the 2020 spring semester, some adjustments needed to be made to the milestones. A new timeline was introduced.

Milestone	Date	Duration
Submit Budget to Battlebots Club	7-Dec	
Fall Semester Ends	13-Dec	
Spring Semester Starts	13-Jan	
Senior Design II Presentaion	20-Jan	
Redesigning	28-Jan	11-Feb
Order Materials	16-Mar	
Spring Break	16-Mar	
Budget Approved	20-Mar	
Material Orders approved	20-Mar	
Theoretical Machining	30-Mar	7-Apr
Meeting over schedule changes	2-Apr	
Theoretical Assembly	7-Apr	10-Apr
Bot Simulation	7-Apr	14-Apr
Final Presentation	18-Apr	
Final Report	18-Apr	
Spring Semester Ends	1-May	

Table 6. Key Milestones, Actual, UC 2020 Battlebot

PLAN FOR FABRICATION & ASSEMBLY

Frame Fabrication Plan

No frame components were able to be manufactured due to lab closure. Manufacturing plans were gone over in detail with VPC North Laboratory advisers. The processes needed to complete and assemble the frame are detailed below. See the drawings in Appendix C if further detail is needed. Multiple component drawings have been made to simplify the reading of dimensions.

One-Piece Frame

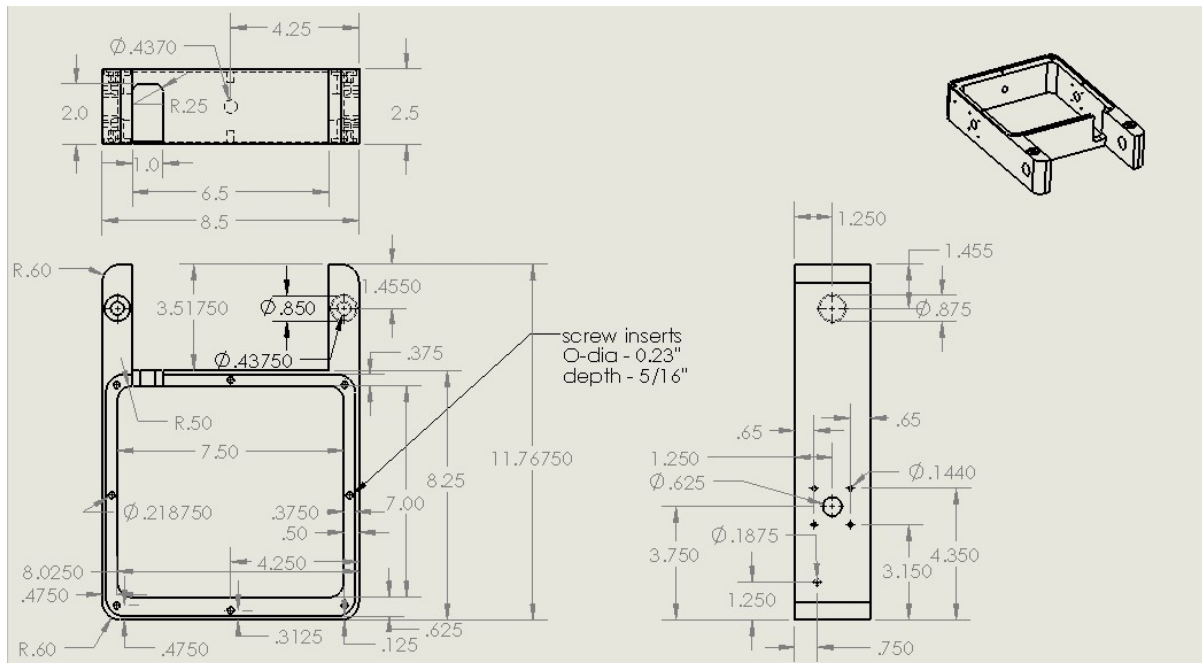


Figure 31. Frame Dimensions

The frame's UHMWPE materials are in the possession of the UC Battlebots Club, if future teams would like to move forward with this frame design. Two frames are to be manufactured out of two 12 x 12 x 2 ½ inch UHMWPE blocks; one frame per block. Before processing, it must be ensured that all tools are appropriate for plastic cutting. All outer cuts, holes, and fillets are to be manufactured first. The cut for the weapon and the center-cut are to be done last. This will ensure structural integrity throughout the machining.

First, the 12 x 12 inch UHMWPE block should be cut down to 12 x 8 ½ inches using a bandsaw. The resulting blocks will be the 12 x 8 ½ inch block, used for the frame, and a 12 x 3 ¾ inch block that will be used to manufacture four skirts, a rear wall/plate used for physical testing purposes (sample wall should be ¾" thick, same as the rear wall) and four drive motor support blocks. See the drive fabrication plans for details on the support block. Next, all exterior holes must be drilled using a drill press. For drilling, a bit with minimal flutes is preferred for cutting plastic. A 1-flute or 2-flute is optimal. These bits are limited at VPC North Laboratory and may need to be purchased. The holes to be drilled are:

- The rear orientation peg hole, 7/16th dia.

- The drive shaft holes, two total, on the left and right side, 5/8" dia.
- The drive shaft screw holes, which surround the drive shaft hole. Eight total, four on the left and right, 0.144" dia.
- The weapon shaft holes, on the left and right, two total, 7/8" dia.
- The skid hole, on the top of the left and right wing. Two total, counterbore 0.2", 0.85" dia.
 - Discuss this with the VPC advisers/Battlebot club. There was debate on the utility of counterboring the skids. This process is optional. If not done the skid length must be changed accordingly.
- The skid-bolt hole, centered with the skid hole, two total. Threaded to fit the 7/16th bolt, 7/16th dia.

Next, the top and bottom of the bot is to be recessed 0.09" using a CNC machine and the appropriate minimal-flute bit. See drawing for dimensions. After this, the cover screw-insert holes may be made using the CNC machine. Alternatively, the holes can be made using a drill press. For hole placement, glue a paper template of the top and bottom covers to the frame.

- Eight holes on the top and bottom, 16 total, 5/16" depth, 0.23" dia.

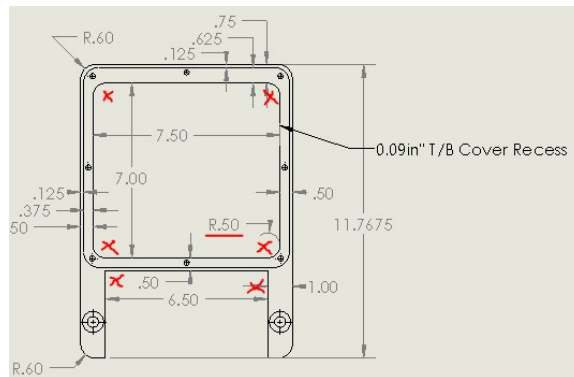


Figure 32. Frame Drill Locations for Major Cuts

Next, the large center-cut and the cut for the weapon are to be made. For the center cut, first drill four holes in the interior corners of the bot, drilling through the 2.5" thick body. Locations shown by the red "X" above. Ideally the drill should be 1" dia. to match the 0.5" interior filleted radius, but a smaller diameter drill may be used, and fillets adjusted later. Make the interior cut using a bandsaw. To do this, cut the bandsaw, thread it through the hole, and weld the saw back together, and make the cut. To make the cut for the weapon use the same method, drilling corner holes, and then moving to the bandsaw.

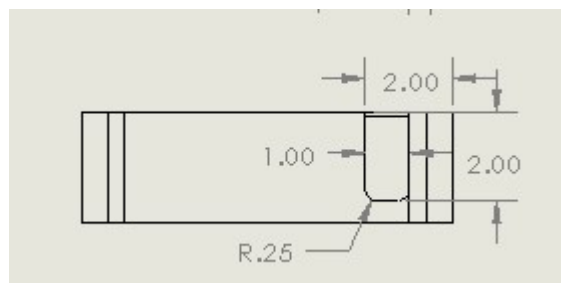


Figure 33. Frame Weapon Belt Hole Dimensions

Next, the weapon belt hole should be made using a bandsaw. Finally, adjust the fillets appropriately. Interior fillets may be adjusted using a file, grinder, or bandsaw. Exterior fillets are to be ground down using a belt sander. Note: the final exterior dimensions are 12 x 8 ½ x 2 ½ inches; the length of the front wings may need to be ground down further to fully expose the drum teeth. Based on the design the front should be ground down, so the overall length is approximately 11.8". Mount the drum to the frame to determine if the weapons teeth are properly exposed. Repeat the process for the remaining UHMWPE block, in order to have a spare frame.

Top and Bottom Cover

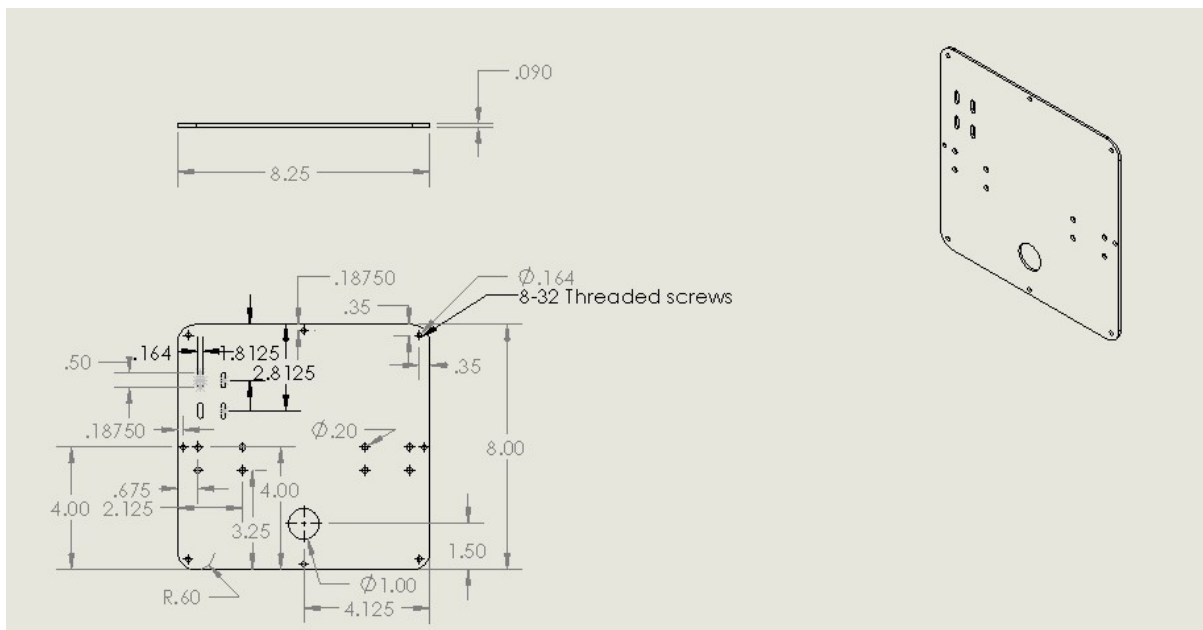


Figure 34. Top Plate Dimensions

An 18 x 18 x 0.09 inch thick sheet of 6061 aluminum was purchased and is in the possession of the UC Battlebots club, if the covers are to be made. The 18 x 18-inch sheet is to be cut into four 8 x 8 ¼ inch rectangles using a plasma cutter. The spare aluminum may be used for reinforcement armor, if applicable. If additional armor is not desired all trimmings can be scrapped. The 0.6" exterior corner fillets are to be made using a plasma cutter. All holes must be drilled using a drill press or hand drill, as they are too small for a plasma cutter. To do this, create or print out a 1:1 template of the cover plate, and glue it to the aluminum. Create pilot holes based off of the template locations, and drill holes of the appropriate diameter using a hand drill or drill press. The slots in the upper left-hand corner can be created using a drill press for the initial hole, and a dermal to lengthen the slot profile. The 1" dia. kill switch access hole, at the bottom center, can be cut using a hole saw. The kill switch access hole should be cut only on the top plate. The bottom cover will not have this hole. Repeat the process for the remaining plates.

