Battlebot: Beetle Weight 1.5 kg

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by

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ABSTRACT

We began Senior Design thinking we were making a battlebot in the 15 lb class but ended up in the 1.5 kg beetle weight class due to funding cuts. This was not an issue for us as we had only done research and concept design at this point. Once we learned of the new weight class limitations, we refocused our research on beetlebots. After selecting our final design and undergoing one revision, our beetlebot began to take form.

We felt that the fabrication was an integral part of the project and wanted to do as much as could ourselves. The Victory Parkway Campus was where the precision machining took place. We spent many hours there fabricating our more complex components. Our beetlebot performed very well considering it was our first build, our team of two, and our inexperience in soldering.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

Our team must design, fabricate, and pilot a 1.5 kg battlebot (beetle weight) to win a competition against other battlebots in the same weight class, while working within given parameters such as cost, time, and components.

RESEARCH

BACKGROUND AND SCOPE OF THE PROBLEM

History & Nature of the Problem

To compete in and win an internal beetle weight competition amongst UC students in the battlebots club. Each team must design, build, and operate their battlebot until they win or are eliminated. The club is using Fighting Robots Association (FRA) Competition Regulations document as a guide to help determine the competition (1). The battlebot teams compete against each other to determine which of them has the superior build along with who executes their maneuvering strategies best. Managing trade-offs will also be critical in the design phase, as our limitation and design path will force us to pursue benefits of one area while sub-optimizing another. The critical trade-offs are: Speed, Time, Drive systems, Weight, Cost, and Energy storage (2).

Who is impacted by the problem?

All the competitors are impacted by this problem. Each team in this competition must work together to deliver their best battlebot build and strategy to win. The team will devote a good portion of their senior year to the development of their battlebot. The members of the teams must use knowledge of mechanical design and product development to create a design that will stand up to the other battlebots.

What is the magnitude of the problem?

This problem has the greatest of magnitude as it is a demonstration of our teams accumulated knowledge from our undergrad classes and five coop rotations to work as a team to design, fabricate, and compete with a battlebot. Both our graduation and the completion of our minor relies upon this competition. This project will cost us at least a semester's worth of time for the design work and then another semester for the building, testing, and competition, approximately 30 weeks. This project will be funded by the UC Battlebots Club with a cap of $340 so any further investment will be out of our pockets.

How is the problem currently being addressed?

The current problem is new to UC, as they have never done beetle weight class builds. The beetle weight class has been around for a while, although for this document's research section we are being asked to use UC's history. The problem is currently being addressed with different combinations of the three main variables between battle bots of this weight class: weapon, frame/armor, and drive train. A good majority of the battlebots are designed to have symmetrical top and bottom so they can operate after being flipped. The first-place winners of the Fall 2018 Collegiate Clash utilized a centralized single tooth disk in combination with ramp-like frame/armor on all sides (3). The ramp frame forced the other battlebots up it, exposing the under carriage to the CCW rotation of the single tooth disk. The disk would impact the other battlebot with great force, flipping it high into the air. The results to the other battlebot would be the initial impact of the disk and the ground impact from the flip. Also, the battlebot had a chance of ending up flipped on its top without a way of flipping itself back over.

The current solutions are not so much inadequate, as almost any design of battlebot paired with an experienced operator can be a formidable opponent, but our goal is to optimize all factors during the creation process as to eliminate any inadequacies associated with different build types. There are general inherent inadequacies that appear with certain match ups of battlebots types that have a "rock-paper-scissor" relationship. Generally, "wedges tend to flip over the spinners, which in turn tend to cut off hammers, which tend to puncture or damage the wedges" (4). The ways to overcome these inherent inadequacies is quality of build and operation of the battlebot. The gap that our team will strive to fill is not a well-defined gap as we have little information on our direct competitors, but we aim to make up any weak points in our design with superior operating skills. The previous winners' matches of Xtreme BOTS competitions will be studied and examined to learn different operating strategies and maneuvers.

We have studied the last five years of battlebots created by seniors of UC for their senior design capstone projects. Below is the data from each teams' robot and a listed of pros and cons associated with each. Not all the teams competed, but each report has value in the *Recommendations* section where they discuss what they learned from their experience.

Competition	2020 Xtreme Collegiate Clash 15lb combat competition
Place	COMPETITION CANCELED
Team Members	Team “Mamba” - Nicholas D’Angelo, Evan Ruthsatz, Daniel Wittmann (5)
Battlebot Name	Mamba
Battlebot Type ○ Drive ○ Weapon ○ Frame ○ Armor	Horizontal Spinner ○ Gearbox (47:1) (2 Wheel) ○ Horizontal Bar Spinner, v-belt pulley driven ○ Box, Aluminum 6061 alloy ○ Polycarbonate sheeting

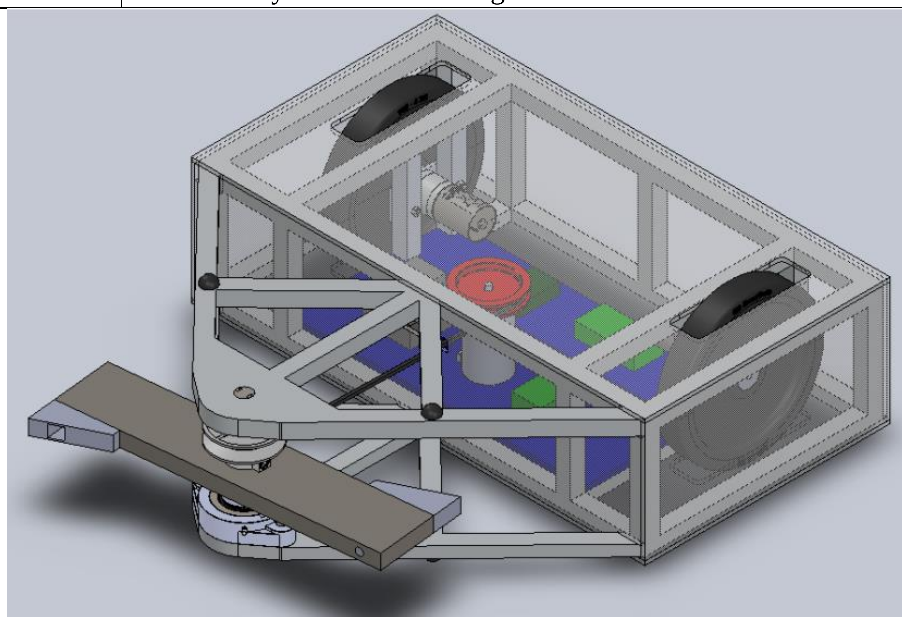


Figure 1: 2020 UC Senior Capstone - Mamba CAD

Pros

- Similar design to Battlebot champion “TOMBSTONE”
  - Weapon
- Sturdy Frame
- Symmetrical design (Functional if flipped)
- Protected wheels

Cons

- Was not completed
  - No testing done
  - Never fully assembled
- Weapon is centered height wise, could be taken advantage of by ramp type bots

This bot had a very promising design, having an overall similarity to the mighty TOMBSTONE. There is much to be speculated since it was never built and tested.

Competition	2020 Xtreme Collegiate Clash 15lb combat competition
Place	COMPETITION CANCELED
Team Members	Fred Schroeder, Isabella Long, Mathew Itapson (6)
Battlebot Name	N/A
Battlebot Type ○ Drive ○ Weapon ○ Frame ○ Armor	Drum Spinner One Piece Frame ○ Gearbox (47:1) (2 Wheel) ○ Horizontal Drum, timing belt driven ○ UHMWPE Polyethylene (one piece) ○ 0.09" 6061 aluminum plates

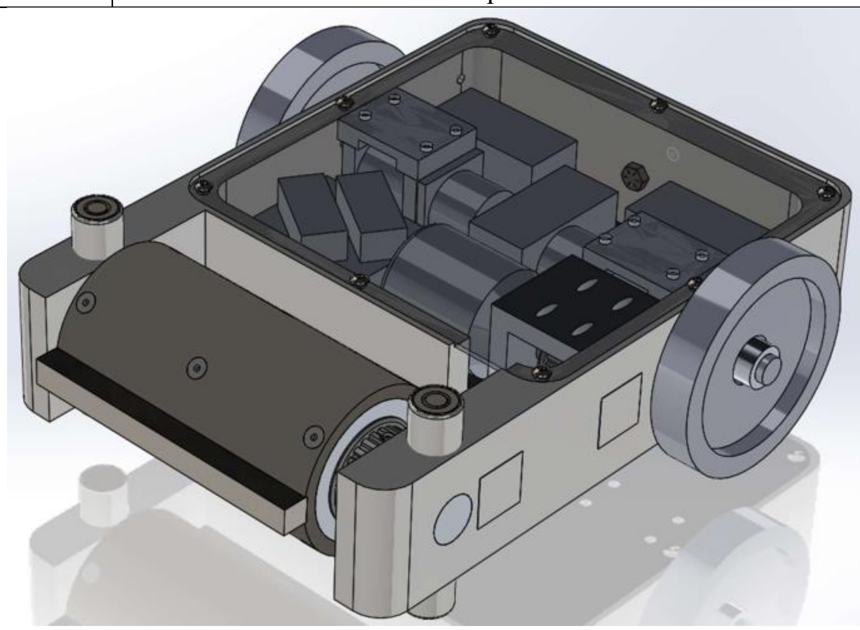


Figure 2: 2020 UC Senior Capstone - CAD

Pros

- Unique Frame material
- One-piece frame
- Symmetrical design (Functional if flipped)

Cons

- Was not completed
  - No testing done
  - Never fully assembled
- Limited attack range, weapon does not protrude very far from frame
- Exposed wheels

There is much to be speculated since it was never built and tested.

Competition	2019 Xtreme Collegiate Clash 15lb combat competition
Place	Knocked out after 1st match?
Team Members	Markus Cheslock, Justin Giese (7)
Battlebot Name	RATCHET
Battlebot Type ○ Drive ○ Weapon ○ Frame ○ Armor	Drum Spinner One Piece Frame ○ Gearbox (20:1), 2-wheel ○ vertical plate spinner with flared edges, timing belt driven ○ two side plates & three crossbars (7075-T6 Al) ○ Shell (6061 Al)

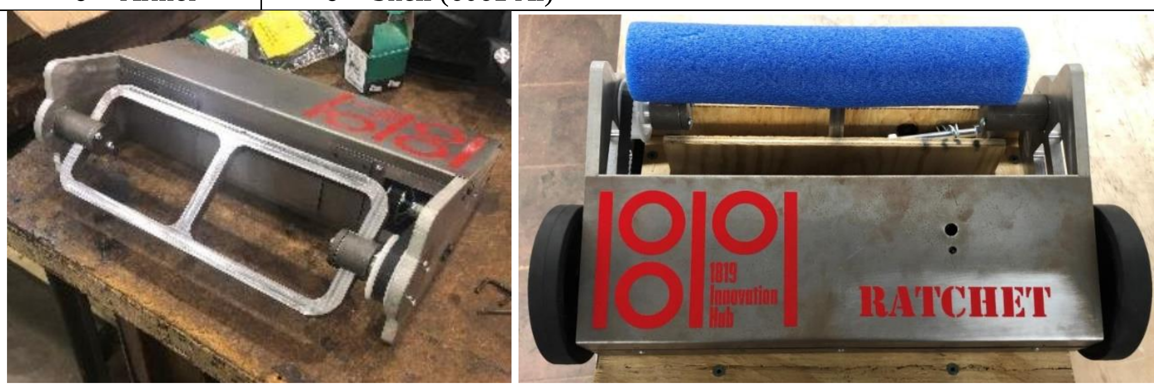


Figure 3: 2019 UC Senior Capstone - RATCHET

Pros:

- Frame and armor prevented internal components from damage
- Wheels had good traction
  - Weight distributed higher on wheels axis
- Good maneuverability from drivetrain
- Symmetrical design (Functional if flipped)
- Large range of attack

Cons:

- Weapon too thin
  - Warped after multiple weapon-to-weapon hits
  - Bent shaft, prevented weapon from rotating
- Exposed wheels
- Semi exposed weapon drive

Figure 4: RATCHET Combat

Lost to the 1st place winner, Pramheda, of the competition. The match was ended in just under a minute. After the second weapon-to-weapon blow, RACHET's plate spinner weapon stopped functioning. Both hits sent RACHET one to two feet into the air.

The match was brought to an end when Pramheda rammed RATCHET against the wall, flipping it to its backside and damaging the armor in such a way that the damaged, protruding armor prevented the wheels from making contact with the ground. This prevent RATCHET from moving at all and the match was called. Pramheda’s speed, ramp body type, and weapon all proved to counter RATCHET’s design.

The resulting images show the damage done to the weapon (Warped) and the armor.

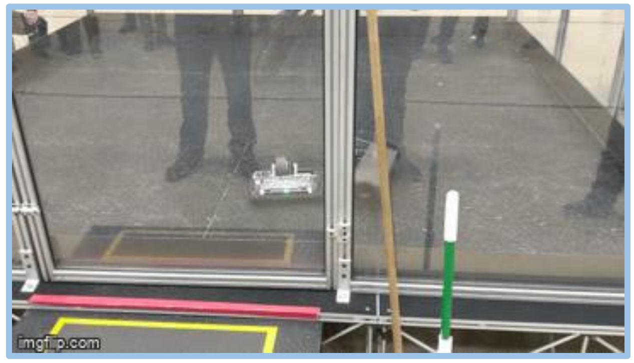


Figure 5: RATCHET’s Defeat

Figure 6: Warped Weapon

Figure 7: Crack in Weapon

Figure 8: Puncture in Armor

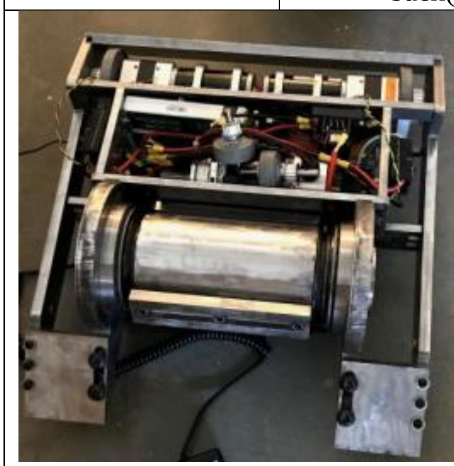
Competition	2018 UC 120 lb. Battlebot Team
Place	Did not compete (scheduling issues)
Team Members	James Brickell, Bryant Himes, Markus Peoples, Grace Pharo (8)
Battlebot Name	Ravager
Battlebot Type ○ Drive ○ Weapon ○ Frame ○ Armor	Drum Spinner ○ Timing belt (cogged belt), 4-wheel ○ Horizontal drum, 2 mounted teeth (S7 Tool Steel), v-belt driven ○ Box, exposed, 4140 Annealed Steel (Same as armor) ○ .5” 4141 Steel Plates: 2 front (angled), 2 side (horizontal), 1 back(angled)
	

Figure 9: 2018 UC Senior Capstone - Ravager

Pros:

- Utilized hexagonal holes (honeycomb) to lighten the frame’s weight, while still providing the needed structure
- Front ramps to get under opponents
  - Front and back ramps lessen the chance of opponent using ramps on them

Cons:

- No armor on top or bottom
  - Exposed internal components
- Frame bent during drop test (2 story)
- Front wheels had friction due to the use of bushings
- Very small range of attack
  - Teeth of weapon do not protrude past round housing on either side of it

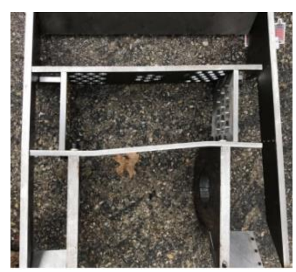


Figure 10: Frame Drop Test Damage

If this team had competed, I do not think *Ravager* would have performed very well. If it were hit into the air, I would expect similar damage to the frame and fasteners as learned from their drop test. The weapon is also an issue as range to so small, due to the housing on either side, that the operator would need great skill to be able to land successful hits to the opponent. The lack of any protection on top is also a huge weak point. The best thing this bot had going for it was the ramps on the front and back that may flip the opponent or allow them to get underneath.

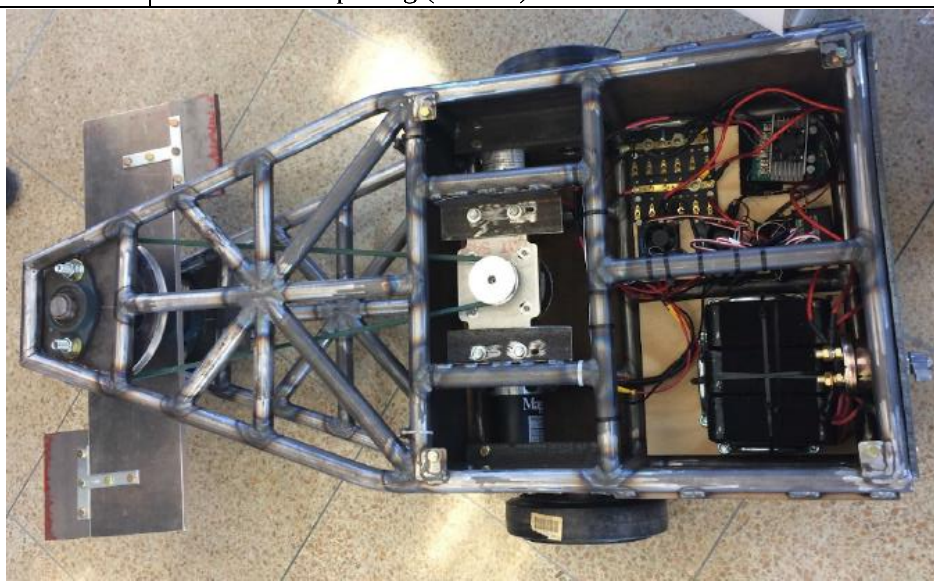
Competition	2018 Battlebot competition (220lb)
Place	Report does not include competition data, competition post-graduation
Team Members	Benjamin Schenck, Nathan Hunt, Dan Schaefer, Reginald Glossett (9)
Battlebot Name	Robostein
Battlebot Type ○ Drive ○ Weapon ○ Frame ○ Armor	Horizontal Blade ○ Gear box, taken from 2011 CATastrophe team (2-wheel) ○ Horizontal rotating blade, v-belt driven ○ Welded extrusion, box shaped ○ Metal plating (AR400)
	

Figure 11: 2018 UC Senior Capstone - Robostein

Pros:

- Large attacking diameter and large weapon
- All components shielded with thick armor

Cons:

- Exposed belt system left their weapon open to potential damage.
- Potential weapon slippage due to single sheave system
- Cannot be operated if flipped over
- Exposed wheels

It is speculated that if Robostein was to compete in its current state that it may not do as well as it potentially could. If the exposed belt that powered their weapon was to be damaged this could leave Robostein defenseless. This would most likely cause them to be defeated. The current state also does not allow for Robostein to be operated if it were to be flipped over, which would again leave it open to defeat. Since it did not get to compete before the report was written the team picked out some design changes they wanted to implement before they would compete post-graduation. Many of these changes would fix the disadvantages that were listed above.

Competition	2018 RoboGames 60lb combat class
Place	Did not compete?
Team Members	Ryan South, Carson Burden (10)
Battlebot Name	
Battlebot Type ○ Drive ○ Weapon ○ Frame ○ Armor	Spinning Drum ○ Direct Drive? Built in gear box? (2-wheel) ○ Spinning drum with 2 teeth, belt driven ○ Welded aluminum extrusion, box ○ Aluminum plating

Figure 12: 2018 UC Senior Capstone

Pros:

- Can be operated if flipped over
- Solid weapon
- Good traction

Cons:

- Slow; making it hard to avoid competitors' robots
- Teeth on weapon are welded which does not allow for adjustments or replacement
- Low level of handling
- Unable to address all issues identified during testing due to budget and time constraints
- Vibration issues when running weapon at high speeds

It does not appear that this robot was used in a competition as of the submission of this report. I assume that this robot would not have performed very well. I think the biggest issue would have been the combination of the robot's slow speed and low level of handling. This would essentially make the robot a sitting duck against competitors. I believe this robot could probably cause a decent amount of damage if it could manage to land a hit on the competitor. The weapon was made from a very strong material and was pretty solid. This was probably the best feature on this robot as it could cause a lot of damage not be easily deformed or damaged.

Competition	2017 RoboGames competition (120lb)
Place	Did not compete
Team Members	Matt Riordan, Thomas Mooney, John Tzioumis, Kyle Bohman, Vincent Sobocinski (11)
Battlebot Name	
Battlebot Type o Drive o Weapon o Frame o Armor	Horizontal Spinner o Gear box (27:1) (4-wheel) o Horizontal rotating blade with chains, v-belt driven o Welded Aluminum extrusion, box o Acrylic sheet, titanium honeycomb and aluminum plate

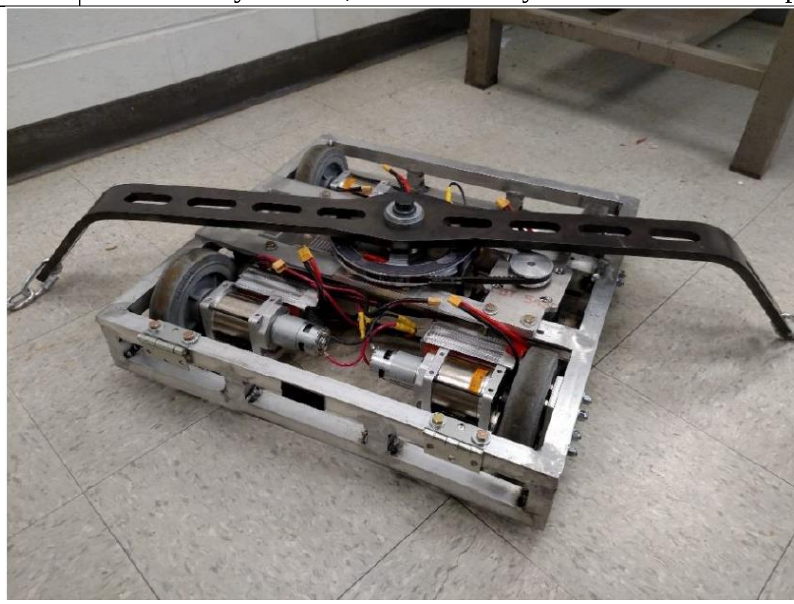


Figure 13: 2017 UC Senior Capstone

Pros:

- Armored wheels
- Survived 15-foot drop test with minimal structural damage
- Strong and durable weapon

Cons:

- Weld failures in the frame
- Initial dimensioning issues when originally assembling

This team was unable to compete due to scheduling issues with the Robogames competition. I believe that this robot would have done well in the Robogames competition. The robots weapon had a large diameter which not only would cause damage to opponents but also doubled as protection because shielded the entire robot. Allow the robot could not be operated if it were flipped over the spinning weapon would most likely be able to correct the robot’s orientation. I think these features would make this robot very successful if it were to compete.

Competition	2016 RoboGames (120lb)
Place	Won 3 matches
Team Members	Daniel Sizemore, Lance Stahler, Mathew Mideros, Brenton Cates (12)
Battlebot Name	HellCat
Battlebot Type o Drive o Weapon o Frame o Armor	Rotating Drum o Gearbox (chain and sprocket ratio 8.3:1) (2-wheel) o Rotating drum with 2 teeth, belt driven o Bolted aluminum extrusion (80/20), box o AL-6XN 1/8” plating

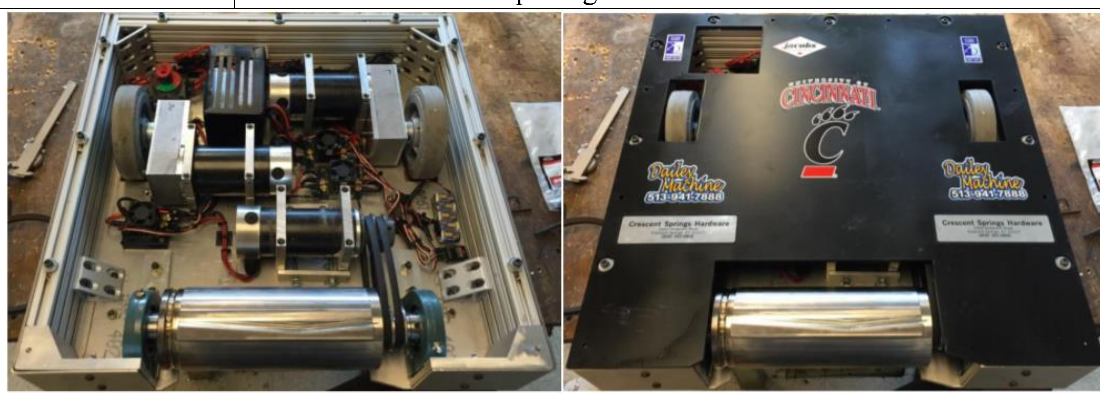


Figure 14: 2016 UC Senior Capstone - HellCat

Pros:

- Weapon was very effective once exposed from frame (modification mid competition)
- Symmetrical (functional when flipped)
- Strong armor (won them the first match)

Cons:

- Small attack range
  - Drum teeth did not protrude far enough (flush with frame)
  - Was not able to damage opponents

This battlebot had a huge design fall regarding its weapon, it had very limited range due to being so far inset into the frame. This team had a very interesting set of matches as they made a very risky modification that ended up earning them two more victories. They failed to directly attack their first opponent, but very victorious because the opponents’ bot became unresponsive after land a couple of hits. The front end of the bot was so damage that the team opted to cut a good deal of it off, allowing the weapon to be able to reach its opponents, but also exposing the weapons bearings. They defeated a wedge type and full-body spinner type during the two subsequentially matches. The fourth match was their final when a horizontal drum type bot that damaged the exposed bearing, rendering their weapon useless.

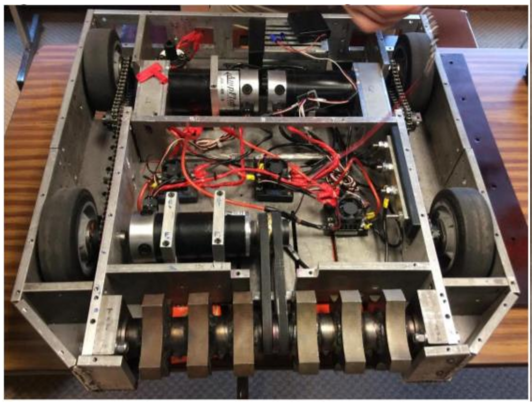
Competition	2014 USATL BotsIQ Competition (120-pound class)
Place	Report does not include competition data, competition post-graduation
Team Members	Nick Manning, Wesley Creed, Nicole Campbell, Tim Shallenberger (13)
Battlebot Name	
Battlebot Type ○ Drive ○ Weapon ○ Frame ○ Armor	Rotating Drum ○ Gearbox with 3 step chain & sprocket reduction (8.3:1) (4-wheel) ○ Rotating drum with 6 bolted “blades” with 2 teeth, belt driven ○ Salvaged 2024 Aluminum plating, box ○ Titanium honeycomb, for top armor plate
 	

Figure 15: 2014 UC Senior Capstone

Pros:

- Multiple “blades”
- Good maneuverability and traction
- Strong titanium honeycomb armor
- Symmetrical (operates when flipped)

Cons:

- Bored weapon’s shaft, weakened the strength (tried to lessen overall weight)
- Did not reinforces bearings
- Controls became mirrored
  - Recommends gyro meter to detect orientation and auto correct controls
- Weight problems, stemming from frame size
- Titanium honeycomb not very machinable
- Weapon drive belts exposed

This battlebot had much potential. An overall well-rounded design, the only disadvantage would be match up type. A flipping or ramp type battlebot may be able to inflict damage by launching it into the air. The weapon system was also noted as a potential weak point. The team had hollowed out the shaft of the weapon in an attempt to save weight, but it significantly weakened it. When the controls were not mirrored, testing showed great mobility.

Competition	Battle Bots IQ (120lb) (Robogames: Olympics of robotics) 2013 ComBots
Place	Eliminated during 2nd match, 36 total competitors
Team Members	Chris Ramhap, Preet Ahluwalia, Travis Copas, Jason Doerr (14)
Battlebot Name	Battlecat
Battlebot Type o Drive o Weapon o Frame o Armor	Spinning Drum o Gearbox(4-wheel) o Spinning drum with welded teeth, belt driven o Aluminum 6061-T651 Box o Frame doubled as armor

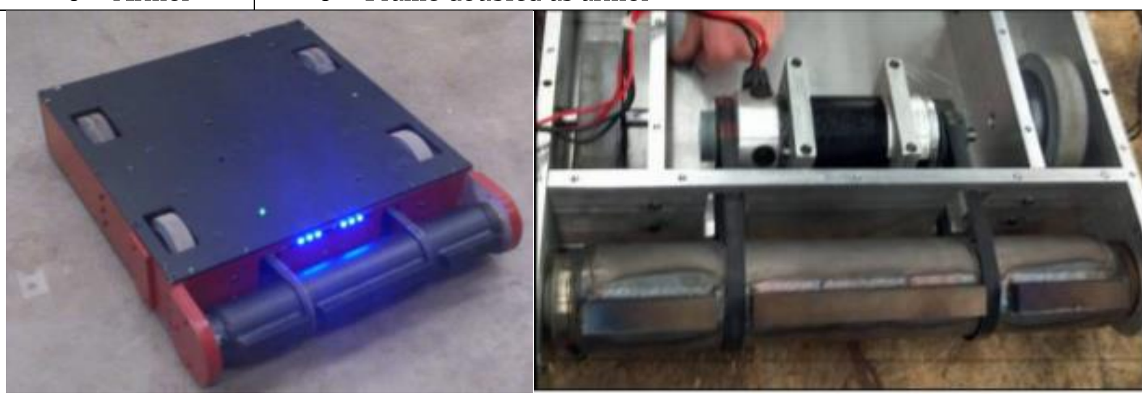


Figure 16: 2013 UC Senior Capstone - Battlecat

Pros:

- Large attack range
- Symmetrical (operational when flipped)

Cons:

- Did not handle well
  - Wheels did not provide enough traction (uneven arena floor) (used duct tape as quick fix)
  - Motor had too much torque
- Poor wiring
  - Came undone when slammed into wall
- Did not design with spare parts in mind
- Frame tied directly into weapon functionality

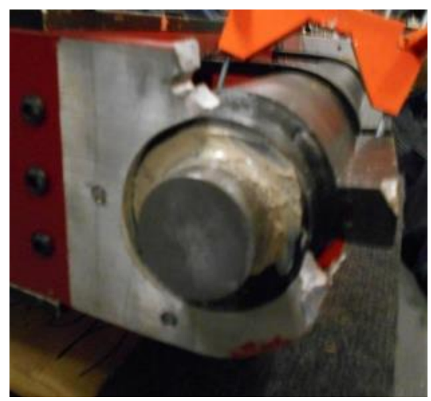


Figure 17: Battlecat Battle Damage

The *Battlecat* did not fare well in the competition. First round the frame was damaged resulting in the weapon being non-functional. The next match was against a ramp type battlebot. The opponent had speed and maneuverability advantages over the Battlecat. Battlecat was rammed into a wall that loosened the wiring of the bot resulting in a loss of power to both weapon and one of the drive motors. The match was lost and subsequently Battlecat was eliminated from the competition. This team did not provide research into the frame design or do any FEA testing besides the weapon. The frame breakage could have been avoided if they had run more initial tests.

Electronics

Because this year's battlebot will be in the beetle weight category there is a standard layout which is followed for Battlebots due to their size and weight requirement. The standard components used will be one 12-volt LiPo battery, at least two brushed drive motors, one brushed or brushless weapons motor, one receiver, two speed controllers and a universal battery elimination circuit. (15) Depending on how many wheels you want your beetlebot to have an addition ESC and drive motor can be added for each wheel after two. The LiPo battery will be used to power all the electronics inside the battle bot include the two brushed motors used to drive the bot and the weapon motor, which has the option of being brushed or brushless. The receiver will allow for the robots drive and weapon to be controlled using a transmitter, which will be essential for using in a competition. The speed controllers, or ESCs, will allow you to control the amount of voltage powering the motors which will control the speed of your battlebot. The universal battery elimination circuit is what allows for the battery's voltage to be stepped down to prevent it from frying things like the beetlebots ESCs and motors which may require a lower voltage. (15)

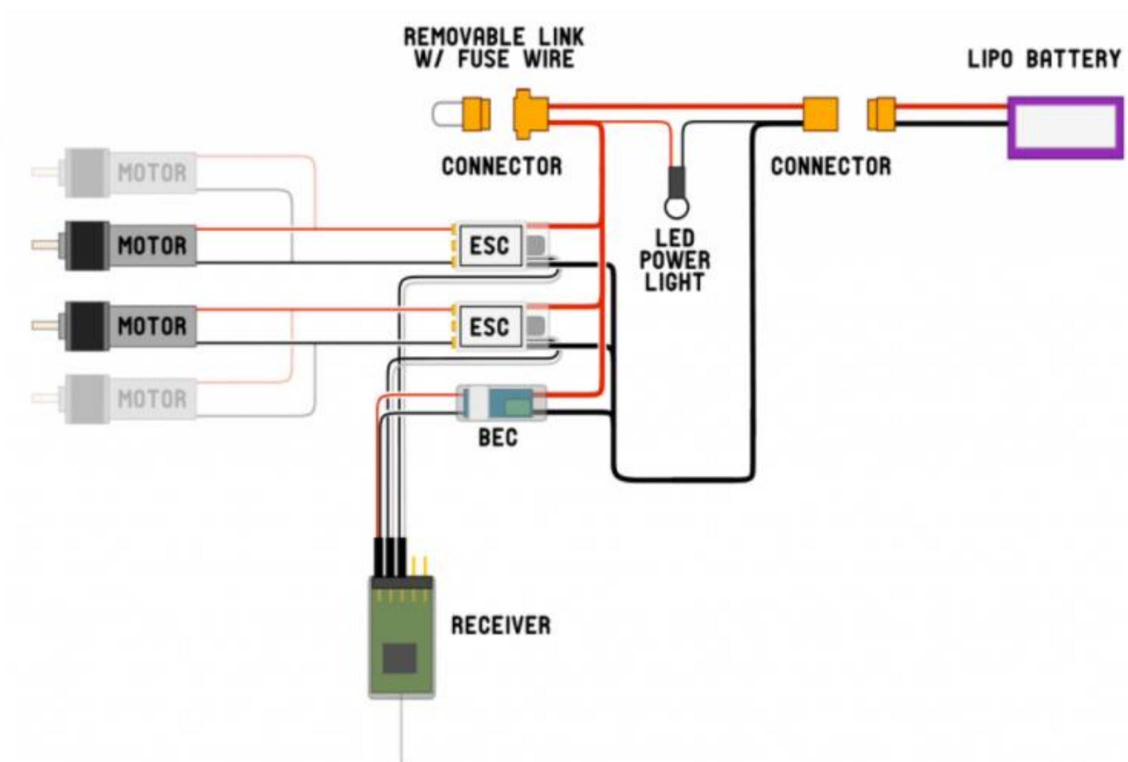


Figure 18: Drive Circuit Layout (15)

Summary of FRA Build Guide

1. General Rules

   All participants will be building and operating at their own risk. All must take precautions in order to prevent harming yourself or others during building, testing, and competing. All rules and regulations are mandatory and must be followed. If your design does not fit into a category specified in this document, please contact the FRA. Creativity is encouraged but using a loophole could cause you to be disqualified from a competition. Your robot must be inspected, and you are required to disclose and potential dangers to those inspecting it. Robots may only be activated in the arena or testing areas. You may not enter the arena with live robots without permission and supervision from the event organizer. All weapons must be secured using a locking bar. The design must ensure that the weapon cannot be fired during the activation process. All high-speed weaponry with a single linkage must have a tether to ensure moving parts cannot break free during operation. When not in an arena or testing area, all robots must be on carrying cradles so they cannot move if they are turned on and to prevent them from rolling or falling off tables. If safety restrictions are placed on your robot, you are responsible for ensuring they are always adhered to. Builders are expected to follow basic safety practices. Equipment which produces smoke, debris or other harmful substances may only be used in dedicated areas.

2. Weight Class

The beetleweight weight class has a maximum weight of 1.5 kilograms. Robots with legs or walkers can weigh up to twice the specified weight in all classes. Legs must have at least two degrees of freedom. Robots with sliding or rolling mechanisms do not fit this classification. Max weight includes all consumables. Max weight does not include anything that will be removed when robot is operating. If robot has interchangeable parts the heaviest set up is used when measuring its weight.

3. Mobility

All robots must have easily visible mobility to compete. Methods of mobility include rolling, walking, shuffling, ground effect (i.e. hovering) and jumping or hopping. Event organizers may impose additional restrictions for the safety of the event.

4. Radio and Control Requirements

Transmitters may not be turned on at events without explicit permission from the organizer. Radio systems must comply with restrictions put in place by local regulatory bodies and applicable laws. Radio systems cannot cause interference to other frequency users. Commercial Digital Spread Spectrum 2.4 GHz is recommended for combat robotics in al weight classes. IR, 27/40 MHz AM/FM, 40 MHz FM Digital, 2.4 GHz DSS, and 459 MHz Digital are all acceptable frequencies. All dangerous systems must have a failsafe device. The failsafe must bring the systems to an off position if the transmitter signal experiences interference or is lost. These devices must failsafe when receiver battery is low, or power is completely lost. Failsafe's can be plug in commercial devices as well as digital switches. Failsafe's must meet all the requirements listed. PCM failsafe's must be set correctly to ensure safe operation of the robot and are strongly discouraged. Care must be taken when using servo/ pot/ micro-switch interfaces as these will remain in their last position with loss of power leaving the weapon active. Failsafe lights are encouraged but not required. Remote kills, which would be used to activate the failsafe, are encouraged as well as this will allow for deactivation of the robot outside a fully enclosed arena and would prevent accidental operation of controls. All devices must operate to the tech checkers satisfaction in order to compete. Frequencies must be easily changeable. Transmitter power may not exceed what is specified by local regulatory body or applicable laws. Home built remote control systems must first be approved by the event organizer and tech checker. These are not recommended. Radio equipment can be operated independently of the removable link. Certain frequencies may be reserved by the event for testing and safety and cannot be used by builders. Radio telemetry is permitted on 433 MHz and 2.4 GHz but must be approved by event organizer.

5. Autonomous/ Semi-Autonomous Robots

Please contact event organizer ahead of time if you plan to bring an autonomous robot or a robot with significant autonomous function. Autonomous robots must have the ability to be remotely armed and disarmed. While disarmed or deactivated the robot may not function autonomously. Must have additional lights to signify if it is in autonomous mode or not. Must have a failsafe if there is loss of power or radio signal. In case of damage to components that remotely disarm the robot, the robot must automatically deactivate after 4 minutes.

6. Electrical Power

Robots must incorporate a way or removing all power to weapons and drive systems that can be operated easily without easily without endangering the person turning it off. The main power cutoff must be a removeable link. This link must be accessible, visible, and clearly marked. The removable link can be covered but the cover must be able to be removed without the use of any tools. Cabling must be of sufficient grade and suitably insulated for max operational voltage and current. Current cannot be carried through exposed components. Robots must have at least one surface mounted power light. Robot must be able to be activated and deactivated using a removeable link. Voltage cannot exceed 75V for DC or 50V for AC except where prior approval has been confirmed.