Skids

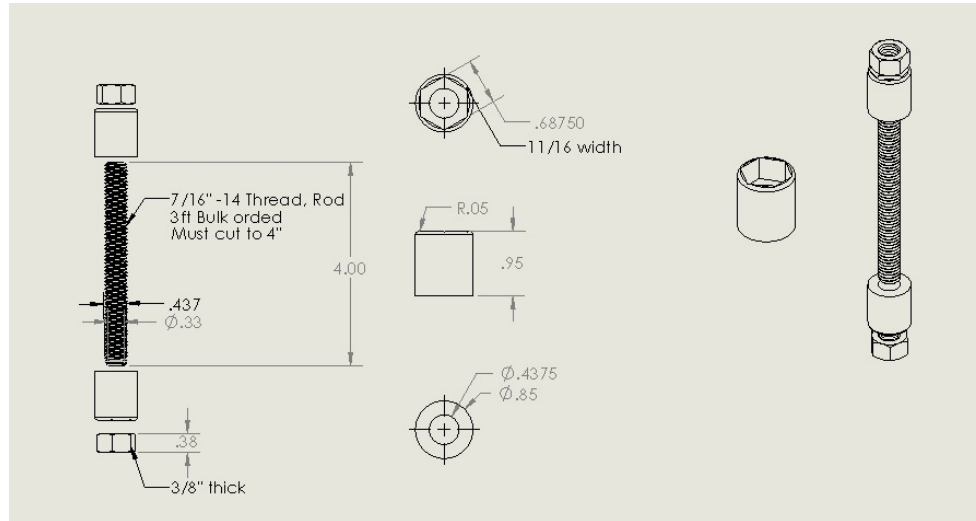


Figure 35. Skid Dimensions

The skids are to be made out of the scrap UHMWPE material. Four 1 x 1 x 2 ½ inch blocks should be cut from the scrap 12 x 3 ¾ inch block. These blocks can be shaped to their appropriate outer diameter using a lathe or belt sander. Next, cut the skids to the appropriate 0.95” length. The 7/16th center hole can be made using a drill press. The hole to hide the nut is to be counterbored a minimum of 3/8”.

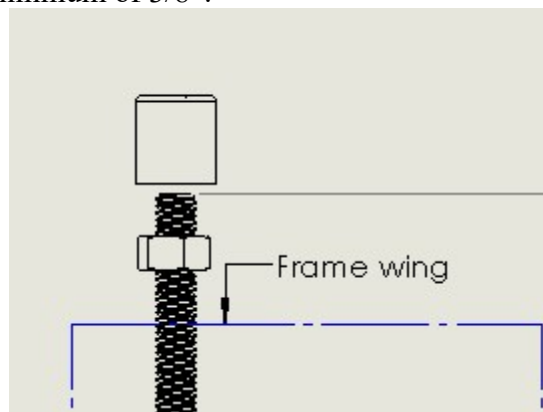


Figure 36. Skid Alternative Nut Placement

Alternatively, the nut can go on before the skid, so it is flush with the face of the frame wing. This will eliminate the process of counterboring the skid 3/8”, as the nut proceeds the mounting of the skid. If this is done, the 7/16th hole must be threaded so it fits the 7/16th rod. Repeat the process for all four skids.

The threaded rod was ordered as a single 3ft rod and must be cut to the 4” length using a chop saw or a band saw. Cut two 4” rods for the skid. Cut a 2” rod for the rear orientation bolt. Alternatively, the appropriate 4” and 2” threaded rods may be purchased. It was not in our teams’ budget to do so. Repeat this process so there are an appropriate number of spare skids and bolts. Our team originally planned on making one set of spares.

Theoretical Reinforcement Armor

If there is weight to spare, after a full assembly has been performed, it is recommended reinforcement armor be fabricated. As the design currently stands, reinforcements would have to be small, as there is little weight to spare. Placement of this armor is dependent upon where weak points are found after physical testing. See Theoretical System Testing, the Frame Testing Plan. Based on solidworks FMEA testing, the weakest points are the top plate, the center of the side walls, and the center of the rear wall, in that order. The wheels are also a key weak point, but wheel armor was decided against due to the rarity of direct wheel attacks, and the tendency of wheel armor to deform and restrict wheel movement. UHMWPE has excellent shock absorption qualities, but poor hardness. Due to this, a hard material should be selected as exterior armor. As this armor will have to be lightweight, 0.09" 6061 aluminum has the desired weight and hardness properties. A harder and or thicker material type would be more desirable. This armor is not to exceed the length, width, or height of the bot, as it may start to interfere with other system components. Armor dimensions will depend on the weight requirements and desired function. Armor holes can be drilled with a drill press and the proper drill bits, as discussed in previous frame fabrication components. A screw pilot hole will be needed in the frame. Armor can be secured to the bot using wood screws. Do not place armor over existing screw/bot locations, as wood screws can only be inserted/removed a few times before stripping the hole material.

Frame Assembly

The assembly of the frame is relatively simple. All needed materials are in possession of the UC Battlebots Club. First, insert the 8-32 brass screw inserts into the 16 top and bottom cover holes in the frame. These will be a tight fit, and may need to be hammered in. For additional strength, E6000 glue or an epoxy can be purchased and applied to the inserts during installation. Any additional armor may be installed now, using wood screws. Wood screws will need to be purchased. Next install the 2 inch, 7/16th rear orientation bolt using two 7/16th nuts. Install the bottom plate using eight 8-32 screws. Next the drive train, electronics, insulation, and weapon components must be installed. For the skids, place the weapon drum assembly in the proper location, and screw in the two 4 inch, 7/16th skid bolts. Next screw on the appropriate 7/16th nuts and skids. Ensure that the bot sits level. Finally install the top plate using eight 8-32 screws. It is recommended to weigh the bot, once assembled.

Weapon Fabrication Plan

All machining operations were to be completed twice, once for the main weapon assembly, and once for the backup weapon assembly.

Outside Drum Cylinder

In order to reduce cost while still maintaining reasonable strength, scrap steel pipe with 2 7/8" OD and 3/16" thickness was used for the outside drum cylinder. There were significant delays in ordering parts caused by the higher than normal number of senior design teams participating in Battlebots design, since the club leaders had to carefully consider what teams would receive what funding. This is one of several reasons why scrap metal was used

(another being the aforementioned and significant cost reduction), because it allowed machining to start earlier than would otherwise be possible. In the end, no machining was completed on any components other than the outer drum cylinder (whose materials were purchased ahead at a David Hirschberg scrapyard) before all UC facilities were closed down, because funding issues caused so many major delays.

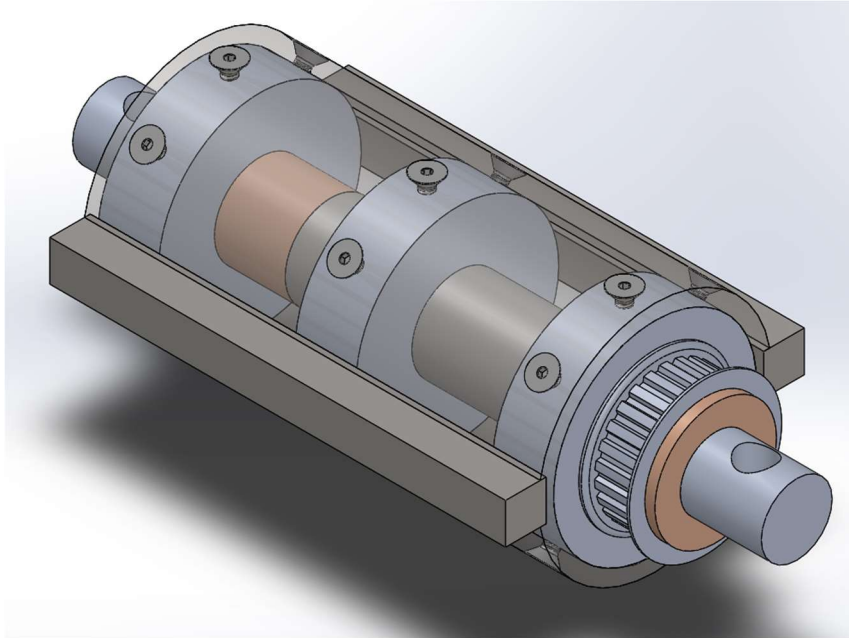


Figure 37. Full drum assembly, transparent to show internal components

To machine the outer drum cylinder, the pipe first had to be cut to length using a band saw. The pipe was cut with an additional 1/8" length to leave room for face cuts to ensure a smooth end surface and an accurate length. After initial cuts, the cylinder was put on a lathe (tightened down without touching the back face of the lathe, to ensure the pipe was perpendicular to center) and machined to a flat surface. Once flatness was achieved on one side, the pipe was flipped, and tightened into place with the now flat face forced flat against the back of the lathe using a few taps from a rubber mallet. From here, the pipe was machined to length by making several larger rough passes, followed by smaller passes removing less material, until the length was approximately correct according to measurement via calipers.



Figure 38. Face cuts on the lathe

Once the face cuts were completed, the outer edge was deburred using the belt sander. The inner diameter was deburred using a swivel headed deburring tool.

Next, the grooves were machined by using a mill, clamping on the parallel face cuts made in the previous step. The center of the cylinder was found using a centering tool for the X axis, and by touching off the top of the pipe to zero the Z axis. Each groove was machined in using three passes: two rough passes, and a shallower finishing cut. After the first groove was machined, the edges were deburred using a flat deburr file placed over the full length of both cuts to maintain even depth on each side. The part was then flipped to rest on these deburred surfaces in order to ensure the second groove would be 180° from the first groove.



Figure 39. Drum, after milling first groove

Once both grooves were machined into the drum cylinder pipe, a deburr file was used to deburr the full length of the top edges, as well as any remaining burrs on the face edges of the cylinder. At this point, the outer drum cylinder was complete prior to required interactions with other components (specifically the aluminum support discs).



Figure 40. Finished outer drum grooves; backup and main

Due to the COVID-19 outbreak, no further machining was able to be completed. All further sections detail the machining that would have been completed, had the machine shops not been closed.

Aluminum Support Discs (x3 per weapon assembly)

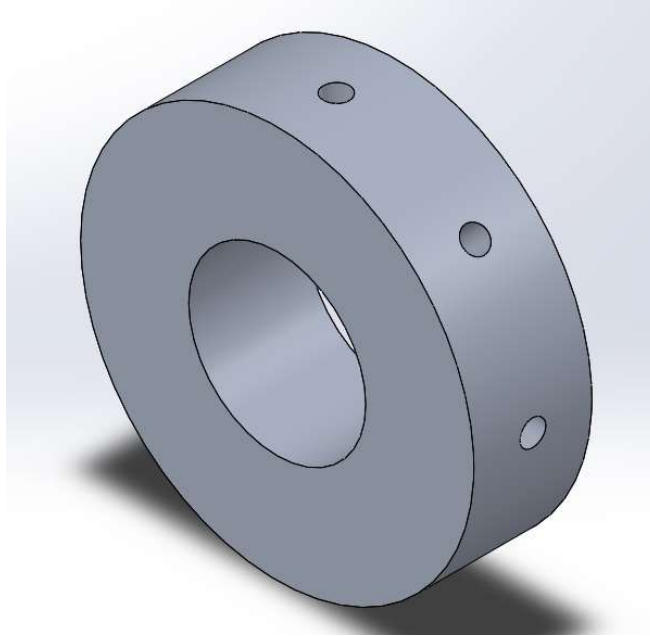


Figure 41. Aluminum support - SolidWorks drawing

The aluminum supports were to be milled out of $\frac{3}{4}$ " thick scrap aluminum plate. Because the plate had a flat surface finish and was already to size as far as disc width, only the outer and inner diameter of the disc needed to be accounted for at this stage.

For the correct inner diameter, the plate would be clamped down in a manual mill, with the larger flat surface facing up. Using a 1 $\frac{1}{8}$ " endmill, the center hole of the final supports would be machined along the plate, spaced to leave room for the outer diameter of the support and for the mill which will cut the outer diameter, doubled. To achieve the correct outer diameter, the plates were to be CNC machined using a small mill, programmed to cut circles around the holes machined in the previous step, slightly larger than final size (+.01"). For this process, the full plate would be clamped down on to the machine table. Because the plates should fit inside the drum as snugly as possible, the plates would be sanded down to final size manually. Realistically, because the plates will also be screwed into the drum in 6 places each, it is acceptable for the plates to be a bit smaller than the ID of the drum, provided the spacing is not excessive.

Prior to pressing the plates into the drum, the bushings must be pressed through the center holes of the plates, ensuring that the correct length of bushing is sticking out each end of the center support plate. This will help with proper distancing when inserting the plates into the drum. Once the aluminum plates were pushed into the drum, the final 82° screw head and 5/32" screw shaft holes would be machined through the drum and supports at the same

time, in order to prevent possible issues with hole locations matching up. Once the holes were drilled and tapped, the screws would be screwed into the drum.

Aluminum Shaft

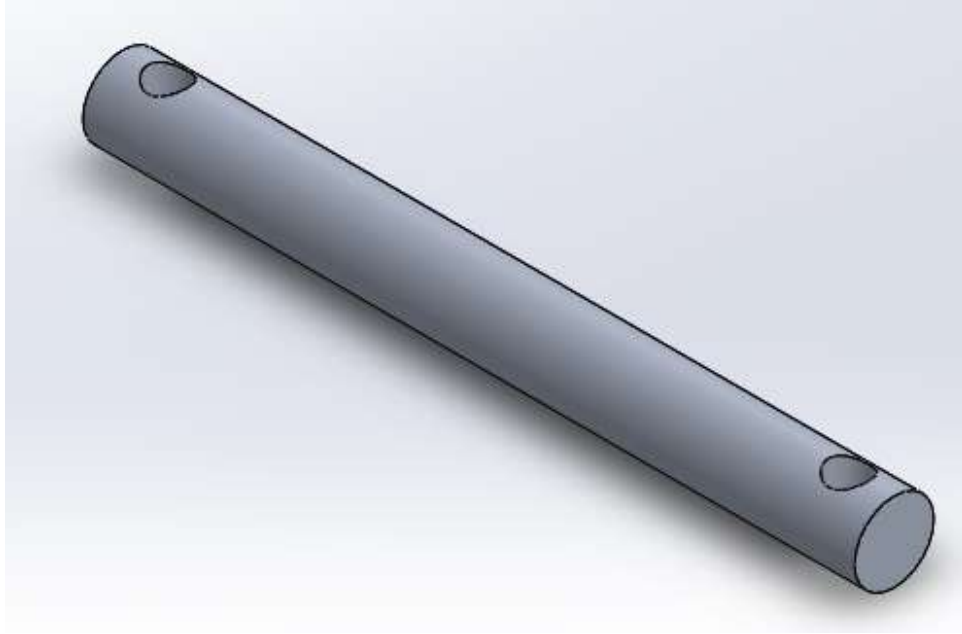


Figure 42. Weapon shaft

The aluminum shaft which the drum assembly sets on during combat was to be purchased at the correct OD, long enough to accommodate the creation of two shafts. Similar to the initial drum steps, the shaft would be cut with a band saw with a small amount of plus stock, and faced down to length on the lathe in order to achieve a smooth surface finish at the /ends. Then, the holes for the attachment screws would be milled out using a 7/16" endmill and later tapped.

Weapon Motor Support Block

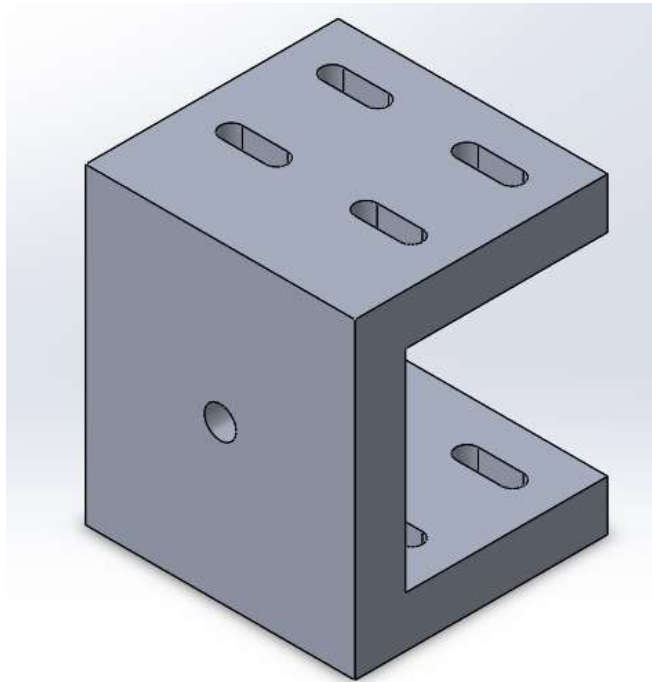


Figure 43. Weapon support "C" block

The weapon support block was to be manufactured out of spare scrap aluminum, or other inexpensive metals if aluminum wasn't available. Since it is not a component that experiences significant critical loads, the strength of the material the C block is made out of is less important than with other components.

First the block would be rough cut close to the final outer dimensions. Then, to prevent later deformation, the slots would be milled first through the entire thickness of the block. Then, the block would be turned on its side, and the main "C" shape would be milled out. Finally, with the part turned so that the bottom of the "C" was facing down, the final hole for the weapon motor pin to go through would be milled using an appropriately sized endmill.

Drum Pulley

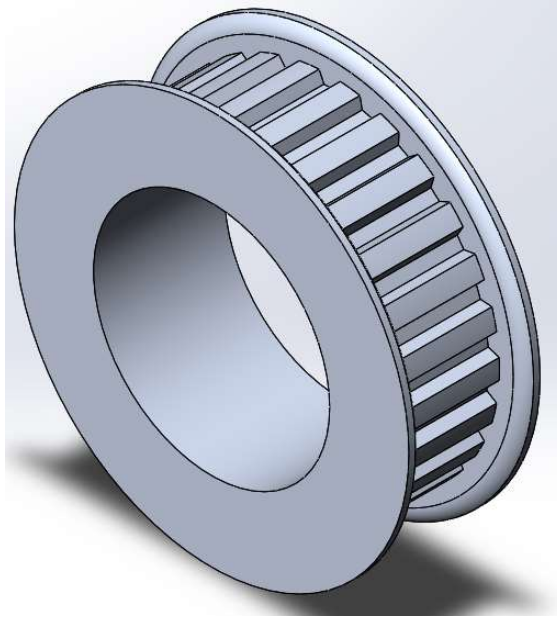


Figure 44. Drum pulley

Ideally, the center hole of the pulley would be milled out at the same time as the aluminum support that it would be welded to. First, the purchased pulley would be welded to the side of the plate for the support, as centered to the intended center of the plate as possible. After welding, the pulley and support would be milled to create the hole for one of the bushings to be pressed into.

Drum Teeth

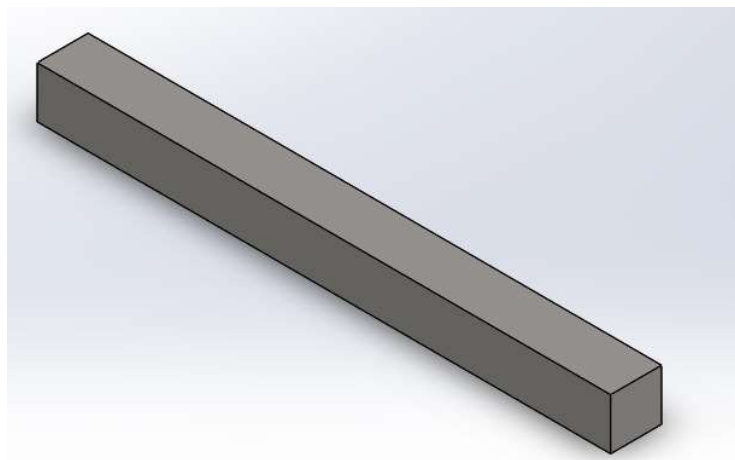


Figure 45. Drum weapon contacting teeth

The contacting teeth of the drum were obtained at correct outer dimensions, and were to be cut to length using the band saw, with any rough edges deburred off. Finishing cuts were not expected to be necessary, due to the relatively large tolerance on the length ($\pm 1/16$ ", to prevent contacting the frame wall if oversized).

Drivetrain Fabrication Plan

For the drive train the goal is more assembly than fabrication. The gearbox, motor, wheel, bronze bushing, and screws have already been built by the manufacturer. Fabrication for the drive is mainly focused on the support blocks and the motor guard.

For the motor guard, fabrication is simple.

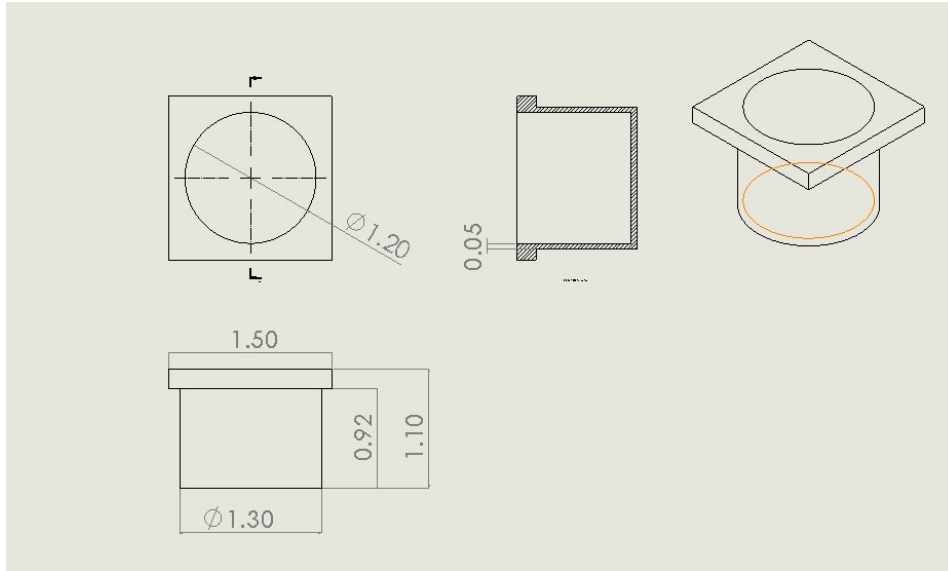


Figure 46. Drivetrain support drawing A

This model would then be brought to the 1819 building to be 3D printed. Excess material would be cleaned off. With the size of the printers, two could be printed at the same time to save on fabrication time.