7. Batteries

Batteries must be adequately protected within the body shell and securely fixed to minimize the chance of being punctured or coming loose during combat. Battery terminals must be protected to prevent short circuits. Permitted batteries are ones that cannot spill or spray any of their contents when inverted. Car and Motorcycle batteries are prohibited. Nickel-cadmium, Nickel-metal Hydride, Sealed Lead Acid, Lithium Iron Phosphate, and Lithium Polymer batteries are all approved for use in the beetleweight weight class. The maximum cell count and voltage for each battery is 30 cells and 36V for Nickel-cadmium, 30 cells and 36V for Nickel-metal Hydride, 18 cells and 36V for Sealed Lead Acid, 12 cells and 39.6V for Lithium Iron Phosphate, and 12 cells and 44.4V for Lithium Polymer. Battery cells may be connected in parallel to increase capacity and discharge current. Improper charging may result in fire and/ or explosion. Only chargers specifically designed for the battery may be used. The rate of charge may not exceed the manufacturers specification. Sealed Lead Acid, Nickel-cadmium, Nickel-metal Hydride, and Lithium Iron Phosphate can all be used without any specific precautions. Lithium Polymer batteries have specific limitations and extra precautions which must be adhered to. They must be balance charged to prevent damage from occurring to the cells. Chargers that do not have incorporated balancing circuitry are not permitted. A voltage cut-out or alarm is recommended to help prevent the batteries from becoming damaged by over-discharge. A fuse rated below the max burst discharge of the battery must be fitted. Roboteers using LiPo batteries must provide a LiPo sack. LiPo batteries must be removed, inspected, and placed into a LiPo sack before and during the charging process. LiPo batteries must not be left unattended at any time during the charging process. If this rule is broken your robot will be removed from the event. LiPo batteries with any evidence of damage must be placed into a LiPo sack and removed to a safe area.

8. Rotational Weapons

The weapon must spin down to a full stop in under 60 seconds. If a robot exceeds 2 or more of the 3 requirements it must be submitted for review and be pre-approved by the even organizer: the spinning element is more than 20% of the robot's total weight, the spinning element spins above 500 RPM, or the spinning element is greater than 500 mm in diameter.

9. Weapon Restrictions

Weapons that are forbidden from use due to invisible damage include electricity, radio frequency, radio frequency noise, and electromagnetic fields. Weapons which cause combat to stop such as entanglement devices are forbidden. Any rotating weapon that exceeds the manufacturers specifications are forbidden. Commercially manufactured, hardened steel blades that may shatter are not allowed. Commercial blades cannot exceed a length of 20 cm. Projectiles must be able to be stopped at full speed via a tether no longer than 2.5 m. Heat and fire are forbidden as weapons but may be acceptable in some events in the form of generated heat to damage an opponent, flammable liquids, or gases, or explosive or flammable solids.

CURRENT STATE OF THE ART

Armor/Frame:

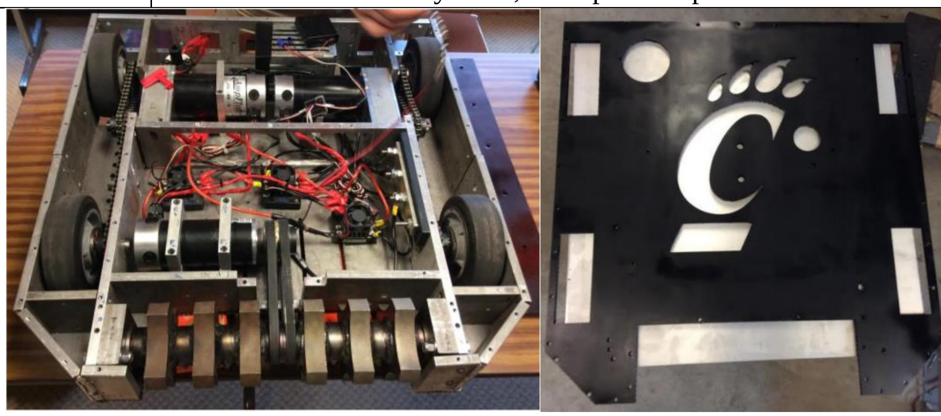
Team Members	Nick Manning, Wesley Creed, Nicole Campbell, Tim Shallenberger (13)
Battlebot Name	
Battlebot Type o Frame o Armor	Rotating Drum o Salvaged 2024 Aluminum plating, box o Titanium honeycomb, for top armor plate
	

Figure 15: 2014 UC Senior Capstone

Pros:

- The frame has well placed structural walls that create compartments of negative space to place the components
- The front corners were eliminated, creating air pockets to better absorb hits
- Both were recycled from previous battlebots
- Armor plate very light weight

Cons:

- Titanium honeycomb armor plate not very machinable
- Large frame

While the frame has good structure and provides compartments for all the components the overall size could have been shrunk. Shrinking the frame to have less open area would have also saved some weight that would have benefitted the bot better than hollowing out the drum. Armor plate could have been made out of an easier to handle material, but the build was limited to using all recycled components.

Team Members	Black Lighting Robotics (16)
Battlebot Name	Phantom II
Battlebot Type ○ Frame ○ Armor	Horizontal Spinner ○ Aluminum frame, box ○ Onyx (3D printed), for top armor plate; UHMW, Side armor; 0.05” 4130 steel, heat treated wedge

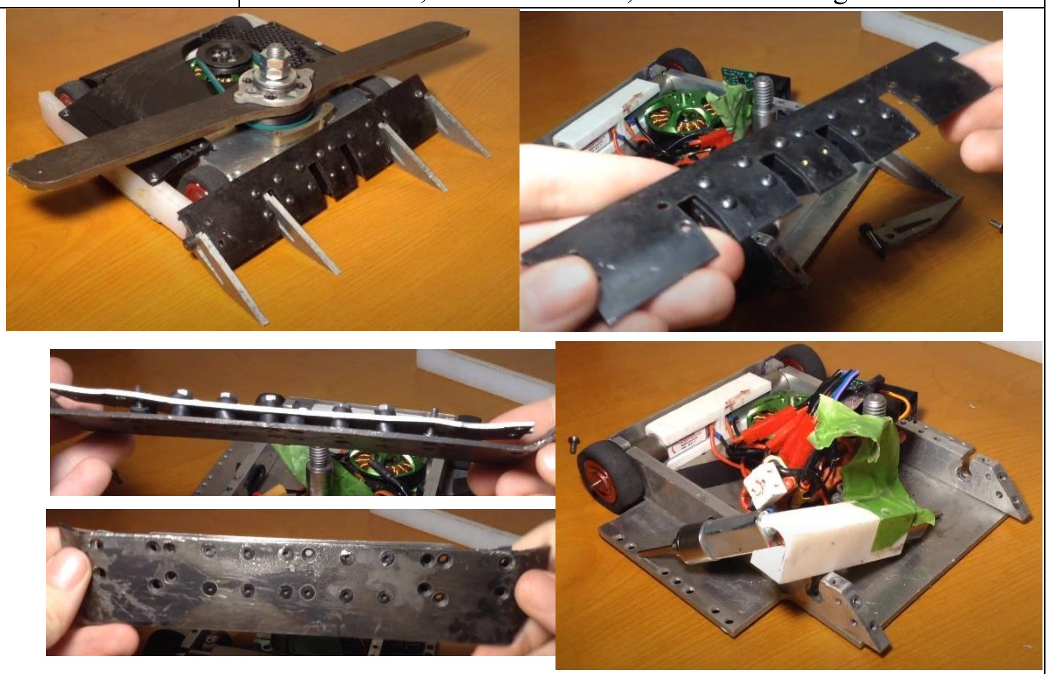


Figure 19: Black Lighting Robotics – Phantom II

Pros:

- ○ UHMW armor (17)
  - ○ Tough and durable
  - ○ Low friction, self-lubricating
  - ○ Excellent abrasion resistance
  - ○ “Chunks off” when hit
  - ○ Low cost
- ○ Onyx armor
  - ○ Protected itself from its own blade deflection
  - ○ 3D printed, can create complex shapes easily
- ○ Wedge
  - ○ Modular
  - ○ Full wedge has shock absorbers

Cons:

- ○ Not enough clearance between weapon and top armor plate
- ○ Onyx armor didn’t hold up to a direct hit from another horizontal spinner

Team Members	Black Lightning Robotics (18)
Battlebot Name	Vortex
Battlebot Type ○ Frame ○ Armor	Shell spinner (full body spinner) ○ Aluminum “H” ○ Aluminum shell spinner

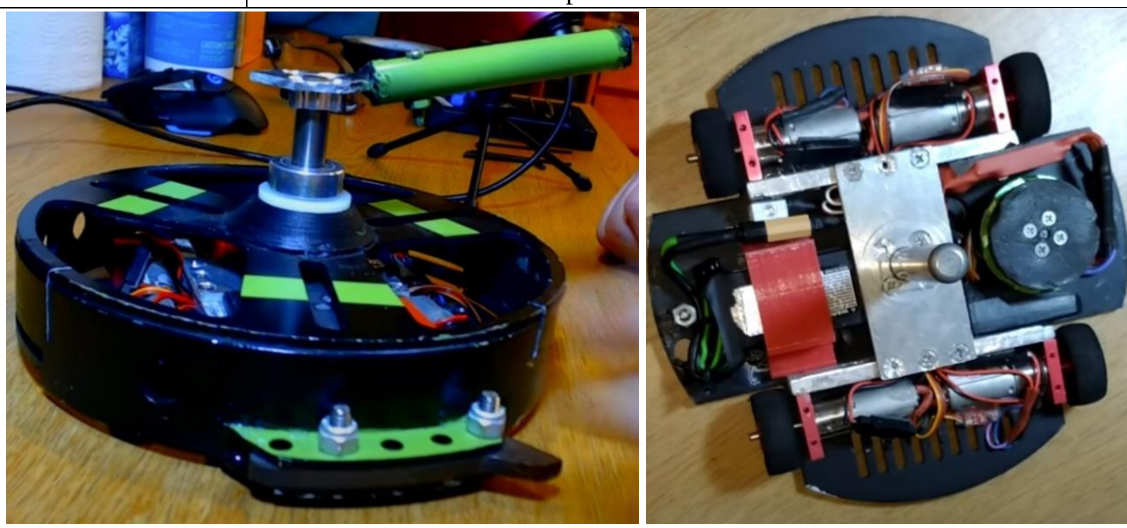


Figure 20: Black Lighting Robotics – Vortex

Pros:

- ○ Armor doubles as a weapon
- ○ Simple design

Cons:

- ○ Openings too large on top surface of shell spinner
- ○ Shell spinner made from aluminum

There is a lot of potential for shell spinner type bots. Having a dual-purpose armor that also serves as the weapon and enclose the whole bot is very efficient with size and materials. The downfall of this particular bot is its material selection and manufacturing of its shell. The aluminum shell was stitch welded together and did not hold up very well. Also, the large openings on the top do not provide the protection needed for the internal components. With a different approach for the material and design of the spinner, this design can be more successful.

Drive Train:

Team Members	Robert Cowan (19)
Battlebot Name	Anxiety Attack
Battlebot Type ○ Drive	Horizontal Spinner ○ Brushless motor to planetary gear box, rear wheels; belt driven front wheels

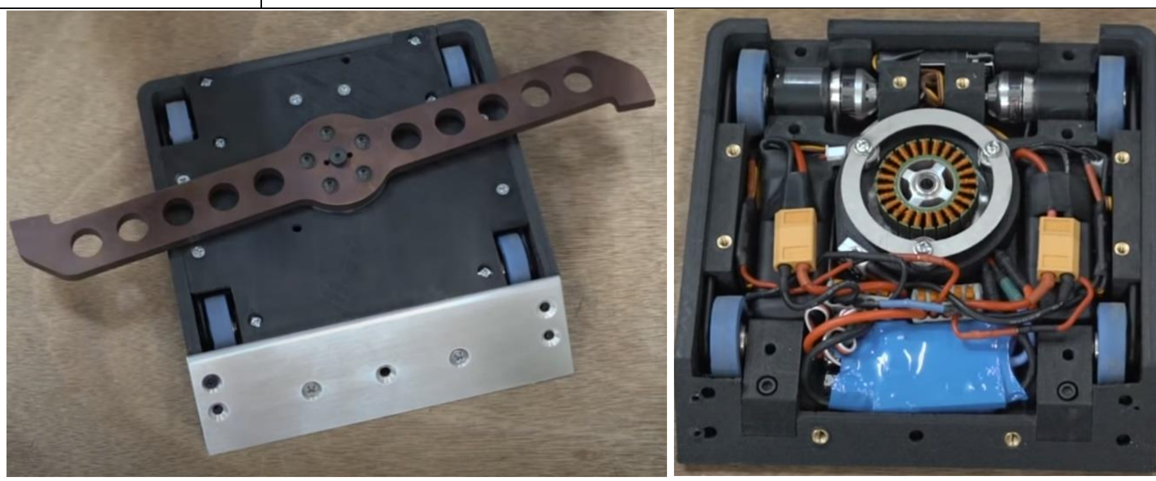


Figure 21: Robert Cowan – Anxiety Attack

Pros:

- Two motors to drive the four-wheel setup
    - Saved power consumption
    - Saved weight
    - More compact design
- Small turning radius
- Even if the belts are damaged, it still should have rear drive

Cons:

- Some front wheel slippage
    - No belt tensioner
- Brushless motors harder to program

This build utilizes two brushless motors attach to 22 mm planetary gear boxes driving the rear wheels with belts running from the rear wheel to the front wheels. this give the bot tank like controls allowing it to rotate about its center when the wheels are being driven in opposite directions.

Team Members	Mario Jayes (20)
Battlebot Name	Cheat Code
Battlebot Type ○ Drive	Drum Spinner ○ Brushed motor to gearbox, Rear wheels; Timing belt driven front wheels

Figure 22: Mario Jayes – Cheat Code

Pros:

- ○ Belt protection
- ○ Small turning radius
- ○ No belt slippage

Cons:

- ○ Brushed motors generally weigh more than brushless
- ○ Small clearances around drive system

This build's drive train suffered from damaged armor that created friction on the wheels. The use of timing belts eliminates the possibility of slippage and ensures the power transferred is used by the front, driven wheels.

Team Members	Carter Schultz (21)
Battlebot Name	Cpt. Hook
Battlebot Type ○ Drive	Vertical crusher ○ Brushed motor to gearbox

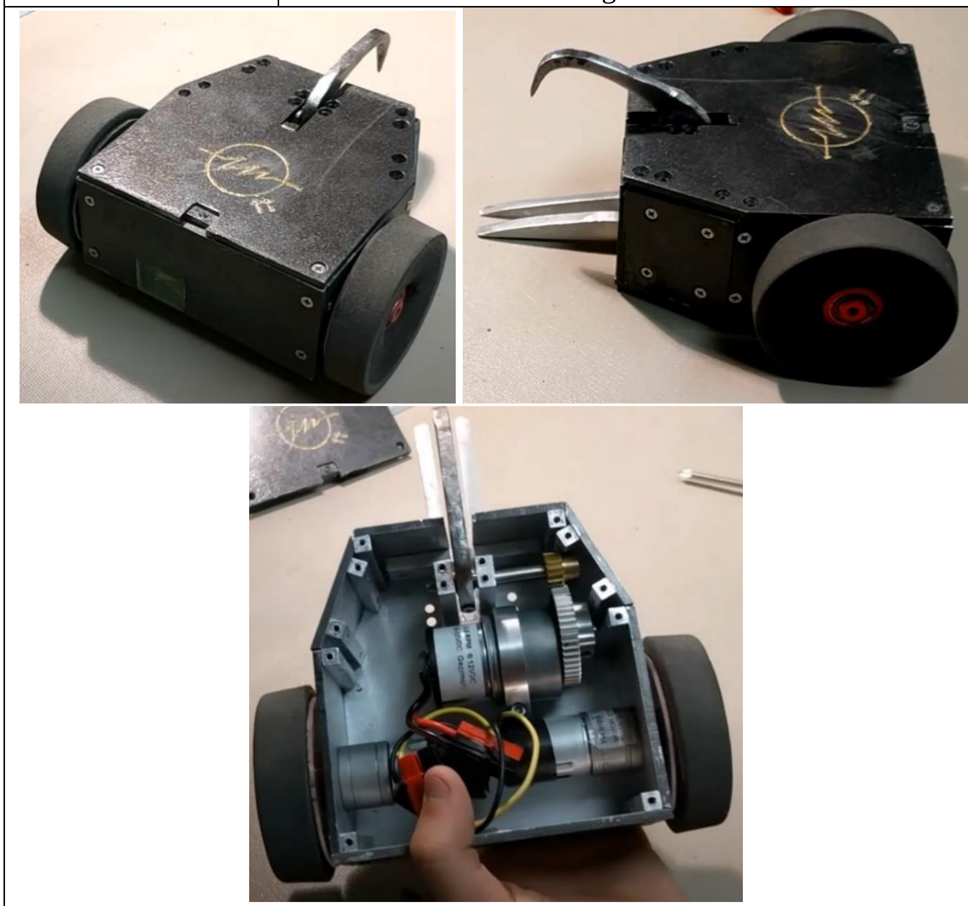


Figure 23: Carter Schultz – Cpt. Hook

Pros:

- ○ Direct drive to the wheel, no other secondary wheels to drive
- ○ Simplicity
- ○ Responsive
- ○ Less power consumption
- ○ Tight turning radius

Cons:

- ○ Heavier motor/gearbox assembly

This Drive system is simple and straight forward. It is easily replaceable. The larger diameter wheel will provide plenty of ground contact. The use of brushed motors allows for an easier wiring setup.

Drum Spinner

Drum Spinners are one of the most common weapon types for all weight classes of battlebots. These weapons typically consist of a solid drum with one or more teeth attached to it. This allows for a high force to be exerted upon its opponents due to large mass and high acceleration. The drums solid body makes the weapon less susceptible to damage that would render it unusable. The two most common ways for this weapon to be operated are either via chain or belt drives. One feature that makes this weapon versatile is the chosen direction of rotation. If it rotates upwards it “has the ability to fling a robot in the air” which allows the fall to add to the total damage. (22) The other option is to have it rotate downwards. In this case the spinner will be used to break pieces off of the opponent otherwise the robot with the spinner could be thrown into the air and in turn cause damage to itself instead. Another benefit to this style of weapon is that the robot can be designed to operate after being flipped. If designed and correctly used this style of weapon can be very effective. One disadvantage to this design is the robot’s “small strike zone”. (23)

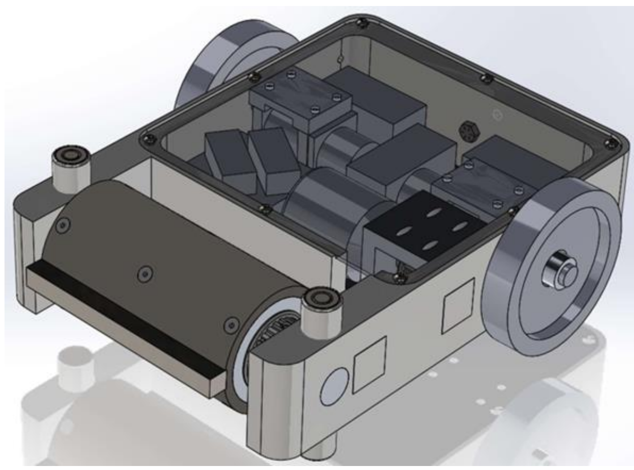


Figure 2: 2020 UC Senior Capstone - CAD (6)

Horizontal Spinner

Horizontal spinners, like drum spinners, are a very common weapon choice for battlebot competitions. These weapons are often a thick bar or disc that is rotated about its center on a shaft at a high speed. Horizontal spinners can be very versatile in their designs which can be altered to allow for maximized damage. (22) These weapons are typically driven with either belts or chains. Depending on the design of the frame that could leave this system open and vulnerable to attack which could then disable the robots weapon costing it the battle. (23) Another potential issue with this weapon choice is the possibility that with the high RPM of the weapon the robot could face recoiling effects after hitting an opponent or a wall of the arena. (23)

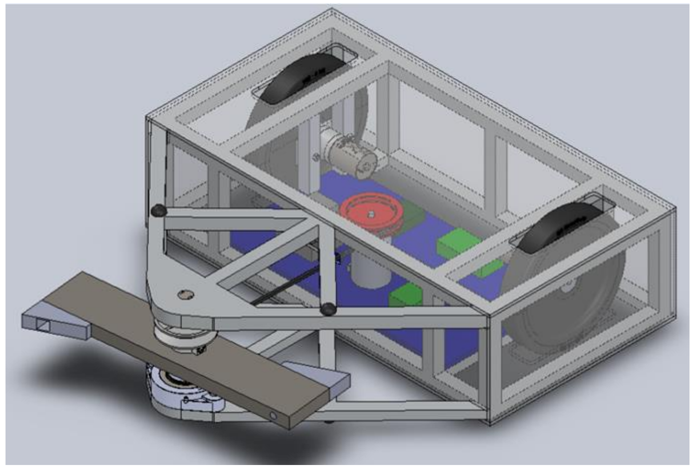


Figure 1: 2020 UC Senior Capstone - Mamba CAD (5)

Hammer/Axe Bots

Hammer or axe bots are another popular style of weapons used for battlebots. Like the name suggests these robots use a hammer or axe style weapon to try land a deadly hit on the tops of their opponents. There are a couple of different ways these weapons can be driven such as chain and gear drives. (24) These weapons are good for damaging an often-vulnerable part of the robot and cause severe damage to the internals of its opponent. The key to using this style of weapon is to increase the mass of your hammer. (22) A larger mass is needed to make up for the short amount of time the hammer must swing. (22) This is done in order to increase the energy of impact the hammer has. (22) One issue with this is that if the mass of the hammer is too large the momentum of using it can send the bot into the air which it would most likely cause damage to itself. (24) These weapons are also out in the open leaving them vulnerable to bots with spinners.

Figure 24: Example of a battlebot utilizing the hammer style weapon (24)

END USER

Our end user is a beginner wanting to start their first build of a battlebot. There is a wide range of ages and amount of technical experience for end users. Age ranges start at the high school level and don't really have a ceiling. The technical experience required that would be very helpful is fluency in CAD and simulation software. Also, fabrication experience would be beneficial depending on what materials are being used. Mechanical and electrical experience will help with powering and determining outputs of components. Besides that, not much prior knowledge is required for building a battlebot due to the number of guides in print and video that are freely available. A team structure is beneficial to a first build but not required.

The needs of the end user would be internet access, CAD software, a minimum budget of a couple hundred dollars, fabrication equipment, and a competition. Some of these needs can be outsourced, but that comes with a cost. The internet access provides a way for researching building guides and accessing online stores that specialize in battlebot and hobbyist components. CAD software lets you flesh oust design concepts, create drawings, and models for fabrication. The simulation software checks your design for weaknesses prior to fabrication, helping inform the final design. The budget is for materials, components, equipment, or any outsource manufacturing processes you may need. The fabrication equipment required is based on the materials that are being used but are commonly: soldering iron, mill, 3D printer, grinder, and/or welder. Heat treating is a commonly used secondary process used for weapons as well. The final need is to compete in a competition, as that is the real test of how successful your battlebot is.

The main concerns for the end use are time management and keeping the bot under a certain weight. There are many different weight classes to compete in and for this end user it is a beetle weight competition which requires the bot to be between 150 and 1500 g (0.33 – 3.31lbs). This balance is often reached by compromise. Time management is also a concern as most teams aim to compete in a specific competition. It is very beneficial to be able to create and stick to a schedule to make sure the build is complete, any testing is conducted, and modifications made are done prior to the competition.

The end user for this beetlebot would be ourselves along with any other first-time beetle weight battlebot builder. Since this is the first time that UC is participating in a beetle weight battlebot competition it will be up to us to lay the groundwork for future UC BattleBot Club members. Our designs will be available to future club members to use for parts, inspiration, or both. Although there are many design specifications for the beetle weight battlebot competitions, we will be focusing mainly on the weight and size specifications along with any battery safety standards set in the rule book by the Fighting Robots Association. Other specifications are not as important to us primarily because our competition will be an inhouse competition amongst other senior design students and club members.

CONCLUSIONS AND SUMMARY OF RESEARCH

The specific problem that needs to be addressed is creating a durable and reliable build. This conclusion has come from the data from the survey as well as countless forum entries were members reiterated it. The durability speaks to how many hits can your bot receive and still function. How many time times can it get knocked into the air and impact the ground? How will the wiring hold up? What level of functionality will remain after receiving multiple hit? How reliable are your bot's components? Do they function to 100% of their ability? Can your weapon reliably startup in the same amount of time consistently? These are the questions we hope to solve during our first build.

This is not an easy task for beginners, as a lot of the learning process is hands on when building. From the research done, the battlebot creators benefit greatly from iteration. They learn what they can from each match they compete in and adapt their battlebot to fix the weakness or inadequacy. The best performing beetlebots are generally well-rounded bots that have benefitted from multiple iterations. There is nothing really missing from the current technology, but there will always be room for innovation. Our goal is to provide the battlebot club with a well performing beetlebot that will potentially win the competition, but also be an opportunity for club members iterate on and learn from.

QUALITY FUNCTION DEPLOYMENT

CUSTOMER FEATURES

These features were presented on our customer survey to help us determine the demanded quality of the consumer. The survey polled 30 people with a scale of 1 through 7 (whole number increments) from least important to very important. The features were averaged and consolidated to better fit the HoQ template.

1. Armor
2. Durability
3. Frame
4. Large range of attack
5. Maneuverability
6. Overall size
7. Ramp-like armor/frame (Front)
8. Small turning radius
9. Speed
10. Weapon type

ENGINEERING CHARACTERISTICS

The characteristics were developed to best measure the customer features.

1. Total Weight [kgs]
2. Footprint Size [m^2]
3. Frame Material Yield Strength [MPa]
4. Armor Yield Strength [MPa]
5. Armor Hardness [HB]
6. Torque to Wheels [N*m]
7. Battery life [mA*h]
8. Weapon Fatigue Strength [MPa]
9. Torque to Weapon [N*m]
10. Weapon Yield Strength [MPa]
11. Range of attack [m^3]
12. Wheel Diameter [m]

HOUSE OF QUALITY

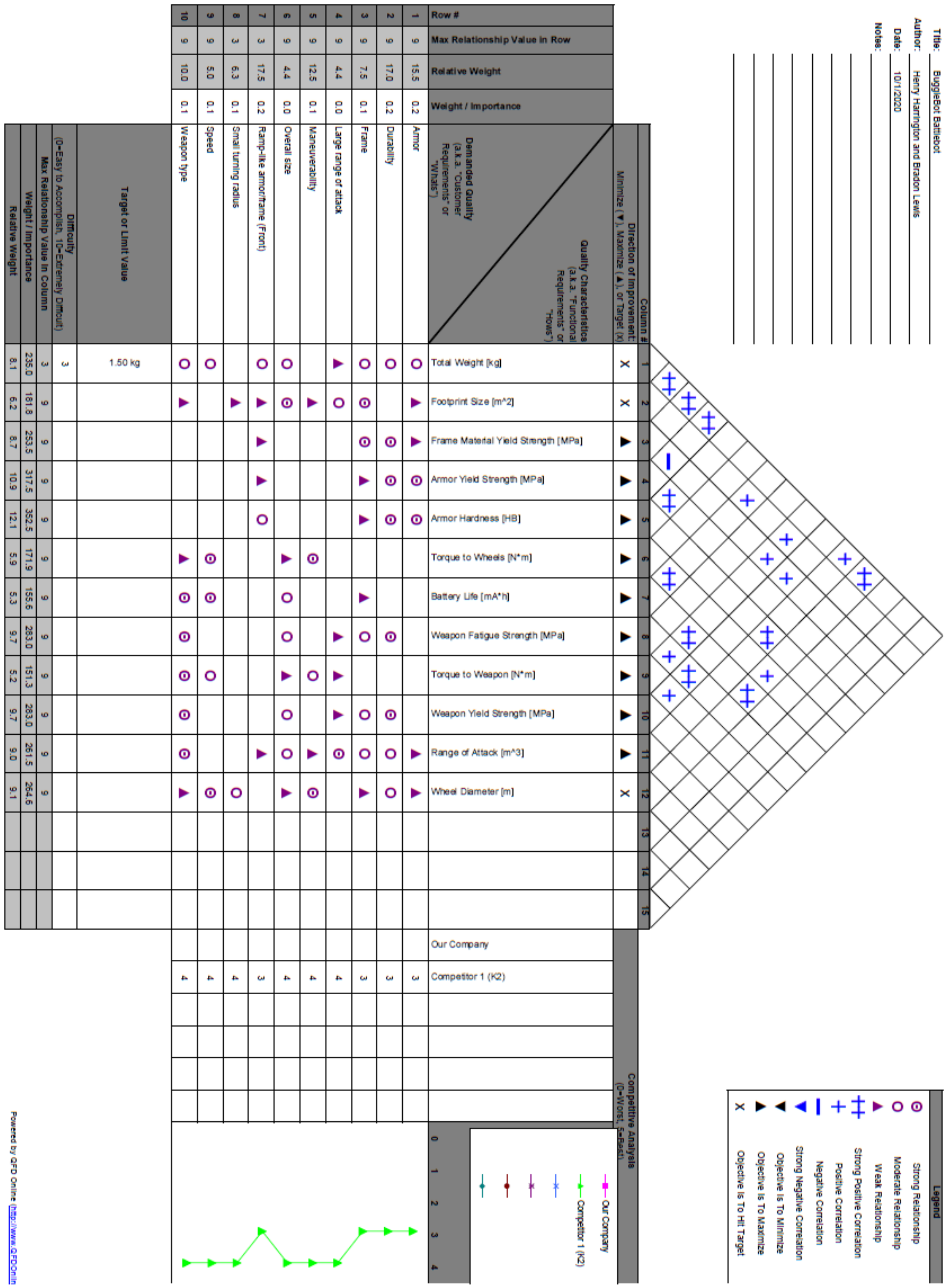


Table 1: House of Quality

PRODUCT OBJECTIVES

The objectives listed below are ordered from most important to least based on their calculated relative weight from the HoQ.

1. Armor Hardness (12.1%)
    a. Type of material
    b. Treatments/secondary processes
2. Armor Yield Strength (10.9%)
    a. Type of material
    b. Thickness of armor
3. Weapon Fatigue Strength (9.7%)
    a. Type of material
    b. Geometry of weapon
4. Weapon Yield Strength (9.7%)
    a. Type of material
    b. Geometry of weapon
5. Wheel Diameter (9.1%)
    a. Size of wheels
6. Range of Attack (9.0%)
    a. Size of weapon
    b. Type of weapon
7. Frame Material Yield Strength (8.7%)
    a. Type of material
    b. Geometry of frame
8. Total Weight (8.1%)
    a. Weight must not exceed 1.5 kg (not counting safety restraints)
9. Footprint Size (6.2%)
    a. Must be large enough to accommodate all components
10. Torque to Wheels (5.9%)
    a. The wheels must be provided with enough torque to maneuver robot
11. Battery Life (5.3%)
    a. Must last long enough for match duration
12. Torque to Weapon (5.2%)
    a. The weapon must be provided with enough torque to impact opponent robots

DESIGN

DESIGN SELECTION

To make the final selection, our team used a series a of weighted matrixes to determine the best combination of our individual concepts for the final beetlebot design. *Table 2* depicts a weighted score for each individual concept with and equal weight of 25% for each of the criteria. *Table 3* rates the compatibility, how well/easy the concepts can be merged into one design of each armor/frame concept to each weapon concept. *Table 4* takes the compatibility scores, weights them 25%, and sums them with the individual scores from *Table 2*. The final design will incorporate a drum spinner style weapon with a box type frame/armor and a front wedge.

Concept Selection Weighted Matrix					
Rating Scale: 1-5 (1 = Worst - 5 = Best)					
	Concept #	**Effectiveness [0.25]**	**Manufacturability [0.25]**	**Repairability [0.25]**	**Weighted Total**
Armor / Frame	Concept 1 (Box, Front Wedge)	3.5	4	4.5	3
	Concept 2 (Box, All Sides Wedge)	4.5	3.5	3.5	2.875
	Concept 3 (Hexagonal)	3	3	5	2.75
Weapon	Concept 1 (Drum Spinner)	4.5	3.5	4	3
	Concept 2 (Vertical Spinner)	4	5	3	3
	Concept 3 (Eggbeater)	3.5	4	1	2.125

Table 2: Concept Selection Weighted Matrix

Compatibility Matrix: Rates how well the components can be merged into a final beetlebot.				
Rating Scale: 1-5 (1 = Least Compatible - 5 = Most Compatible)				
	Concept #	**Weapon**		
		Concept 1 (Drum Spinner)	**Concept 2 (Vertical Spinner)**	**Concept 3 (Eggbeater)**
Armor / Frame	Concept 1 (Box, Front Wedge)	4	2	3
	Concept 2 (Box, All Sides Wedge)	3.5	1	2.5
	Concept 3 (Hexagonal)	4	4	3.5

Table 3: Concept Compatibility Matrix

Final Concept Selection Matrix: Summation of all scores for each concept combination						
#	**Armor / Frame Concept**	**Weapon Concept**	**Concept Selection Score**		**Compatibility Score [0.25]**	**Total**
			Armor / Frame Score	**Weapon Score**		
1	Concept 1 (Box, Front Wedge)	Concept 1 (Drum Spinner)	3	3	1	7
2	Concept 1 (Box, Front Wedge)	Concept 2 (Vertical Spinner)	3	3	0.5	6.5
3	Concept 1 (Box, Front Wedge)	Concept 3 (Eggbeater)	3	2.125	0.75	5.875
4	Concept 2 (Box, All Sides Wedge)	Concept 1 (Drum Spinner)	2.875	3	0.875	6.75
5	Concept 2 (Box, All Sides Wedge)	Concept 2 (Vertical Spinner)	2.875	3	0.25	6.125
6	Concept 2 (Box, All Sides Wedge)	Concept 3 (Eggbeater)	2.875	2.125	0.625	5.625
7	Concept 3 (Hexagonal)	Concept 1 (Drum Spinner)	2.75	3	1	6.75
8	Concept 3 (Hexagonal)	Concept 2 (Vertical Spinner)	2.75	3	1	6.75
9	Concept 3 (Hexagonal)	Concept 3 (Eggbeater)	2.75	2.125	0.875	5.75

Table 4: Final Concept Selection Weighted Matrix

Concept 1 – Armor/Frame

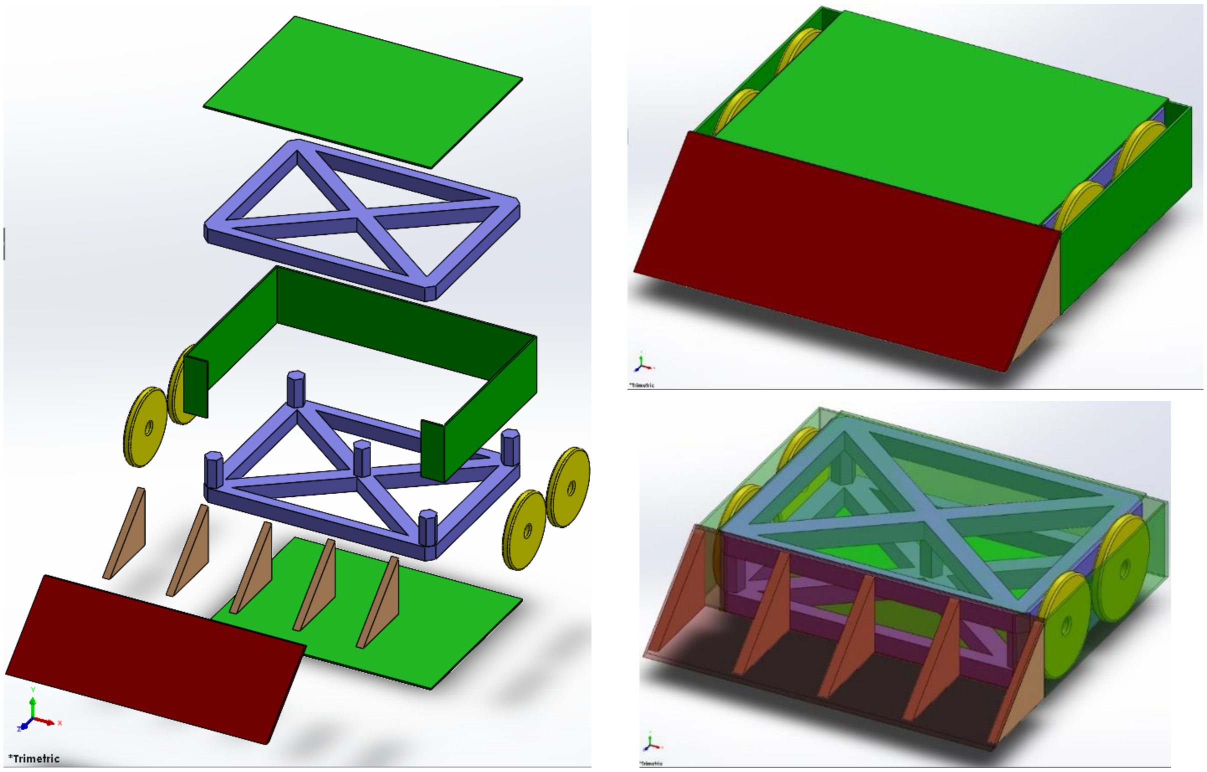


Figure 25: Concept 1 Trimetric Exploded, Transparent, & Normal Views

Frame – Box
Armor – Fully covered, wedge plate at front
Drive – Motor to gearbox, two-wheel rear, timing belt to two front wheels

This bot concept utilizes four wheels, front wedge, and box frame construction. The front wedge will help deflect hits and get under opponents to flip them. Mostly symmetrical design allows for bot to operate when inverted. Four-wheel drive system will provide adequate torque as project objective states. Rear wheels will be driven by gear box to motor assemblies. Attached to those wheels will be timing belts to transfer power to the front wheels. Frame and armor materials will meet product objectives for properties and will have equal priority on this build. Weight and footprint size are able to be met as this design is scalable and can be adjusted to meet the criteria.

Concept 1 – Weapon - Drum Spinner

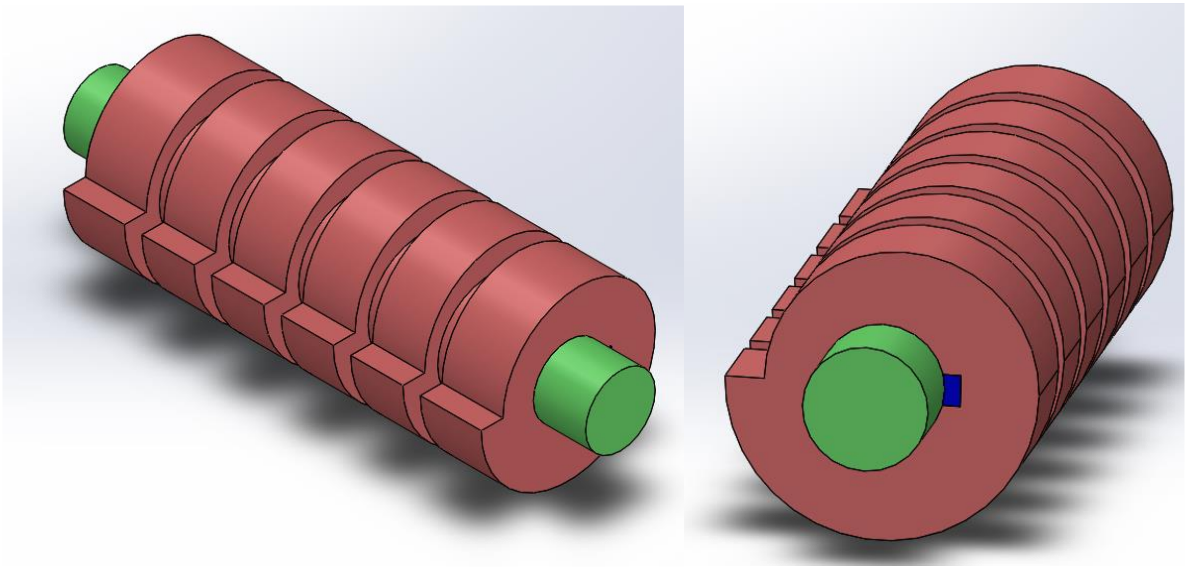


Figure 26: Isometric and side views of concept 1 – drum spinner

Drum spinners are a simple, yet effective weapon when it comes to battlebots and this design is no different. This drum spinner would rotate with the “teeth” of the weapon spinning upwards (clockwise). This would allow for the weapon to fling opponents into the air and cause a great deal of damage upon impact on the arena floor. The weapon will also be effective in chipping away at the armor of the opponent’s robot. The drum spinner would be driven in one of two different ways. The first option is to use direct drive which would be achieved by connecting the weapons motor directly to the drive shaft (green). The other option would be to have the weapon driven by a belt. The belt would be connected to one end of the shaft (green) and the other to the motor’s shaft. The belt drive has some advantages to it as it does not require the motor to be in line with the weapon, which saves space and protects the weapon from being disabled. It will also be better at absorbing shock than the motor would be if it were in direct contact with the weapon. This design would be effective in achieving our product objectives because by using the right materials the geometry and thickness of this weapon would allow for a strong yield and fatigue strength for the weapon. This weapon would also be effective in achieving a decent range of attack due to the size of the weapon.