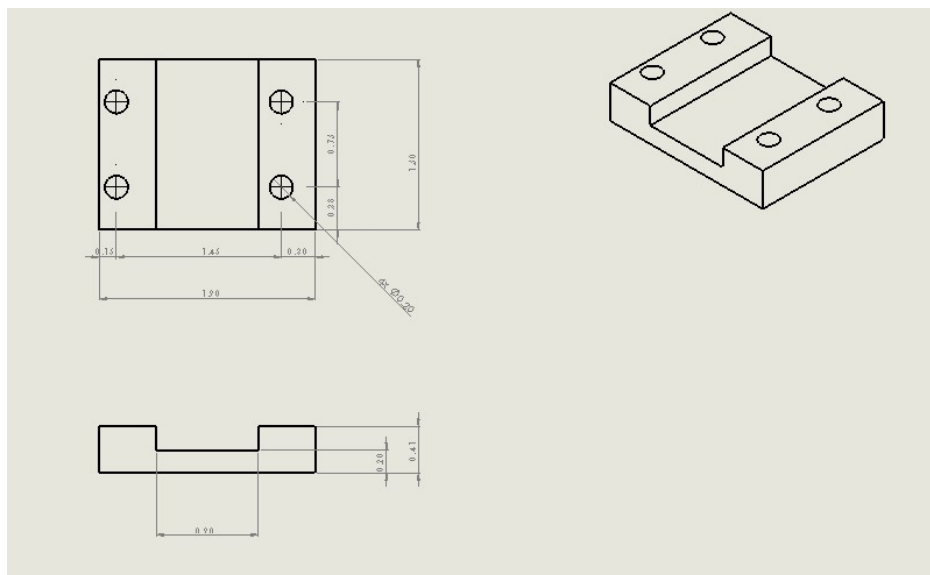


Figure 47. Drivetrain support drawing B

As for the support blocks, the fabrication plan was similar. A model was designed in solidworks then redesign with suggestions from battlebot club members to make the blocks better at staying in place. Initially the plan for fabrication included having the support blocks 3D printed at the 1819 building but it was later decided that stronger supports could be made by using the excess material from the frame waste. The plan was to take the frames material and cut it to size with the bandsaw at the VPC lab. The holes for the supports would be drilled using the same 1-flute drill as for the frame since the same screws would be used for the frame as for the support blocks.

THEORETICAL SYSTEM TESTING

Frame Testing Plan

The frame is to be tested in several ways before competing. Firstly, a ½” and a ¾” thick plate is to be cut from the UHMWPE scrap block, as discussed in the fabrication section. These plates represent the front/side, and rear walls of the bot, respectively and should be of similar dimensions. These plates are to be set up in a vice in the club’s battlebots testing arena and receive blows from a spinning weapon of one of the club’s bots. Spinning weapons are the most commonly seen in competition, so this should be performed before testing against other weapon types. The goal is to observe and record how many direct hits the walls can take before failing. This will provide valuable data that can be utilized in competition. If the plates receive 4+ hits without failure, it is recommended to test the spare frame against a direct hit from a spinning weapon. The center of the rear or side walls is a good location to place the hit. Do not hit the front wings. The corners may be fragile without the extra structural integrity of having the weapon drum installed. Do not take this test to failure. The goal of this test is to see if there is any global deformation on the frame. With this data, it can be determined where to add reinforcement armor, if there is weight to spare. Areas of breakage or deformation would be good locations to reinforce, if possible. See Frame Fabrication Plan, Theoretical Reinforcement Armor.

The top and bottom plates may be tested using the same method above. Scrap material of the same thickness, or an additional spare plate may be tested. Severe deformation is expected.

Once the bot has been fully assembled, the stability of the frame/weapon attachment points should be tested. This should be done by testing the weapon at competition speeds, against some scrap material in the club’s battlebots testing arena. Once the test has completed, examine the weapon/frame connection points and connection screws/bolts. If any deformation is seen on the frame, immediate reinforce should be added to that point, as the bot is at risk for tearing itself apart. This is a worst-case scenario; no deformation is expected. If any of the screws/bolts are loose, examine their threading. Consider rethreading, wrapping the bolt/screw in plumbers’ tape, or gluing it in (if it is not expected to be removed). Rerun this test until satisfactory results are achieved.

Finally, an orientation test should be performed. Fully assemble the bot components, besides the power connections. Orient the bot to sit on the front, side, and rear faces. The bot should right itself to sit level as designed. The rear orientation bolt may need to be lengthened if it fails to right the bot. Whether or not any electronics shifted out of place can also be seen by this test and adjusted accordingly.

Weapon Testing Plan

The weapon assembly will be tested for force delivered when attacking, as well as structural integrity/durability. The two major tests that will cover each of these areas will be an attack test against spare frame material, to test and judge the output/damage dealing capabilities of the weapon, and a drop test, to simulate received impacts to the overall assembly.

For the attack test, a 3/4" thick UHMWPE plates will be cut from the frame scrap block, similar to those used for the frame tests, above. Each plate will be separately placed in a vice grip inside the battlebots testing cage and attacked, with the intention of dealing one solid hit for analysis sake. One will be attacked by our battlebot, and one by the battlebot club bot, Jeff, which is a bot that has seen some success in previous years. Once the tests are complete, the two plates will be compared to see how much damage was dealt by each bot. If our weapon did similarly to or better than the Jeffbot, this test will be considered a success. Naturally, due to the different weapon configurations (vertical spinner vs. drum spinner), the angle of attack may be different and create different damage patterns, so another way of analyzing the damage dealt would involve considering the sound of the impact, any major dents/breaks in the material, any movement of the plate in the vice grip, et cetera.

For the drop test, the assembled backup drum will be dropped from a 6-foot height, in order to simulate impact forces. From a 6-foot height, the impact force felt by the drum should equal approximately 861 lbf, about 2.87 times the expected 300 lb force that the drum assembly is expected to deliver/generally receive in combat. Based on the virtual tests done through Solidworks, the weapon should show minimal deformation in response to the impact, but this would of course be compared/analyzed to the real-world results. The main considerations for analysis would be the distance (in inches) that the metal deformed, as well as the distance of any movement (also in inches) of the internal support structures.

Drivetrain Testing Plan

Drivetrain testing will be conducted in two phases. The first phase of testing involves the drivetrain as a unit separate from the rest of the bot. The drivetrain configuration will be completely built. A battery will be connected to the configuration to test that the motor does not have any issues running. This will also serve as a test for the wheels unencumbered speed. The battery will be run until its death to confirm that it can run for the 3 minutes it is expected to do for combat. After this has been completed a drop test will be done at the

projected standard 6-foot drop.

The second phase of testing will be done with the complete bot assembly. We will test to see how the drivetrain handles movement with the weight of the rest of the bot. Some practice runs in the battlebots demo cage will be conducted to test the actual speed of the bot. This speed will be compared to the calculated speeds as well as the speed of the Jeffbot to see how we compare to potential competition. We will also use this time to observe how the inertia of the drum affects the bot's mobility. Adjustments will be difficult to make at this stage so this test will be to determine if any further changes need to be made and plan for how to maneuver the bot during combat.

For the electronics testing, we plan to test each battery to make sure it holds charge. Each motor will go through a similar test as describe previously to guarantee that they can run without complication for the competition. After the bot is fully assembled with the electronics; a similar test to the orientation test described in the frame planned testing will be conducted to see how the electronics and drivetrain configuration position are effected by the changes to orientation of the bot and adjustments will be made accordingly.

PREDICTED PERFORMANCE

Frame

It is the job of the frame to protect the bot's vital components, and accommodate the drivetrain and weapon designs. With a lowest frame safety factor of 5.26, and a weight of 3.64lbs, this frame performs well at meeting the weight and strength requirements. The top and bottom plates are at risk, with a safety factor of only 1.3. With its one-piece design, damage on this frame is difficult to repair, and any major damage will require a full frame replacement. This design is expected to be able to receive multiple hits and last multiple competition rounds before replacement is necessary.

In the best-case scenario, this bot would compete against a horizontal/vertical spinner, or a wedge bot/flipper of approximately the same height. In this scenario, all blows are delivered to the frame, as is expected. The frame can sustain multiple hits from these bots, especially when impacted on the corners. The solid one-piece frame will allow the forces inflicted to be distributed more evenly, and encounter fewer stress concentration points. The frame will defend our vital components long enough for us to disable the competing bot. If repairs are needed, ideally there will be ample time to swap out the frame for a spare.

In the worst-case scenario, this bot would compete against a hammer bot or a vertical spinner with the ability to strike the top of the bot. In this case, there would be major damage to the bot in one to three direct hits. Our team was banking on not facing a bot like this, as they are rare at low weight classes, and a 0.09 inch aluminum top plate is a "standard" practice, at this weight class. Also, any scenario where our bot is immobilized could be catastrophic. This may happen through our bot getting pinned, standing vertically, on the rear plate, against the competition wall. This would allow other bots to take direct shots at our top plate. If the bot is immobilized, and oriented flat, the worst-case would be repeated shots on the center of the rear plate, as it has the lowest safety factor and the rear orientation bolt allows for a stress concentration point to form. If our frame needed replacement, the worst-case scenario would be having less than 30 minutes in-between matches to perform repairs. Our team planned on practicing rebuilding the bot, and our rebuild time was estimated at 30 minutes. If frame repairs could not be done, the next competition would result poorly.

Weapon

The weapon was designed with damage output in mind, though in order to maintain its damage-dealing capacity, it must also have a strong structural integrity. The ½" square keystick teeth welded to the outer drum allow the weapon to deliver damaging force quickly and decisively. The biggest strength of the weapon design is its high inertia and wide area of attack (the entire front of the battlebot is covered by the weapon). However, because the majority of the weight of the drum is towards the outside generating inertia, the inside of the drum pipe is a natural weak spot. To ensure a strong defense, three aluminum supports inside the pipe prevent collapsing or warping of the drum when attacked.

In the best-case scenario, the upward turn of the weapon would cause the opponent to be knocked into the air with every hit, dealing extra damage as they hit the ground as well as disorienting the driver and giving a chance of them landing in an orientation which renders them immobile. Successfully shearing the wheels or denting the gearbox shaft of opponents would also be best-case. Hitting the back of opponents (a common weak point) or disabling their weapon systems is also a good strategy.

Another best-case scenario is that the spin-up time of the weapon is much faster than the opponent's, allowing us to get early and decisive blows in. A fast spin-up time will also prevent the opponent from attempting to take advantage of our momentary defenselessness in the front. The sooner the weapon reaches max speed, the sooner the front of the bot becomes well-fortified in both offense and defense.

In the worst-case scenario, the welds holding the teeth on to the drum could fail, causing the main attacking point of the weapon to shear off. If this happens, the deformation of the teeth could also gum up the front of the bot and push it up off the ground, making steering difficult. The drum could also be deformed by direct hits in between the aluminum supports, especially by a vertical spinner weapon, which could also cause the weapon to become stuck and unusable. It is also possible that because the belt that drives the drum is relatively unprotected, it could suffer a direct hit and break, immediately deactivating the weapon until the belt can be replaced between rounds. (It is worth noting that the lack of protection of the belt was something of a design choice, however, since any minor armor in this region would likely be deflected into the pulley system, creating a higher chance of failure than without armor.)

Another way that the drum could be disabled is by electronics failure. While unlikely, it is possible that under the stress of a longer match, the weapon motor or ESCs could burn out. Because we didn't have the budget for any spare electronics, any failures in this area would disqualify us from any further battles. For better or worse, most battlebots fights do not last the full 3 minutes allotted, so overuse of the circuitry to the point of burnout is not a major concern realistically.

Drivetrain

The drivetrain was designed to give us high maneuverability and mobility for combat against other bots. In theory the bot can achieve speeds of 17.37mph running at full power for the 3 minutes that each battle will take.

In the best-case scenario the bot is very agile and capable of dodging attacks from opposing bots during battle. The battery would not die for the duration of the fight. The bot would be fast enough and deal enough damage for there to not be a need for it to fight the entire 3 minutes so recharging time would be reduced. No amount of hits would move or break the bot's drivetrain configuration. Also, the bot would stay responsive the entire bout and the kill switch would stop it as soon as it is triggered.

In the worst-case scenario, the bot burns up too much power under the stress of the bot and cannot perform satisfactorily. The bot would be too slow to deal any damage to our opponents and too sluggish to avoid taking large amounts of damage. The battery could combust, compromising the internal components of the bot. The insulation would get inside of the motor guard, slowing down the motor or potentially damaging it. The bot takes an unfortunate hit and the drive configuration is dislodged from its location immobilizing the bot. The shaft of the drive train could get bent or broken. Damage to the shaft would be the most significant problem as there are no spares or backups. If significant damage is done to the shaft it would make controlled movement either difficult or impossible. If controlled movement becomes impossible the bot could get disqualified from combat.

FUTURE RECOMMENDATIONS & FUTURE WORK

If a future senior design team would like to move forward with our design, please discuss with Dr. Dong and members of the UC battlebot club, as they have valuable insight on the design aspects, ideas for further improvement, and are in possession of all purchased parts (if parts have not been reutilized by another bot). Please give special attention to ordering the parts, fabrication, and physical testing, as the work was not completed by our team, and there may be unforeseen obstacles. To all future battlebot senior design teams, the following is recommended:

In Designing the Bot

- Verify design ideas with Battlebots Club members: Club members provided valuable design insight that influenced many of our choices. Pitch your design, from operation to fabrication, to club members and get recommendations early.
- Have a deadline for a final design. Our team changed our design many times, causing schedule delays, as we needed to reduce calculations, testing, and finding the proper components to order. Set a firm date for final design changes, as they end up costing a fair bit of time.
- Keep the design below weight. For a 15lb, it is recommended the design weigh 13-14lbs, as 1-2lbs may be used by insulation, wiring, weld material, and screws/bolts.
- For the frame. Calculate the safety factor early in the design phase, as a low safety factor will cause major redesigns.
- For the weapon, focus on distributing the weight of the weapon to maximize inertia. Also, ensure the weapon is balanced, as this is necessary for good rotation.
- For the drivetrain, talk to battlebots club members and learn how to wire the bot properly. Club members are experienced in this area.

In Selecting Components and Budgeting

- Get the components selected and budget approved ASAP. Push the UC battlebots club members to set budgets, approve budgets, and order parts as early as possible. There are many steps to this process, and it was a major set-back in the timeline of our team.
- Budget conservatively. The money we expected to have was cut several times, obtaining sponsors can help ease the budget.
- Prioritize duplicate components. Spare components are necessary for repair purposes. Learn which components typically break, and prioritize those over other components, when budgeting.
- Salvage parts. The VPC North manufacturing lab professors have many recommendations for the best scrap yards.
- Weapon motors, drive motors, and batteries run out quickly, as there is a rush on them during competition season. Purchase these early and consider purchasing them with personal funds to get them sooner.

In Fabrication and Testing

- Discuss fabrication plans with manufacturing lab professors early. They will give you a good idea of what is practical for manufacturing and they will let you know if you have to purchase any additional tooling.
- Leave ample time for fabrication, assembly, and testing by getting orders in early.

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APPENDIX A

XTREME COLLEGIATE CLASH TECHNICAL REGULATIONS

15 lb Technical Regulations for Xtreme BOTS Regional Competitions Revision Date:
January 11, 2017

1. General

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

1.2. If you have a robot or weapon design that does not fit within the categories set forth in these rules or is in some way ambiguous or borderline, please contact info@xtremebots.org. Safe innovation is always encouraged, but surprising the event staff with your brilliant exploitation of a loophole may cause your robot to be disqualified before it ever competes.

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

1.4. Each event has safety inspections. It is at their sole discretion that your robot is allowed to compete. As a builder you are obligated to disclose all operating principles and potential dangers to the inspection staff.

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

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

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

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

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

1.5.5. Weapon locking pins must be in place when weapon power is applied during a robot's power-on procedure. This includes all powered weapons regardless of the power source or weight class.

1.5.6. It is expected that all builders will follow basic safety practices during work on the robot at your pit station. Please be alert and aware of your pit neighbors and people passing by. Continued failure to follow safety directions could result in an individuals or the entire team disqualification for the event. (This includes and is not limited to wearing SAFETY GLASSES at ALL times while in the pit area.)

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

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

3. Mobility

3.1. All robots must have easily visible and controlled mobility in order to compete. Methods of mobility include:

3.1.1. Rolling (wheels, tracks or the whole robot)

3.1.2. Non-wheeled: non-wheeled robots have no rolling elements in contact with the floor and no continuous rolling or cam operated motion in contact with the floor, either directly or via a linkage. Motion is “continuous” if continuous operation of the drive motor(s) produces continuous motion of the robot.

3.1.3. Shuffling (rotational cam operated legs)

3.1.4. Ground effect air cushions (hovercrafts)

4. Robot control requirements:

4.1. Tele-operated robots must be radio controlled via 2.4GHz Spread Spectrum radio systems.

4.2. Tethered control is not allowed.

4.3. Radio system restrictions for this event with corresponding weight and or weapon restrictions:

4.3.1. Radio systems that stop all motion in the robot (drive and weapons), when the transmitter loses power or signal, are required for all robots. This may be inherent in the robots electrical system or be part of programmed fail-safes in the radio.

4.3.2. All robot radio systems must be Spektrum (preferred) or Hobby King 2.4 ghz spread spectrum radio systems. No other radio systems are allowed.

5. Autonomous/Semi-Autonomous Robots: Any robot that moves, seeks a target, or activates weapons without human control is considered autonomous. If your robot is autonomous contact league personnel.

5.1. Autonomous robots must have a clearly visible light for each autonomous subsystem that indicates whether or not it is in autonomous mode, e.g. if your robot has two autonomous weapons it should have two “autonomous mode” lights (this is separate from any power or radio indicator lights used).

5.2. The autonomous functionality of a robot must have the capability of being remotely armed and disarmed. (This does not include internal sensors, drive gyros, or closed loop motor controls.)

5.2.1. While disarmed, all autonomous functions must be disabled.

5.2.2. When activated the robot must have no autonomous functions

enabled, and all autonomous functions must failsafe to off if there is loss of power or radio signal.

5.2.3. In case of damage to components that remotely disarm the robot, the robots autonomous functions are required to automatically disarm within one minute of the match length time after being armed.

6. Batteries and Power

6.1. The only permitted batteries are ones that cannot spill or spray any of their contents when damaged or inverted. This means that standard automotive and motorcycle wet cell batteries are prohibited. Examples of batteries that are permitted: gel cells, Hawkers, NiCads, NiMh, dry cells, AGM, LiIon, A123 LiFe Nano Phosphate. Lithium Polymer batteries (LiPo) are prohibited (Fire and explosion hazard exists when incorrectly charged, shorted, or punctured). If your design uses a new type of battery, or you are not sure about it, contact info@xtremebots.org.

6.2. All nominal onboard maximum voltages are limited to: 24 Volts for 15# class robots for this league. (It is understood that a charged battery's initial voltage state is above their nominal rated value)

6.3. All electrical power to weapons and drive systems (systems that could cause potential human bodily injury) must have a manual disconnect that can be activated within 15 seconds without endangering the person turning it off. (E.g. No body parts in the way of weapons or pinch points.) Shut down must include a manually operated mechanical method of disconnecting the main battery power, such as a switch (Hella, Whyachi, etc) or removable link. Relays may be used to control power, but there must also be a mechanical disconnect. Please note that complete shut down time is specified in section 1.5.

6.4. All efforts must be made to protect battery terminals from a direct short and causing a battery fire. All Robots must have a separate light per circuit that is easily visible from the outside of the robot and shows that its circuit's power is activated. LED's and fiber optics are good, low power options for this.

7. Pneumatics

7.1. All 15# robots must use Low Pressure Air systems. (LPA)

7.2. Pneumatic systems on board the robot must only employ non- flammable, nonreactive gases (compressed air or disposable CO2 cartridges are permissible).

7.3. Example diagrams of typical pneumatic systems:

7.3.1. 15# class robots - CO2 based systems, see attachment below

7.4. Pneumatic system refilling process:

7.4.1. You must have a safe way of refilling the system and determining the on board pressure.

7.4.2. The maximum pressure that may be stored or used for the 15# class robot is 150 PSI or less. The maximum total volume of pressurized gas is 8 cubic feet at standard temperature and pressure.

7.4.3. All components must be used within the specifications provided by the manufacturer or supplier. If the specifications aren't available or reliable, then it will be up to the Safety Official to decide if the component is being used in a sufficiently safe manner.

7.5. You must have a safe and secure method of refilling your pneumatic system.

All LPA systems must have the standard Schrader valve for refilling; all CO2 systems must use single use tanks.

7.6. All pneumatic components on board a robot must be securely mounted. Particular attention must be made to pressure vessel mounting and armor to ensure that if ruptured it will not escape the robot. (The terms 'pressure vessel, bottle, and source tank' are used interchangeably)

7.7. All pneumatic components within the robot must be rated or certified for AT LEAST the maximum pressure in that part of the system. You may be required to show rating or certification documentation on ANY component in your system.

7.8. All pressure vessels must be rated for at least 120% of the pressure they are used at. (This is to give them a margin of safety if damaged during a fight.) It is not permissible to use fiber wound pressure vessels with liquefied gasses like CO2 due to extreme temperature cycling.

7.9. All primary pressure vessels must have an over pressure device (burst/rupture disk or over pressure 'pop off') set to no more than 130% of that pressure vessels rating. (Most commercially available bottles come with the correct burst assemblies, use of these is encouraged)

7.10. If regulators or compressors are used anywhere in the pneumatic system there must be an (additional) over pressure device downstream of the regulator or compressor set for no more than 130% of the lowest rated component in that part of the pneumatic system.

7.11. All pneumatic systems must have a manual main shut off valve to isolate the rest of the system from the source tank. This valve must be easily accessed for robot deactivation and refilling. It must also be out of any danger areas.

7.12. All pneumatic systems must have a manual bleed valve downstream of the main shut off valve to depressurize the system. This bleed valve must be easily accessed for deactivation. This valve must be left OPEN whenever the robot is not in the arena to ensure the system cannot operate accidentally.

7.12.1. It is required to be able to easily bleed all pressure in the robot before exiting the arena. (You may be required to bleed the entire system if it is believed that you have any damaged components.)

7.13. All pneumatic systems must have appropriate gauges scaled for maximum resolution of the pressures in that part of the system.

7.14. If back check valves are used anywhere in the system you must ensure that any part of the system they isolate can be bled and has an over pressure device.

8. Hydraulics

8.1. Robots in the 15# class are NOT allowed to use hydraulics.

9. Internal Combustion Engines (ICE) and liquid fuels.

9.1. Robots in the 15# class are NOT allowed to use ICE.

10. Rotational weapons or full body spinning robots:

10.1. Spinning weapons that can contact the outer arena walls during normal operation must be pre-approved by the event. (Contact with an inner arena curb, or containment wall is allowed and does not require prior permission.)