Page Break

DESIGN ALTERNATIVES

Concept 2 - Armor/Frame

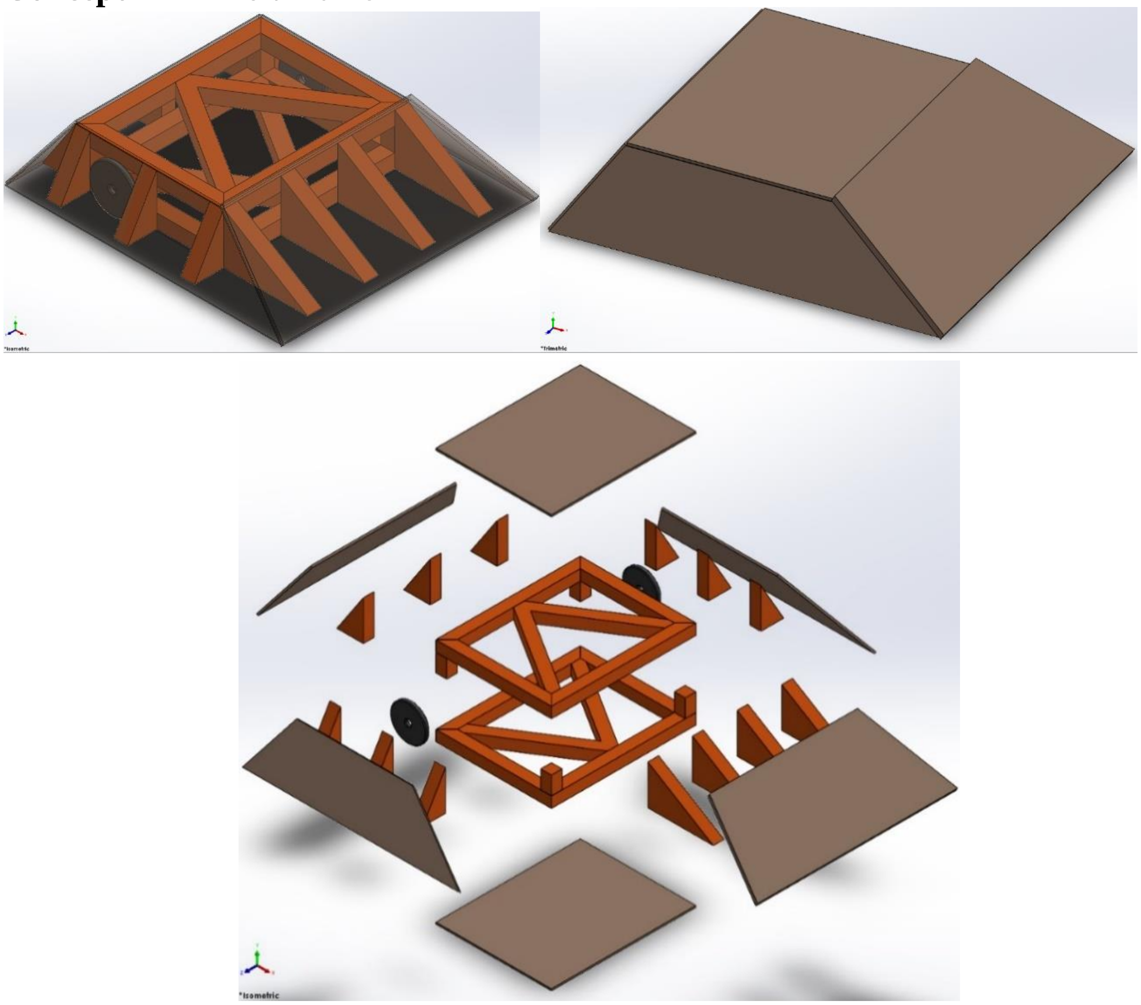


Figure 27: Concept 2 Trimetric Exploded, Transparent, & Normal Views

Frame – Box
Armor – Fully covered, Ramps on all sides, Larger wedge plate at front
Drive – Motor to gearbox, two-wheel drive, rear

This bot concept features armor on all sides, a compact box frame, and a two-wheel drive. The armor provides protection on all sides and incorporates a heavier plate at the front. The ramp like armor present on the front, sides, and rear allow for deflection of hits and helps get under bots. Getting under other bots can flip them. Armor plates protect the wheels. Low profile design makes it hard for other bots to get under it. The box style frame provides structure for the armor and keeps the internal components safe. The triangular wedges around the perimeter of the box provide support for the armor. The bot will be driven via motor to gearbox assemblies located in the rear of the frame. There will be low friction nubs or free wheels located at the front of the bot. This design can allow for meeting the product objectives for yield strength and hardness of the armor and frame. The wheel diameter is adjustable and can be increased further if the triangular wedges are spaced further apart. This design is also scalable to meet the footprint and weight objectives.

Concept 3 - Armor/Frame

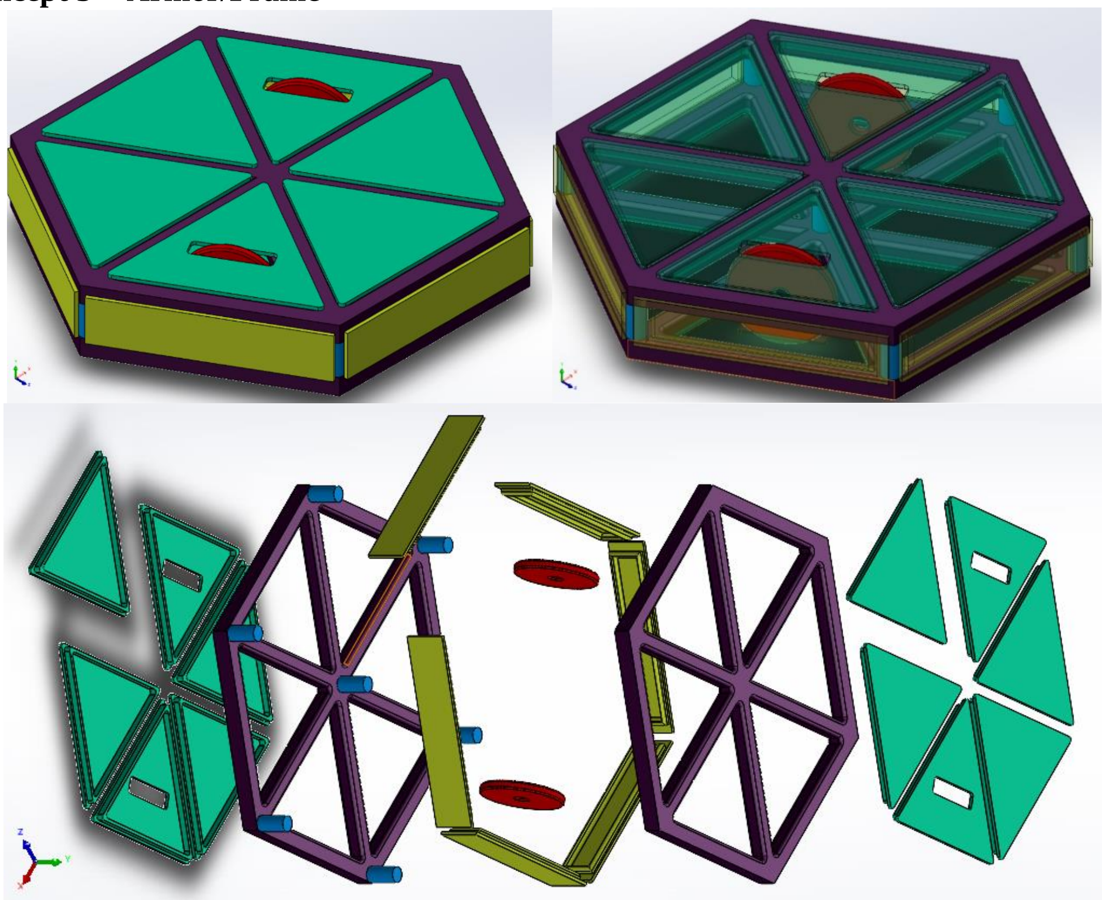


Figure 28: Concept 3 Trimetric Exploded, Transparent, & Normal Views

Frame – Hexagonal box
Armor – Fully covered, Insertable armor plates
Drive – Motor to gearbox, two-wheel drive, central

This bot utilizes a hexagonal frame with replaceable armor plates that can be inserted into the frame. The panel armor design allows for easy access to the inside of bot. The two wheels are driven by motor to gearbox assemblies and are centrally located. The wheels are as protected as they can be in a flippable design. The bot would have low friction nubs to help movement. The design is symmetrical, allowing for operation when inverted. There is a larger job to be done by the fame, sense it exposed and can receive hits, so the frame material would take priority over the armor panels. The armor material could be made out of different materials to increase strength in certain areas, like the panels over the wheels. the hexagonal shape of the frame creates chambers where components can be safely mounted. Total weight will be a tradeoff between the armor and frame, with the frame taking priority in importance. This design should adequately meet the project objectives.

Concept 2 – Weapon – Vertical Spinner

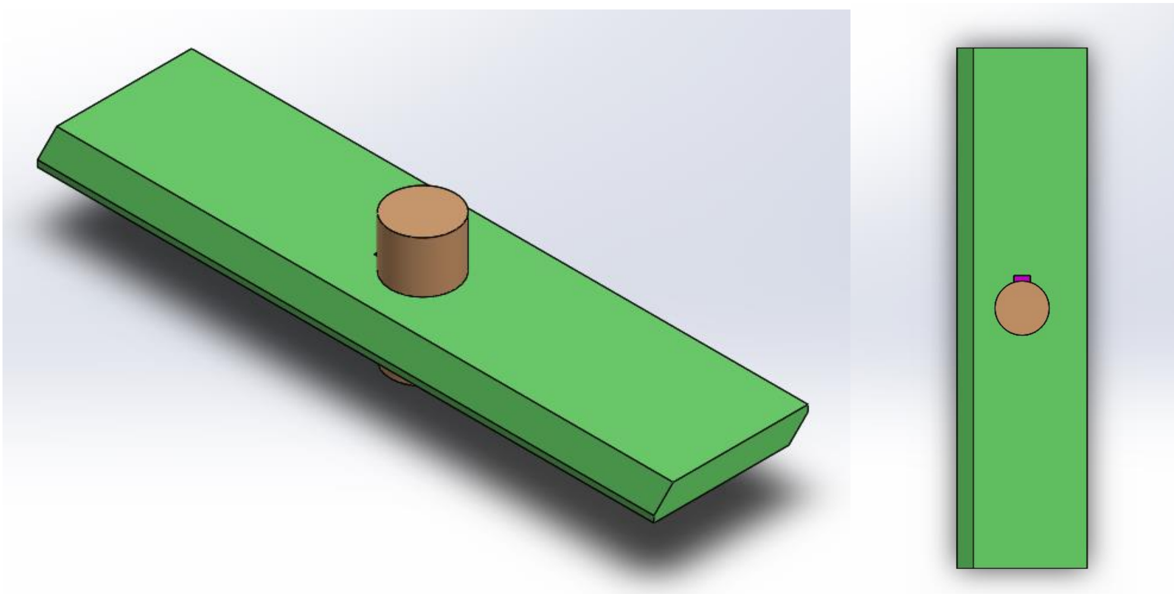


Figure 29: Isometric and top view of concept 2 – vertical spinner

Vertical spinners are a great way to defend yourself due to their large range of attack. This vertical spinner would rotate with the "front" edge of the weapon spinner clockwise. This would allow for the weapon to smash into the opponent like a blade and cause a great deal of damage upon impact. The weapon may also be effective in defending itself from the opponent's robot, depending on their type of weapon. The reason for the chamfers on opposite sides of the weapon is so that is the robot was flipped upside down the bladed edge would still be what is hitting the opponent. The vertical spinner would be driven in one of two different ways. The first option is to use chain drive which would be achieved by attaching a sprocket to the drive shaft (orange) and the motor shaft and then connecting them with a chain. The other option would be to have the weapon driven by a belt. The belt would be connected to one end of the shaft (orange) and the other to the motor's shaft. The belt drive has some advantages to because unlike the chain, debris will be much less likely to get caught in it which could cause the chain to break or fall off of the sprocket making the weapon disabled. It will also be better at absorbing shock than the chain would be. Although the chain would be made of metal making it less likely to be cut during a battle, the belt is less rigid allowing it to absorb a hit whereas the chain could break. This design would be effective in achieving our product objectives because by using the right materials and thickness combined with the geometry of this design would allow for a strong yield and fatigue strength for the weapon. This design concept has the largest range of attack as it would span most of the diameter of the weapon, which would help us to achieve our product objectives.

Concept 3 – Weapon - Eggbeater

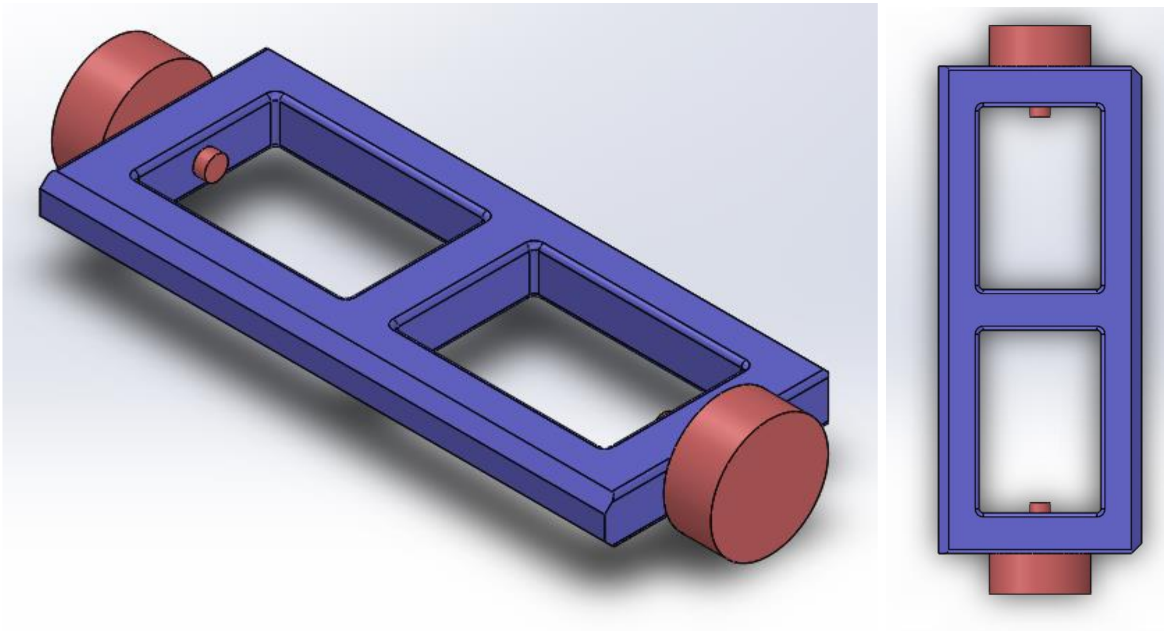


Figure 30: Isometric and top view of concept 3 – eggbeater

Eggbeaters are similar in their working concept to a drum spinner style weapon. This eggbeater would rotate clockwise so that the edge of the weapon can fling opponents into the air and cause a great deal of damage upon impact on the arena floor. The weapon will also be effective in chipping away at the armor of the opponent's robot. The bearing assemblies on the sides of the weapon will allow for it to rotate smoothly while being driven by the weapon's motor. The eggbeater would be driven in one of two different ways. The first option is to use direct drive which would be achieved by connecting the weapons motor directly to the bearing assembly (red). The other option would be to have the weapon driven by a belt. The belt would be connected to one bearing assembly (red) and the other to the motor's shaft. The belt drive has some advantages to it as it does not require the motor to be in line with the weapon, which saves space and protects the weapon from being disabled. It will also be better at absorbing shock than the motor would be if it were in direct contact with the weapon. This design would be effective in achieving our product objectives as long as we use the right materials and thickness then the geometry of this weapon would allow for a strong yield and fatigue strength for the weapon. This weapon would also achieve our product objective, range of attack as it would do an effective job of defending the robot.

ENGINEERING CALCULATIONS

List of equations (in order of use)

Inertia [kg·m^2]

Hollow Cylinder: $I = \frac{1}{2}m(r_1^2 + r_2^2)$

Angular Velocity $\left[\frac{rad}{s}\right]$

$\omega = RPM * \left(\frac{2\pi}{60}\right)$

Kinetic Energy [J]

$KE_{rotational} = \frac{1}{2}I\omega^2$

$KE_{linear} = \frac{1}{2}mv^2$

Impulse [N]

$J = F_{Avg}\Delta t$

Loading Conditions – required yield and tensile strength of material

Max Force expected to be exerted on frame & armor:

This will be the expected impact force that the beetlebot could receive during a match. This analysis will consider the maximum force that could be delt as a worst-case scenario. The assumptions about the motor and weapon are based of the 30-30-25-15 rule, where 30% of the beetlebot's total weight is devoted to the weapon system (4). The determined max force, that will be applied to our beetlebot's components, is found to be 185 N (208 lbf).

Assumptions → Beetlebot is at full 1.5 kg limit [m_{bot}]
→ Beetlebot has a forward-facing, CCW rotating, horizontal drum weapon
→ Drum weapon will be approx. as a hollow cylinder [I]
→ Weapon system is 4.5 kg
→ Weapon drum has an outer radius of 0.025 m [r_2]
→ Weapon drum has an inner radius of 0.0047625 m [r_1]
→ Weapon drum has a mass of 3.5 kg [m]
→ Weapon motor has an RPM of 20000
→ Velocity of beetlebot is 2 m/s [v_{bot}]
→ Time of impact is 0.1 s [Δt]

$$I = \frac{1}{2}m(r_1^2 + r_2^2) = \left(\frac{1}{2}\right)(3.5)(.0047625^2 + .0025^2) = 5.063E^{-5}\ kg \cdot m^2$$

$$\omega = RPM * \left(\frac{2\pi}{60}\right) = 20000 * \left(\frac{2\pi}{60}\right) = 2094.395\frac{rad}{s}$$

$$KE_{rotational} = \frac{1}{2}I\omega^2 = \left(\frac{1}{2}\right)(5.063E^{-5})(2094.395^2) = 111.044\ Joules$$

$$KE_{Moving\ Bot} = \frac{1}{2}m_{bot}{v_{bot}}^2 = \left(\frac{1}{2}\right)(1.5)(2^2) = 3.000\ Joules$$

$$KE_{Total} = KE_{rotational} + KE_{Moving\ Bot} = 111.044 + 3.000 = 114.044\ Joules$$

$$KE_{Total} = \frac{1}{2}m_{bot}{v_f}^2 \rightarrow 114.044 = \left(\frac{1}{2}\right)(1.5)\left({v_f}^2\right) = 12.331\frac{m}{s}$$

$$J = F_{Avg}\Delta t = m\Delta v \rightarrow F_{Avg}(0.1) = (1.5)(12.331) = 184.965\ N \approx 185\ N$$

Material Selection

Frame

Material	UHMW Polyethylene	(25)		
Density	0.949	$\frac{g}{cm^3}$	0.0343	$\frac{lb}{in^3}$
Tensile Strength	305.8-407.8	$\frac{kg_f}{cm^2}$	4350 – 5800	psi
Yield Tensile Strength	39	MPa	5660	psi
Impact Strength	8.968	$\frac{J}{cm}$	16.8	$\frac{ft-lbs}{in}$
Hardness	Durometer	65D-67D	(Medium)	

Table 5: UHMW Polyethylene Properties

Armor

Material	Polycarbonate	(26)		
Density	1.24	$\frac{g}{cm^3}$	0.0448	$\frac{lb}{in^3}$
Tensile Strength	713	$\frac{kg_f}{cm^2}$	10000	psi
Yield Tensile Strength	58.6-70.0	MPa	8500-10200	psi
Impact Strength	0.481-9.61	$\frac{J}{cm}$	0.900-18.0	$\frac{ft-lbs}{in}$
Hardness	Rockwell M	70.0-75.0		

Table 6: Polycarbonate Properties

Weapon, Drum & Shaft

Material	7075-T6 Al	(27)		
Density	2.81	$\frac{g}{cm^3}$	0.102	$\frac{lb}{in^3}$
Tensile Strength	572	MPa	83000	psi
Yield Tensile Strength	503	MPa	73000	psi
Hardness	Rockwell A	53.5		

Table 7: 7075-T6 Aluminum Properties

Power & Torque Calculations

Drivetrain

Determining wheel diameter and RPM needed to cross full length of the arena:

$Arena\ Area \rightarrow A_{Arena} = 17.361\ ft^2 = 2500\ in^2$

$Arena\ Length \rightarrow L_{Arena} = 4.167\ ft = 50\ in$

$Disered\ time\ to\ transverse\ arena = 2\ \text{sec}$

$Desired\ Velocity \rightarrow V_{Desired} = \dfrac{unit\ legnth}{unit\ time} = \dfrac{4.167\ ft}{2\ sec} \rightarrow 2.083\dfrac{ft}{s} = 25\dfrac{in}{s}$

$Wheel\ Diamter \rightarrow D_{Wheel} = 2.875\ \text{in}$

$Wheel\ Circumference \rightarrow C_{Wheel} = \pi D_{Wheel} \rightarrow \pi(2.875) = 9.032\ in$

$Minimum\ Number\ of\ Wheel\ Revolutions \rightarrow R_{n,min} = \dfrac{L_{Arena}}{C_{Wheel}} = \dfrac{50\ in}{9.032\ in} = 5.536\ revs$

$Minimum\ Wheel\ Revolutions\ per\ Unit\ Time \rightarrow = \frac{5.536\ revs}{2\ sec} = 2.768\frac{rev}{sec} = 166.076\ RPM$

Torque:

Assumptions → weight is evenly distributed between its two rear wheels
→ wheel material (rubber Tread Durometer 40 Shore A) approx. as clean & dry rubber
→ arena floor material approx. as clean & dry steel

$Load\ on\ Wheel \rightarrow L_{1\ Wheel} = \left(\dfrac{W_{Beetlebot}}{\#\ of\ wheels}\right) = \left(\dfrac{3.307lb}{2}\right) = 1.653lb$

(28) Coefficient of friction between wheel and arena floor → $f = 0.95$

$Wheel\ Friction\ Force \rightarrow F_{f,wheel} = L_{1\ Wheel}f = (1.653)(0.95) = 1.570lb$

$Wheel\ Friction\ Torque \rightarrow \tau_{f,wheel} = F_{f,wheel}\left(\dfrac{D_{Wheel}}{2}\right) \rightarrow (1.570lb)\left(\dfrac{2.875in}{2}\right)$
$= 2.257in - lb$

Drive Motors Properties

$Gear\ Ratio = 63:1$

$Nominal\ Voltage = 12\ V$

$No\ Load\ RPM = 220\ RPM$

$Rated\ RPM = 180\ RPM$

$Rated\ Torque = 0.8\ kg - cm$

$Stall\ Torque = 4.6\ kg - cm$

$No\ Load\ Current = 0.08\ A$

$Stall\ Current = 1.6\ A$

Theoretical max speed of bot with selected motor:

$V_{Beetlebot} = \left(\dfrac{D_{Wheel}}{2}\right)\left(\dfrac{2\pi}{60}\right)RPM = \left(\dfrac{2.875}{2}\right)\left(\dfrac{2\pi}{60}\right)(180) = 27.096\dfrac{in}{s} = 2.258\dfrac{ft}{s} = 0.688\dfrac{m}{s}$

Motor torque to overcome static friction of wheels on arena:

$Rated\ Torque = 0.8\ kg - cm = 0.694\ in - lb$

$Rated\ Torque\ with\ 63:1\ reduction = (0.694\ in - lb)(63) = 43.745\ in - lb$

Turning Radius:

$Wheel\ Center\ to\ Center\ Distance \rightarrow d_{Wheel,C2C} = 8.918in$

$$180°\ Turn\ Arc\ Length = \left(\frac{C_{Turning\ Diameter}}{2}\right) = \left(\frac{2\pi 8.918}{2}\right) = 28.017in = 2.335ft$$

$$180°\ turn\ time \rightarrow t_{180°\ Turn} = \left(\frac{180°\ Turn\ Arc\ Length}{V_{Beetlebot}}\right) = \left(\frac{2.335}{2.258}\right) = 1.034s$$

<u>Weapon</u>

<u>Weapon Motor Properties</u>

$Nominal\ Voltage = 12\ V\ (4000\ KV)$
$No\ Load\ RPM = 44440\ RPM$
$Load\ RPM = 36360\ RPM$
$No\ Load\ Current = 2.5\ A$
$Load\ Current = 26.5\ A$

$$Max\ Power = load\ current\ x\ voltage = 26.5\ A\ x\ 12\ V = 318\ Watts$$

$$Torque_{output} = \frac{Power}{\omega} = \frac{318}{1903.81} = 0.167\ Nm$$

$$\omega = RPM * \left(\frac{2\pi}{60}\right) = 18180 * \left(\frac{2\pi}{60}\right) = 1903.81\ \frac{rad}{sec}$$

$$M_{Weapon} = 93.715\ g = 0.093715\ kg$$

$$I = \frac{1}{2}M(R_1^2 + R_2^2) = \frac{1}{2} * .093715 * (.0047625^2 + .02611^2) = 3.3 * 10^{-5}\ kg * m^2$$

$$KE_{rotational} = \frac{1}{2}I\omega^2 = \frac{1}{2} * (3.3 * 10^{-5}) * 1903.81^2 = 59.8\ Joules$$

$$KE_{Moving\ Bot} = \frac{1}{2}mv^2 = \frac{1}{2} * (1.5) * 0.688^2 = 0.355\ Joules$$

$$Weapon\ Diameter = 52.21\ mm = 0.05221\ m$$

$$spin\ up\ time = 3 * \left[\frac{0.63*\omega*I}{Torque}\right] = 3 * \left[\frac{0.63*1903.81*3.3*10^{-5}}{0.167}\right] = 0.71\ s$$

$$L\ (momentum) = I\omega = 3.3 * 10^{-5} * 1903.81 = 0.0628\ \frac{kgm^2}{s}$$
$$v = r\omega = 0.02611 * 1903.81 = 49.7\frac{m}{s}$$

Shaft and Key Calculations

$$F_{avg}\ on\ shaft = \frac{Weapon\ Mass\ x\ v}{Impact\ Time} = \frac{0.093715*49.7}{.01} = 465.8\ N$$
$$Tensile\ Strength\ of\ 7075 - T6\ Aluminum = 572\ MPa$$
$$Shaft\ S_n = 0.5(Ultimate\ Tensile\ Strength) = 0.5(572000000) = 286\ MPa$$

$C_s = \left(\frac{D}{0.3}\right)^{-.11} = \left(\frac{0.375}{0.3}\right)^{-.11} = 0.9758$
$Desired\ reliability = 0.999 \rightarrow C_R = 0.75$
$C_{st} = 1.0$
$C_m = 1.0$
$Shaft\ S_n' = S_n C_m C_{st} C_R C_s = 286(1)(1)(0.75)(0.9758) = 209.3\ MPa$

Key Dimensions = 0.09375” x 0.09375” = 0.00238125m x 0.00238125m ; L = ?
Key Material – 6061 Aluminum
Key Seat Depth and Key Hub Depth = h/2 = 0.046875” = 0.001190625 m
$Force\ on\ Key = \frac{Torque}{shaft\ radius} = \frac{0.167}{0.0047625} = 35.1\ N$
$Shear\ Force\ (\tau) = \frac{F}{A_s} = \frac{35.1}{0.00238125^2} = 6184028.7\ Pa = 6.18\ MPa$
$\tau_d = \sigma_d = \frac{0.5S_y}{N}\ ; N = 3, S_y = 83\ MPa;\ \frac{0.5*83}{3} = 13.83\ MPa$
$Shear\ L_{min} = \frac{2T}{\tau_d DW} = \frac{2(0.167)}{13830000(.0047625)(.00238125)} = 0.00213\ m$
$Compression\ L_{min} = \frac{4T}{\sigma_d DH} = \frac{4(0.167)}{13830000(.0047625)(.00238125)} = 0.00426\ m$
$\therefore L = 0.5" = 0.0127\ m$

Factors of Safety

Frame

Each of the Finite Element Analysis (FEA) depicted in the figures below were simulated in SOLIDWORKS 2020 Simulation software. The material of the frame (UHMW Polyethylene) is closely approx. with PE High Density Film. In the figures below, he directional green arrows represent the fixturing of the frame, while the purply-pink directional arrows represent the force enacted on the frame. The fixturing represents the beetlebot being pinned against the arena wall and receiving the impact.

Based on the results of the FEAs and the calculated safety factors, the combination of the frame’s geometry and material will be sufficient for withstanding a minimum 2.4X the max expected force before yielding.

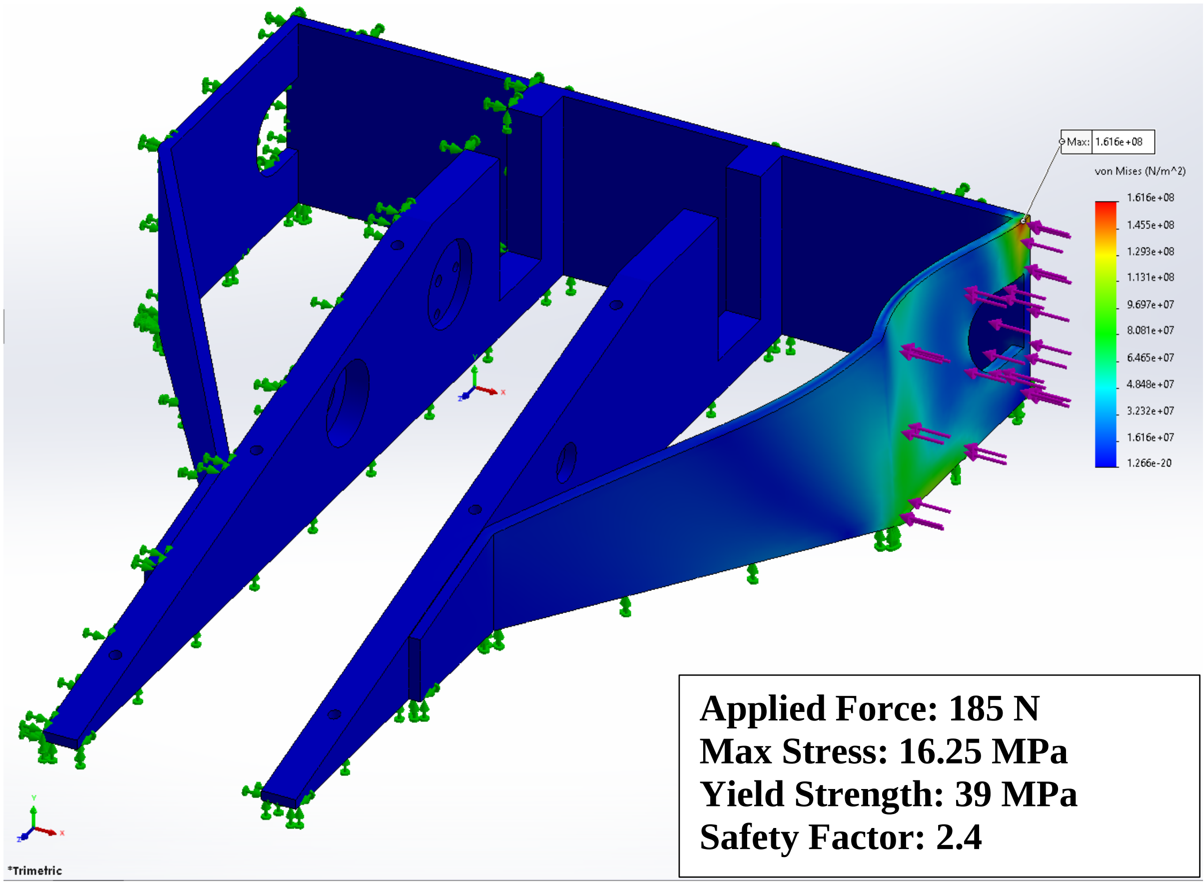


Figure 31: Frame Stress Analysis 1 – Pinned against wall, Force applied to right side

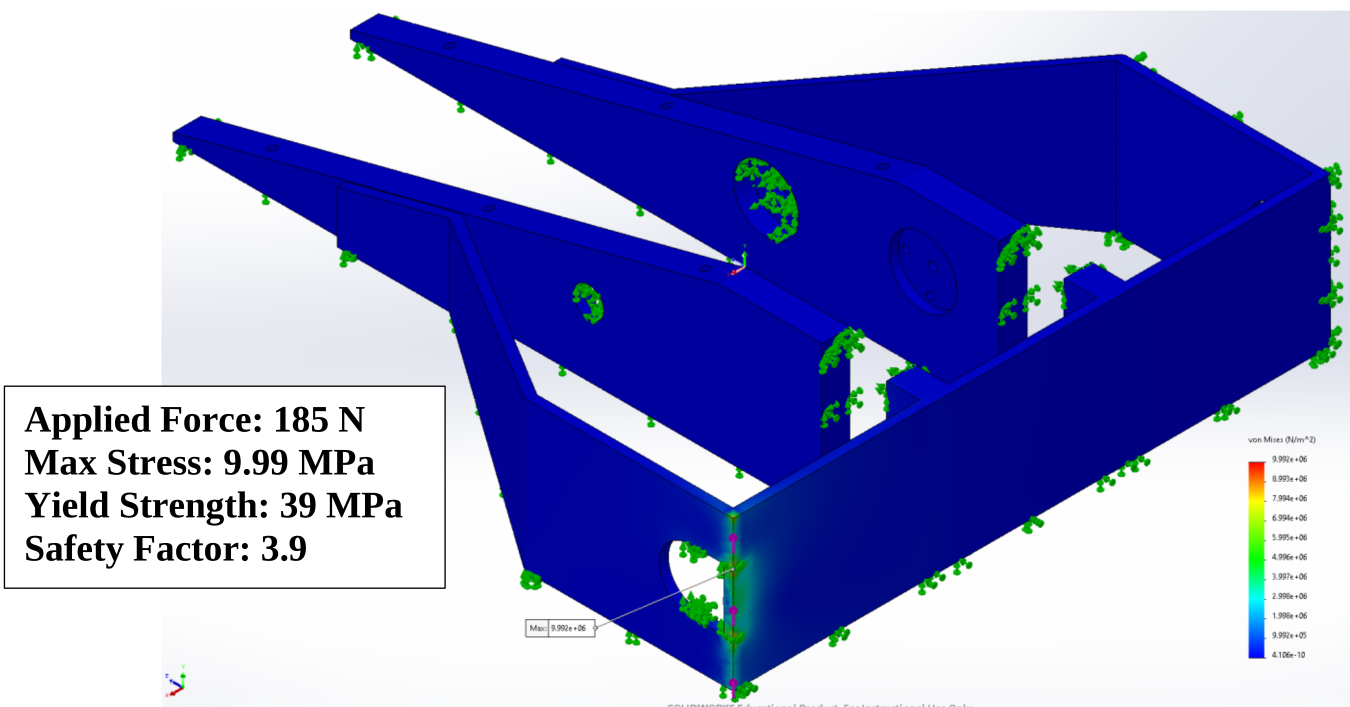


Figure 32: Frame Stress Analysis 2 – Pinned against wall, Force applied to corner

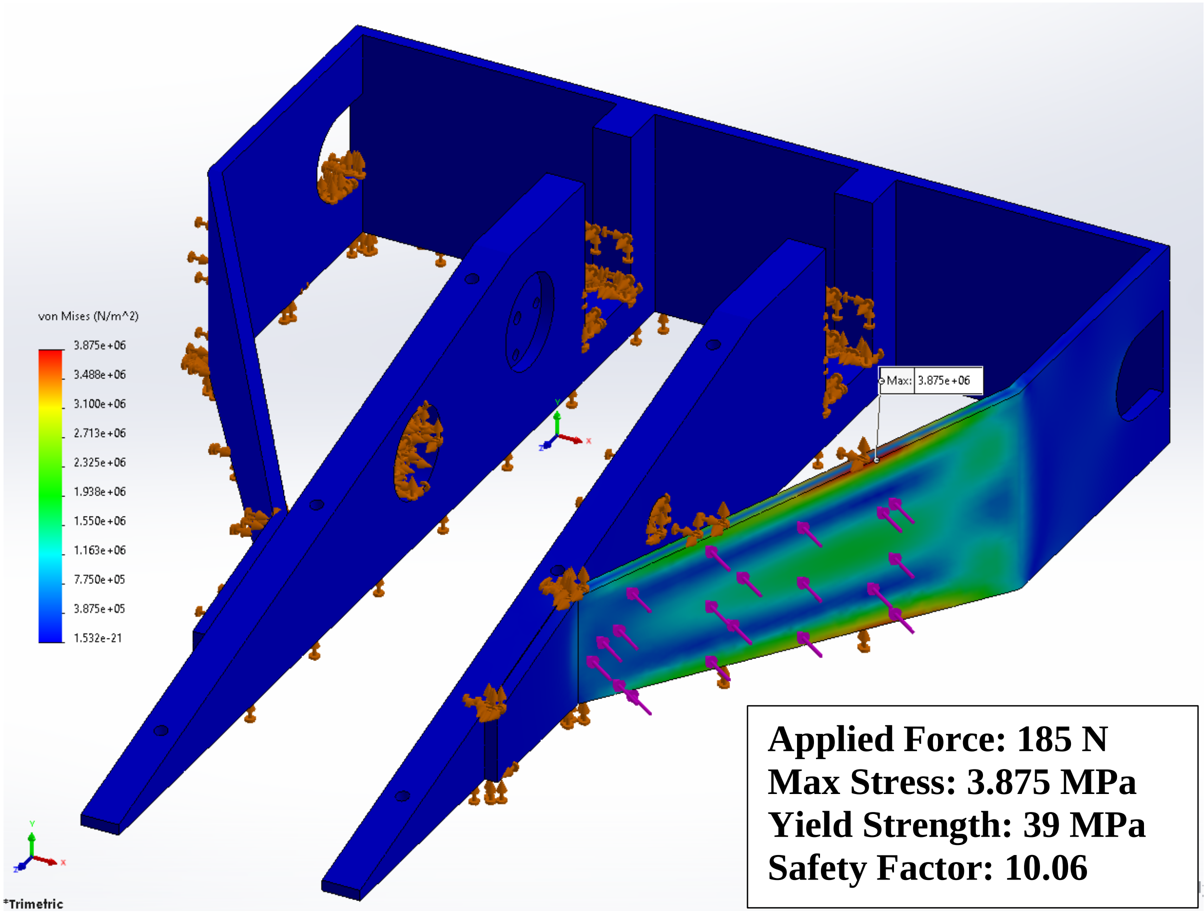


Figure 33: Frame Stress Analysis 2 – Pinned against wall, Force applied to diagonal wall

Armor

Each of the Finite Element Analysis (FEA) depicted in the figures below were simulated in SOLIDWORKS 2020 Simulation software. The material of the frame (UHMW Polyethylene) is closely approx. with PE High Density Film. The material of the armor is Polycarbonate. In the figures below, he directional green arrows represent the fixturing of the frame and armor, while the purply-pink directional arrows represent the force enacted on the armor and frame.