10.2. Spinning weapons must come to a full stop within 30 seconds of the power being removed.

11. Springs and flywheels

- 11.1. Springs used in robots will use the remaining rules in this section. Safe operation, good engineering and best practices must be used in all systems.
- 11.2. Any large springs used for drive or weapon power must have a way of loading and actuating the spring remotely under the robots power.
 - 11.2.1. Under no circumstances must a large spring be loaded when the robot is out of the arena or testing area.
 - 11.2.2. Small springs like those used within switches or other small internal operations are exempt from this rule.
- 11.3. Any flywheel or similar kinetic energy storing device must not be spinning or storing energy in any way unless inside the arena or testing area.
 - 11.3.1. There must be a way of generating and dissipating the energy from the device remotely under the robots power.
- 11.4. All springs, flywheels, and similar kinetic energy storing devices must fail to a safe position on loss of radio contact or power.
- 12. Forbidden Weapons and Materials. The following weapons and materials are absolutely forbidden from use:
 - 12.1. Weapons designed to cause invisible damage to the other robot. This includes but is not limited to:
 - 12.1.1. Electrical weapons
 - 12.1.2. RF jamming equipment, etc.
 - 12.1.3. RF noise generated by an IC engine. (Please use shielding around sparking components)
 - 12.1.4. EMF fields from permanent or electro-magnets that affect another robot's electronics.
 - 12.1.5. Weapons or defenses that stop combat completely of both (or more) robots. This includes nets, tapes, strings, and other entanglement devices.
 - 12.2. Weapons that require significant cleanup, or in some way damages the arena to require repair for further matches. This includes but is not limited to:
 - 12.2.1. Liquid weapons. Additionally a bot may not have liquid that can spill out when the robot is superficially damaged.
 - 12.2.2. Foams and liquefied gasses
 - 12.2.3. Powders, sand, ball bearings and other dry chaff weapons
 - 12.3. Un-tethered Projectiles (see tethered projectile description in Special Weapons section 13.1)
 - 12.4. Heat and fire are forbidden as weapons. This includes, but is not limited to the following:
 - 12.4.1. Heat or fire weapons not specifically allowed in the Special Weapons section (13.1.1)
 - 12.4.2. Flammable liquids or gases
 - 12.4.3. Explosives or flammable solids such as:
 - DOT Class C devices
 - Gunpowder / Cartridge Primers
 - Military Explosives, etc.
 - 12.5. Light and smoke based weapons that impair the viewing of robots by an Entrant, Judge, Official or Viewer. (You are allowed to physically engulf your opponent with your robot however.) This includes, but is not limited to the following:

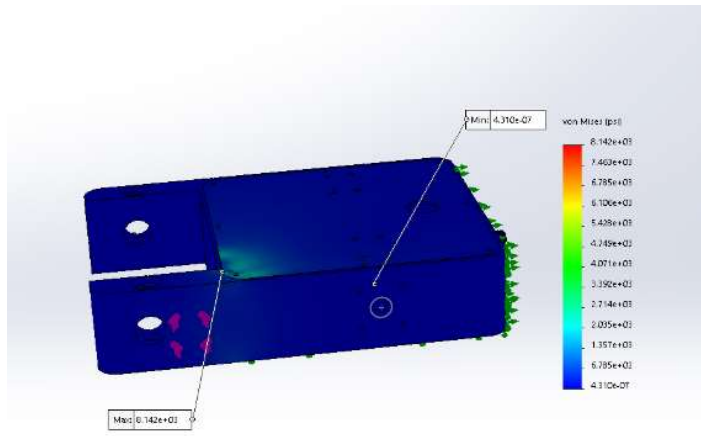
- 12.5.1. Smoke weapons not specifically allowed in the Special Weapons section (13.1.1)
- 12.5.2. Lights such as external lasers above „class I“ and bright strobe lights which may blind the opponent.
- 12.6. Hazardous or dangerous materials are forbidden from use anywhere on a robot where they may contact humans, or by way of the robot being damaged (within reason) contact humans.
- 13. Special weapon descriptions allowed at this event:
 - 13.1. Tethered Projectiles are allowed at these events, and must be no longer than 3 feet.
 - 13.1.1. Heat, Smoke and Fire are not allowed at these events.

APPENDIX B

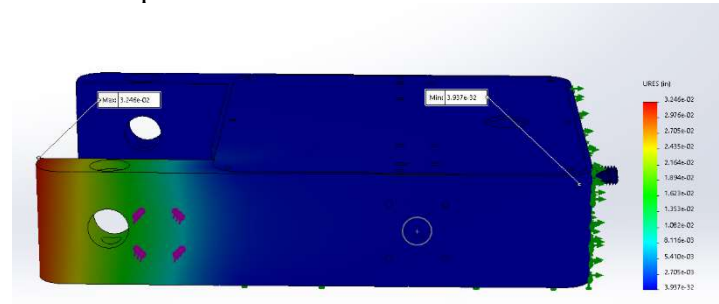
Additional Stress Test

Frame Stress Test

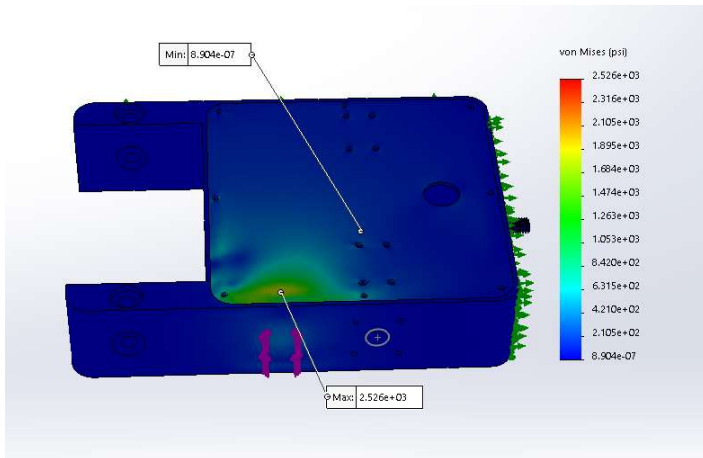
Front Corner Test
160lb stress



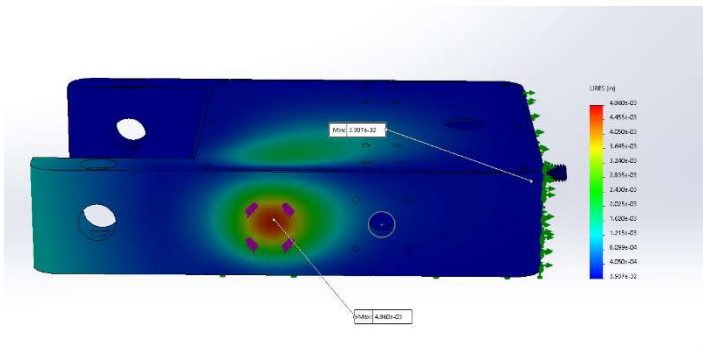
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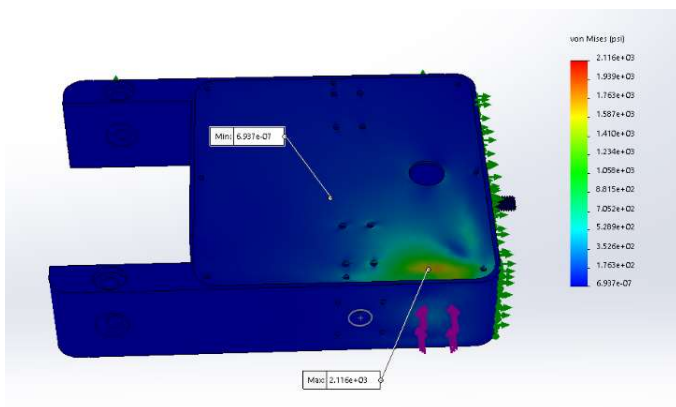
Right Side, Middle Test
160lbf stress



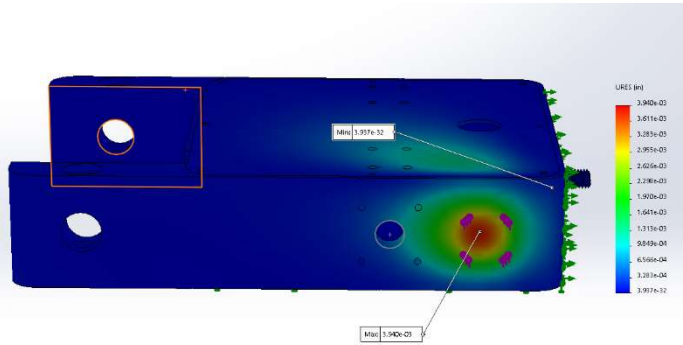
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Right Side, Rear Test
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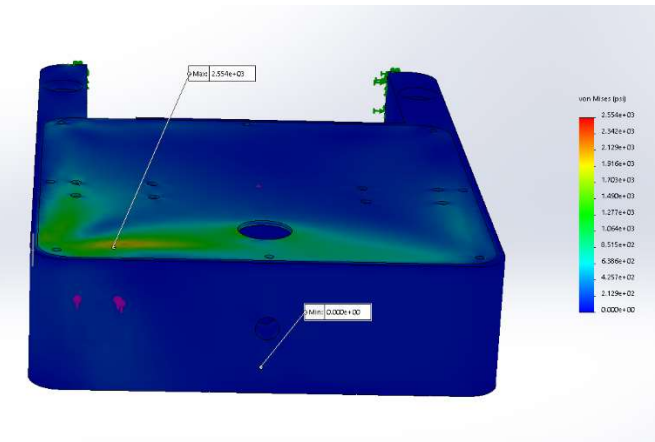


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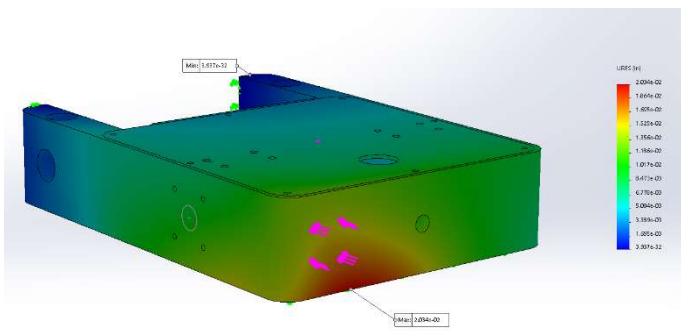


Rear Plate, Corner Test

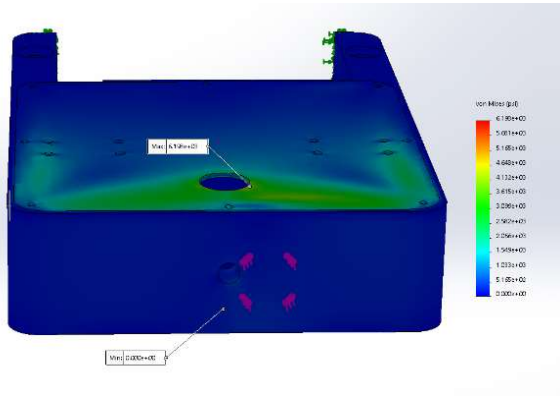
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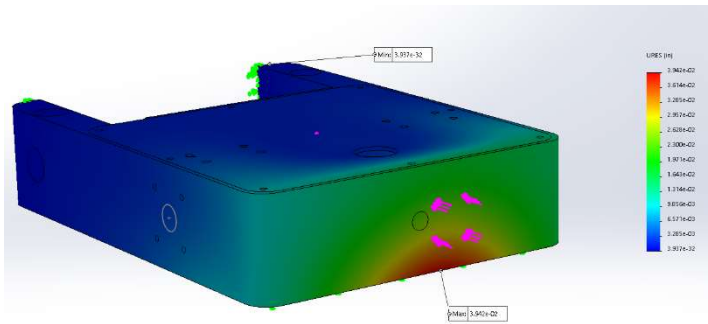
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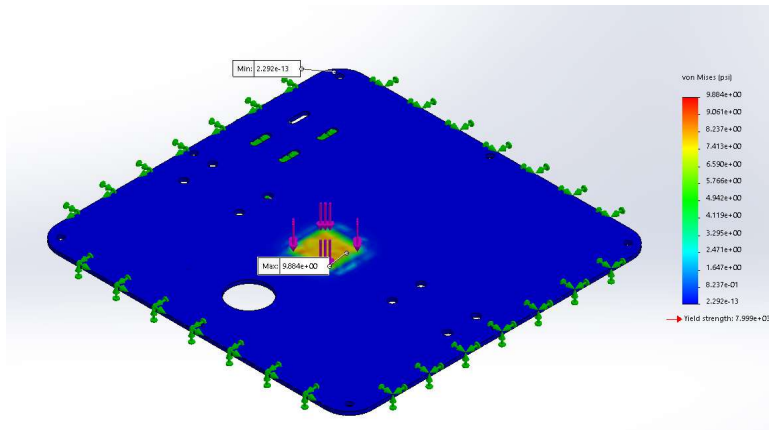
Rear Plate, Middle Test
160lbf stress



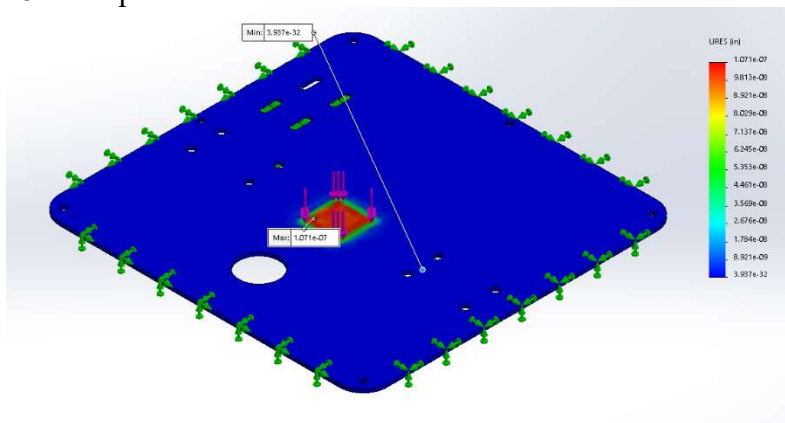
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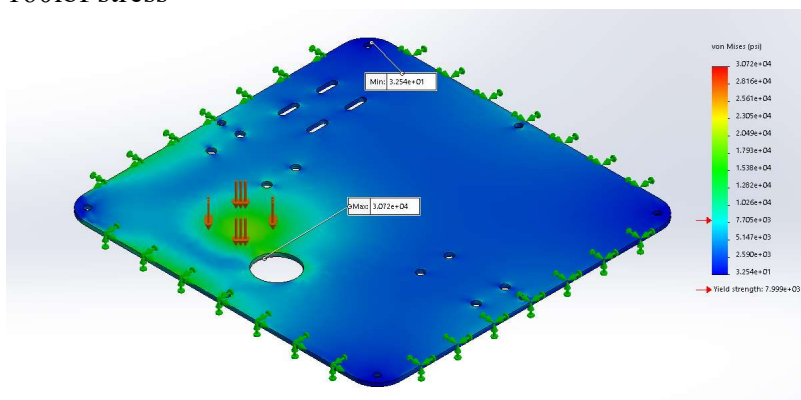
Top Plate Test
15lbf stress



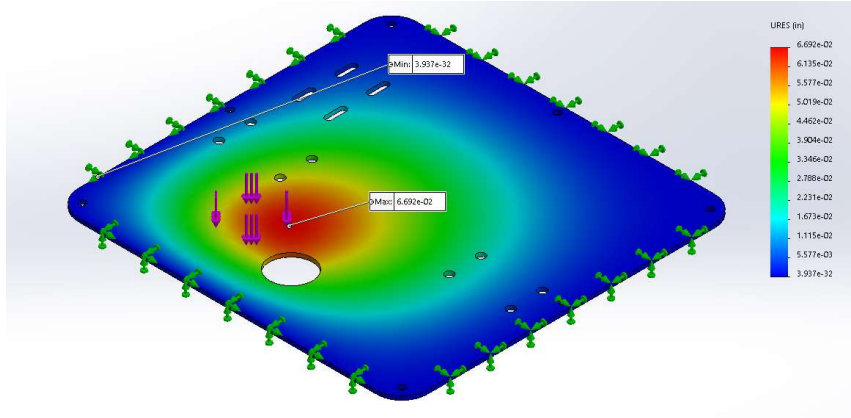
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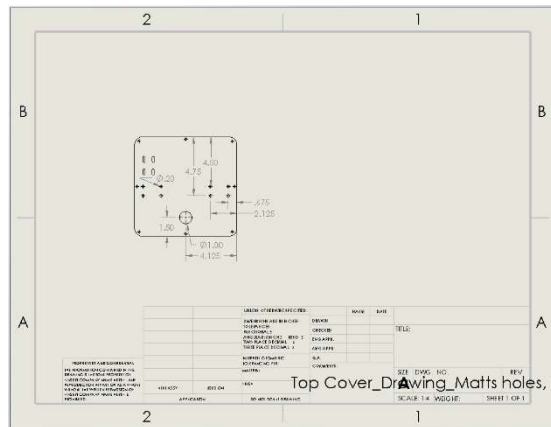
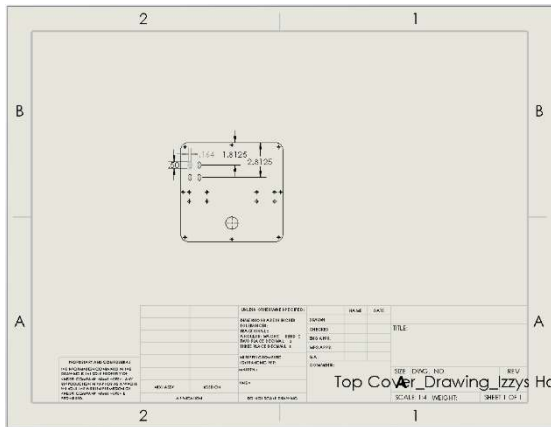


Top Plate Test
160lbf stress

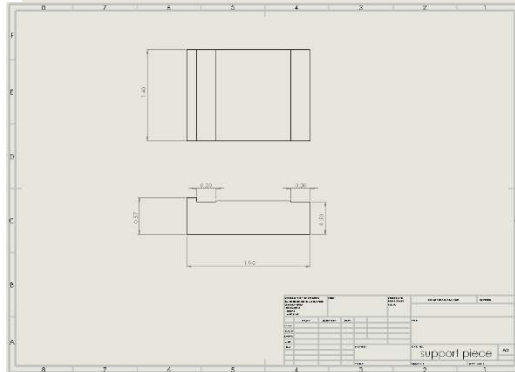
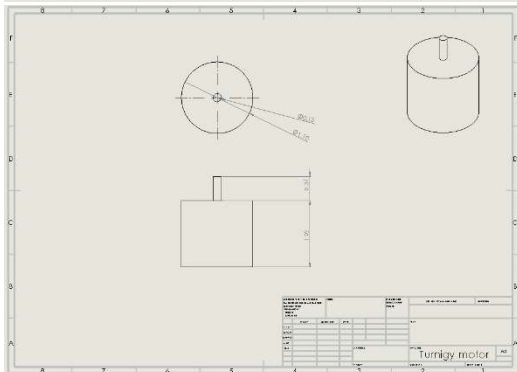
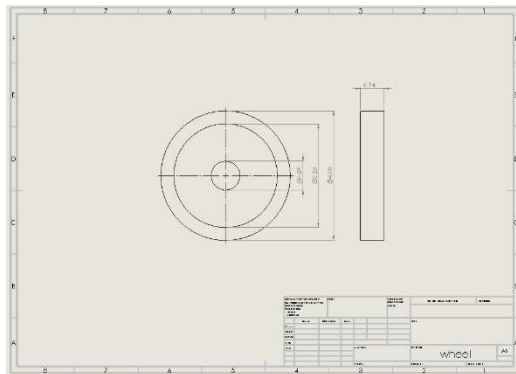
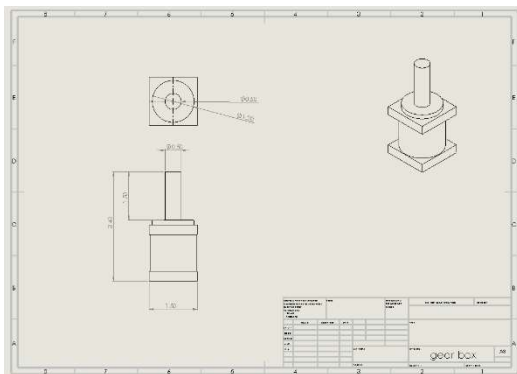