Based on the results of the FEAs and the calculated safety factors, the combination of the armor's geometry and material with added structure from the frame, will be sufficient for withstanding a minimum 1.59X the max expected force before yielding.

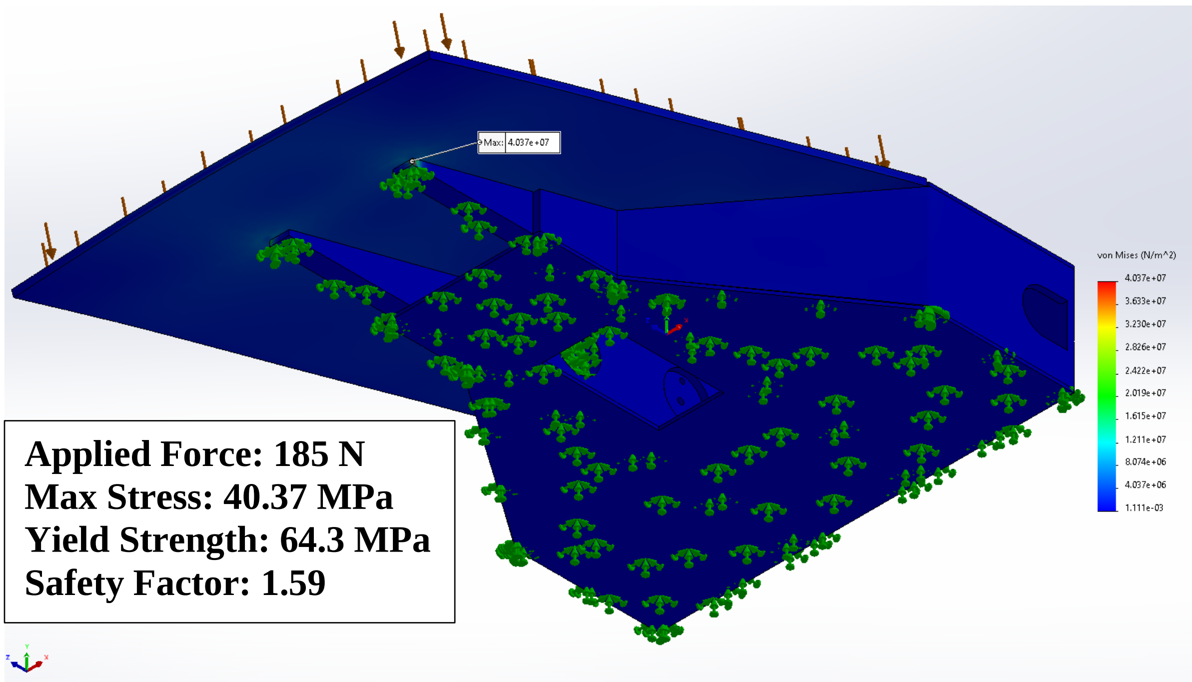


Figure 34: Armor/Frame Stress Analysis, Force applied to wedge

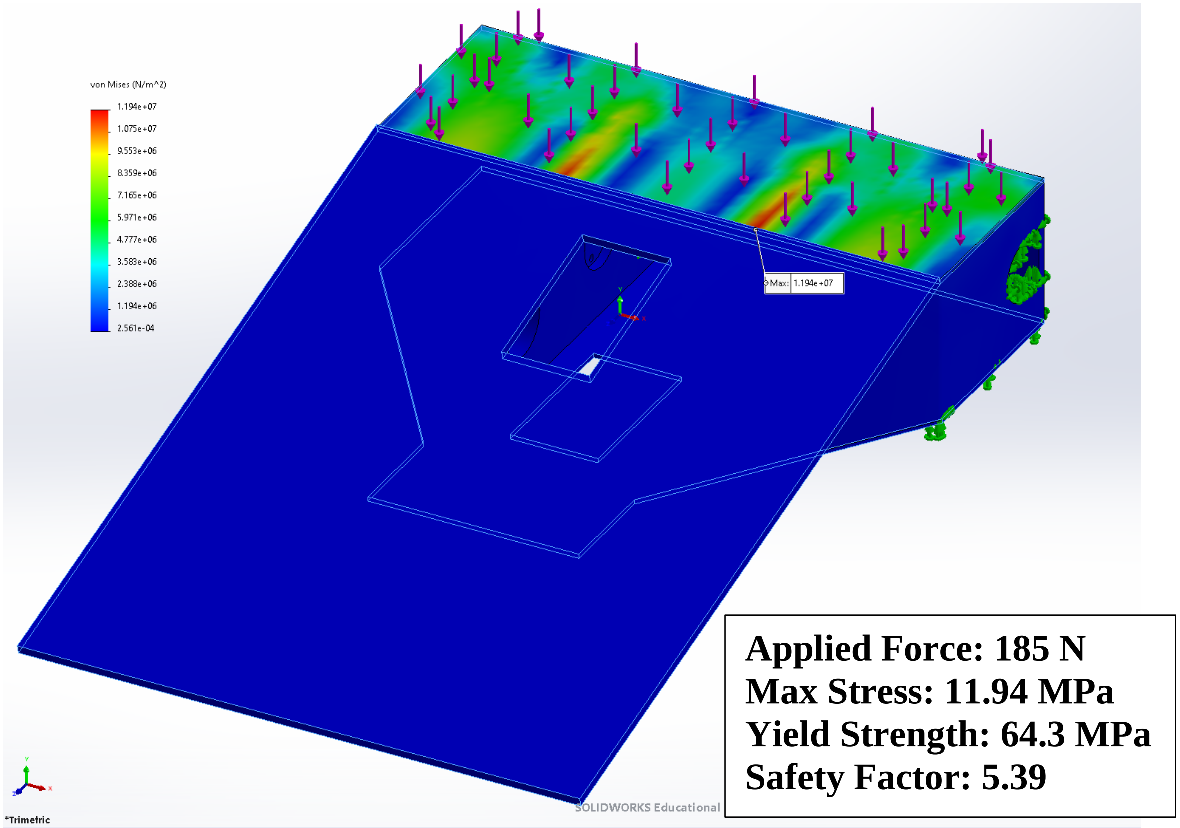


Figure 35: Armor/Frame Stress Analysis, Force applied to top plate

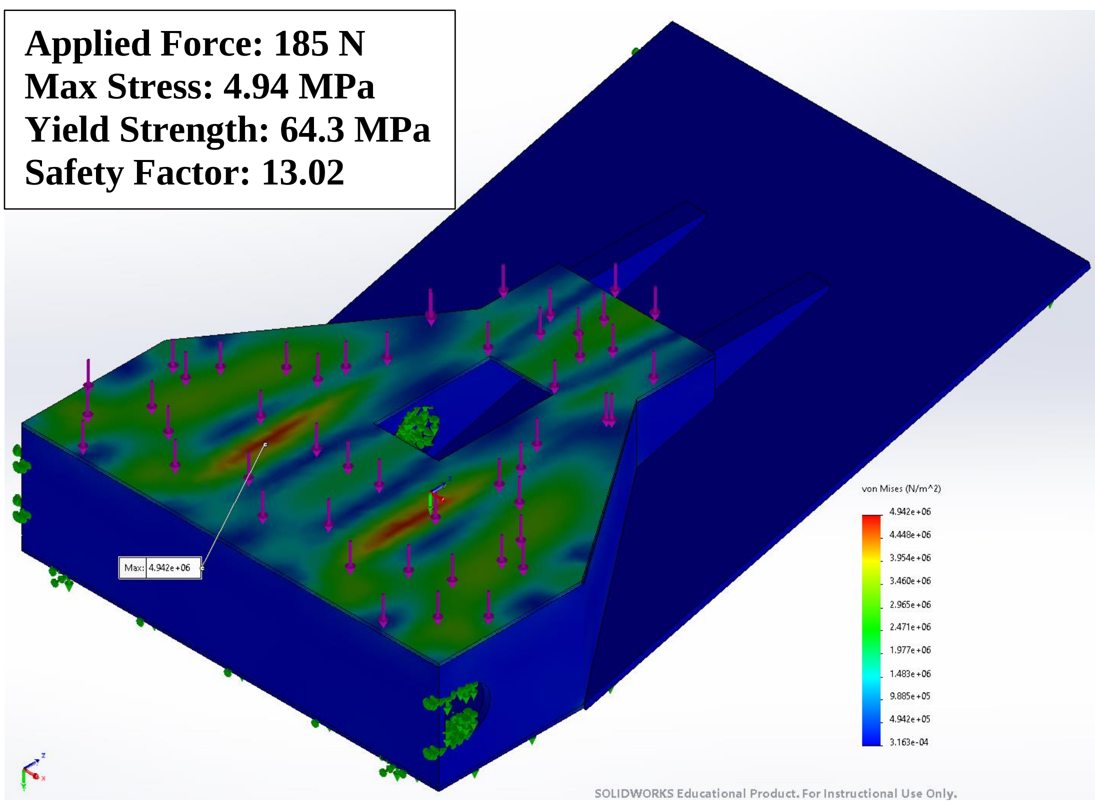


Figure 36: Armor/Frame Stress Analysis, Force applied to bottom plate

Weapon shaft

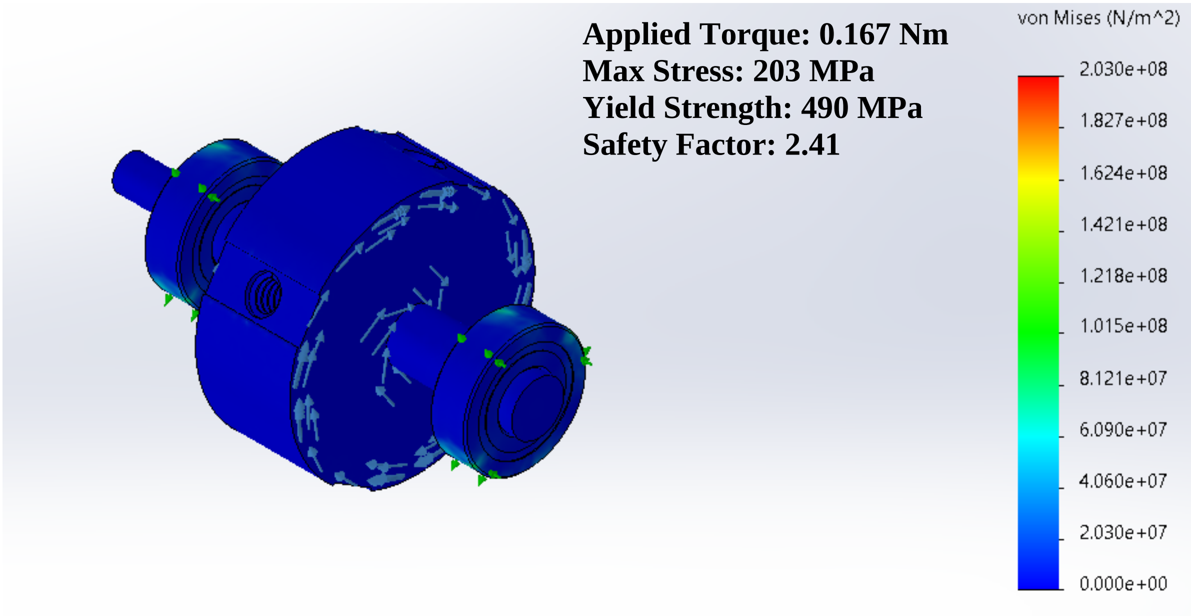


Figure 37: Weapon Stress Analysis, Motor Torque Applied to Shaft

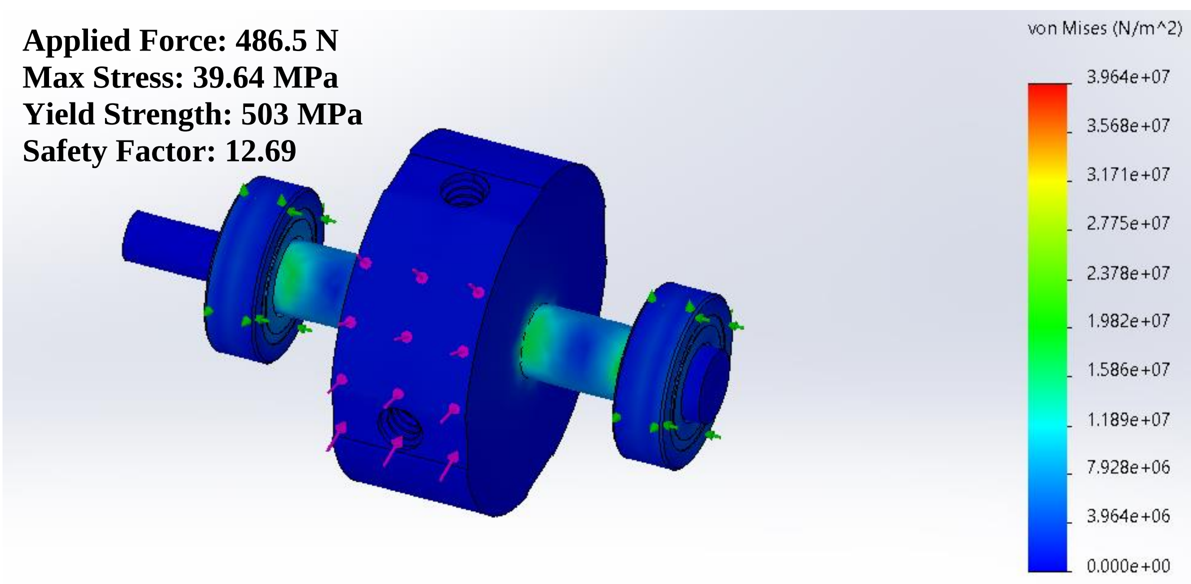


Figure 38: Weapon Stress Analysis, Average Weapon Force Applied to Itself

MANUFACTURING DRAWINGS

The drawings below are all in inches unless otherwise specified. Drawings were only created for the more complex components that needed to be fabricated.

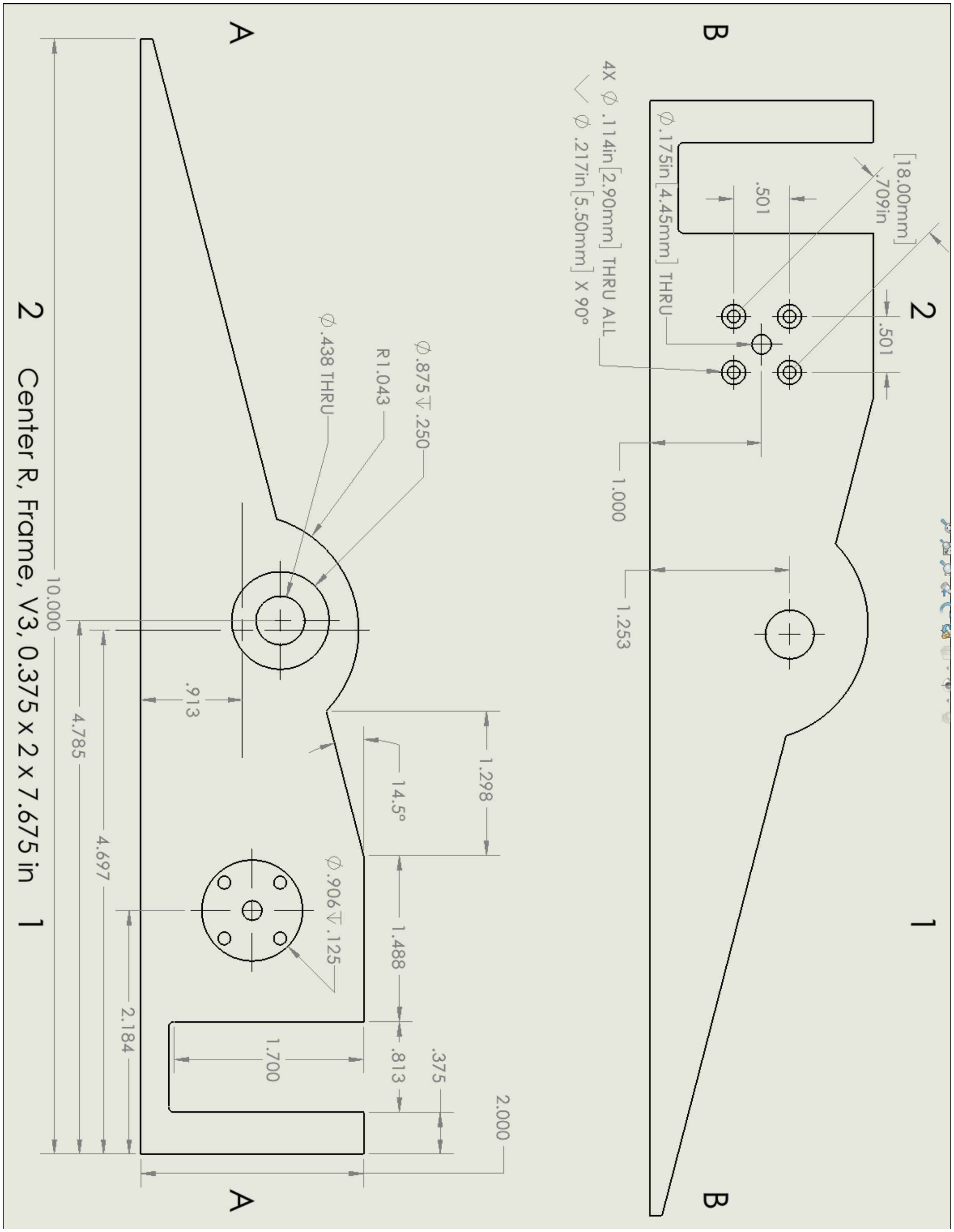


Figure 39: Frame, Center Right, Drawing

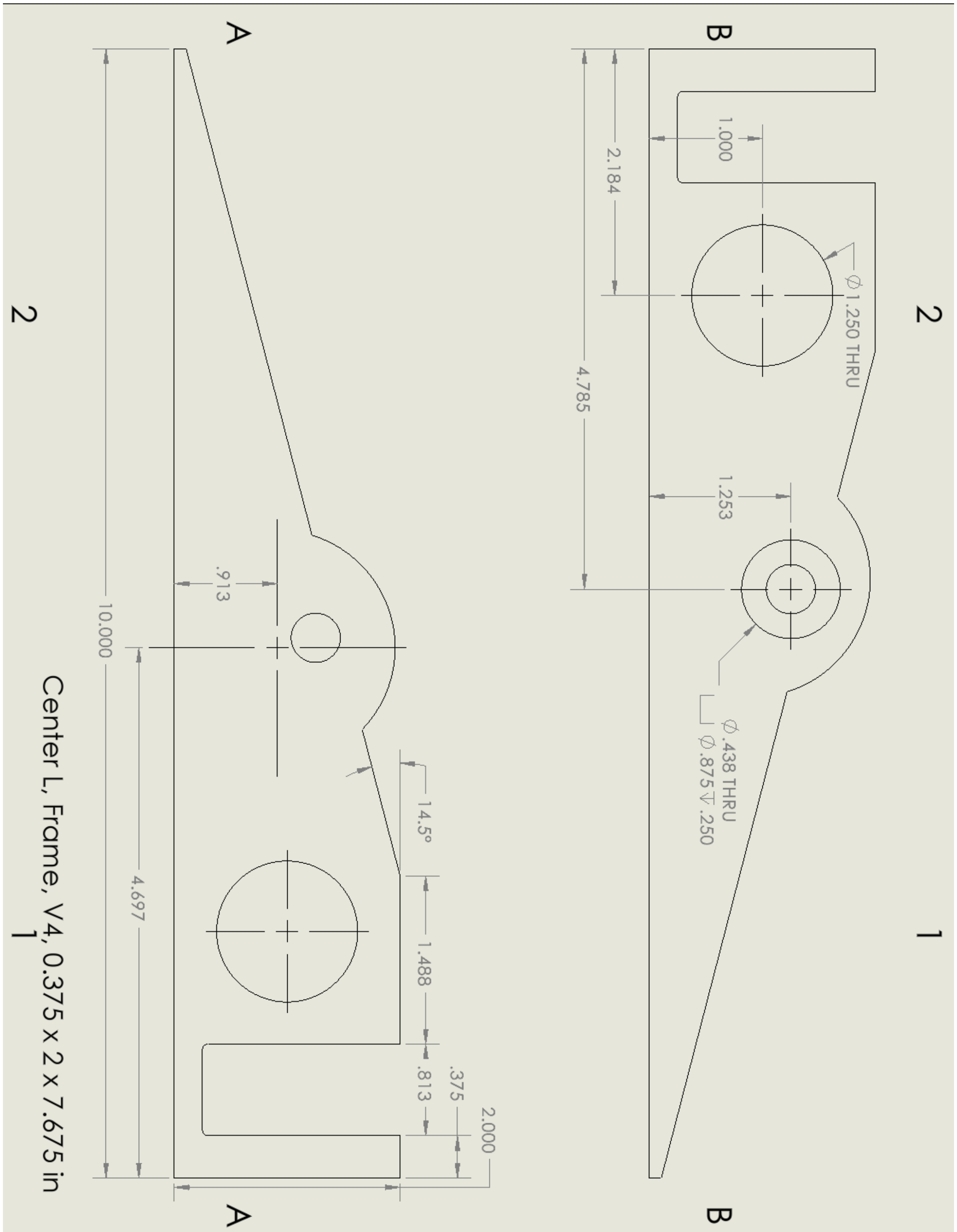


Figure 40: Frame, Center Left, Drawing

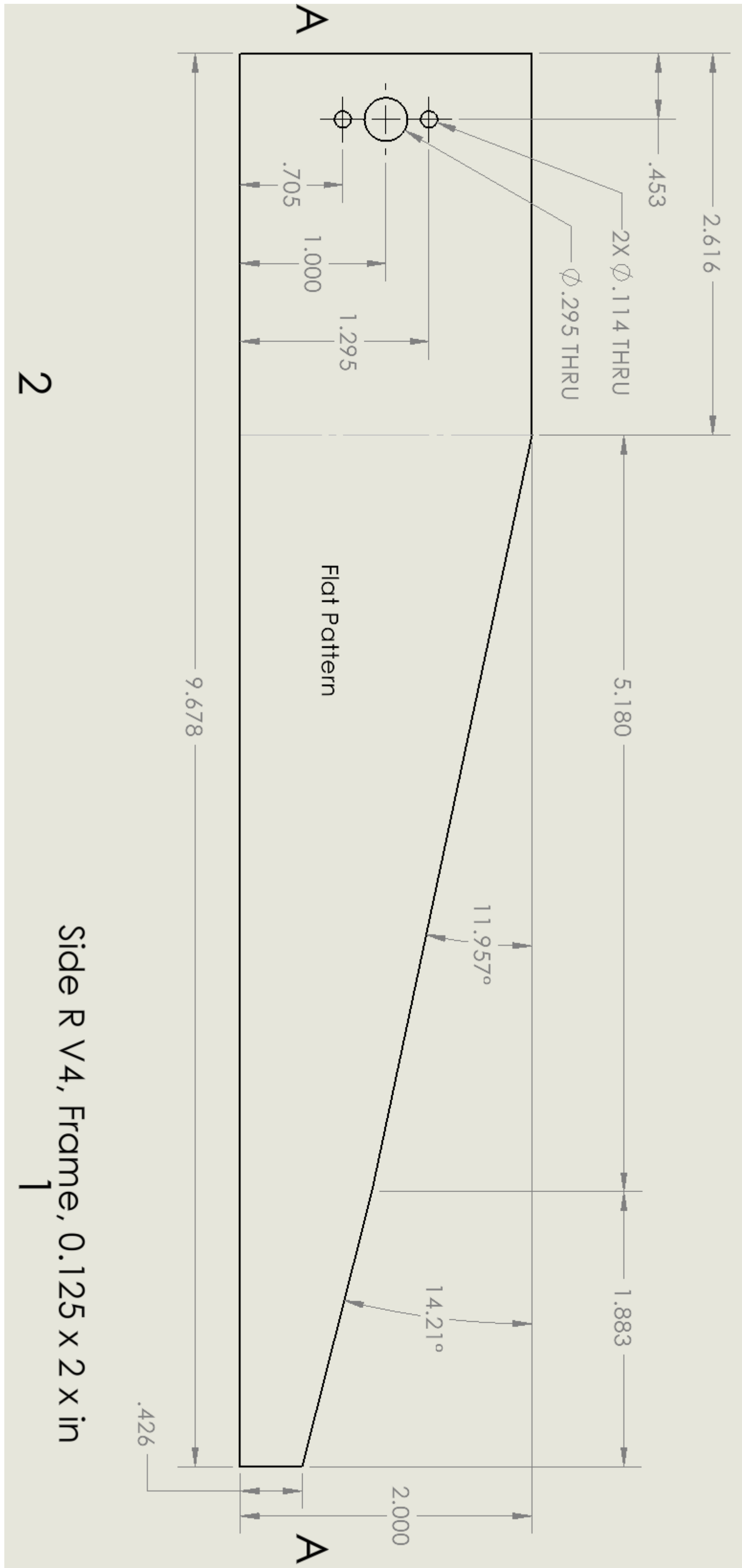


Figure 41: Frame, Sides, Flat, Drawing

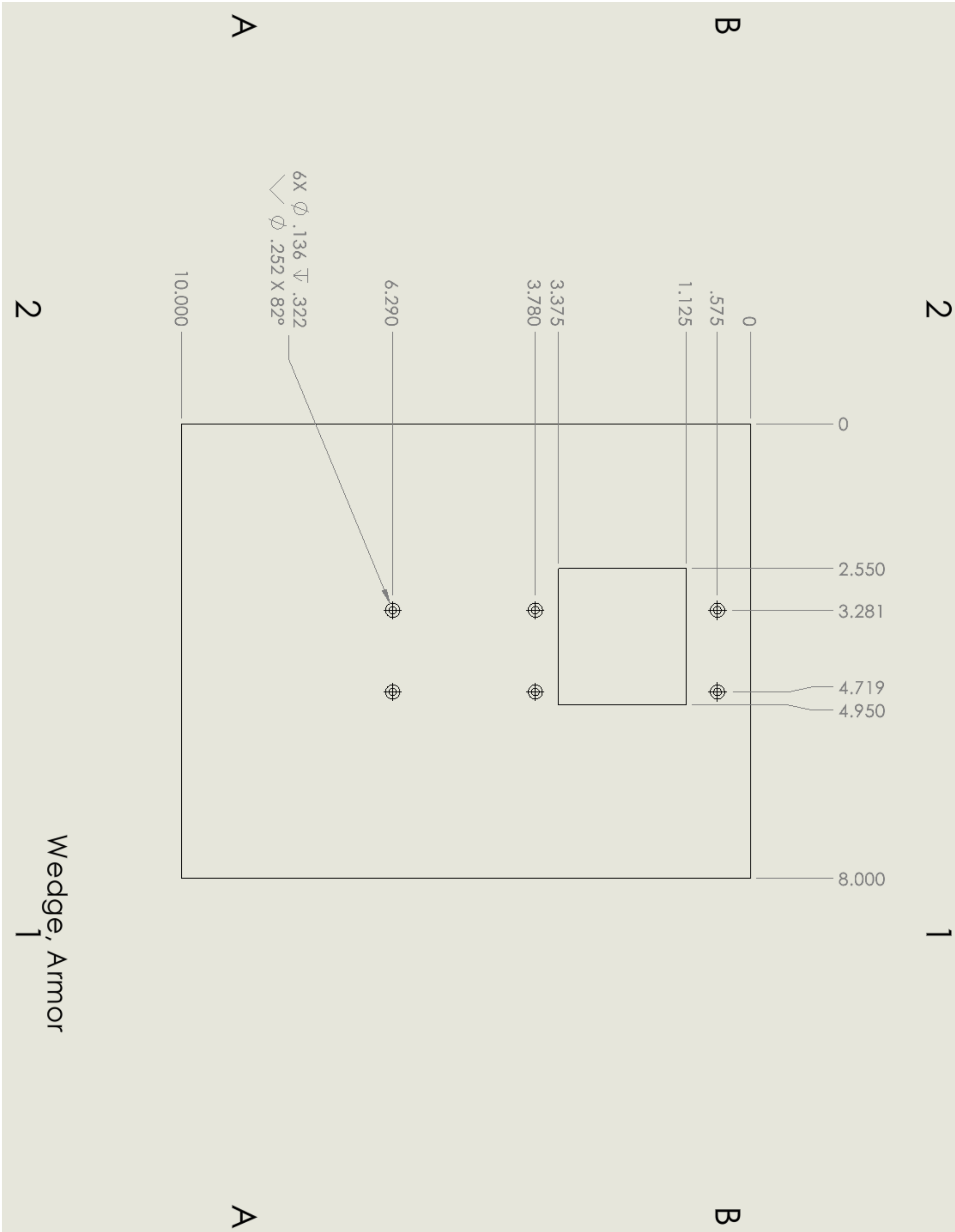


Figure 42: Wedge, Armor, Drawing

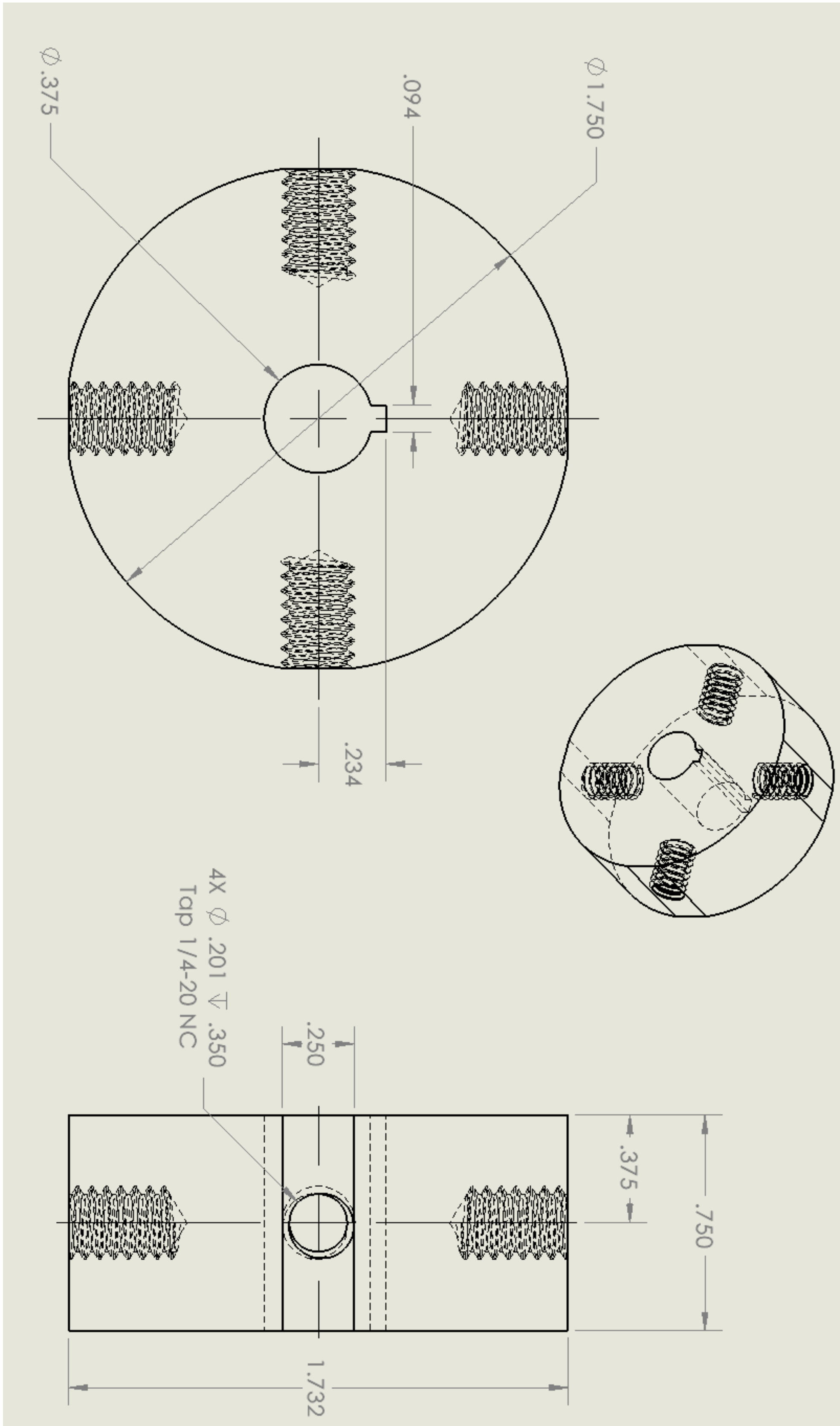


Figure 43: Drum, Weapon, Drawing

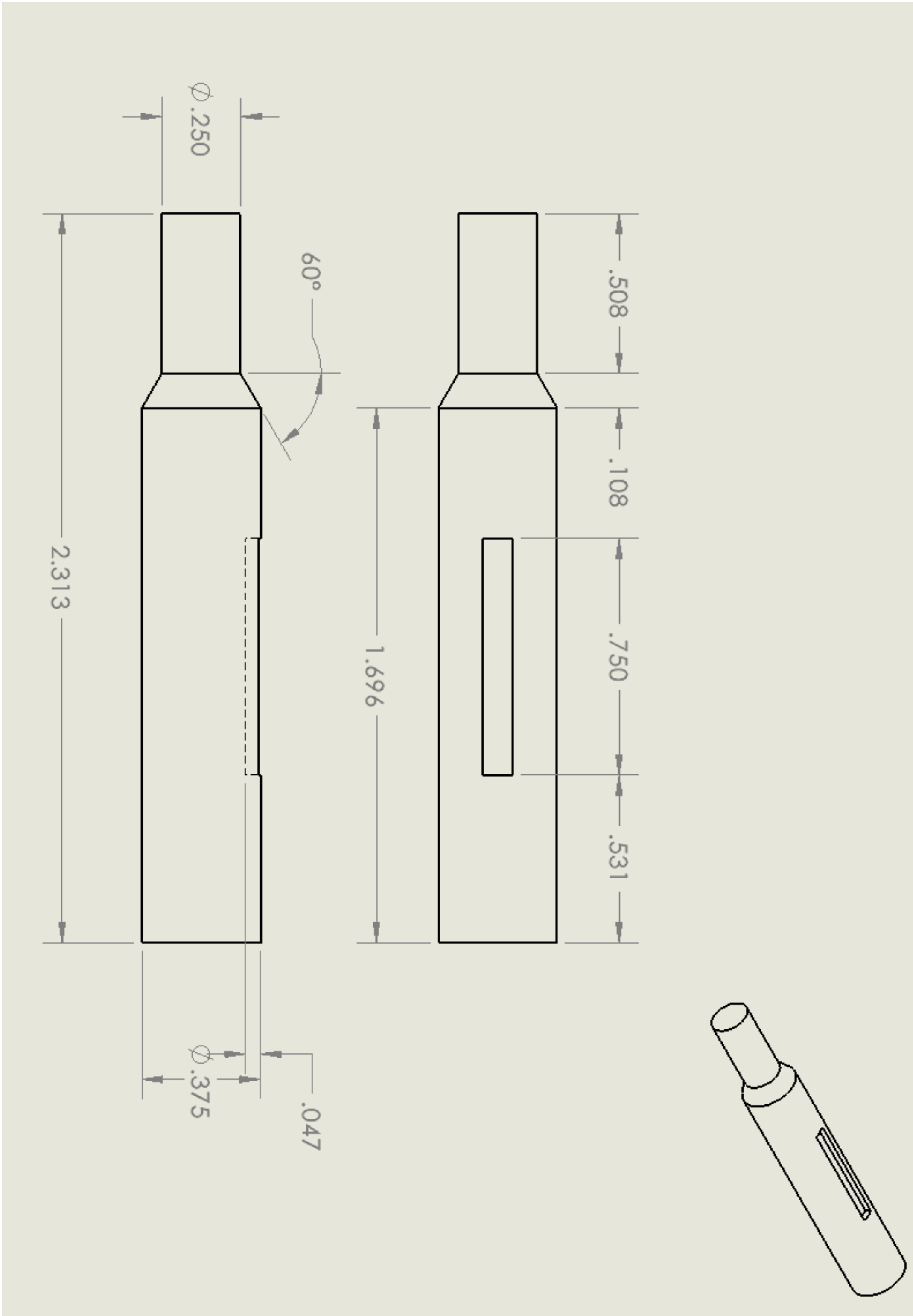


Figure 44: Shaft, Weapon, Drawing

BILL OF MATERIAL

ITEM NO.	PART NUMBER	QTY.
1	Center R, Frame, V3, 0.375 x 2 x 7.675 in	1
2	Center L, Frame, V4, 0.375 x 2 x 7.675 in	1
3	Back, Frame, 0.125 x 2 x 8 in	1
4	Side R V4, Frame, 0.125 x 2 x in	1
5	Side L V4, Frame, 0.125 x 2 x in	1
6	Bottom Plate V4, Armor	1
7	Bottom Plate V4, Front, Caster, Armor	1
8	Wedge V4, Polycarbonate 0.125 in V3	1
9	Support Center, Frame	1
10	Support Center, Frame, Short	1
11	Brace, Frame, Long	2
12	Brace, Frame, Short	2
13	Top Armor, Polycarbonate 0.0625in, 2.8 x 8 in	1
14	Top Strip, Frame, 0.125 x 1 x 8 in	1
15	T81P-29, 2.875in, BaneBots	2
16	Wheel Hub, T81H-RM41, 4mm shaft, BaneBots	2
17	L-Bracket,Drivetrain Motor, pololu-20d-mm-metal-gearmotor-bracket	2
18	Motor, Drivetrain, 20d-metal-gearmotor-63-78	2
19	Snap Ring, Wheel Hub	2
20	Set Screw, Wheel Hub	2
21	2415T130_COUNTERSUNK FLANGE-MOUNT BALL TRANSFER	1
22	15t_pulley	1
23	Set Screw, Pulley	2
24	60355K450_BALL BEARING	2
25	Weapon Motor, Brushless, Turnigy 2815 EDF Outrunner 4000kv for 55-64mm	1
26	Drum, Weapon V3, Keyed, D1.75 x L0.75 in	1
27	92314A315_18-8 STAINLESS STEEL HEX HEAD SCREWS	4
28	30t_pulley, 0.25in bore	1
29	Shaft V4, Ø 0.375 X L 3.75in, Shoulder Ø 0.25, Weapon	1
30	98491A098_OVERSIZED STEEL MACHINE KEY STOCK	1
31	Belt 201 mm 67 T	1
32	99461A520_THREAD-FORMING SCREW FOR PLASTIC	30
33	93395A182_TYPE 316 SS FLAT-HEAD SOCKET CAP SCREW	5
34	91430A085_METRIC FLAT HEAD SLOTTED MACHINE SCREW	4
35	96367A921_PEEK MACHINE SCREW	26
36	92470A152_PAN HEAD PHILLIPS SCREW FOR SHEET METAL	5
37	91430A081_METRIC FLAT HEAD SLOTTED MACHINE SCREW	2
38	92451A148_BRASS FLAT HEAD SLOTTED MACHINE SCREW	9
39	Insert, Brass, 6-32	9
40	Support, Motor, Weapon	1
41	Frame, Support, Arch, Battery V2	1
42	Support, Arch, Frame, Battery V2	1
43	Guard, Weapon Motor	1
44	Guard, Pully Large	1
45	Cover, Belt, Weapon Motor	1
46	Battery, Turnigy Graphene 1000mAh 3S 45C LiPo Pack XT60	1
47	Receiver, Turnigy T6A-V2 AFHDS Mode 2 2.4GHz 6Ch Transmitter & Receiver	1
48	ESC Brush, Drive Motor	2
49	ESC Brushless, Weapon Motor	1
50	XT60FemaleConnector	4
51	XT60MaleConnector	4

Table 8: BOM

BUILD AND TEST

DISCUSSION OF THE MANUFACTURING PROCESSES UTILIZED

For the fabrication and manufacturing of our components we chose to utilize the labs within UC's Victory Parkway campus for our machining needs. Shoutout to Nicholas Plataniotis & Brian Yockey who were invaluable for their expertise and guidance in the machine shop. For the electrical components we soldered them ourselves off campus with a borrowed soldering kit. For the other components we fabricated off campus we utilized tools we had around such as circular saws, jigsaws, and a 3D printer.

Machining

Component → *Weapon Shaft Pulley, S3M Timing Pulley, 30 Tooth*
Operation → *1x 0.25"Through Drill → Increase ID for weapon Shaft*
Machine → *Mill*
Location → *Victory Parkway or Off Campus*
Operator → *Self*

Figure 45: Increasing Center Hole for Shaft, Weapon Pulley, Fabrication

Component → *Drum, Weapon, 7075 T6 Aluminum Round Bar, OD 1.75" X L 0.75"*
Operation → *4x Facing, 4x Drill & Tap, 1x Drill, Key Slot*
Machine → *Bandsaw, Mill, Hand Tap, Broach Press*
Location → *Victory Parkway*
Operator → *Self*

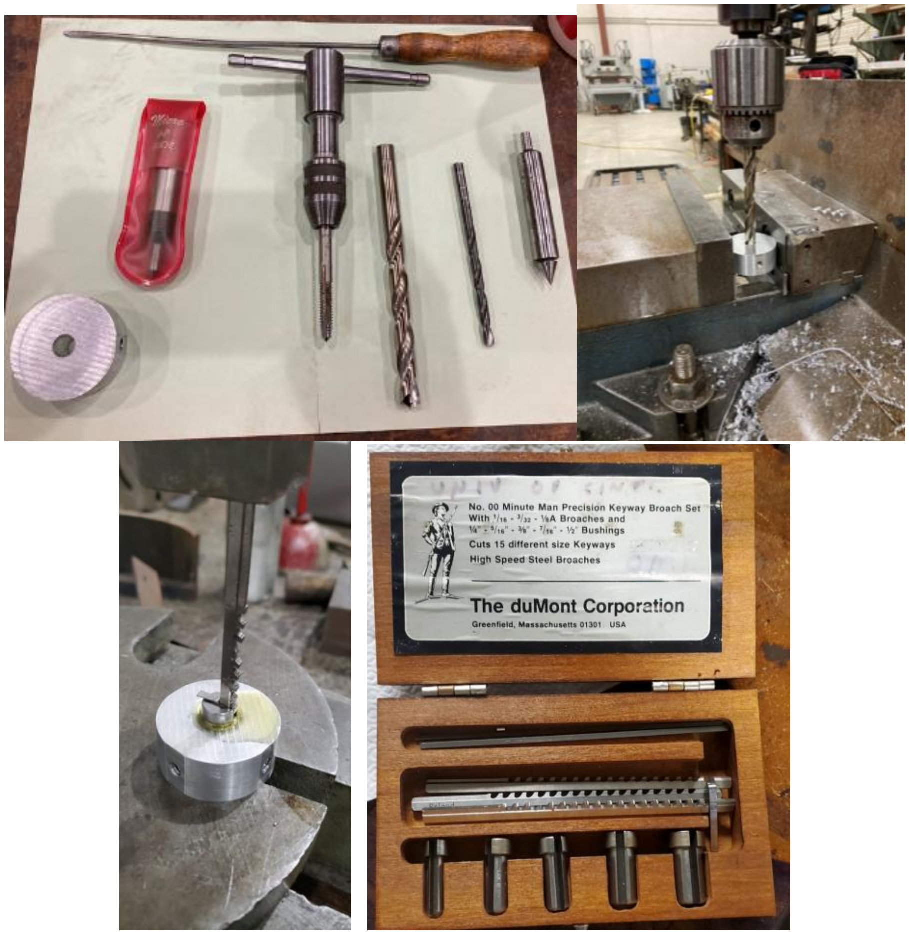


Figure 46: Weapon Drum Fabrication

Component → *Shaft, Weapon, 7075 T6 Aluminum Round Bar 3/8, L 3.25”*
Operation → *1x Turning, Cut, Key Slot*
Machine → *Bandsaw, Lathe, Mill*
Location → *Victory Parkway*
Operator → *Self*

Figure 47: Weapon Shaft Fabrication

Component → *Key, Weapon, Zinc-Plated 1018-1045 Steel Square Bar 0.093”, L0.5”*
Operation → *Cut to Length*
Machine → *Bandsaw*
Location → *Victory Parkway*
Operator → *Self*

Component → *Armor Plate Material, Polycarbonate Sheet 1/8 & 1/16, L8" x W10"*
Operation → *Cut, Drill*
Machine → *Jig Saw, Hand Drill*
Location → *Off Campus*
Operator → *Self*

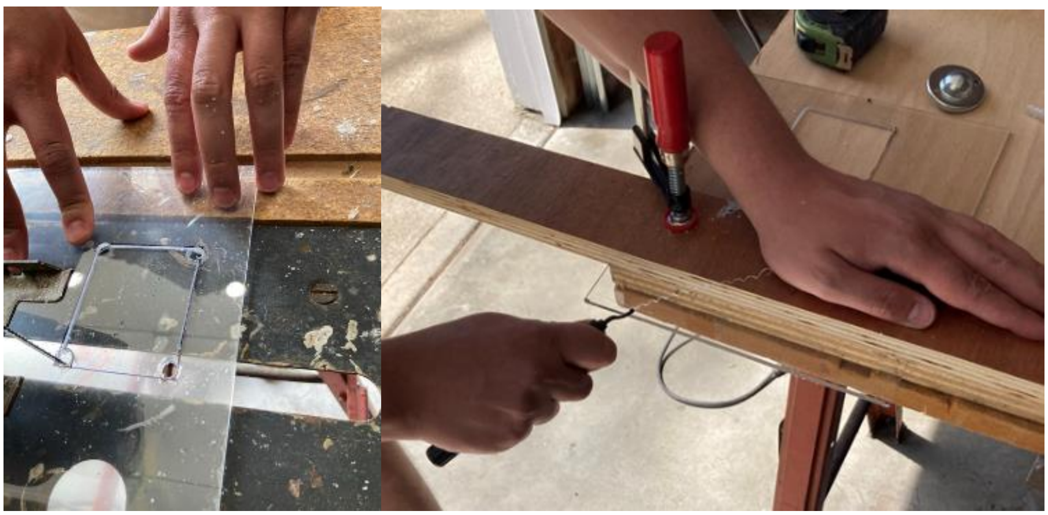


Figure 48: Polycarbonate Wedge Fabrication

Component → *Frame Material, UHMW Polyethylene Sheet 8" x 10", 0.375" & 0.125”*
Operation → *Cut, Drill, Bend*
Machine → *Circular Saw, Jig Saw, Mill*
Location → *Victory Parkway and Off Campus*
Operator → *Self*

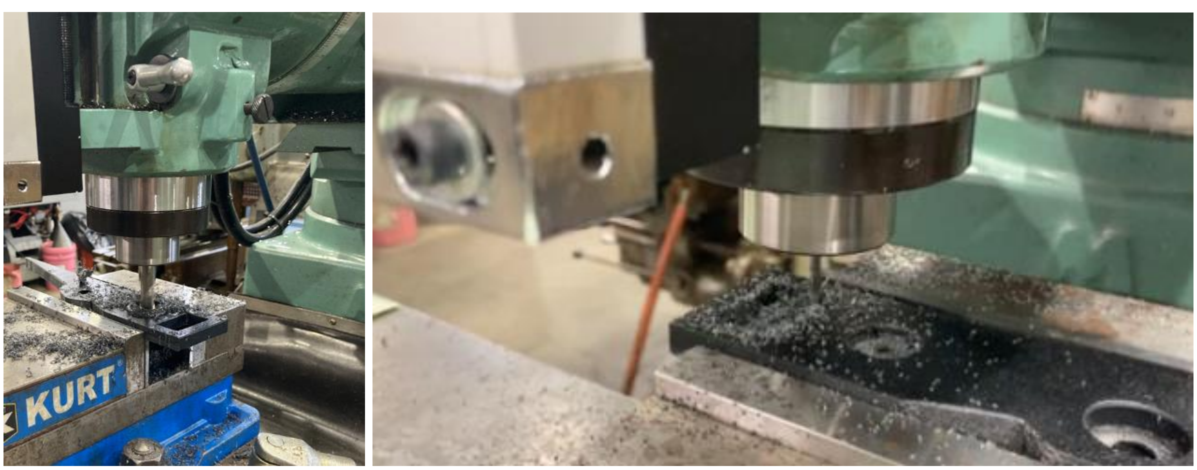


Figure 49: Frame Fabrication

Electrical

The electrical components were wired and soldered at off campus by us after a short demonstration from the club. The circuit diagrams (Figure 18) were used as an example and general layout to create our final wiring diagram (Figure 51).

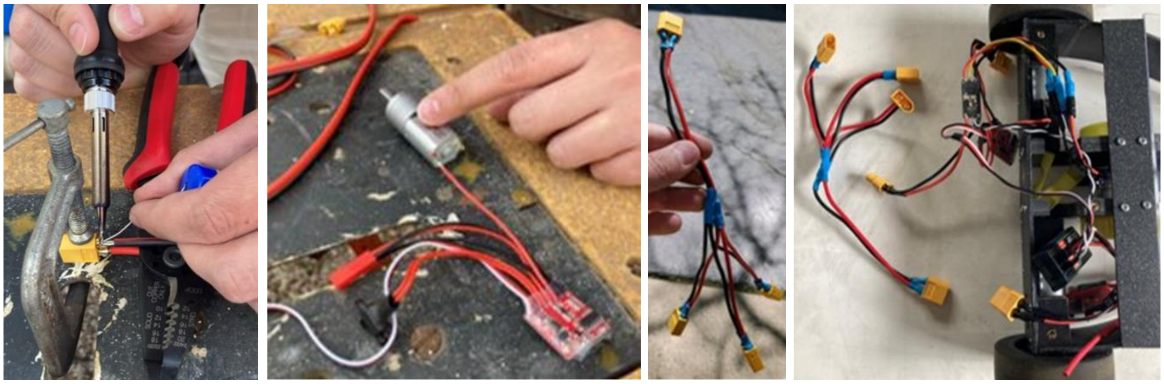


Figure 50: Soldering Electrical components

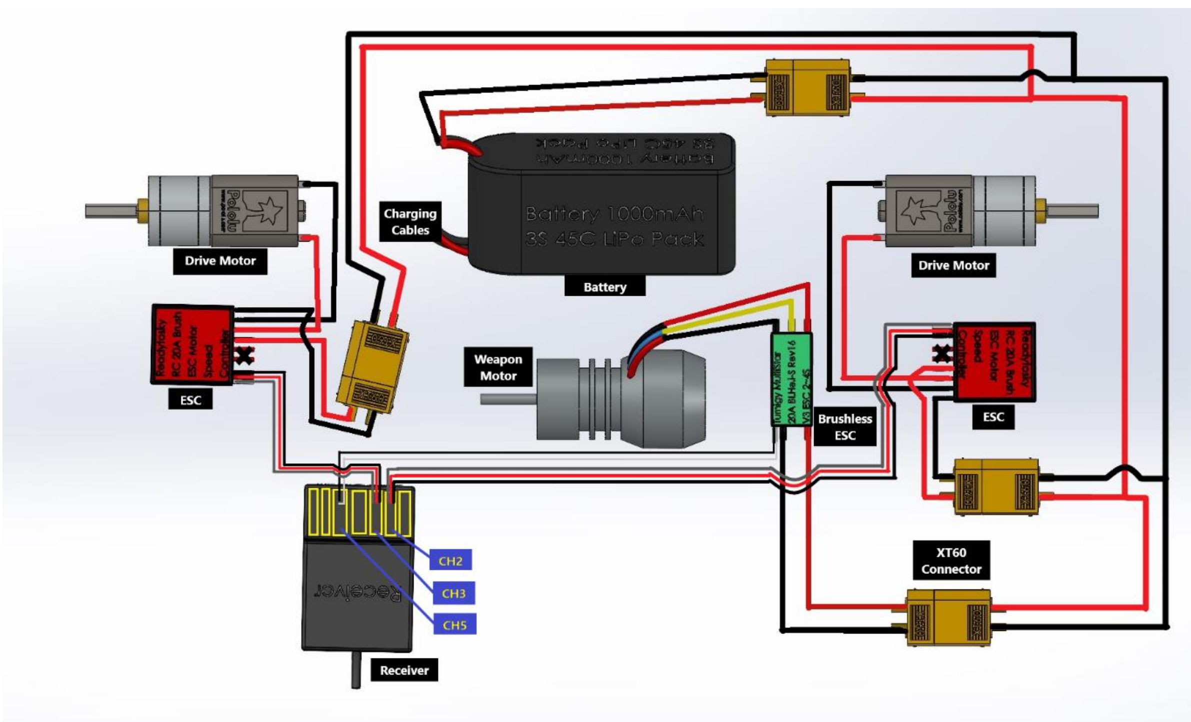


Figure 51: Actual Wiring Diagram

Assembly

Our Beetlebot was assembled with a mix of hardware (such as bolts, screws, and nuts) along with some adhesives. For most of the frame's assembly we first glued the pieces together and drill in hardware after the glue had set. The material was ruffed with sandpaper prior to gluing to insure a strong bond. The glue and clamps helped the material stay together while drilling in hardware.

One design iteration that was done here was with the curved side panels. The polyethylene did not want to hold a bend, so we opted to just attach them to the back of the bot and clamp them into position up by the ball caster. This gave the sides a curve rather than the designed bend. With the frame having changed shape slightly we outline the new shape of the bottom plate right on the polycarbonate sheet from the frame and cut it out.

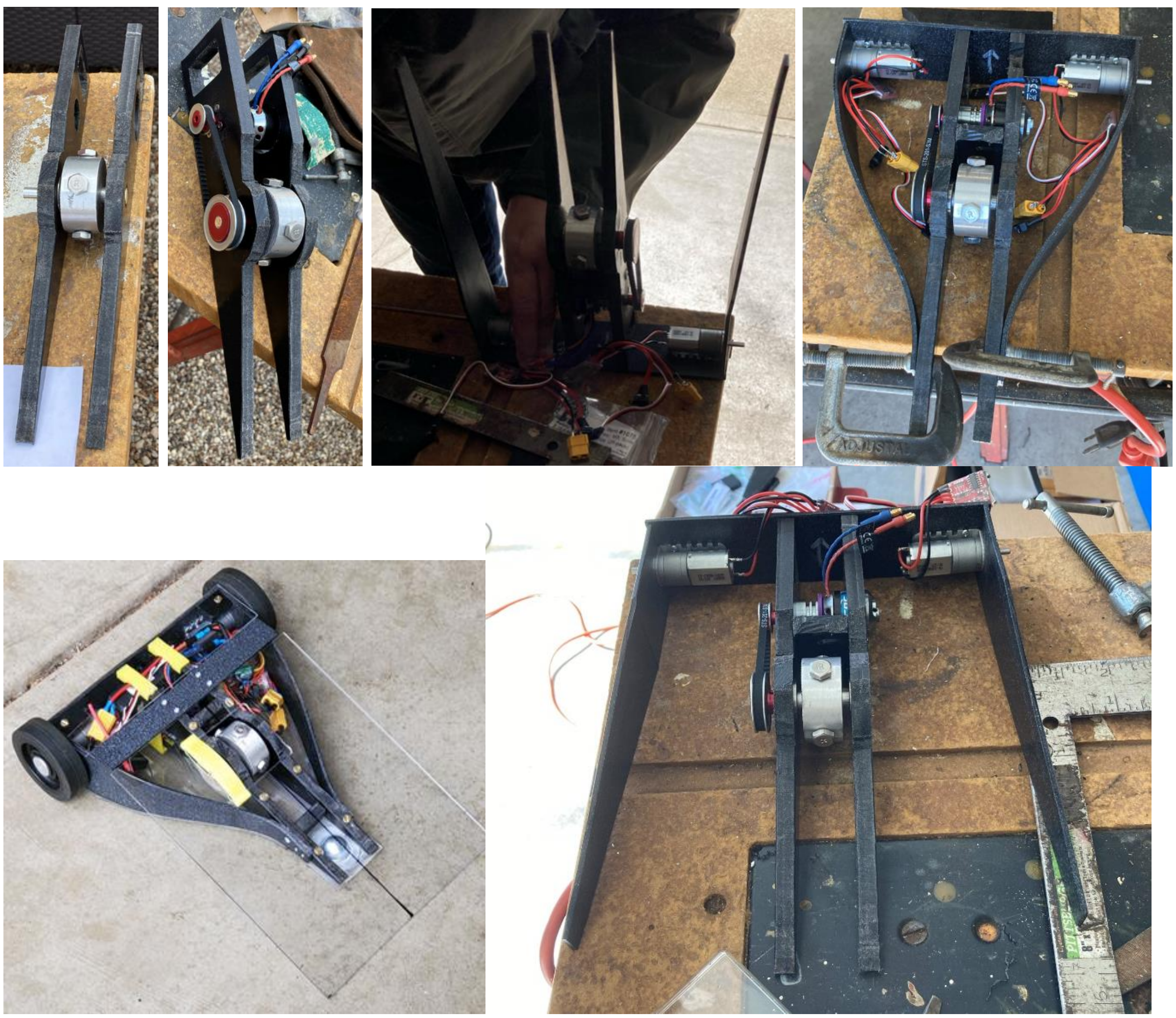


Figure 52: Beetlebot Assembly Stages

TEST PROCEDURE AND CRITERIA

The tests below will be conducted in the order they appear. These tests will take place at Victory Parkway campus and off campus. The tests that we decided to conduct on our battlebot were influenced heavily by the results of our Quality Function Deployment. The QFD allowed us to see what “customers” valued most in a battlebot. Depending on what features they found most important we compiled a list of testing we planned on completing.

Other than the testing listen below we had originally planned on doing a drop test of our frame and a test to determine whether or not our battlebot could flip itself over from the upside-down position to the right side up position. Due to time constraints coupled with the fact that we did not want to break our battlebot before the competition, we did not proceed with these tests. Overall, the tests we were unable to complete would have been somewhat unnecessary as nothing related to these tests took place in the competition.

Assemble and Test Electronics

Criteria: Transmitter functions as expected (drive controls & weapon spin up)
No loose connections or solder joints/ stay intact after some jostling/pulling

Verify that outputs respond to controls
Verify transmitter is functional

Complete Assembly

Criteria: Beetlebot is able to reach calculated speed
Weapon spin up time is as calculated
Weapon is able to deal damaging impact

Drive Test
Weapon spin up time
Weapon Impact Test

TEST RESULTS AND FINDINGS

Our initial testing took place at the beginning of April. For our test we plugged our battery into our electrical circuit and powered up all of our components for the first time. Initially we were unfamiliar with which channels on our receiver correlated with what controls but were eventually able to verify it through plug and play. Once this was complete, we were able to then test the outputs of our controller, verifying that moving the control sticks drove our beetlebots wheels and a dial drove our weapon. This verified both the transmitter and control's output.

The next set of testing was done about two weeks later. For these tests we tested to make sure our beetlebots drive functioned properly with a drive test. For this we simply drove the beetlebot around testing its ability to turn and move in different directions. We then tested the weapon's ability to spin up to full speed and its ability to cause damage. These took place in the UC Battlebot club's testing chamber, which doubled as the battle arena for our competition. We tested our weapon on spare pieces of material that the club had from previous builds. The pieces that we used were a mix of extruded plastic, 3D printed filament and sheet metal. Overall, our beetlebot did some noticeable damage, but nothing as extreme as we initially expected. We believe this was largely due to the fact that the "teeth" on our weapon were not very long and therefore struggled somewhat to get a grip on opponents. Due to these findings, we determined we would lie a little more heavily on the wedge aspect of our beettlebot and operate primarily as a defensive style beetlebot instead of offensive.

Finally, the competition hosted by the UC battlebots club was the final test. This did the best job of testing our project objectives which included armor hardness, armor and weapon yield strength, weapon fatigue strength, frame material yield strength, total weight, battery life, and torque to the weapon and wheels. These product objectives were determined through our QFD and are what we determined would be a good measure of what features our customers felt were the most important.

Our beetlebot stood up well to the others we faced in the competition. We were able to win our first battle against a vertical spinner, which we were most concerned about. Our armor did a great job of deflecting the opponents hits other than a small cut in the back of bot and a crack in one of our wheels, which remained functional. The second round is where we took the most damage. The beetlebot we faced used a saw blade, which shredded one of our tires and cut a hole in the side of our beetlebots frame. Luckily, the bot remained fully functional although we did swap out our extra wheels for the final "round robin" round. For the overall results of the competition, we came in second place, therefore we feel as though our beetlebot was a good solution to our defined problem statement.

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

At the end of Senior Design II, we had a total budget of $380.55. We were able to find a pair brushed ESCs on Amazon.com that were cheaper than just one of the DFRobot ones. We found a couple more cost saving component changes and were able to get the total cost down to about $360 by the start of SDIII. Some of the added costs to this was hardware that needed to be longer due to design changes. One of the late design iterations that was added was the inclusion of brass inserts. The inserts would better allow for removing the wedge and top polycarbonate pieces instead of screwing them directly to the frame material. The inserts their screws were an added cost. 16 gauge was also purchased late into fabrication because the club supplied wire was too large of gauge for our liking.

One of the components that we ended up not needing was the UBEC. It was originally going to step down the battery voltage to power the receiver. Since we were unexperienced on the wiring side of things, we had created the wiring diagram and reviewed with the club president. We later learned it was not needed because our specific ESCs provided power to the receiver.

Some of the used components were not counted towards the overall budget. The PETG 3D printed components were not counted as the 3D printer and material was already owned. The Krazy glue and some of the larger hardware was also not counted as it was just on hand. Solder was purchased to replace the solder we used in our borrowed soldering kit.

Item	Description	Used On	Dimensions [mm]	Vender	Qty	Price Per Unit [USD]	Total Price [USD]
Transmitter & Receiver	Turnigy T6A-V2 AFHDS Mode 2 2.4GHz 6Ch Transmitter w/Receiver	Electronics	L47.25 x W31.5 x H20 (Assumed)	https://hobbyking.com/en_us	1	$30.59	$30.59
Brushed ESCs	DFRobot 20A Bidirectional Brushed ESC Speed Controller (XT60 Connector)	Electronics	L42 x W28 x H15 (including heat sink)	https://www.robotshop.com/	2	$18.00	$36.00
Brushless ESC	Turnigy MultiStar 20A BLHeli-S Rev16 V3 ESC 2~4S (Opto)	Electronics	L27 x W12	https://hobbyking.com/en_us	1	$10.59	$10.59
LiPo Battery	Turnigy Graphene 1000mAh 3S 45C LiPo Pack w/XT60	Electronics	L76 x W35 x H22	https://hobbyking.com/en_us	2	$13.45	$26.90
UBEC	Turnigy HV SBEC 5A Switch Regulator (8-42V input)	Electronics	59 x 10 x 25	https://hobbyking.com/en_us	1	$9.84	$9.84
Drive Motors - Brushed Gear	63:1 Metal Gearmotor 20Dx43L mm 12V CB	Electronics	D20 x L44.7	https://www.pololu.com/	2	$21.95	$43.90
Motor Mount, L-Bracket, Pair, D20 mm	Pololu 20D mm Metal Gearmotor Bracket Pair	Electronics	H21.5 x L51.5 x W20 x 1.5 thick	https://www.pololu.com/	1	$6.95	$6.95
Mounting Hardware, Motor Mount	M3, Machine Screw	Hardware	M3 x L5	https://www.pololu.com/	1	$0.99	$0.99
Weapon Motor - Brushless	Turnigy 2815 EDF Outrunner 4000kv for 55/64mm	Electronics	L51 x D28	https://hobbyking.com/en_us	1	$13.69	$13.69
Mounting Hardware, Weapon Motor	316 Stainless Steel Hex Drive Flat Head Screw	Hardware	90 Degree Countersink, M2.5 x	https://www.mcmaster.com/	1	$3.91	$3.91
XT60 Connectors	Genuine XT60 Nylon Connectors Male/Female (5 pairs)	Electronics		https://hobbyking.com/en_us	1	$3.41	$3.41
LiPo Bag	Turnigy® Fire Retardant LiPoly Battery Bag (190x68x50mm) (1pc)	Electronics	190 x 64 x 50	https://hobbyking.com/en_us	0	$2.95	$0.00
Weapon Shaft Pulley ALT	FingerTech S3M Timing Pulley 30T No Hub	Weapons	bore with no hub, Width: 11.3mm (0.446")	https://www.fingertechrobotics.com/	0	$7.10	$0.00
Weapon Shaft Pulley	FingerTech S3M Timing Pulley	Weapons	30 Tooth	https://www.fingertechrobotics.com/	1	$5.89	$5.89
Motor Pulley	FingerTech S3M Timing Pulley	Weapons	15 Tooth	https://www.fingertechrobotics.com/	1	$4.51	$4.51
Belt, Timing	FingerTech S3M Timing Belt	Weapons	67 Tooth - 201 mm	.com/	1	$2.95	$2.95
Bearing	Ball Bearing, Shielded, Trade Number R6-2Z, for 3/8" Shaft Diameter	Weapons	ID 0.375", OD 0.875", W 0.281"	https://www.mcmaster.com/	2	$6.45	$12.90
Drum Material	7075 T6 Aluminum Round Bar	Weapons	OD 1.75" X L 0.75"	https://www.midweststeelsupply.com/	1	$10.53	$10.53
Weapon Studs	18-8 Stainless Steel Hex Head Screws (5 Pack)	Weapons	1/4"-20 Thread Size, 1/4" Long	https://www.mcmaster.com/	0	$7.01	$0.00
Weapon Studs/Set Screw	18-8 Stainless Steel Hex Head Screw (50 Pack)	Weapons	1/4"-20 Thread Size, 7/8" Long	https://www.mcmaster.com/	1	$4.41	$4.41
Weapon Shaft	7075 T6 Aluminum Round Bar 3/8	Weapons	OD 0.375" X L 12"	https://www.midweststeelsupply.com/	1	$7.52	$7.52
Key, Shaft to Weapon	1018-1045 Carbon Steel, L12"	Weapons	0.09375" X 0.09375" X L0.25"	https://www.mcmaster.com/	1	$1.24	$1.24
Wheels	BaneBots Wheel, 2-7/8" x 0.8", Hub Mount, 40A, Orange	Drivetrain	2.875" x 0.8"	http://www.banebots.com/	2	$2.45	$4.90
Wheels	BaneBots Wheel, 2-7/8" x 0.8", Hub Mount, 60A, Black	Drivetrain	2.875" x 0.8"	http://www.banebots.com/	2	$2.45	$4.90
Hubs, Wheels	T81 Hub, 4mm Shaft	Drivetrain		http://www.banebots.com/	2	$3.15	$6.30
Ball Caster	Recessed Flange-Mount Ball Transfer	Drivetrain	D21/32" x H27/32"	https://www.mcmaster.com/	1	$5.92	$5.92
Frame Material	UHMW Polyethylene Sheet 8" x 10" x 0.125"	Armor/Frame	L 10" X W 8" X 0.125"	https://www.fingertechrobotics.com/	1	$6.24	$6.24
Frame Material	UHMW Polyethylene Sheet 8" x 10" 0.375"	Armor/Frame	L 10" X W 8" X 0.375"	https://www.fingertechrobotics.com/	1	$12.13	$12.13
Armor Plate Material	Polycarbonate Sheet 1/8	Armor/Frame	L 8" X W 10" X 0.125"	https://www.fingertechrobotics.com/	1	$6.75	$6.75
Armor Plate Material	Polycarbonate Sheet 1/16	Armor/Frame	L 8" X W 10" X 0.0625"	https://www.fingertechrobotics.com/	1	$5.72	$5.72
Battery to Charger Adapter	T-Connector to XT60 Battery Adapter Lead (2pc)	Electronics		https://hobbyking.com/en_us	1	$3.27	$3.27
Shipping, Banebots				http://www.banebots.com/	1	$8.75	$8.75
Shipping, Finger Tech				https://www.fingertechrobotics.com/	1	$17.70	$17.70
Shipping, Robotshop				https://www.robotshop.com/	1	$2.99	$2.99
Shipping, Midwest Steel Supply				https://www.midweststeelsupply.com/	1	$10.00	$10.00
Shipping, Pololu				https://www.pololu.com/	1	$2.22	$2.22
Shipping, Mcmaster				https://www.mcmaster.com/	1	$5.99	$5.99
Shipping, Hobby King				https://hobbyking.com/en_us	1	$15.10	$15.10
						Total [USD]	$380.55

Table 9: Proposed Budget

1		School Year*	Team Name*	Total Cost	Out of Pocket	Budget	Uneeded
2		2021	Bradon L & Henry H	$399.94	$60.14	$340.00	$9.26
6	Description*	Qty.	Price Per Unit*	Total	Manufacture	Vender*	Sub Assem
7	Wheels - BaneBots Wheel, 2-7/8" x 0.8", Hub Mount, 40A, Orange	2	$3.50	$7.00	Banebots	Banebots	Drivetrain
8	Wheels - BaneBots Wheel, 2-7/8" x 0.8", Hub Mount, 60A, Black	2	$3.50	$7.00	Banebots	Banebots	Drivetrain
9	Hubs, Wheels - T81 Hub, 4mm Shaft	2	$4.50	$9.00	Banebots	Banebots	Drivetrain
10	Shipping, Banebots	1	$9.29	$9.29	Shipping	Banebots	Shipping
11	Weapon Shaft Pulley - FingerTech S3M Timing Pulley 30T	1	$6.07	$6.07	FingerTech	Fingertechrobotic	Weapon - Ne
12	Motor Pulley - FingerTech S3M Timing Pulley 15T	1	$4.64	$4.64	FingerTech	Fingertechrobotic	Weapon - Ne
13	Belt, Timing - FingerTech S3M Timing Belt 201mm (67T) (60)	1	$3.03	$3.03	FingerTech	Fingertechrobotic	Weapon - Ne
14	Frame Material - UHMW Polyethylene Sheet 8" x 10" x 0.125"	1	$6.43	$6.43	FingerTech	Fingertechrobotic	Armor/Frame
15	Frame Material - UHMW Polyethylene Sheet 8" x 10" 0.375"	1	$12.50	$12.50	FingerTech	Fingertechrobotic	Armor/Frame
16	Armor Plate Material - Polycarbonate Sheet 1/8	1	$6.96	$6.96	FingerTech	Fingertechrobotic	Armor/Frame
17	Armor Plate Material - Polycarbonate Sheet 1/16	1	$5.89	$5.89	FingerTech	Fingertechrobotic	Armor/Frame
18	Shipping, Finger Tech	1	$17.70	$17.70	Shipping	Fingertechrobotic	Shipping
19	Brushless ESC - Turnigy MultiStar 20A BLHeli-S Rev16 V3 ESC 2~4S (Opto)	1	$10.59	$10.59	Turnigy	Hobbyking	Electronics
20	LiPo Battery - Turnigy Graphene 1000mAh 3S 45C LiPo Pack w/XT60	2	$13.45	$26.90	Turnigy	Hobbyking	Electronics
21	LiPo Bag - Turnigy® Fire Retardant LiPoly Battery Bag (190x68x50mm) (1pc)	1	$2.95	$2.95	Turnigy	Hobbyking	Electronics
22	Battery to Charger Adapter - T-Connector to XT60 Battery Adapter Lead (2pc)	1	$3.27	$3.27	Hobbyking	Hobbyking	Electronics
23	Shipping, Hobby King	1	$15.10	$15.10	Shipping	Hobbyking	Shipping
24	Transmitter & Receiver - Turnigy T6A-V2 Mode 1 AFHDS 2.4GHz 6Ch Transmitter w/Receiver	1	$30.59	$30.59	Turnigy	Hobbyking	Electronics
25	XT60 Connectors - Genuine XT60 Nylon Connectors Male/Female (5 pairs)	1	$3.41	$3.41	Hobbyking	Hobbyking	Electronics
26	Weapon Motor - Brushless - Turnigy 2815 EDF Outrunner 4000kv for 55/64mm	1	$13.69	$13.69	Turnigy	Hobbyking	Electronics
27	Mounting Hardware, Weapon Motor - 316 Stainless Steel Hex Drive Flat Head Screw	1	$3.91	$3.91	Mcmaster	Mcmaster	Hardware
28	Bearing - Ball Bearing, Shielded, Trade Number R6-2Z, for 3/8" Shaft Diameter	2	$6.48	$12.96	Mcmaster	Mcmaster	Weapon
29	Weapon Studs - 18-8 Stainless Steel Hex Head Screws (5 Pack)	1	$7.01	$7.01	Mcmaster	Mcmaster	Weapon
30	Key, Shaft to Weapon - Zinc-Plated 1018-1045 Steel, 12" Long, 3/32" x 3/32"	1	$1.86	$1.86	Mcmaster	Mcmaster	Weapon
31	Ball Caster - Recessed Flange-Mount Ball Transfer - Steel Housing, 0.625" Diameter Steel Ball	1	$5.04	$5.04	Mcmaster	Mcmaster	Drivetrain
32	Self Tapping Screws - Phillips Rounded Head Thread-Forming Screws - for Plastic, 18-8 Stainless Steel, Number 0 Size, 3/8" Long	1	$12.69	$12.69	Mcmaster	Mcmaster	Hardware
33	Drive Motors - Brushed Gear - 63:1 Metal Gearmotor 20Dx43L mm 12V CB	2	$21.95	$43.90	Pololu	Pololu	Electronics
34	Motor Mount, L-Bracket, Pair, D20 mm - Pololu 20D mm Metal Gearmotor Bracket Pair	1	$6.95	$6.95	Pololu	Pololu	Electronics
35	Mounting Hardware, Motor Mount - M3, Machine Screw	1	$0.99	$0.99	Pololu	Pololu	Hardware
36	Shipping, Pololu	1	$2.22	$2.22	Shipping	Pololu	Shipping
37	UBEC - RMRC 5A Power Regulator 5-6V UBEC	1	$5.99	$5.99	RMRC	Racedayquads	Electronics
38	Shipping, RaceDayQuads	1	$3.56	$3.56	Shipping	Racedayquads	Shipping
39	Brush ESC - Readytosky RC 20A Brush ESC Motor Speed Controller w/Brake for RC Car Boat Tank(2PCS)	1	$14.99	$14.99	Readytosky	Amazon	Electronics
40	Weapon Shaft - High-Strength 7075 Aluminum Rod 3/8" Diameter, 24" Long	1	$8.66	$8.66	Mcmaster	Mcmaster	Weapon
41	Weapon Drum - High-Strength 7075 Aluminum Rod 1 3/4" Diameter, 6" Long	1	$27.46	$27.46	Mcmaster	Mcmaster	Weapon
42	Duracell - CopperTop AA Alkaline Batteries - 8 Count	1	$6.99	$6.99	Duracell	Amazon	Electronics
43	Brass Inserts 6-32 internal threads	4	$1.44	$5.75			Hardware
44	Brass Slotted Flat Head Screw 6-32 Thread Size, 1/2" Long	8	$0.29	$2.33			Hardware
45	M2.5 x 0.45 mm Thread, 12 mm Long	4	$0.38	$1.50			Hardware
46	16 Guage Wire	1	$0.00	$0.50			Electronics

Table 10: Actual Budget

SCHEDULE, PROPOSED /ACTUAL

The proposed schedule was created near the end of Senior Design II, so the actual schedule only depicts the schedule of Senior Design III. The delays for the actual schedule were comprised of mainly communication issues. We waited until after our first meeting (01/21/2021) with professor Dong to start ordering parts. We submitted the majority of our purchase requests the next day. Some of them the school took care of and order, but there were multiple orders that the school couldn’t place, and we were required to do a RSO for them.

Fabrication and assembly were delayed due to our weapon shaft order being misplaced. We were waiting to receive the drum and shaft material before we went to VPC to begin machining. The shaft was addressed incorrectly and delivered to the Automotive Club. The shaft was thought to be found but we were given the wrong material. The correct shaft was finally located, and we swapped it with the incorrect material. Once we had both materials, we went to VPC on the first day we were both available.

The issue with receiving all of our parts were a credit card issue. The original order of wheels and hubs from Banebots was canceled due to issues with UC’s payment method. The problem with that was it was never communicated to us and the Banebots person was very hard to get a hold of. Mr. Banebots eventually called us back and told us what had happened to our original order. We then re-ordered the wheels and hubs and finally received them on 04/08/2021.

With us undertaking all the fabrication ourselves, it took a lot longer than originally anticipated. One reason fabrication took longer was we were making duplicates of our components since the material had to be ordered in larger then needed quantities. Soldering of the electrical components was a real learning experience since neither of us had any real experience. There was some guidance needed at a club meeting to help complete the wiring.

Testing wasn’t started until we completed the electrical system, so that was delayed until we finished the fabrication and assembly. Testing I was just for the electrical system and checking control layout. A second round of testing was for the actual running of the beetlebot as a whole. We didn’t assemble the wheel components until the week of the tech expo and competition, so we ran out of time for any design revisions, although we didn’t really learn of any changes to be made until after the competition. We did have a design revision at the beginning of SDIII though and we made some design iterations and additions as we went assembling the beetlebot.

The rest of the delays were out of our hands as they were the competition date and presentation dates.

Proposed Schedule **Beetlebot - Wedge/Horizontal Drum**		*2020*					*2021*			
		August	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**
Senior Design I	Problem Statement	08/16/2020								
	Final Research		09/18/2020							
	Quality Function Deployment			10/01/2020						
Senior Design II	Final Concept Selection				11/02/2020					
	Bugdet Proposal Review				11/21/2020					
	Presentations (Proposal & Design Info)					12/01/2020				
	Final Part Selection					12/08/2020				
	Finalized Design					12/08/2020				
Senior Design III	Part Ordering						01/11/2020			
	Fabrication & Assembly						01/25/2020			
	Testing I							02/17/2020		
	Design Revisions							02/28/2020		
	Testing II								03/15/2020	
	Tech Expo									04/01/2020
	Internal Competition									04/15/2020
	Final Report									04/21/2020

Table 11: Proposed Schedule

Actual Schedule **Beetlebot - Wedge/Horizontal Drum**		*2021*			
		January	**February**	**March**	**April**
Senior Design III	Part Ordered	01/23/2021	← **+12 days**		
	Fabrication & Assembly	**+30 days** →	02/24/2021	→	04/12/2021
	All Parts Delevired				04/08/2021
	Testing I			**+44 days** →	04/02/2021
	Design Revisions				N/A
	Testing II			**+28 days** →	04/12/2021
	Tech Expo Round I			**-1 days** →	04/14/2021
	Tech Expo Round II				04/15/2021
	Internal Competition			**+2 days** →	04/17/2021
	Final Presentation			**-2 days** →	04/19/2021
	Final Report				04/25/2021

Table 12: Actual Schedule

SUSTAINABILITY AND MATERIAL USAGE

Sustainability and Material usage was not a concern or consideration for this project. As far as using material more efficiently, this could have been accomplished with more communication between the other beetlebot teams. There could have been some connectors, wiring, and other components bought together to save some money. Communication would have been easier if we had all been taking classes in person. Also having some prior build knowledge would have helped select various components as a group, as this was most of the teams' first build.