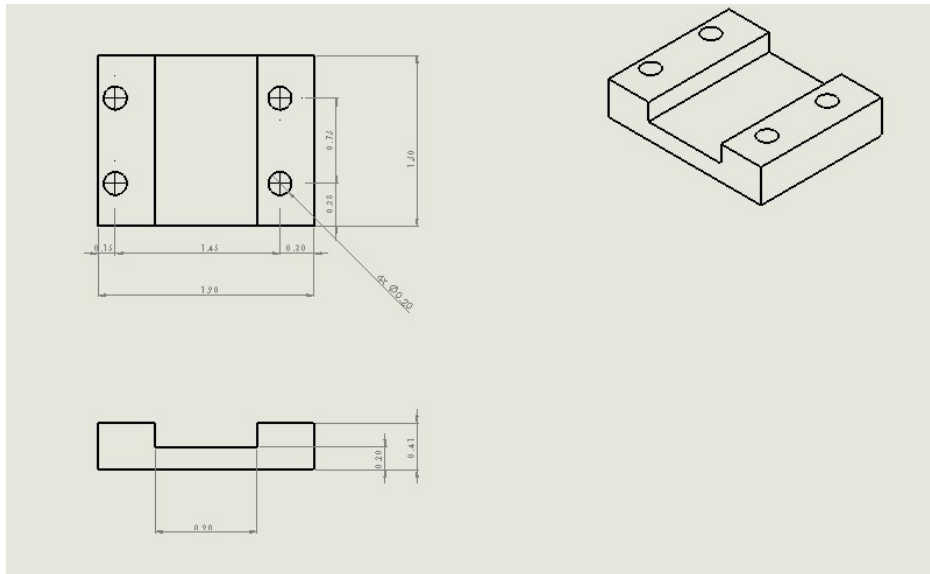
15lbf displacement





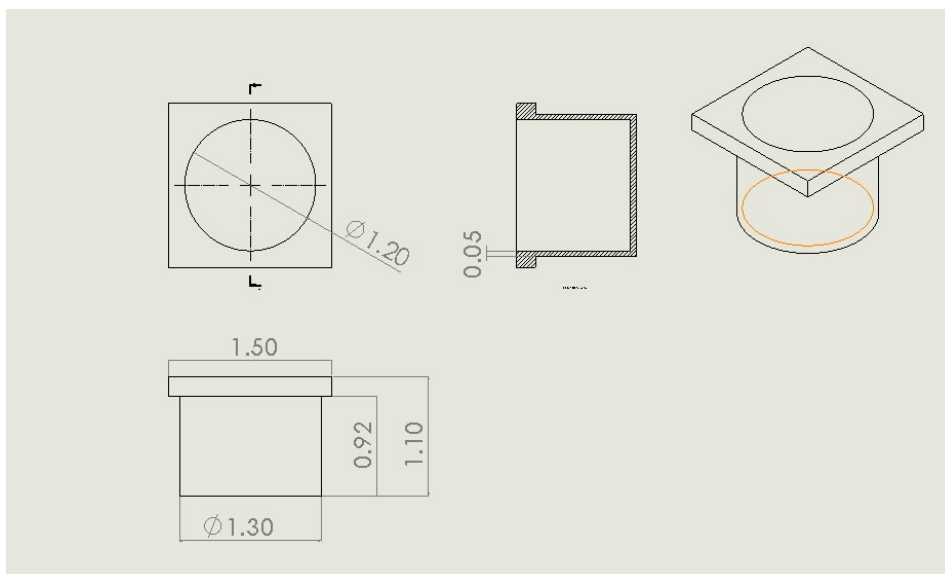
Drive Train Drawings

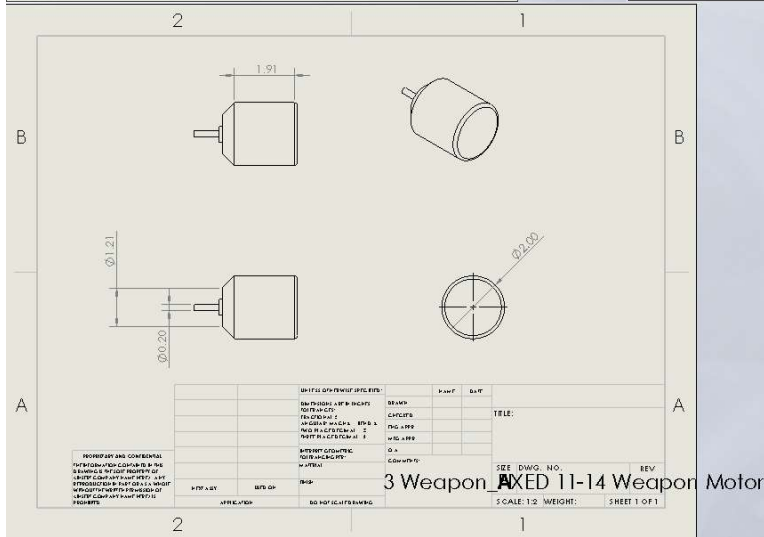
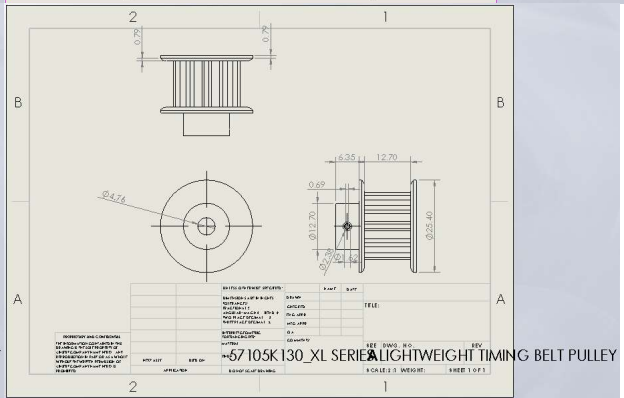
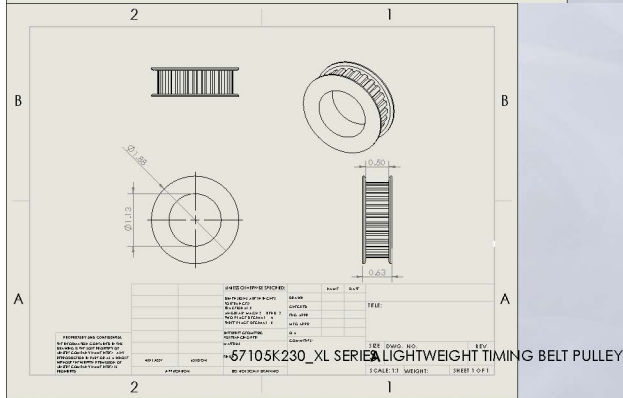
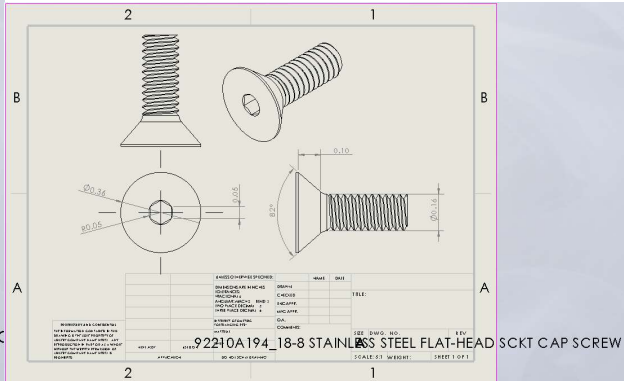
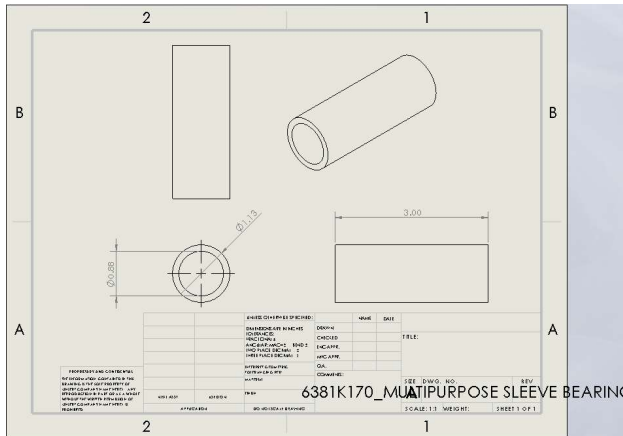




			<p>T81K Reference Quick DRAFT - 13 Sep 2016</p>
			<p>Marking</p> <p>Inch Up - On Down - Off</p> <p>Binary 3/16 In</p> <p>Metric Up - On Down - Off</p> <p>Binary mm</p>
			<p>Stock Part Number:</p> <p>T81K-XXXX</p> <ul style="list-style-type: none"> Number of Holes Size (1/16in or mm) Unit (In, Mmm) Size Shape (Hex/Hex) T81-H00

Important Note:
 Hex Screw Holes are not fully threaded, they are oversized to the threads
 Hubs are designed so that the bore can be increased by upto 1mm





APPENDIX D
Battlebot Customer Survey

To make a design work, there must be sacrifices in other design elements. In your experience what elements of design have been key to your success in fights, and/or should be prioritized over others? (1 = Low priority 5 = Top Priority)

Frame Design	1	2	3	4	5	N/A
Armor Design	1	2	3	4	5	N/A
Weapon Design	1	2	3	4	5	N/A
Control Electronics	1	2	3	4	5	N/A
Drive train	1	2	3	4	5	N/A

What elements of frame design would you prioritize to make a successful 15lb battlebot? (1 = Low priority 5 = Top Priority)

Ease of Repair/ Part Replacement			1	2	3	4	5	N/A
Frame Strength		1	2	3	4	5	N/A	
Low Frame Weight			1	2	3	4	5	N/A
Internal Storage space (for motors, belts etc.)		1	2	3	4	5	N/A	
Well Armored			1	2	3	4	5	N/A
Ability to Flip the Opponent (Equipped with a wedge, etc.)	1	2	3	4	5	N/A		

How important do you perceive an attractive/exciting design is, as it pertains to a bot fight and showmanship? (1 = Low priority 5 = Top Priority)

Showmanship	1	2	3	4	5	N/A
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When selecting frame & armor construction materials, what attributes should be prioritized for a 15lb Battlebot? (1 = Low priority 5 = Top Priority)

Material Cost	1	2	3	4	5	N/A
Material Strength	1	2	3	4	5	N/A
Material Machinability	1	2	3	4	5	N/A

Material Weight	1	2	3	4	5	N/A
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What areas of a 15lb Battlebot need to be the most protected / armored?

(1 = Low priority 5 = Top Priority)

Front Face	1	2	3	4	5	N/A
Side Faces	1	2	3	4	5	N/A
Rear Face	1	2	3	4	5	N/A
Undercarriage	1	2	3	4	5	N/A
Top Cover	1	2	3	4	5	N/A
Weapon Attachment Point	1	2	3	4	5	N/A
Front Corners	1	2	3	4	5	N/A
Rear Corners	1	2	3	4	5	N/A
Electronics Storage Spaces	1	2	3	4	5	N/A
Wheels	1	2	3	4	5	N/A

What elements of weapon design would you prioritize to make a successful 15lb Battlebot? (1 = Low priority 5 = Top Priority)

Ease of Repair/ Part Replacement			1	2	3	4	5	N/A
Material Strength			1	2	3	4	5	N/A
High Weight			1	2	3	4	5	N/A
Ability to Flip the Opponent			1	2	3	4	5	N/A
High Weapon Speed			1	2	3	4	5	N/A

When selecting weapon construction materials, what attributes should be prioritized for a 15lb Battlebot? (1 = Low priority 5 = Top Priority)

Material Cost	1	2	3	4	5	N/A
Material Strength	1	2	3	4	5	N/A
Material Machinability	1	2	3	4	5	N/A
Material Weight	1	2	3	4	5	N/A

Of the following general weapon designs, which do you think would be

most effective for a 15lb Battlebot? (Please circle)

Horizontal spinner	Drum spinner	Saw
Vertical Spinner(not drum)	Flipper	Wedge

Why? _____

What elements of drive train design would you prioritize to make a successful 15lb Battlebot? (1 = Low priority 5 = Top Priority)

Ease of Repair/ Part Replacement	1	2	3	4	5	N/A
Material Strength	1	2	3	4	5	N/A
Weight	1	2	3	4	5	N/A
Durability	1	2	3	4	5	N/A
Speed/Maneuverability	1	2	3	4	5	N/A

Which drive train do you believe make a successful 15lb Battlebot? (1 = Low priority 5 = Top Priority)

Gear Train	Chain Drive	Belt Drive
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Why? _____

Which wheel configuration do you believe make a successful 15lb Battlebot? (1 = Low priority 5 = Top Priority)

2-wheel	3 or more	Tread
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How would you most optimally distribute the weight of a 15lb Battlebot? (Please add up to 100%)

Weapon System

10% 15% 20% 25% 30% 35% 40% 45% 50%
55% 60% 65% 70% 75% 80% 85% 90% 100%

Drive Train System

10% 15% 20% 25% 30% 35% 40% 45% 50%
55% 60% 65% 70% 75% 80% 85% 90% 100%

Frame & armor

10% 15% 20% 25% 30% 35% 40% 45% 50%
55% 60% 65% 70% 75% 80% 85% 90% 100%

APPENDIX E

Expanded BOM, Cost, and Material Vendors can be found at the following archived link:

<https://docs.google.com/spreadsheets/d/1QKVLzKltOOd7NQ-tYDYujgQiw6P5kobHDAfs1bFXqo0/edit?usp=sharing>

car salesman: *slaps roof of SPLURT*
this bad boy can fit so many ESCs in it