CONCLUSIONS

Our beetlebot was a success and we were able to accomplish most of what we set out to do in our problem statement. Although we started out to design a 15 lb battlebot, the switch to the beetlebot weight was early enough where it didn't affect any designs. We designed, fabricated, and piloted our beetlebot to great success during the competition. Our final weight was well within the 1.5 kg limits (1.3 kg), it was completed on time and we had only external damage done to our beetlebot during the competition. Total cost was higher than our allotted budget, but our total cost of $400 was the lowest out of all four groups. Although we did not win the competition, our beetlebot was the only one that was still functioning as designed by the end.

The research gathered helped us narrow down the type of battlebot that we were going to design and informed us of the inherent tradeoffs between each design. Looking at previous years of battlebots designed by UC seniors was helpful in some ways even though we were designing a beetlebot. Not only were we able to see the design of the various systems, but the senior design reports were a great look into the whole build process. The research into beetlebots was more directly helpful as their design featured components and ideas that were specific to the weight limitations. These designs had less information compared to reading through a whole senior design report, but we located a couple breakdown videos and instructional vlogs that helped us get started with component and material selection. We compared the pros and cons of each of the battlebots we researched and selected from them to focus on for state of the art for each system.

The current state of the art examples we selected definitely informed part of our design. The wedge and weapon combination that appeared on some of them spoke to us. Since the competition arena we were to fight in had no traps or pits our main focus was doing direct damage to opponents. Having a wedge that forces opponents into a weapon was the idea we stuck with and elaborated on.

From the survey responses the customer features were gathered, and the engineering characteristics were developed from them. We met most of our project objectives that were determined from the HoQ. The top four criteria of the armor and weapon properties were met with their material selection of polycarbonate and 7075-T6 Al. Our wheel diameter was incorporated into our design very well as there were centered vertically on the frame and lined up perfectly with our selected ball caster and the downward angle of the frame was designed to allow the full sheet of the wedge material to skim the same plane as the wheels. The total weight was not exceeded. All the components had plenty of room within our beetlebot. Our battery also performed great and was able to provide plenty of juice for the duration of the matches (three minutes). The torque to the wheels and weapon was one area that we would improve in. After the competition we learned that increased torque for the drive motors would have helped forcing lower profile bots up onto the ramp. Our weapons damaging ability would have also benefited from a better motor. The torques were towards the bottom of the list with less importance weighted to them, so our beetlebot successfully met 10/12 of the objectives.

Building the beetlebot was completed slower than we would have liked, but the results were still satisfactory. We choose to undertake the fabrication process ourselves utilizing the machines at VPC. We wanted to do the work ourselves and not just hand over our components to 1819 to be made for us. This was a lengthy process since we were both only able to fit two nights a week into our schedule. Both Nicholas Plataniotis & Brian Yockey were a great help at refreshing us on the machines and providing advice on processes such as cutting the keyway into the weapon drum. We machined multiple of weapon components successfully and machined the more complex frame pieces there.

The electrical system was the most challenging for us since we were inexperienced with soldering. Kyle Pecenko graciously lent us his soldering kit, so we could do it on our own time and not just at the club meetings. It was slow going at first trying to solder improperly with an oxidized tip but with practice, youtube videos, and some advice from Chase Pownell (Battlebot Club President) we were successful in soldering all needed electrical components.

Testing was negatively affected by the lengthy build process as we finished on 12th of April, the Tech Expo started on the 14th and the competition was held on the 17th. With only a few days to test and create a tech expo video, we limited our testing to only the essentials. If we had been able to complete the build earlier, we would have done more in-depth testing and possibly a design revision if needed. We were already $60 out of our pockets at this point so we probably wouldn't have made any major changes.

Our teams project management was overall good. We only went $60 over budget which is the least amount of all four teams. There were a couple components that we ended up not needing but that only accounted for about $9. Not counting the unneeded items our total budget would have been $390 which would have been better than our real total of $400. The shipping and receiving of some of the components led to delays in our building process and ideally, we would have ordered parts at the end of SDII. We would also suggest just ordering the components yourself and let UC repay via RSOs. Even though you will not get reimbursed for the tax it would ensure that you oversee the shipping and receiving and not have packages get misplaced. Although you can save some money by letting UC order components at McMaster-Carr because they don't have to pay shipping. Ordering components earlier and by ourselves would have better helped us stick to our proposed schedule. Although we completed our build fairly close to the competition, we were still happy with our final result and didn't have a whole lot to troubleshoot.

This being our first build and our team only comprised of only two people, compared to two other groups of three and one group of four, we consider our beetlebot highly successful. During the competition, our beetlebot only suffered exterior damage. All of our wiring and internal components remained together and functional throughout the competition. Other opponents suffered from damaged wiring rendering their systems nonfunctional. The only component that we replaced between matches was our wheels because they had been cut up by a horizontal saw blade. They were still plenty functional, but we had another set. Our beetlebot was still fully functional by the end of the competition.

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APPENDIX A: SURVEY

Survey

BattleBot Beetle Weight (1.5kg) 1st Build Recommendations

There is a total of 28 Questions (6 Sections). We very much appreciate your time and thank you for your submission. Our team is creating a 1.5 kg battlebot (beetle weight) to compete 1V1 in a 5'X5' arena. This survey is to gather customer data for our project and to create a Quality Function Deployment. This will be our first build and have minimal prior knowledge of 1.5 kg designs. Any suggestions of other 1.5 kg bots that we should study are very welcomed as well as any other general recommendations you may have (last questions).

Skip to question 1Skip to question 1

General Build

1. Offense Focused

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

2. Defense Focused

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

3. Low Profile (close to ground to prevent other bots from getting under)

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

4. Maneuverability

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

5. Durability

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

6. Components are easily replaceable

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

Maneuverability

7. Small Turning Radius

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

8. Speed

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

9. Overall Size

Mark only one oval.

	1	2	3	4	5	6	7	
Small	◯	◯	◯	◯	◯	◯	◯	Large

10. Number of Wheels

Mark only one oval.

1	2	3	4	5	6
◯	◯	◯	◯	◯	◯

Offensive

11. Modular Weapon

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

12. Direct Damaging Weapon

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

13. In-Direct Damaging Weapon (i.e. hitting bot into air and impacting the arena)

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

14. Large Range of Attack

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very Important

15. Fast weapon start-up

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very Important

16. Ramp-like armor/frame (to get under other bots)

Check all that apply.

- [ ] Front
- [ ] Rear
- [ ] Sides

Defensive

17. Frame

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very Important

18. Armor

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very Important

19. Symmetrical (Operational when inverted, flipped)

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

20. Protected Wheels

Mark only one oval.

	1	2	3	4	5	6	7	
Least Important	◯	◯	◯	◯	◯	◯	◯	Very Important

Comparative Questions:
K2

Using Bugglebots 2-year consecutive champion, K2, as a top tier battlebot, please rate the following:
Please watch for info on K2 -> Bugglebot 2019 Final Heat:
https://www.youtube.com/watch?time_continue=1&v=gKFeolPdzo4&feature=emb_logo

21. Weapon system

Mark only one oval.

	1	2	3	4	5	6	7	
Weak	◯	◯	◯	◯	◯	◯	◯	Perfect

22. Defensive system

Mark only one oval.

	1	2	3	4	5	6	7	
Weak	○	○	○	○	○	○	○	Perfect

23. Maneuverability

Mark only one oval.

	1	2	3	4	5	6	7	
Weak	○	○	○	○	○	○	○	Perfect

24. Overall Size

Mark only one oval.

	1	2	3	4	5	6	7	
Weak	○	○	○	○	○	○	○	Perfect

25. Drivetrain Reliability

Mark only one oval.

	1	2	3	4	5	6	7	
Weak	○	○	○	○	○	○	○	Perfect

26. Weapon Reliability

Mark only one oval.

	1	2	3	4	5	6	7	
Weak	○	○	○	○	○	○	○	Perfect

27. What is the best or your favorite 1.5 kg beetle battlebot build type or specific name:

28. Any other feedback, suggestions, or helpful links. Thank you for your time.

BattleBot Beetle Weight (1.5kg) 1st Build Recommendations

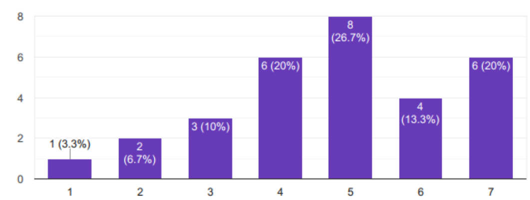
30 responses

Publish analytics

General Build

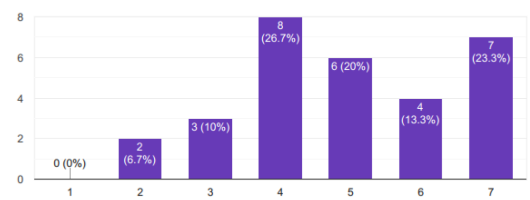
Offense Focused

30 responses



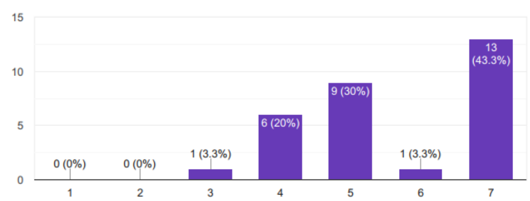
Defense Focused

30 responses



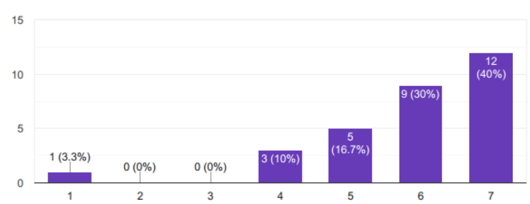
Low Profile (close to ground to prevent other bots from getting under)

30 responses



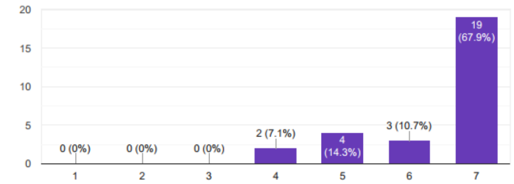
Maneuverability

30 responses



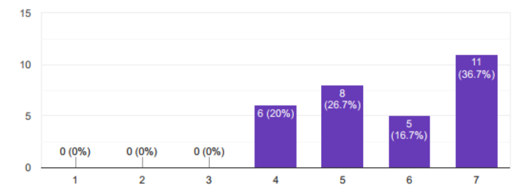
Durability

28 responses



Components are easily replaceable

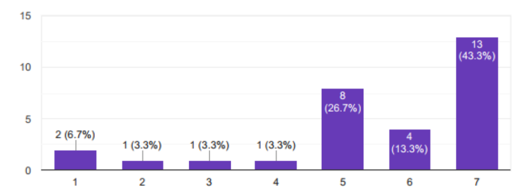
30 responses



Maneuverability

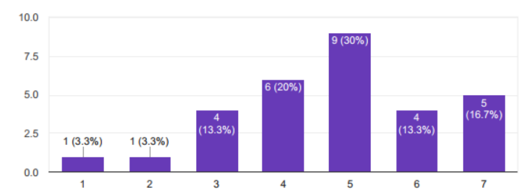
Small Turning Radius

30 responses



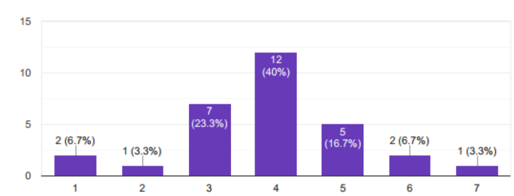
Speed

30 responses



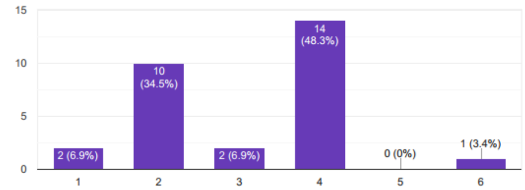
Overall Size

30 responses



Number of Wheels

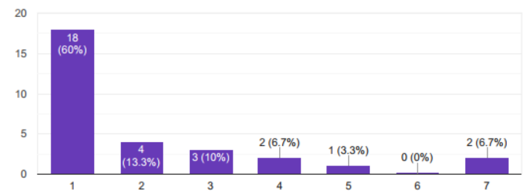
29 responses



Offensive

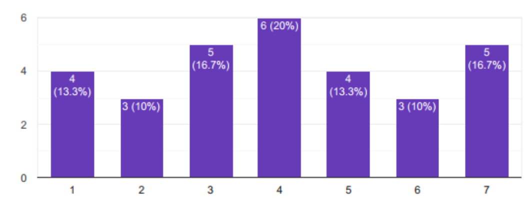
Modular Weapon

30 responses



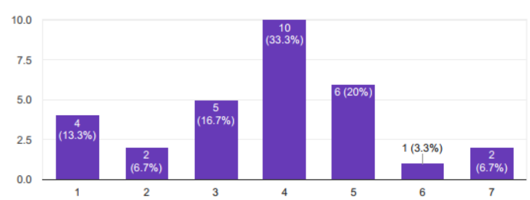
Direct Damaging Weapon

30 responses



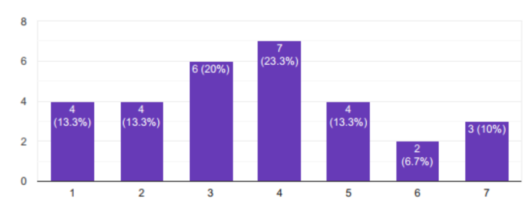
In-Direct Damaging Weapon (i.e. hitting bot into air and impacting the arena)

30 responses



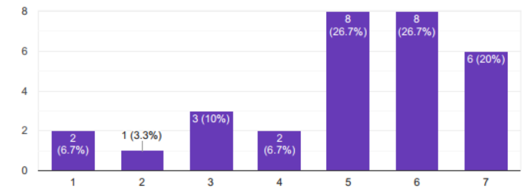
Large Range of Attack

30 responses



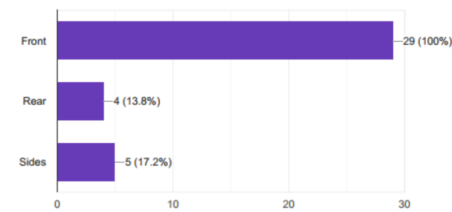
Fast weapon start-up

30 responses



Ramp-like armor/frame (to get under other bots)

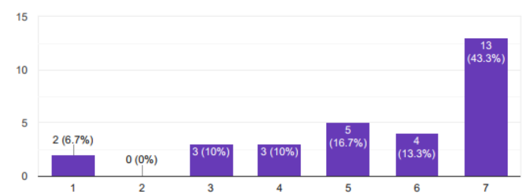
29 responses



Defensive

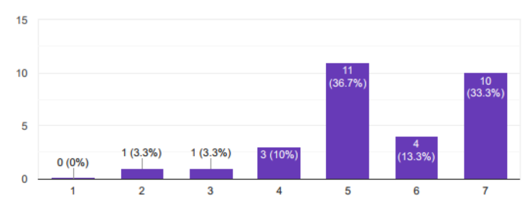
Frame

30 responses



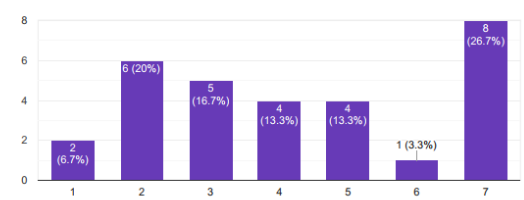
Armor

30 responses



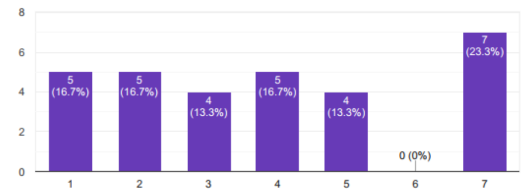
Symmetrical (Operational when inverted, flipped)

30 responses



Protected Wheels

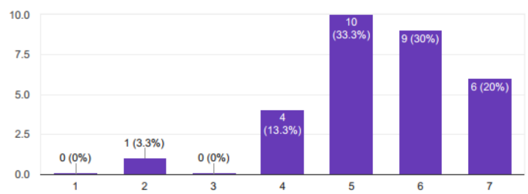
30 responses



Comparative Questions: K2

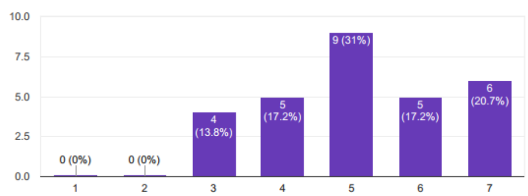
Weapon system

30 responses



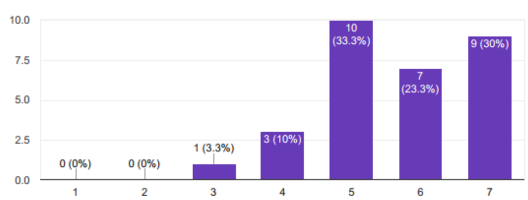
Defensive system

29 responses



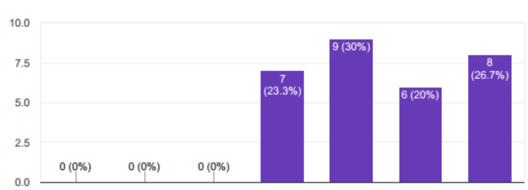
Maneuverability

30 responses



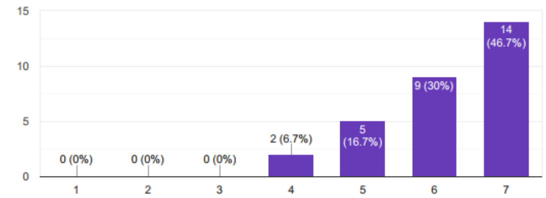
Overall Size

30 responses



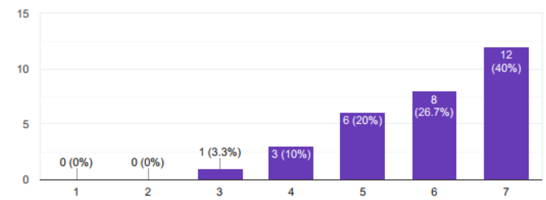
Drivetrain Reliability

30 responses



Weapon Reliability

30 responses



What is the best or your favorite 1.5 kg beetle battlebot build type or specific name:

19 responses

Portable Apocalypse or Tiny Huge

rev 4

"Low Low Man" (Robert Cowan) https://duckduckgo.com/?q=%22Low+Low+Man%22+(Robert+Cowan)&t=chrome&ia=web

Let the good times roll (drum spinner) and wajoo (shell/full body spinner)

Spinner

Favourite (not best) is 100% offensive. What is armour? I'm using 1-3mm of HDPE mainly with 2 5mm thick sections. It is dumb but entertaining.

Lifter/clamper e.g Grab Crab

Some of the best beetles are powerful wedges, D2 kits. Most other weapon types will work fine, though.

Any other feedback, suggestions, or helpful links. Thank you for your time.

10 responses

Watch events to get ideas and inspiration! I would reccomend the beetlweight Euros 2019, battle of the burgh and SXS.

Generally it is best to do a weaponless wedge type first but go for it if you want to go straight into the deep end! Also note that the American beetleweights aren't 1.5kg I think, but 1.36kg or 3 pounds.

One thing to keep in mind is that the answer to some of the questions here can vary depending on the design you go with. A flipper might not need to run upside down because it's weapon only works right-side up, so it is best to build it to allow itself to flip back over. A vertical spinner, like biteforce, would want the ability to run upside down and it could use its weapon to flip itself back over.

for a first time build keep it simple and with in the ability of you and your team

Many of the questions that you asked were very subjective. For example you could have a competitive robot that focuses on any of the topics listed in the first section. Overall it is Important to put more your weight into whatever you want to prioritize for your design. Also turning radius is not a factor as basically everything does and should

APPENDIX B: FRA BUILD RULES

FRA

FIGHTING ROBOTS ASSOCIATION

Build Rules

International Build Rules and Regulations

2018 Edition

Latest Version

The most up to date revision of this document can always be found at:
http://www.fightingrobots.co.uk/

Copyright

1. General

1.1 Participation
All participants build and operate Robots at their own risk. Fighting Robots is inherently dangerous. There is no amount of regulation that can encompass all of the dangers involved. Please take care to not hurt yourself or others when building, testing and competing. Compliance with all event rules and competition regulations is mandatory. It is expected that competitors stay within the rules and procedures of their own accord and do not require constant policing.

1.2 Loopholes
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 the Fighting Robots Association. 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 Safety Inspections
Each event has safety inspections known as Tech checks. It is at the inspector's 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.

1.4 Activation
Robots must only be activated in the arena, testing areas, or with expressed consent of the event organiser and the safety officials. All activation and de-activation of robots must be completed from outside the arena barrier or within specially designated areas. You must never enter the arena with live robots without the express permission and supervision of the event organiser.

1.5 Safety Covers
All Robots not in an arena or official testing area must have secure safety covers over any sharp edges and pinch hazards. Safety covers must be designed in such a way that they cannot be dislodged unintentionally.

1.6 Locking Bars
All weapons must be secured using a locking bar. The locking bar must be designed in such a way that it can quickly and easily be installed or removed without touching the weapon. The design must ensure that the weapon cannot be fired during the activation process.

1.7 Tethers
All high-speed weaponry with a single linkage, such as axes and flippers, must carry a suitable tether to ensure moving parts cannot break free from the chassis during operation.

1.8 Carrying Cradles
All robots not in an arena or official testing area must be raised on their carrying cradles in a manner so that their motive power cannot cause movement if the robot were turned on, or cannot roll or fall off a pit table. Runaway robots are VERY dangerous.

1.9 Restrictions
In some situations, the safety inspection team may deem it necessary to place restrictions on your robots operation for safety purposes. It is entirely your responsibility that these restrictions are adhered to at all times.

1.10 Power Tools
It is expected that builders will follow all basic safety practices such as gloves and goggles when operating any machinery. The use of welders, grinders and other equipment that may produce smoke, debris or other harmful substances is only permitted in dedicated workshop areas. Please take care of yourself and others around you.

2. Weight Classes

2.1 Weight Classification

- Antweight: Maximum 150g
- Beetleweight: Maximum 1.5kgs
- Featherweight: Maximum 13.6kgs
- Lightweight: Maximum 30kgs
- Middleweight: Maximum 55kgs
- Heavyweight: Maximum 110kgs

2.2 Legged Robots
Legged Robots or "Walkers" can weigh up to twice the specified weight in all classes. A walker must employ moveable legs to support its weight. Each leg must have at least 2 degrees of freedom. Robots with rolling or sliding mechanisms will not be classified as walkers.

2.3 Consumables
Maximum weight includes all consumables.

2.4 Safety Equipment
Maximum weight does not include safety covers or locking bars that are removed when the robot is activated.

2.5 Interchangeable Panels
If interchangeable panels or weapons are used, the weight is measured with the heaviest set-up in place.

3. Mobility

3.1 Methods
All Robots must have (easily visible mobility) in order to compete. Methods of mobility include:

3.1.1 Rolling
Rolling on wheels or the whole robot rolling.

3.1.2 Walking
Walking such as linear actuator operated legs.

3.1.3 Shuffling
Shuffling mechanisms such as rotational cam operated legs.

3.1.4 Ground Effect
Ground effect air cushions such as a hovercraft

3.1.5 Jumping
Jumping and hopping (although the height may be limited by each event due to arena safety constraints)

3.1.6 Flying
Flying (helium balloons, multirotors, etc.) (Currently flying robots are not allowed unless prior approval by the event has been granted.)

3.2 Restrictions
Event organisers may impose additional restrictions on robots for the safety of the event.

4. Radio control requirements

4.1 Frequencies

4.1.1 Permission
Transmitters must not be turned on at, or near events for any purpose without obtaining explicit permission from the event organiser.

4.1.2 Regulation
Radio systems used at events MUST comply with restrictions put in place by local regulatory bodies and applicable laws. For the UK this is OFCOM. Where a special licence is required for operation of radio equipment the event organiser must be informed and the license must be available for viewing at the event.

4.1.3 Interference
Radio systems MUST NOT cause interference to other frequency users.

4.1.4 Digital Spread Spectrum
Commercial Digital Spread Spectrum 2.4GHz is recommended for combat robotics in all weight classes.

4.1.5 Allowed Frequencies
For use in robots, the following frequencies are allowed:

	AW	BW	FW	LW	MW	HW
IR	✓	✓	X	X	X	X
27/40MHz AM/FM	✓	✓	X	X	X	X
40MHz FM Digital	✓	✓	✓	✓	✓	X
2.4GHz DSS	✓	✓	✓	✓	✓	✓
459MHz Digital	✓	✓	✓	✓	✓	✓

Please note that events may have additional restrictions on allowable frequencies.

Symbols:

✓ = Allowed Frequency
X = Disallowed frequency
AW = Antweight
BW = Beetleweight
FW = Featherweight
LW = Lightweight
MW = Middleweight
HW = Heavyweight

IR = Infra-Red remote control systems – For use with Antweights Only
27/ 40MHz AM/FM = PPM radio systems e.g. Futaba Skysports 4
40MHz FM Digital = 40MHzPCM radio systems e.g. Futaba Fieldforce 6
2.4GHz DSS = Digital Spread Spectrum radio systems e.g. Spektrum DX6
459MHz Digital = Radio systems using 459MHz Modules

4.1.6 Special Exceptions
Use of disallowed frequencies may be permitted in limited circumstances for example if running an armoured radio control car or for older machines providing safe control can be demonstrated. This will be limited to non-competition fights.

4.2 Failsafes

4.2.1 Dangerous Systems
All systems that are deemed to be 'dangerous' (normally the drive and weapons) must have a 'failsafe' device. This MUST bring the systems to a pre-set 'off' or 'zero' position if the transmitter signal experiences interference or is lost. These devices must failsafe when the receiver battery is low or if power is completely lost.

4.2.2 Types of Devices
The failsafe(s) may take the form of plug-in commercial devices; electronic circuitry incorporated into receivers, or other devices. It may also consist of digital switches, which return to pre-set off position on loss of power. Care must be taken in the selection of devices to ensure they meet the requirements specified above.

4.2.3 Built-in Devices
Some receiver failsafes such as PCM do not store the pre-set positions and will take a few seconds from first turning on to receive these settings from the transmitter. This type of failsafe MUST be set correctly to ensure the safe operation of the robot and are strongly discouraged.

4.2.4 Setting Failsafes
Care must be taken to ensure that the failsafe(s) are set correctly.
Particular attention must be taken with programmable failsafe(s) that may be overlooked when transferring receivers between robots or when altering the trim (zero position) on sticks that may affect the 'off' or 'zero' position. With newer receivers it may be necessary to 'bind' your receiver to program the pre-set failsafe positions.

4.2.5 Servo Control
Care must be taken when using servo/ pot/ micro-switch interfaces, as these will remain in their last position with loss of power leaving the weapon active. Additional precautions must be taken when these interfaces are in use.

4.3 Failsafe Light (Advisory)
In addition to the main power light a separate light may also indicate if the robot is in "failsafe", "off" or "zero" position.

4.4 Remote Kill (Advisory)
Robots may incorporate a "remote kill" that brings the robot's failsafe device(s) to the pre-set 'off' or 'zero' position via a switch on the transmitter. This is to allow for de-activation of robots from outside a fully enclosed arena and prevent accidental operation of controls.

4.5 Operation
All device(s) MUST operate to the tech checker's satisfaction before the robot will be allowed to compete.

4.6 Crystals
Where used, spare crystal pairs must be available for each Radio Control set involved in running the robot.

4.7 Changeable Frequencies
Frequencies must be easily changeable e.g. where crystals are used they must be accessible, particularly on the receiver, so that a change of frequency can easily take place.

4.8 Output Power
Transmitter output power must not exceed that specified by the local regulatory body or any applicable laws.

4.9 Home Built
If you are using a home built remote control system, you must first clear it with the event organiser and declare it during 'Tech Check'. Home built remote control systems are not recommended.

4.10 Power Switch
Radio equipment may be operated independently of the removable link, providing that no dangerous systems can be operated with the link removed.

4.11 Reserved Frequencies
The event may have reserved frequencies for testing, safety and arena effects that you may not use.

4.12 Telemetry
Radio telemetry is permitted on 433MHz and 2.4GHz. Please check with the event organiser if you are using radio telemetry.

5. Autonomous/ Semi-Autonomous Robots

Robots that do not require human input for one or more of their functions.

If you are bringing an autonomous robot or a robot with significant autonomous functions please contact your event organiser in advance.

5.1 Remote Operation
Any autonomous function of a robot, including drive and weapons, must have the capability of being remotely armed and disarmed.

5.2 Disarming
While disarmed, the robot is not allowed to function in an autonomous fashion.

5.3 Light
In addition to the required main power light, robots with autonomous functions must have an additional clearly visible light, which indicates whether or not it is in autonomous mode.

5.4 Deactivation
When deactivated 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.

5.5 Timeout
In case of damage to components that remotely disarm the robot, the robot will automatically deactivate 4 minutes after being activated.

6. Electrical Power

6.1 Deactivation
Robots must incorporate a way of removing all power to weapons and drive systems (systems that could cause potential human bodily injury) that can be operated easily without endangering the person turning it off.

6.1.1 Removable Link
The main power cut-off MUST be an insulated, removable link, which must NOT be in place unless the robot is in the arena or under the supervision of a technician. The link must be removable without the use of tools. A key or switch is not allowed.

6.1.2 Accessibility
The link must be positioned in a visible part of the robot's bodywork, fitted away from any operating weaponry or drive, and this position must be clearly marked.

6.1.3 Covers
The link may be fitted under a cover, but the cover must be able to be opened without the use of tools.

6.1.4 Kill Switch
If the robot uses an internal combustion engine(s), the "Power" cut-off must take the form of a clearly labelled "Kill" switch. See Section 7 for further details on engines.

6.1.5 Inverted Link
Robots in the heavyweight class that are capable of being driven inverted, having a removable link fitted that is only accessible when the robot is the right way up, must have a duplicate link fitted in the opposing panel, so as to allow the robot to be disarmed when inverted.

6.2 Cabling
Cabling must be of sufficient grade and suitably insulated for maximum operational voltage and current.

6.3 Exposed Components
Current must not be carried through exposed components.

6.4 Power Light
Robots must have at least one surface mounted non-filament power light that is illuminated when the main link is fitted. The power light may be any colour but must be non-flashing and in contrast with the surroundings.

6.5 Activation
The robot must be capable of being activated and de-activated by way of the removable link from outside an arena. (e.g. in a “bullpen” over a low wall).

6.6 Voltages
Voltage must not exceed 75V for direct current or 50V for alternating current except where prior approval from the event organisers has been confirmed. Note that batteries may have a higher voltage during charging and care must be taken not to exceed these limits.

7. Batteries

For assistance in selecting batteries please contact the Fighting Robots Association.

7.1 Protection
Batteries must be adequately protected within the body shell and securely fixed to minimise the chance of being punctured or coming loose during combat. In addition, packing such as high density foam is recommended to reduce the shock of impacts.

7.2 Terminals
Battery terminals must be protected to prevent short circuits.

7.3 Permitted Types
The only permitted batteries are ones that cannot spill or spray any of their contents when inverted. Standard car and motorcycle wet cell batteries are prohibited.

7.4 Approved Battery Chemistry

	AW	BW	FW	LW	MW	HW
NiCd (Nickel-cadmium)	✓	✓	✓	✓	✓	✓
NiMH (Nickel-metal Hydride)	✓	✓	✓	✓	✓	✓
Pb (Sealed Lead Acid)	✓	✓	✓	✓	✓	✓
LiFePo4 (Lithium Iron Phosphate)	✓	✓	✓	✓	✓	✓
LiPo (Lithium Polymer)	✓	✓	✓	✓	✓	✓

7.5 Maximum Cell Count (series) and voltage

	Number of Cells (series)	Vnom	Vmin	Vmax	Vtotal
NiCd (Nickel-cadmium)	30	1.2v	0.9v	1.9v	36v
NiMH (Nickel-metal Hydride)	30	1.2v	0.9v	1.9v	36v
Pb (Sealed Lead Acid)	18	2.0v	1.5v	2.4v	36v
LiFePo4 (Lithium Iron Phosphate)	12	3.3v	2.8v	3.6v	39.6v
LiPo (Lithium Polymer)	12	3.7v	3.0v	4.2v	44.4v

Vnom – Nominal cell voltage during discharge
Vmin – Minimum cell voltage
Vmax – Peek cell voltage during charging
Vtotal – Nominal pack voltage during discharge

These values are taken as an approximation. Always check the manufacturers specification.

7.6 Parallel Cells
Batteries cells may be connected in parallel to increase capacity and discharge current. Caution must be taken with NiCd and NiMH as these cells may only be connected in parallel during discharge.

7.7 Charging
Improper charging may result in fire and/ or explosion.

7.7.1 Design
Only chargers specifically designed for the battery chemistry may be used. Chargers will be inspected during the Tech Check to ensure correct operation.

7.7.2 Rate of Charge
The rate of charge must not exceed the manufacturer's specification. Note that high charge rates will decrease battery life and performance.

7.8 Pb (SLA), NiCd, NiMH and LiFePo4
The following battery types can be used without any specific precautions although care must be taken when any battery particularly during charging:

- Pb (Sealed Lead Acid, SLA), non-spillable gel type.
- NiCd and NiMH
- LiFePo4 (Lithium Iron Phosphate)

7.8 LiPo

Lithium Polymer batteries have specific limitations and extra precautions which must be adhered to.

7.8.1 Charging

LiPo batteries MUST be balance charged to prevent damage occurring to the cells. Chargers that do not incorporate an integrated balancing circuitry are not permitted.

7.8.2 Voltage Cut-out (Advisory)

The robot may be fitted with an under voltage cut-out or alarm set at or higher than the battery manufacturer's recommendation to prevent the batteries from becoming damaged by over-discharge.

7.8.3 Fusing

A fuse rated below the maximum burst discharge of the battery MUST be fitted. The maximum burst discharge current is calculated by multiplying the C rating by the capacity. E.g. 25C 2200mAh = 55 Amp

7.8.4 Extra Equipment

Roboteers using LiPo batteries must provide a LiPo sack.

7.8.5 Inspection

LiPo batteries must be removed from the robot, inspected and placed into a LiPo sack prior to and during the charging process.

7.8.6 Charging

Lithium batteries must not be left unattended at any time during the charging process. Leaving batteries unattended while charging will be considered a serious breach of pit safety and may result in you and your robot being removed from the event. Event organisers may provide a dedicated area for charging.

7.8.7 Damage

LiPo batteries showing any evidence of damage or swelling must immediately be placed a LiPo sack and removed to a safe, well-ventilated area such as outdoors. Note that LiPo fires occur rapidly and there is a serious risk of personal injury. Use extreme care when handling any battery that shows signs of damage.

8. Internal Combustion Engines

Note: Please check that your event allows internal combustion engines.

8.1 Fuel Capacity
Fuel capacity is limited to 500ml (17floz).

8.2 Fuel Tanks

8.2.1 Plastic
Fuel tanks separate to the engine must be made of an acceptable type of plastic (e.g. nylon).

8.2.2 Metal
If the tank is integral to the engine assembly and is metal, the cap must be plastic or a plastic "pop off" seal fitted.

8.2.3 Protection
The tank must be adequately protected from puncture.

8.3 Fuel Lines
All fuel lines must be of the correct type and held with the correct type of fittings. They must be routed to minimise the chances of being cut.

8.4 Return Spring
A return spring must be fitted to the throttle of all internal combustion engines to return the throttle to "idle" or "off" in the case of servo breakage or failure. This is in conjunction to any failsafe device.

8.5 Clutch
The output of any engines connected to weapons or drive systems must be coupled through a clutch which will de-couple the motor when it is at idle. This does not include motors used for generators and hydraulic pumps.

8.6 Remote Shut-off
All engines must have a method of remotely shutting off.

8.7 Leaks
Any robot with liquid fuel and oil must be designed not to leak when inverted. Minor leakage may be tolerated, however if it affects other robots or becomes a large clean-up issue you will be banned.

8.8 Non-standard Types
Use of internal combustion engines other than standard piston type (e.g. turbines etc.) must be pre-approved by the Fighting Robot Association.

9. Pneumatics

9.1 Allowed Gases
Pneumatic systems must use Carbon Dioxide [CO_2] or Air.

9.2 Maximum Pressure
The maximum pressure at any point within a pneumatics system must not exceed 1000psi (68bar).

9.3 Cylinders
The compressed gas must be stored in a commercially manufactured gas cylinder of appropriate design, specification and certification. Except where the maximum storage pressure is less than 50psi (3.4bar).

9.4 Burst Disc
The gas cylinder must incorporate a burst disc rated below the maximum test pressure of the bottle. Except where the storage pressure is less than 50psi (3.4bar).

9.5 Manual Isolation Valve
Gas cylinders charged to pressures of greater than 50psi must incorporate a manual isolation valve that can be operated from outside of the robot.

9.6 Remote Isolation Valve
Where the manual isolation valve is not integral to the gas cylinder (for example: the gas is normally released as soon as the cylinder is screwed into the mating pneumatic connection) must have an additional remote isolation valve accessible from outside of the robot.

9.6.1 Position
Any remote isolation valve must be positioned to minimise the pipe length between it and the cylinder. This pipe length must fully vent before the cylinder is fully unscrewed from the pneumatic connection.

9.7 Rating
All pneumatic components used with pressures greater than 50psi (3.4bar) must be rated or tested to at least the maximum pressure available in that part of the system. You may be required to provide documentation or certification to support this.

9.7.1 Custom Components
Custom made components, or parts operating above the suppliers maximum working pressure, must be independently tested and certified at 120% of the maximum system pressure available at that point.

9.7.2 Hydraulic Components
Components originally designed for hydraulics use will be de-rated by 50% for pneumatics use.

9.8 Pressure Relief Device
A pressure relief device must be installed in each part of the pneumatics system where a different operating pressure is used.

9.8.1 Rating
Pressure relief devices must have a rating of 1000psi (68bar) or 110% of the pneumatic component with the lowest 'maximum working pressure' rating protected by that particular pressure relief device, whichever is the lower.

9.8.2 Low Pressure Systems
Pneumatic systems employing pressures less than 50psi or systems employing air compressors that have a maximum output pressure lower than the pneumatic component with the lowest 'maximum working pressure' do not require a pressure relief device.
The pressure relief device(s) dictate the maximum pressure available in that part of the pneumatics system. The pressure relief device(s) must have a flow rate capacity that exceeds the maximum flow rate that can be expected under 'over pressure' conditions. Any attempt to falsify the pressure settings of pressure relief device(s) will be considered as gross misconduct by the FRA and may result in expulsion.

9.8.3 Full Pressure Systems
Non-regulated pneumatic systems or pneumatic systems where the regulator is not directly attached to the gas cylinder require that a 1000psi pressure relief device is fitted.

9.8.4 Regulated Systems
Regulated pneumatic systems that operate at less than 235psi (16bar) and where the regulator is directly attached to the gas cylinder do not require a 1000psi pressure relief device before the regulator. The regulator must be rated to 120% of the gas bottle burst disc pressure. A pressure relief device is required down-stream of the regulator rated at 110% of the component with the lowest 'maximum working pressure' rating.

9.9 Pressure Relief Devices
Pressure relief devices must be readily accessible and must be removable for testing purposes.

9.10 Mounting
All pneumatic components must be securely mounted and adequately protected within the body shell. Any component storing gas (i.e. gas cylinders, buffer tanks etc.) must be secured in such a way as it cannot escape the robot even if suffering a rupture.

9.11 Gauges (Advisory)
Pneumatic pressure gauges and pressure test points are not a requirement but may be requested by some event organisers.

9.12 Dump Valve
All pneumatic systems must incorporate a pressure dump valve accessible from outside of the robot. This dump valve will quickly and reliably exhaust all gas downstream of the gas cylinder isolation (or remote isolation) valve including systems with a maximum operating pressure of less than 50psi (3.4bar).

9.12.1 Normally Open
The dump valve must be left open at all times when the robot is not in the arena or testing areas. Where non-return or quick exhaust valves are used, pay particular attention to ensure no part of the system is left pressurised.

9.13 Removable Cylinders
Gas cylinders must be readily removable for inspection and refilling. You must ensure that your gas cylinder connection is compatible with the event organiser's filling stations, or that you have suitable adapters available.

9.14 Heaters and Boosters
Pneumatic systems using heaters or pressure boosters are not permitted.

9.15 Pressure Equipment Directive
Pneumatic components manufactured from 1 June 2002 must carry a CE mark. Pneumatic components 'custom made' since 30 May 2002 must carry a label indicating their non-conformity with the 'Pressure Equipment Directive' and their non-availability for sale. Components manufactured prior to 30 May 2002 are not necessarily required to carry a CE mark.

10. Hydraulics

10.1 Pressure
Hydraulic system pressure (In the actuator or cylinder) must be limited to 10,000psi by way of a maximum pressure relief valve.

10.2 Test Point
A hydraulic test point is a mandatory fitment to allow verification of a robot's maximum system pressure. A team will need its own test gauge and hose.

10.3 Storage Tanks
Hydraulic fluid storage tanks must be of a suitable material and adequately guarded against rupture.

10.4 Standards
Hydraulic fluid lines and fittings must be to British Standard (BS) and/ or to European DIN specifications.

10.5 Ratings
Hydraulic fluid lines and fittings must be capable of withstanding the maximum working pressures used within the robot.

10.6 Protection
Hydraulic fluid lines must be routed to minimise the chances of being cut or damaged.

10.7 Accumulators
Hydraulic accumulators (pressurised oil storage devices) are banned in whatever form they may take.

10.8 Bleeding (Advisory only)
Care needs to be taken when building a hydraulic system that consideration is given to bleeding the system of air. Trapped air in the hydraulic system will degrade the performance of the system and may make a robot run afoul of rule 10.7.

10.9 Power Sources
For power sources (other than electric motors/ petrol engines) please consult the Fighting Robots Association for advice as to suitability.

11. **Rotational weapons** or full body spinning robots

Full body spinning robots with an eccentric mass, are excluded from this section unless they spin over 500 revolutions per minute.

11.1 Stopping Time
The spinning element of any rotational weapon must spin down to a full stop in under 60 seconds.

11.2 Limits
Rotational weapons exceeding any TWO of the three limits below must be submitted for review and be pre-approved by the event organiser.

11.2.1 Weight
The spinning element is more than 20% of the robots total weight. (This includes any directly coupled motor components rotating on the same axis).

11.2.2 Speed
The spinning element spins above 500 RPM.

11.2.3 Size
The spinning element is greater than 500mm in diameter.

12. Springs and flywheels

12.1 Springs
Any large springs used for drive or weapon power must have a way of loading and actuating the spring remotely under the robot's power.

12.1.1 Deactivation
Under no circumstances must a large spring be loaded when the robot is out of the arena or testing area. These devices must be made safe before removing the robot from the arena or testing area.

12.1.2 Small springs
Small springs like those used within switches or other small internal operations are excluded from this rule. In addition, springs used in robots less than 5 kilos may be excepted from this rule. Please contact the Fighting Robot Association for clarification.

12.2 Flywheels
Flywheels or similar kinetic energy storing devices must not be spinning or storing energy in any way, unless inside the arena or testing area. These devices must be made safe before removing the robot from the arena or testing area.

12.2.1 Remote Deactivation
There must be a way of generating and dissipating the energy from the device remotely under the robot's power to allow safe activation and deactivation of the robot.

12.3 Failsafe
All springs, flywheels, and similar kinetic energy storing devices must fail to a safe position on loss of radio contact or power.

12. Weapon Restrictions

The following weapons and materials are forbidden from use: Note: Some of the listed items may be allowed for effects but not as weapons. If you have an application of these items which you feel may be allowed, please contact the Fighting Robot Association.

12.1 Invisible Damage
Weapons designed to cause invisible damage to the other robot. This includes but is not limited to:

12.1.1 Electricity
Electricity as a weapon such as Tesla coils, Van-der-Graaf generators, stun guns, or cattle prods.

12.1.2 Radio Frequency
Radio Frequency jamming equipment or similar devices.

12.1.3 Radio Frequency Noise
Radio Frequency noise generated by an IC engine. Use shielding around sparking components.

12.1.4 Electromagnetic Fields
Electromagnetic fields from permanent or electromagnets, which affect another robots electronics.

12.2 Stopping Combat
Weapons or defences, which tend to stop combat completely, of both (or more) robots. This includes, but is not limited to the following:

12.2.1 Entanglement
Entanglement devices such as nets, fishing line, cables, string, glues or tapes, which require the match to be stopped and the robots separated. (If this occurs the ‘entangler’ forfeits the match)

12.3 Rotating Weapons
The speed of any rotating weapons - e.g. circular saws, carbon or steel cutting discs - must not exceed the manufacturer's specification. The manufacturer's specification must be available for inspection.

12.4 Hardened Blades
Commercially manufactured, hardened steel blades that may shatter are not allowed.

12.5 Blade Length
Commercial blades - e.g. bayonets - must not exceed 20cm in length.

12.6 Untethered Projectiles
Projectiles must have a tether capable of stopping the projectile at full speed and be no longer than 2.5m.

12.7 Heat and Fire
Heat and fire are forbidden as weapons, (however some events may allow limited fire effects). This includes, but is not limited to the following:

12.7.1 Generated
Heat specifically generated to damage an opponent

12.7.2 Flammables
Flammable liquids or gases

12.7.3 Explosives
Explosives or flammable solids such as DOT Class C devices, Gunpowder, Cartridge Primers or Military Explosives, etc.

12.8 Smoke and Light

Smoke and light based weapons, which 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:

12.6.1 Smoke or Dust

Large quantities of smoke or dust. Limited smoke effects may be allowed by some events.

12.6.2 Lights

Lights such as external lasers above Class 2 (1mw) output and bright strobe lights, which may blind the opponent.

12.9 Hazardous Materials

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. If unsure please contact the Fighting Robot Association.

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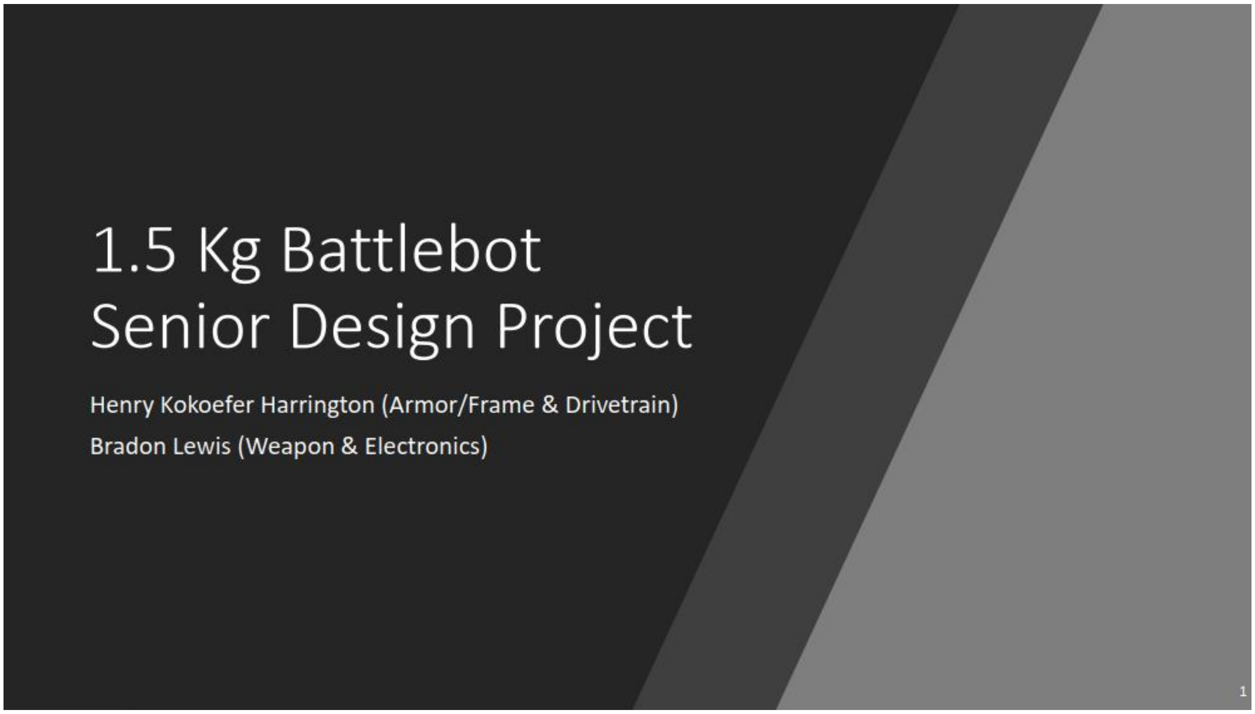
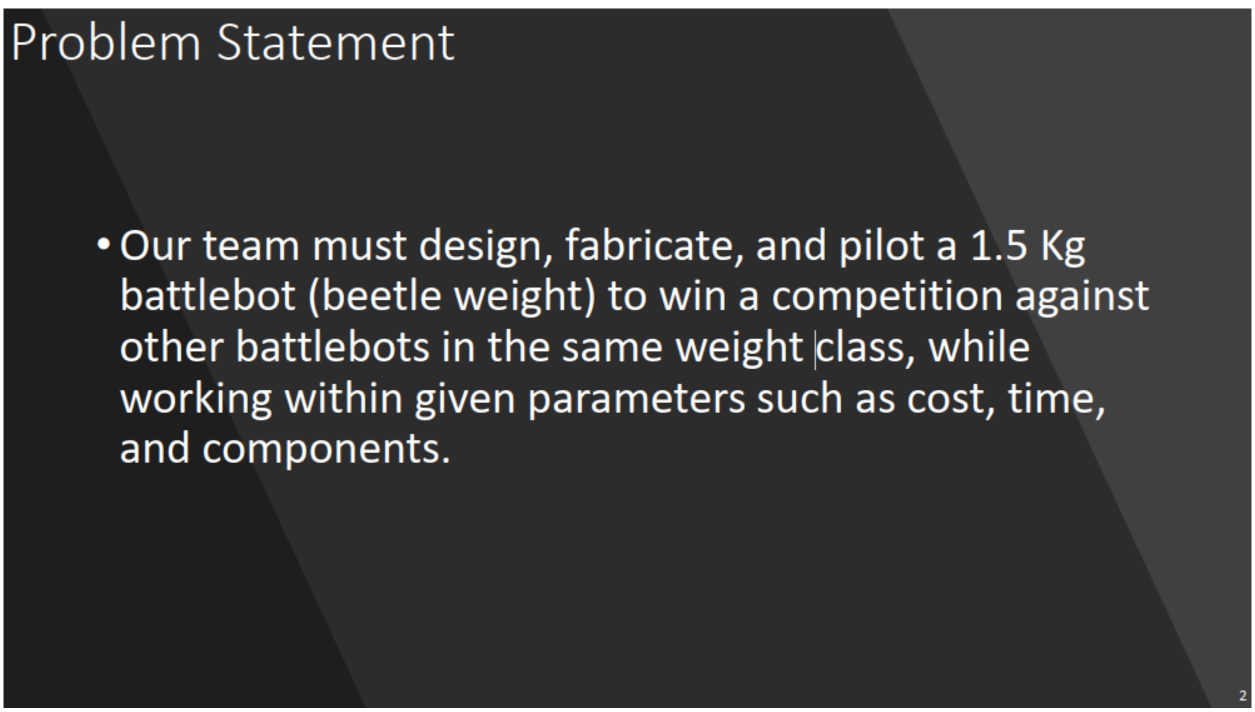
APPENDIX C: FINAL PRESENTATION

Full slideshow is available in the UC repository.





Background and Scope – History and Nature

- To compete in and win an internal beetle weight competition amongst UC students in the battlebots club.
- Each team must design, build, and operate their battlebot until they win or are eliminated.
- The battlebot teams compete against each other to determine which of them has the superior build along with who executes their maneuvering strategies best.

3

Background and Scope: How is it being addressed?

- The current problem is new to UC, as they have never done beetle weight class builds. The beetle weight class has been around for a while, although for this document we are being asked to only use UC's history.
- The problem is currently being addressed with different combinations of the three main variables between battle bots of this weight class:
  - weapon
  - frame/armor
  - drive train
- Majority of the battlebots are designed to have symmetrical top and bottom so they can operate after being flipped.

4

State of the Art

- The first-place winners of the Fall 2018 Collegiate Clash, Pramheda
  - centralized single tooth disk
  - ramp-like frame/armor on all sides
- The ramp frame forced the other battlebots up it, exposing the under carriage to the CCW rotation of the single tooth disk.

5

State of the Art – Armor/Frame

Team Members	Nick Manning, Wesley Creed, Nicole Campbell, Tim Shallenberger (13)
Battlebot Name	
Battlebot Type ○ Frame ○ Armor	Rotating Drum ○ Salvaged 2024 Aluminum plating, box ○ Titanium honeycomb, for top armor plate

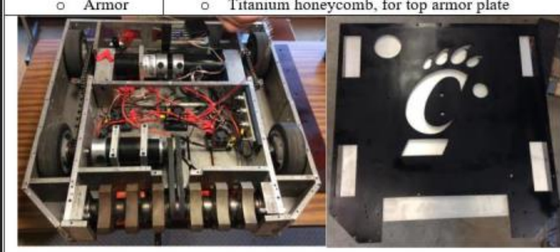


Figure 15: 2014 UC Senior Capstone

Pros:
- The frame has well placed structural walls that create compartments of negative space to place the components
- The front corners were eliminated, creating air pockets to better absorb hits
- Both were recycled from previous battlebots
- Armor plate very light weight

Cons:
- Titanium honeycomb armor plate not very machinable
- Large frame

6

State of the Art – Armor/Frame

Team Members	Black Lighting Robotics (16)
Battlebot Name	Phantom II
Battlebot Type ○ Frame ○ Armor	Horizontal Spinner ○ Aluminum frame, box ○ Onyx (3D printed), for top armor plate; UHMW, Side armor; 0.05" 4130 steel, heat treated wedge

Figure 19: Black Lighting Robotics – Phantom II

Pros:

- UHMW armor (17)
  - Tough and durable
  - Low friction, self-lubricating
  - Excellent abrasion resistance
  - "Chunks off" when hit
  - Low cost
- Onyx armor
  - Protected itself from its own blade deflection
  - 3D printed, can create complex shapes easily
- Wedge
  - Modular
  - Full wedge has shock absorbers

Cons:

- Not enough clearance between weapon and top armor plate
- Onyx armor didn't hold up to a direct hit from another horizontal spinner

7

State of the Art – Armor/Frame

Team Members	Black Lightning Robotics (18)
Battlebot Name	Vortex
Battlebot Type ○ Frame ○ Armor	Shell spinner (full body spinner) ○ Aluminum "H" ○ Aluminum shell spinner

Figure 20: Black Lighting Robotics – Vortex

Pros:

- Armor doubles as a weapon
- Simple design

Cons:

- Openings too large on top surface of shell spinner
- Shell spinner made from aluminum

8

State of the Art – Drive

Team Members	Robert Cowan (19)
Battlebot Name	Anxiety Attack
Battlebot Type	Horizontal Spinner
○ Drive	○ Brushless motor to planetary gear box, rear wheels; belt driven front wheels

Figure 21: Robert Cowan – Anxiety Attack

Pros:

- Two motors to drive the four-wheel setup
  - Saved power consumption
  - Saved weight
  - More compact design
- Small turning radius
- Even if the belts are damaged, it still should have rear drive

Cons:

- Some front wheel slippage
  - No belt tensioner
- Brushless motors harder to program

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State of the Art – Drive

Pros:

- Belt protection
- Small turning radius
- No belt slippage

Cons:

- Brushed motors generally weigh more than brushless
- Small clearances around drive system

Team Members	Mario Jayes (20)
Battlebot Name	Cheat Code
Battlebot Type	Drum Spinner
○ Drive	○ Brushed motor to gearbox, Rear wheels; Timing belt driven front wheels

Figure 22: Mario Jayes – Cheat Code

10

State of the Art – Drive

Pros:

- Direct drive to the wheel, no other secondary wheels to drive
- Simplicity
- Responsive
- Less power consumption
- Tight turning radius

Cons:

- Heavier motor/gearbox assembly

Team Members	Carter Schultz (21)
Battlebot Name	Cpt. Hook
Battlebot Type	Vertical crusher
○ Drive	○ Brushed motor to gearbox

Figure 23: Carter Schultz – Cpt. Hook

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State of the Art – Weapon

Vertical/ Drum Spinner

Pros:

- High exertion force
- Less susceptible to damage
- Versatile in rotation
- Can be operated inverted

Cons:

- Can damage itself
- Small Strike zone

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State of the Art – Weapon

Horizontal Spinner

Pros:
- Flexible design
- Large strike zone
- Potential for heavy damage
- Potential of being invertible
- Offensive and defensive

Cons:
- Potential control issues
- Effects of recoil
- Weapon drive easily damaged

13

State of the Art – Weapon

Hammer/ axe bot

Pros:
- Ability to access vulnerable components
- High impact forces

Cons:
- Control issues
- Momentum of using hammer/axe can damage the robot

14

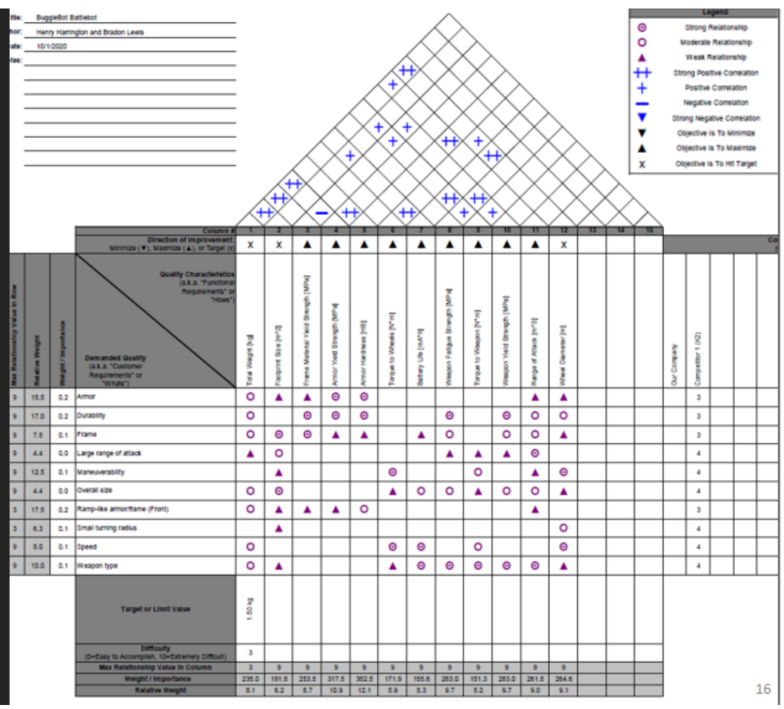
Customer Needs

These features were presented on our customer survey to help us determine the demanded quality of the consumer. The survey polled 30 people with a scale of 1 through 7 (whole number increments) from least important to very important. The features were averaged and consolidated to better fit the HoQ template.

1. Armor
2. Durability
3. Frame
4. Large range of attack
5. Maneuverability
6. Overall size
7. Ramp-like armor/frame (Front)
8. Small turning radius
9. Speed
10. Weapon type

15

House of Quality



16

Project Objectives

1. Armor Hardness (12.1%)
   - The armor material will need to have
2. Armor Yield Strength (10.9%)
   - Type of material
   - Thickness of armor
3. Weapon Fatigue Strength (9.7%)
   - Type of material
   - Geometry of weapon
4. Weapon Yield Strength (9.7%)
   - Type of material
   - Geometry of weapon
5. Wheel Diameter (9.1%)
   - Size of wheels
6. Range of Attack (9.0%)
   - Size of weapon
   - Type of weapon
7. Frame Material Yield Strength (8.7%)
   - Type of material
   - Geometry of frame
8. Total Weight (8.1%)
   - Weight must not exceed 1.5 kg (not counting safety restraints)
9. Footprint Size (6.2%)
   - Must be large enough to accommodate all components
10. Torque to Wheels (5.9%)
    - The wheels must be provided with enough torque to maneuver robot
11. Battery Life (5.3%)
    - Must last long enough for match duration
12. Torque to Weapon (5.2%)
    - The weapon must be provided with enough torque to impact opponent robots

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Concept Design – Armor/Frame

- **Frame** – *Box*
- **Armor** – *Fully covered, wedge plate at front*
- **Drive** – *Motor to gearbox, two-wheel rear, timing belt to two front wheels*

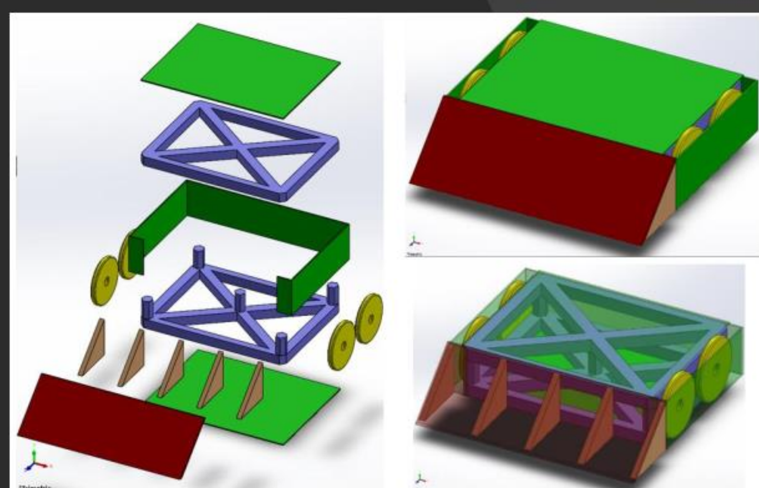


Figure 25: Concept 1 Trimetric Exploded, Transparent, & Normal Views

18

Concept Design – Armor/Frame

- **Frame** – *Box*
- **Armor** – *Fully covered, Ramps on all sides, Larger wedge plate at front*
- **Drive** – *Motor to gearbox, two-wheel drive, rear*

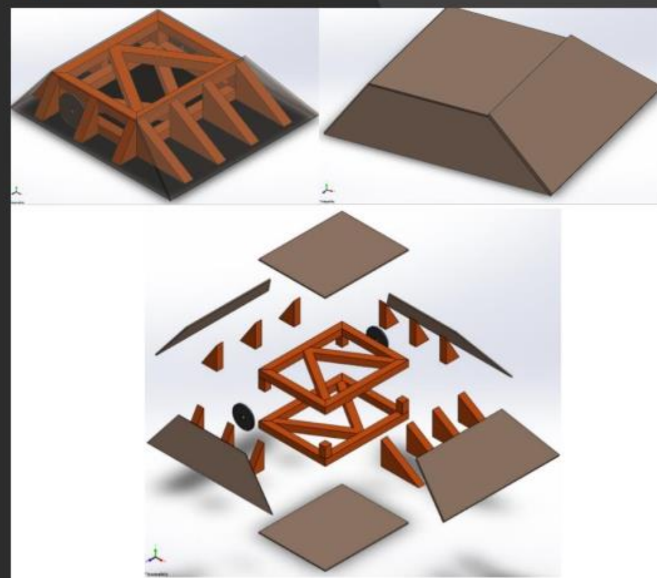


Figure 27: Concept 2 Trimetric Exploded, Transparent, & Normal Views

19

Concept Design – Armor/Frame

- **Frame** – *Hexagonal box*
- **Armor** – *Fully covered, Insertable armor plates*
- **Drive** – *Motor to gearbox, two-wheel drive, central*

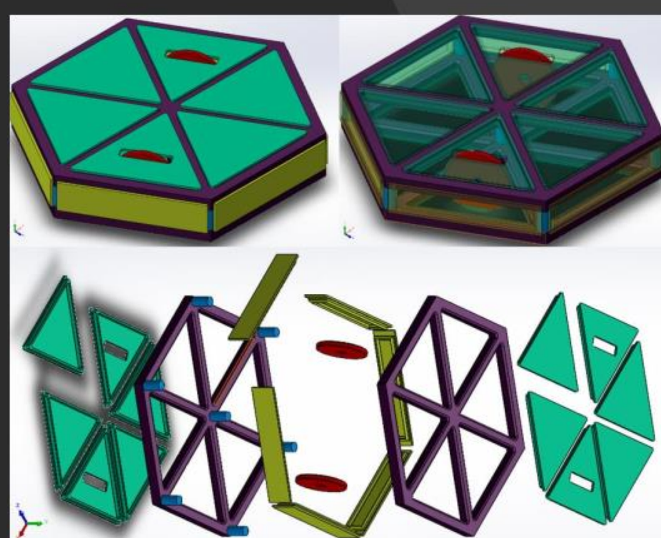
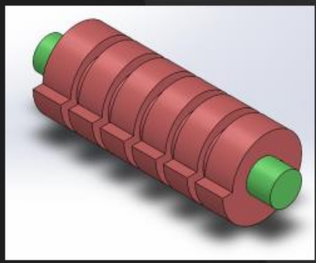


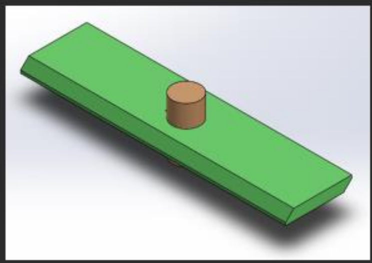
Figure 28: Concept 3 Trimetric Exploded, Transparent, & Normal Views

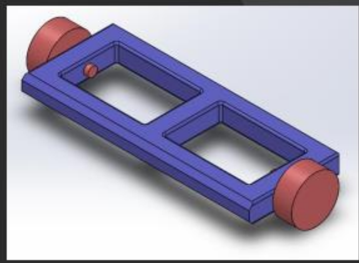
20

Concept Design - Weapon

- There were a total of three total concept designs for the weapon that would be used for our beetlebot. The three types of weapons were a vertical/drum spinner, a horizontal spinner, and an eggbeater style weapon. These were chosen as concept designs due to their effectiveness and ability to distribute large amounts of damage. Below are pictures of each of the concepts.







21

Concept Selection – Weighted Matrix

Concept Selection Weighted Matrix					
Rating Scale: 1-5 (1 = Worst - 5 = Best)					
	Concept #	Effectiveness [0.25]	Manufacturability [0.25]	Repairability [0.25]	Weighted Total
Armor / Frame	Concept 1 (Box, Front Wedge)	3.5	4	4.5	3
	Concept 2 (Box, All Sides Wedge)	4.5	3.5	3.5	2.875
	Concept 3 (Hexagonal)	3	3	5	2.75
Weapon	Concept 1 (Drum Spinner)	4.5	3.5	4	3
	Concept 2 (Vertical Spinner)	4	5	3	3
	Concept 3 (Eggbeater)	3.5	4	1	2.125

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Concept Selection – Compatibility Matrix

Compatibility Matrix: Rates how well the components can be merged into a final beetlebot.

Rating Scale: 1-5 (1 = Least Compatible - 5 = Most Compatible)

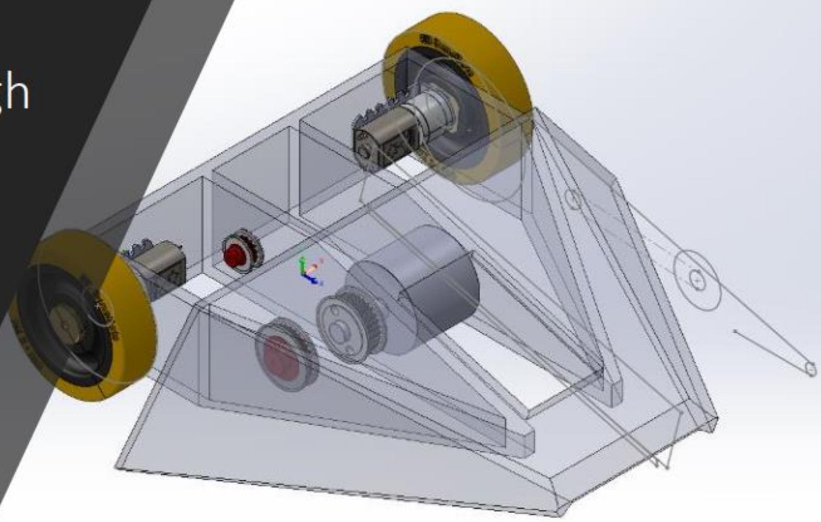
		Weapon		
	Concept #	**Concept 1 (Drum Spinner)**	**Concept 2 (Vertical Spinner)**	**Concept 3 (Eggbeater)**
Armor / Frame	**Concept 1 (Box, Front Wedge)**	**4**	**2**	**3**
	Concept 2 (Box, All Sides Wedge)	**3.5**	**1**	**2.5**
	Concept 3 (Hexagonal)	**4**	**4**	**3.5**

Concept Selection – Final Weighted Matrix

Final Concept Selection Matrix: Summation of all scores for each concept combination

#	Armor / Frame Concept	Weapon Concept	Concept Selection Score		Compatibility Score [0.25]	Total
			Armor / Frame Score	Weapon Score		
1	Concept 1 (Box, Front Wedge)	Concept 1 (Drum Spinner)	3	3	1	7
2	Concept 1 (Box, Front Wedge)	Concept 2 (Vertical Spinner)	3	3	0.5	6.5
3	Concept 1 (Box, Front Wedge)	Concept 3 (Eggbeater)	3	2.125	0.75	5.875
4	Concept 2 (Box, All Sides Wedge)	Concept 1 (Drum Spinner)	2.875	3	0.875	6.75
5	Concept 2 (Box, All Sides Wedge)	Concept 2 (Vertical Spinner)	2.875	3	0.25	6.125
6	Concept 2 (Box, All Sides Wedge)	Concept 3 (Eggbeater)	2.875	2.125	0.625	5.625
7	Concept 3 (Hexagonal)	Concept 1 (Drum Spinner)	2.75	3	1	6.75
8	Concept 3 (Hexagonal)	Concept 2 (Vertical Spinner)	2.75	3	1	6.75
9	Concept 3 (Hexagonal)	Concept 3 (Eggbeater)	2.75	2.125	0.875	5.75

Finalized Concept – rough concept (v1)



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Calculations – Wheel Diameter and RPM

Drive Motors

$Gear\ Ratio = 63:1$
$Nominal\ Voltage = 12\ V$
$No\ Load\ RPM = 220\ RPM$
$Rated\ RPM = 180\ RPM$
$Rated\ Torque = 0.8\ kg - cm$
$Stall\ Torque = 4.6\ kg - cm$
$No\ Load\ Current = 0.08\ A$
$Stall\ Current = 1.6\ A$

Determining wheel diameter and RPM needed to cross full length of the arena:

$Arena\ Area \rightarrow A_{Arena} = 17.361\ ft^2 = 2500\ in^2$
$Arena\ Length \rightarrow L_{Arena} = 4.167\ ft = 50\ in$
$Disered\ time\ to\ transverse\ arena = 2$ sec
$Desired\ Velocity \rightarrow V_{Desired} = \frac{unit\ legnth}{unit\ time} = \frac{4.167\ ft}{2\ sec} \rightarrow 2.083\frac{ft}{s} = 25\frac{in}{s}$
$Wheel\ Diamter \rightarrow D_{Wheel} = 2.875$ in
$Wheel\ Circumference \rightarrow C_{Wheel} = \pi D_{Wheel} \rightarrow \pi(2.875) = 9.032\ in$

$Minimum\ Number\ of\ Wheel\ Revolutions \rightarrow R_{n,min} = \frac{L_{Arena}}{C_{Wheel}} = \frac{50\ in}{9.032\ in} = 5.536\ revs$

$Minimum\ Wheel\ Revolutions\ per\ Unit\ Time \rightarrow = \frac{5.536\ revs}{2\ sec} = 2.768\frac{rev}{sec} = 166.076\ RPM$

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Calculations – weapon speed

Weapon Motor Specs
$Nominal\ Voltage = 12\ V\ (4000\ KV)$
$No\ Load\ RPM = 44440\ RPM$
$Load\ RPM = 36360\ RPM$
$No\ Load\ Current = 2.5\ A$
$Load\ Current = 26.5\ A$

$$Velocity\ Ratio_{Weapon} = \frac{N_{driver}}{N_{driven}} = \frac{15}{30} = 0.5$$

$$Output\ RPM_{weapon} = VR_{weapon} * Input\ RPM = 0.5 * 36360 = 18180\ RPM$$

$$\omega = RPM * \left(\frac{2\pi}{60}\right) = 18180 * \left(\frac{2\pi}{60}\right) = 1903.81\ \frac{rad}{sec}$$

$$Weapon\ Mass = 93.715\ g = 0.093715\ kg$$

$$I = \frac{1}{2}M(R_1^2 + R_2^2) = \frac{1}{2} * .093715 * (.0047625^2 + .02611^2) = 3.3 * 10^{-5}\ kg * m^2$$

$$KE = \frac{1}{2}I\omega^2 = \frac{1}{2} * (3.3 * 10^{-5}) * 1903.81^2 = 59.8\ Joules$$

$$Weapon\ Diameter = 52.21\ mm = 0.05221\ m$$
$$Linear\ Speed = radius * \omega = 0.02611\ m * 1903.81\ \frac{rad}{s} = 49.7\ \frac{m}{s}$$

27

Calculations – Key and Keyway length

$$F_{avg}\ on\ shaft = \frac{Weapon\ Mass\ x\ v}{Impact\ Time} = \frac{0.093715*49.7}{.01} = 465.8\ N$$

$$Tensile\ Strength\ of\ 7075 - T6\ Aluminum = 572\ MPa$$
$$Shaft\ S_n = 0.5(Ultimate\ Tensile\ Strength) = 0.5(572000000) = 286\ MPa$$

$$C_s = \left(\frac{D}{0.3}\right)^{-.11} = \left(\frac{0.375}{0.3}\right)^{-.11} = 0.9758$$

$$Desired\ reliability = 0.999 \rightarrow C_R = 0.75$$
$$C_{st} = 1.0$$
$$C_m = 1.0$$

$$Shaft\ S_n' = S_n C_m C_{st} C_R C_s = 286(1)(1)(0.75)(0.9758) = 209.3\ MPa$$

Key Dimensions = 0.09375" x 0.09375" = 0.00238125m x 0.00238125m ; L = ?
Key Material – 6061 Aluminum
Key Seat Depth and Key Hub Depth = h/2 = 0.046875" = 0.001190625 m

$$Force\ on\ Key = \frac{Torque}{shaft\ radius} = \frac{0.167}{0.0047625} = 35.1\ N$$

$$Shear\ Force\ (\tau) = \frac{F}{A_s} = \frac{35.1}{0.00238125^2} = 6184028.7\ Pa = 6.18\ MPa$$

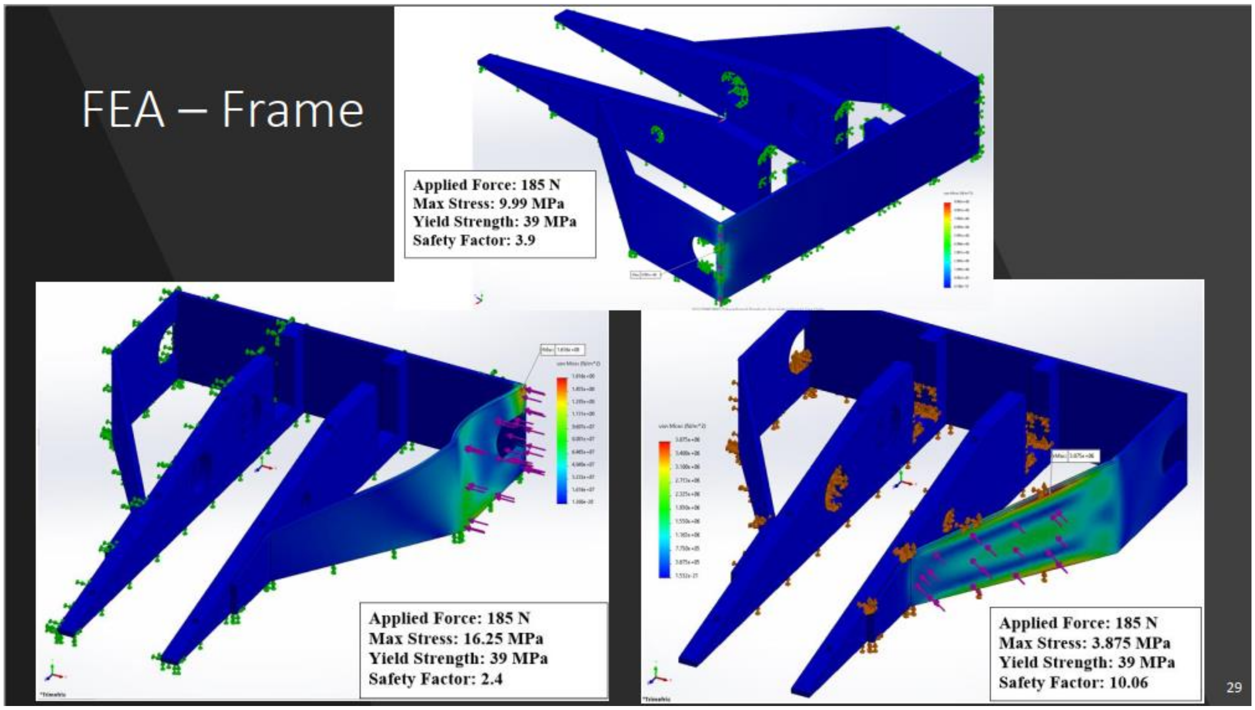
$$\tau_d = \sigma_d = \frac{0.5S_y}{N};\ N = 3, S_y = 83\ MPa;\ \frac{0.5*83}{3} = 13.83\ MPa$$

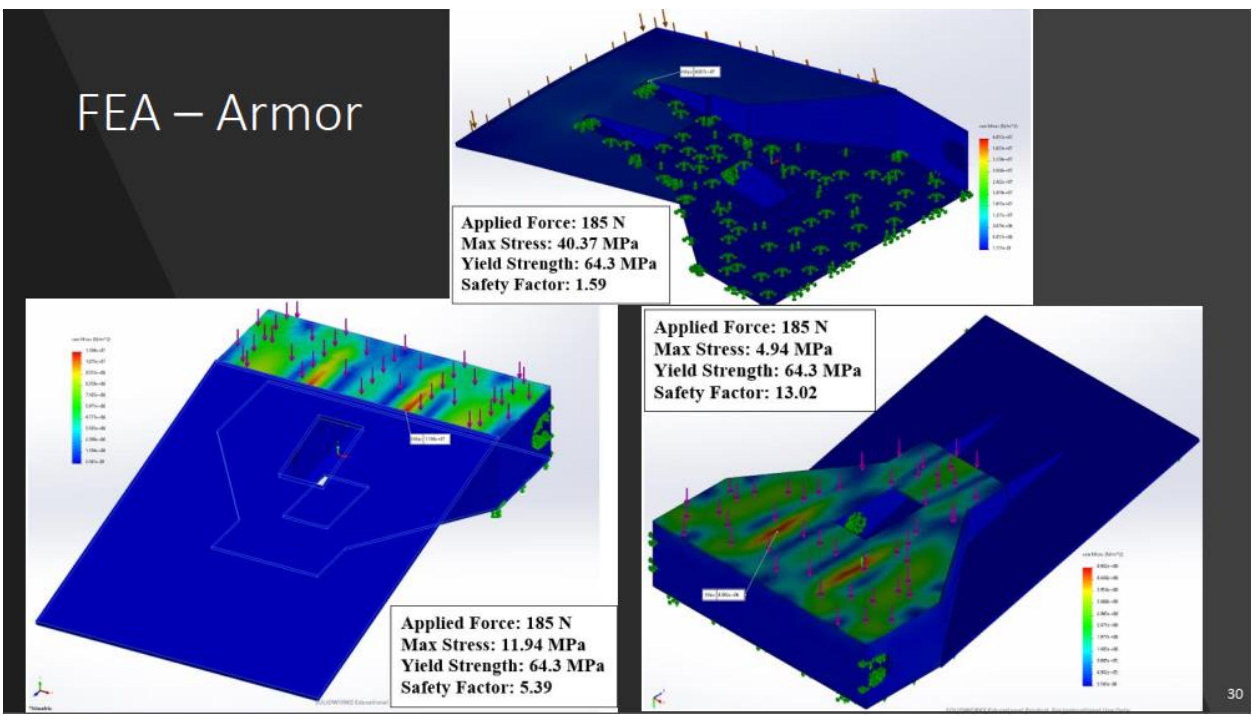
$$Shear\ L_{min} = \frac{2T}{\tau_d DW} = \frac{2(0.167)}{13830000(.0047625)(.00238125)} = 0.00213\ m$$

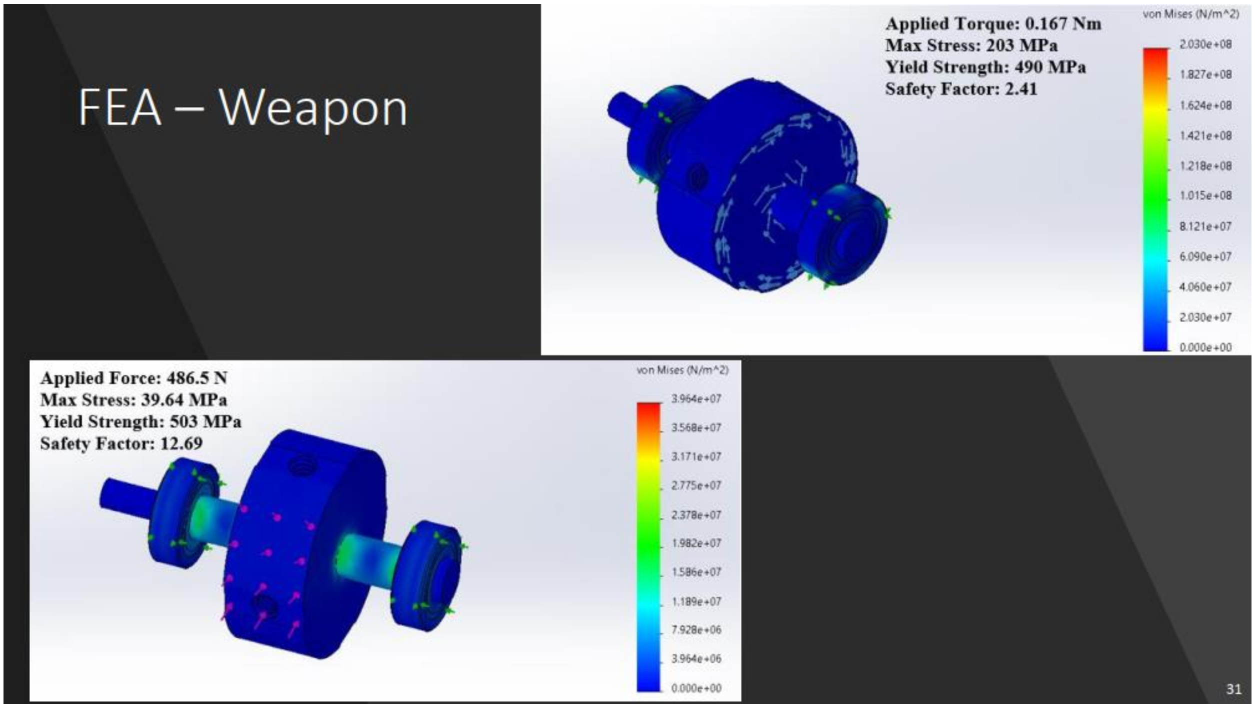
$$Compression\ L_{min} = \frac{4T}{\sigma_d DH} = \frac{4(0.167)}{13830000(.0047625)(.00238125)} = 0.00426\ m$$

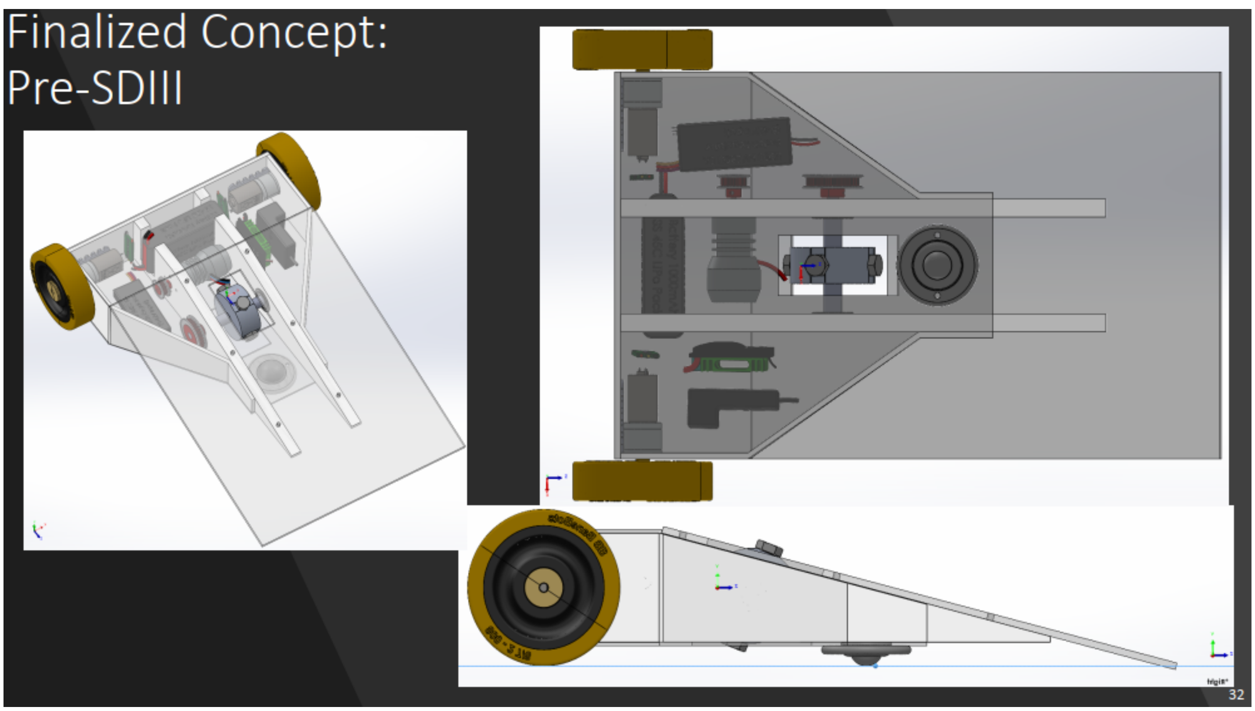
$$\therefore L = 0.25" = 0.00635\ m$$

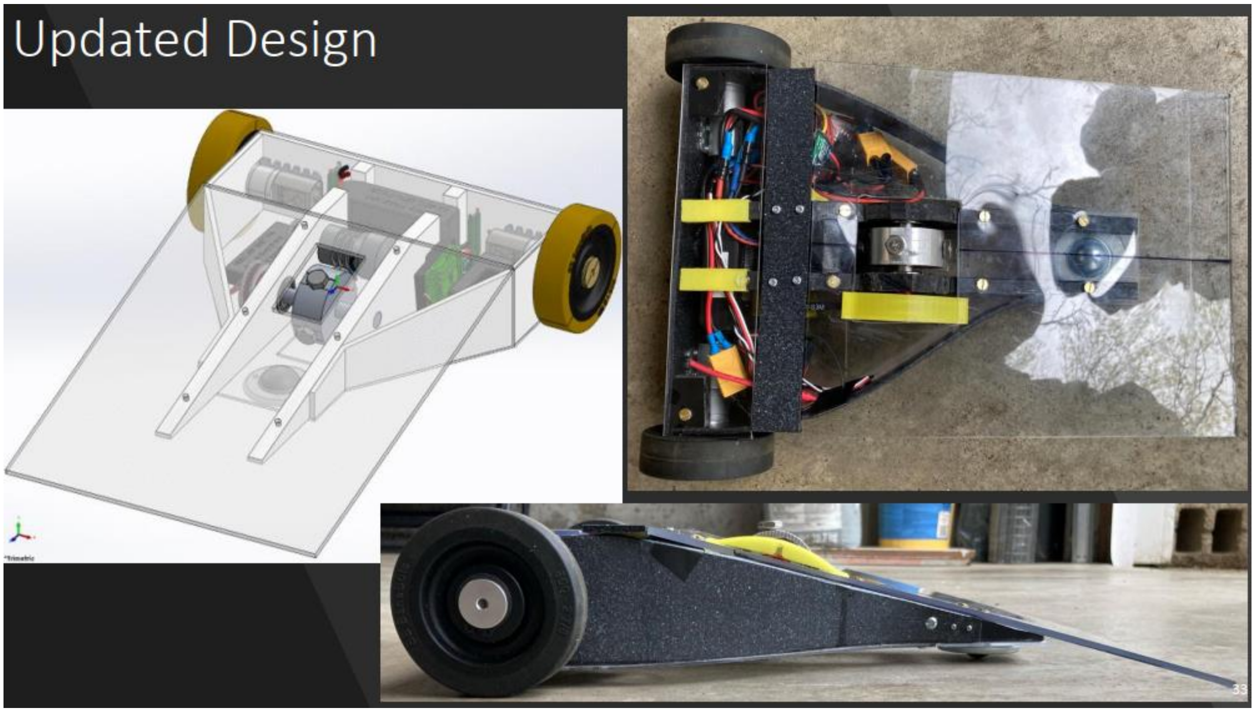
28

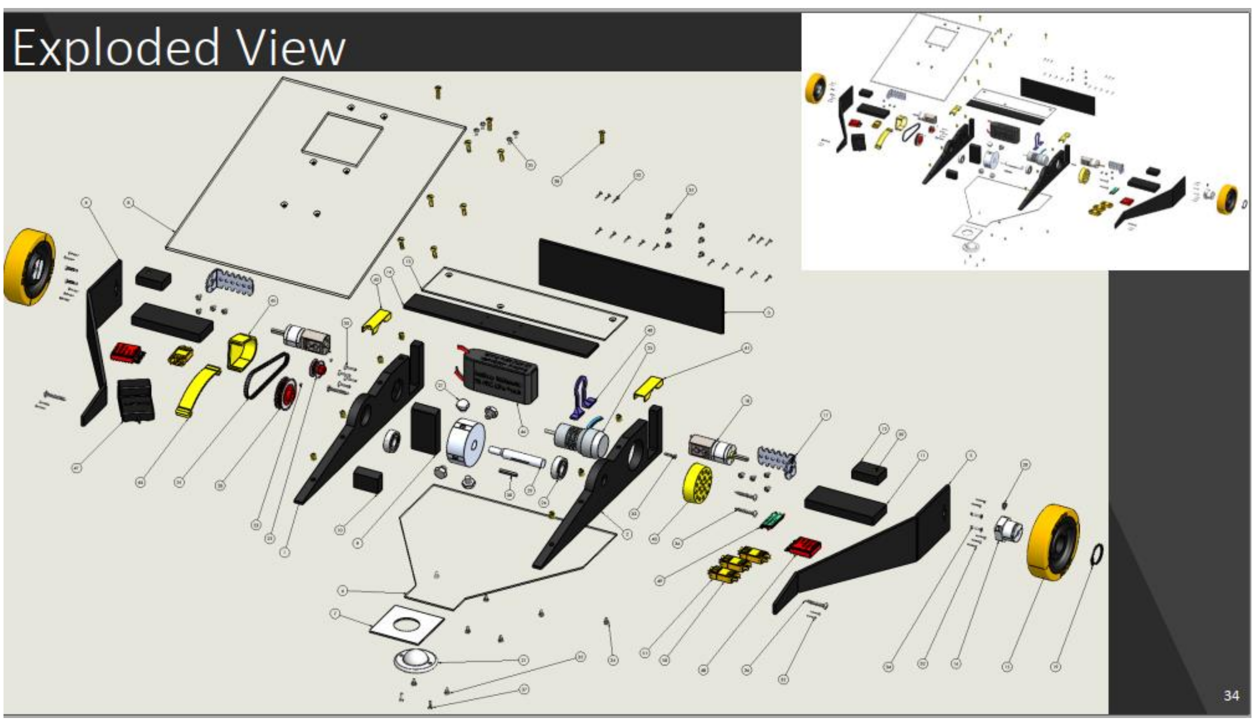

FEA – Frame
Applied Force: 185 N
Max Stress: 9.99 MPa
Yield Strength: 39 MPa
Safety Factor: 3.9
Applied Force: 185 N
Max Stress: 16.25 MPa
Yield Strength: 39 MPa
Safety Factor: 2.4
Applied Force: 185 N
Max Stress: 3.875 MPa
Yield Strength: 39 MPa
Safety Factor: 10.06
29


FEA – Armor
Applied Force: 185 N
Max Stress: 40.37 MPa
Yield Strength: 64.3 MPa
Safety Factor: 1.59
Applied Force: 185 N
Max Stress: 4.94 MPa
Yield Strength: 64.3 MPa
Safety Factor: 13.02
Applied Force: 185 N
Max Stress: 11.94 MPa
Yield Strength: 64.3 MPa
Safety Factor: 5.39
30


FEA – Weapon
Applied Torque: 0.167 Nm
Max Stress: 203 MPa
Yield Strength: 490 MPa
Safety Factor: 2.41
von Mises (N/m^2)
2.030e+08
1.827e+08
1.624e+08
1.421e+08
1.218e+08
1.015e+08
8.121e+07
6.090e+07
4.060e+07
2.030e+07
0.000e+00
Applied Force: 486.5 N
Max Stress: 39.64 MPa
Yield Strength: 503 MPa
Safety Factor: 12.69
von Mises (N/m^2)
3.964e+07
3.568e+07
3.171e+07
2.775e+07
2.378e+07
1.982e+07
1.586e+07
1.189e+07
7.928e+06
3.964e+06
0.000e+00
31


Finalized Concept:
Pre-SDIII
32


Updated Design
33


Exploded View
34

BOM

ITEM NO.	PART NUMBER	QTY.
1	Center R, Frame, V3, 0.375 x 2 x 7.675 in	1
2	Center L, Frame, V4, 0.375 x 2 x 7.675 in	1
3	Back, Frame, 0.125 x 2 x 8 in	1
4	Side R V4, Frame, 0.125 x 2 x in	1
5	Side L V4, Frame, 0.125 x 2 x in	1
6	Bottom Plate V4, Armor	1
7	Bottom Plate V4, Front, Caster, Armor	1
8	Wedge V4, Polycarbonate 0.125 in V3	1
9	Support Center, Frame	1
10	Support Center, Frame, Short	1
11	Brace, Frame, Long	2
12	Brace, Frame, Short	2
13	Top Armor, Polycarbonate 0.0625in, 2.8 x 8 in	1
14	Top Strip, Frame, 0.125 x 1 x 8 in	1
15	T81P-29, 2.875in, BaneBots	2
16	Wheel Hub, T81H-RM41, 4mm shaft, BaneBots	2
17	L-Bracket,Drivetrain Motor, pololu-20d-mm-metal-gearmotor-bracket	2
18	Motor, Drivetrain, 20d-metal-gearmotor-63-78	2
19	Snap Ring, Wheel Hub	2
20	Set Screw, Wheel Hub	2
21	2415T13	1
22	15t_pulley	1
23	Set Screw, Pulley	2
24	60355K45	2
25	Weapon Motor, Brushless, Turnigy 2815 EDF Outrunner 4000kv for 55-64mm	1
26	Drum, Weapon V3, Keyed, D1.75 x L0.75 in	1
27	92314A315	4
28	30t_pulley, 0.25in bore	1
29	Shaft V4, Ø 0.375 X L 3.75in, Shoulder Ø 0.25, Weapon	1
30	98491A098	1
31	Belt 201 mm 67 T	1
32	99461A520	30
33	93395A182	5
34	91430A085	4
35	96367A921	26
36	92470A152	5
37	91430A081	2
38	92451A148	9
39	Insert, Brass, 6-32	9
40	Support, Motor, Weapon	1
41	Frame, Support, Arch, Battery V2	1
42	Support, Arch, Frame, Battery V2	1
43	Guard, Weapon Motor	1
44	Guard, Pully Large	1
45	Cover, Belt, Weapon Motor	1
46	Battery, Turnigy Graphene 1000mAh 3S 45C LiPo Pack XT60	1
47	Receiver, Turnigy T6A-V2 AFHDS Mode 2 2.4GHz 6Ch Transmitter & Receiver	1
48	ESC Brush, Drive Motor	2
49	ESC Brushless, Weapon Motor	1
50	XT60FemaleConnector	4
51	XT60MaleConnector	4

- 51 Unique Components
- 153 Total Components

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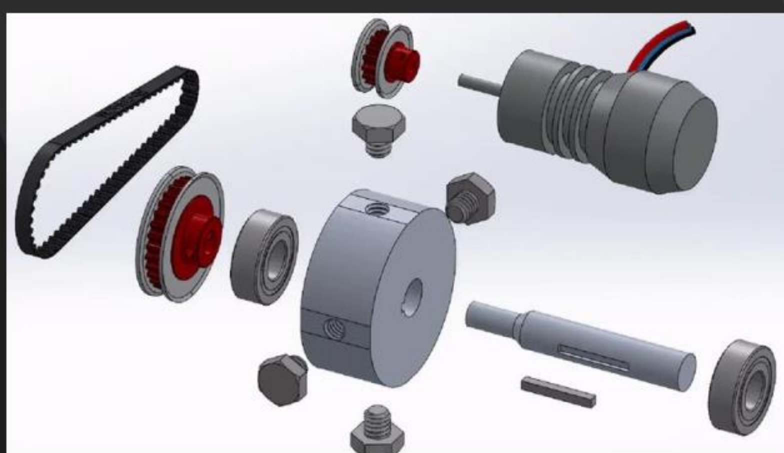
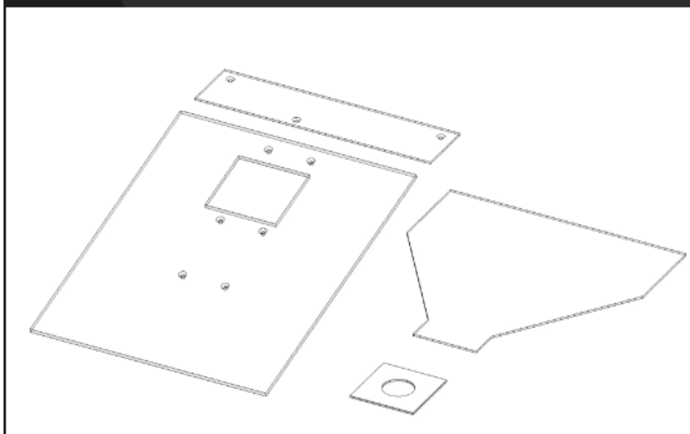
Weapon



36

Material Selection – Armor/Wedge



- Polycarbonate plastic, Sheets
  - Density = 1.24g/cm^3 (0.717oz/in^3)
  - Tensile Strength: 713kgf/cm^2 (10kpsi)
  - Allows inner components to be visible
  - Allows for uninterrupted radio signals
  - High machinability

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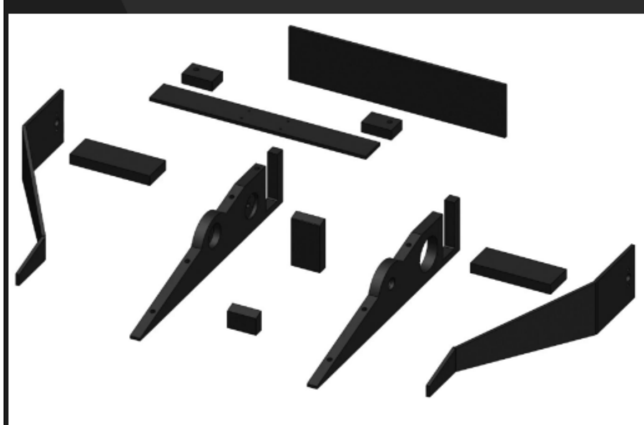
Material Selection –Frame



- UHMW Polyethylene Sheet
  - Density: 0.949g/cm^3 (0.544oz/in^3)
  - Tensile Strength: 4,350-5,800 psi
  - Impact Strength: 16.8 ft.-lbs./in
  - Hardness: Durometer 65D-67D (Medium)
  - High Machinability
  - High Shock Absorption
  - Relatively Low Weight
  - Low Friction

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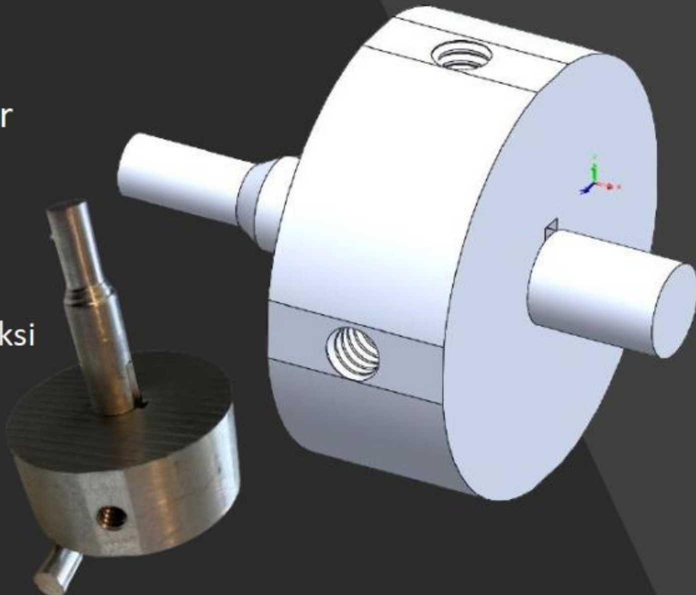
Material Selection – Weapon (Drum & Shaft)

- 7075 T6 Aluminum Round Bar
  - Density = 2.81g/cm^3 (1.632oz/in^3)
  - Tensile Strength, Yield = 73000psi
  - Modulus of Elasticity = 10400 ksi
  - High strength to weight ratio
  - Good Machinability



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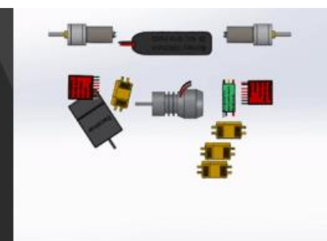
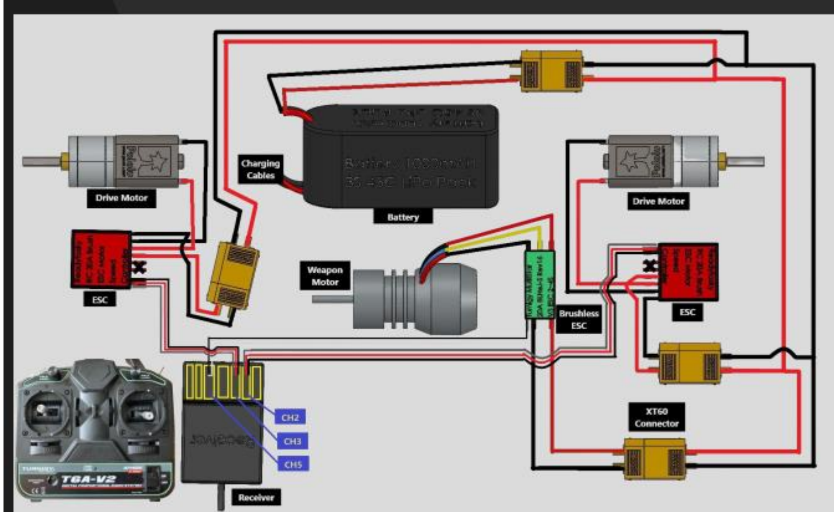
Component Selection – Electrical





Electrical Component Assembly:

- 1x 3s (12 volt) LiPo Battery
- 2x Brushed ESCs
- 2x Brushed Drive Motors
- 1x Brushless ESC
- 1x Brushless Weapon Motor
- 1x Receiver
- 4x Pairs of XT60 Connectors
- 16 Gauge Wire

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Fabrication & Assembly

- Fabrication of metal and plastic components done at Victory Parkway
- Soldered electrical components ourselves
- Assembled Beetlebot with a mix of hardware and Krazy Glue

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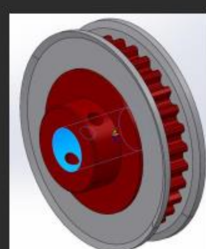
Fabrication and Assembly



Component →	***Weapon Shaft Pulley, S3M Timing Pulley, 30 Tooth***
Operation →	***1x 0.25" Through Drill → Increase ID for Weapon Shaft***
Machine →	***Mill***
Location →	***Victory Parkway***
Operator →	***Self***

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Fabrication & Assembly






Component →	***Drum, Weapon, 7075 T6 Aluminum Round Bar, OD 1.75" X L 0.75"***
Operation →	***Cut to Size, 4x Facing, 4x Drill & Tap, 1x Drill, Broach***
Machine →	***Band Saw, Mill, Manual Tap, Broach Press***
Location →	***Victory Parkway***
Operator →	***Self***

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Fabrication & Assembly




Component →	***Shaft, Weapon, 7075 T6 Aluminum Round Bar 3/8, L 2.3125"***
Operation →	***Cut to length, Turning, Keyway Cutting***
Machine →	***Bandsaw, Lathe, Mill***
Location →	***Victory Parkway***
Operator →	***Self***

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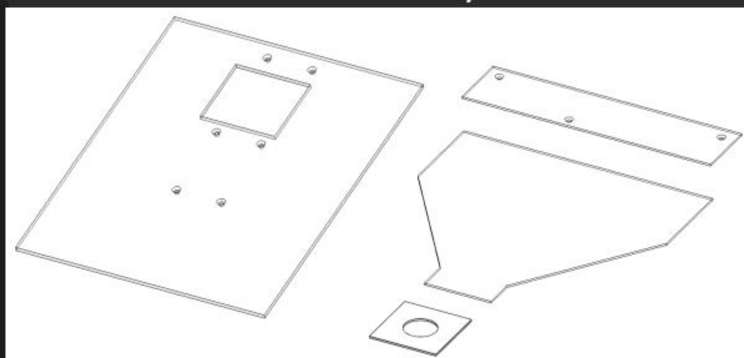
Fabrication & Assembly



Component →	***Armor Plate Material, Polycarbonate Sheet 1/8" & 1/16", L8" x W10"***
Operation →	***Cut, Drill***
Machine →	***Jig Saw, Hand Drill***
Location →	***Off Campus***
Operator →	***Self***

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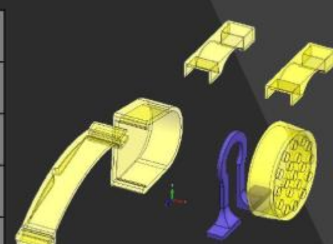
Fabrication & Assembly

Component →	**Guards & Support Pieces (PETG)**
Operation →	***3D Print***
Machine →	***Polaroid PlaySmart 3D Printer***
Location →	***Off Campus***
Operator →	***Self***



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Fabrication & Assembly

Component →	***Frame Material, UHMW Polyethylene Sheet 8" x 10", 0.375" & 0.125"***
Operation →	***Cut, Mill, Drill, Bend***
Machine →	***Circular Saw, Jig Saw, Mill***
Location →	***Victory Parkway and Off Campus***
Operator →	***Self***

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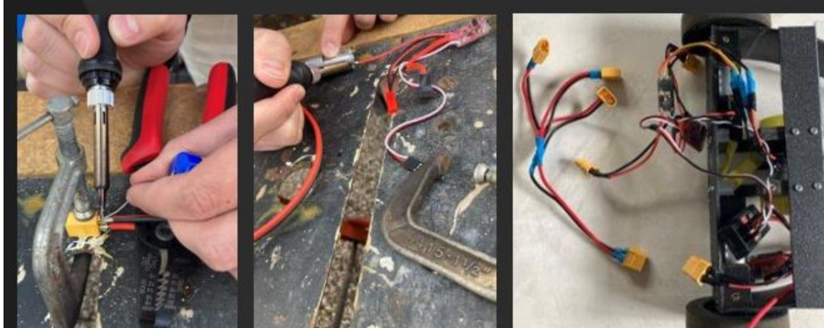
Fabrication & Assembly



Component →	**Weapon & Drive motors, ESCs, and XT60 Connectors**
Operation →	***Soldering, Heat Shrink***
Machine →	***Soldering Iron***
Location →	***Off Campus***
Operator →	***Self***

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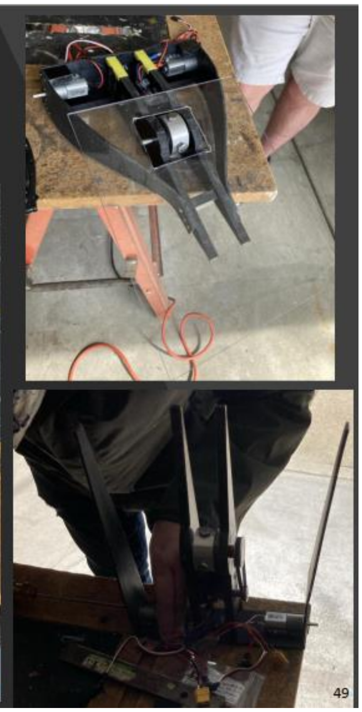
Fabrication & Assembly

Estimated Total Weight [g]	Actual Total Weight [g]
1250.79	1290.00



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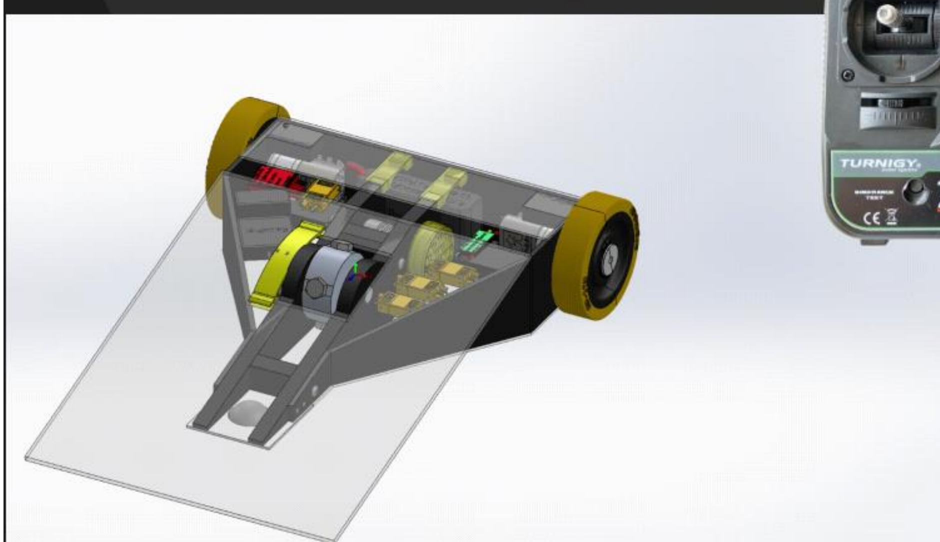
Fabrication & Assembly



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Testing

1. Assemble and Test Electronics – 4/2/2021
   - No loose connections or solder joints
   - Verify drive and weapon motor functionality
   - Verify transmitter functionality

2. Complete Assembly – 4/12/2021
   - Drive Test
   - Weapon spin up time
   - Weapon Impact Test

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Competition (04/17/2021)

Abby, Alex, Emely
Grogu

Chase's Team
Slaystation

Championship Match

Bonus Round: Free For All

Bradon, Henry
Ramp Way to Hell

Kyle, Trey, Sam
Hash Slinging Slasher

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Competition Results

1. Slaystation (2 Wins)
2. Ramp Way to Hell (1 Win, 1 Loss)
3. Hash Slinging Slasher (1 Win, 1 Loss)
4. Grogu (2 Losses)

- For the free for all round the Hash Slinging Slasher was deemed the winner
- While other bots experienced internal and external damage our bot only experienced external damage and remained functional even at the end of the competition

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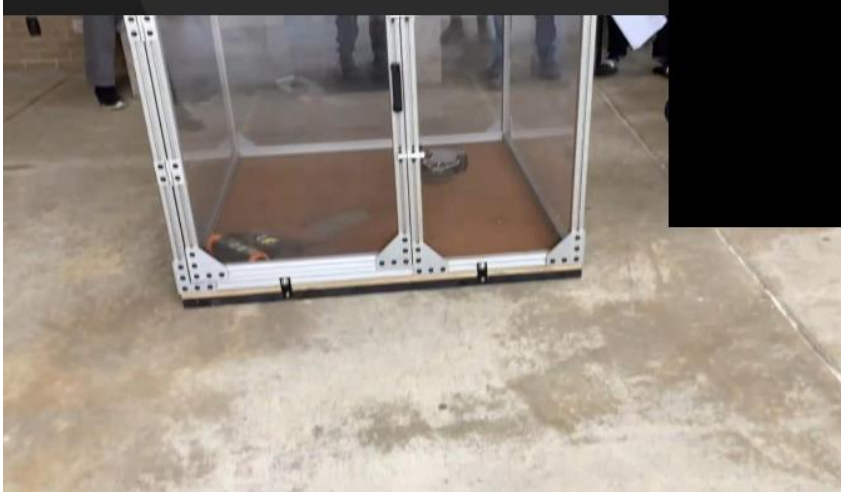
Competition Results: Round 1 (1.5X Speed)

Ramp Way to Hell vs Hash Slinging Slasher



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Competition Results: Round 1, Results
Ramp Way to Hell vs Hash Slinging Slasher
Our bot (Winner)
• External Damage
• Loosened Weapon Bolts (Collision with Wedge)
Their Bot
• Tire Damage
• First Weapon System Failed
• Then Drive System Failed
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Competition Results: Championship Round (2X Speed)
Ramp Way to Hell vs Slaystation
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Competition Results: Championship Round, Results

Ramp Way to Hell vs Slaystation

Our bot
- External Damage
  - Shredded tire (still functional)
  - Hole in sidewall
- No Internal damage
- Loosened Wheels (hub set screws & drive motor mounting screws)

Their Bot (Winner?)
- Drive System not functioning
  - Had to replace entire drive motor

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Recommendations/ Things to Change

- Verify the need for all components, such as the UBEC, which ended up going unused in our design
- Higher torque for drive motor – make it easier to get the wedge under opponents
- Better bracing/mounting for our drive motors – coming loose during battle
- Get involved with Battlebots Club sooner
- Buy extras of small hardware such as bolts and snap rings
- Communicate with other teams about buying different electrical connectors in bulk
  - Such as XT60 or 3.5 mm bullet connectors
- Possibly make the wedge/ramp shorter or move weapon closer to bottom of ramp
  - Hard to engage shorter opponents with weapon unless they drove up the wedge

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Project Management: Proposed Schedule

Proposed Schedule Beetlebot - Wedge/Horizontal Drum		2020					2021			
		August	September	October	November	December	January	February	March	April
Senior Design I	Problem Statement	08/16/2020								
	Final Research		09/18/2020							
	Quality Function Deployment			10/01/2020						
Senior Design II	Final Concept Selection				11/02/2020					
	Bugdet Proposal Review				11/21/2020					
	Presentations (Proposal & Design Info)					12/01/2020				
	Final Part Selection					12/08/2020				
	Finalized Design					12/08/2020				
Senior Design III	Part Ordering						01/11/2020			
	Fabrication & Assembly						01/25/2020			
	Testing I							02/17/2020		
	Design Revisions							02/28/2020		
	Testing II								03/15/2020	
	Tech Expo									04/01/2020
	Internal Competition									04/15/2020
	Final Report									04/21/2020

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Project Management: Actual Schedule

Actual Schedule Beetlebot - Wedge/Horizontal Drum		2021			
		January	February	March	April
Senior Design III	Part Ordered	01/23/2021	← +12 days		
	Fabrication & Assembly	+30 days →	02/24/2021	→	04/12/2021
	All Parts Delevired				04/08/2021
	Testing I			+44 days →	04/02/2021
	Design Revisions				N/A
	Testing II			+28 days →	04/12/2021
	Tech Expo Round I			-1 days →	04/14/2021
	Tech Expo Round II				04/15/2021
	Internal Competition			+2 days →	04/17/2021
	Final Presentation			-2 days →	04/19/2021
	Final Report				04/25/2021

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Project Management: Proposed Budget

Total [USD]	$379.31

Item	Description	Used On	Dimensions [mm]	Vender	Qty	Price Per Unit [USD]	Total Price [USD]
Transmitter & Receiver	Turnigy T6A-V2 AFHDS Mode 2 2.4GHz 6Ch Transmitter w/Receiver	Electronics	L47.25 x W31.5 x H20 (A	https://hobbykir	1	$30.59	$30.59
Brushed ESCs	DFRobot 20A Bidirectional Brushed ESC Speed Controller (XT60 Connecto	Electronics	L42 x W28 x H15 (includi	https://www.rob	2	$18.00	$36.00
Brushless ESC	Turnigy MultiStar 20A BLHeli-S Rev16 V3 ESC 2~4S (Opto)	Electronics	L27 x W12	https://hobbykir	1	$10.59	$10.59
LiPo Battery	Turnigy Graphene 1000mAh 3S 45C LiPo Pack w/XT60	Electronics	L76 x W35 x H22	https://hobbykir	2	$13.45	$26.90
UBEC	Turnigy HV SBEC 5A Switch Regulator (8-42V input)	Electronics	59 x 10 x 25	https://hobbykir	1	$9.84	$9.84
Drive Motors - Brushed Gear	63:1 Metal Gearmotor 20Dx43L mm 12V CB	Electronics	D20 x L44.7	https://www.pol	2	$21.95	$43.90
Motor Mount, L-Bracket, Pair, D20 mm	Pololu 20D mm Metal Gearmotor Bracket Pair	Electronics	H21.5 x L51.5 x W20 x 1.	https://www.pol	1	$6.95	$6.95
Mounting Hardware, Motor Mount	M3, Machine Screw	Hardware	M3 x L5	https://www.pol	1	$0.99	$0.99
Weapon Motor - Brushless	Turnigy 2815 EDF Outrunner 4000kv for 55/64mm	Electronics	L51 x D28	https://hobbykir	1	$13.69	$13.69
Mounting Hardware, Weapon Motor	316 Stainless Steel Hex Drive Flat Head Screw	Hardware	90 Degree Countersink, M	https://www.mc	1	$3.91	$3.91
XT60 Connectors	Genuine XT60 Nylon Connectors Male/Female (5 pairs)	Electronics		https://hobbykir	1	$3.41	$3.41
Weapon Shaft Pulley	FingerTech S3M Timing Pulley	Weapons	30 Tooth	https://www.fin	1	$5.89	$5.89
Motor Pulley	FingerTech S3M Timing Pulley	Weapons	15 Tooth	https://www.fin	1	$4.51	$4.51
Belt, Timing	FingerTech S3M Timing Belt	Weapons	67 Tooth - 201 mm	https://www.fin	1	$2.95	$2.95
Bearing	Ball Bearing, Shielded, Trade Number R6-2Z, for 3/8" Shaft Diameter	Weapons	ID 0.375", OD 0.875", W 0	https://www.mc	2	$6.45	$12.90
Drum Material	7075 T6 Aluminum Round Bar	Weapons	OD 1.75" X L 2"	https://www.mi	1	$10.53	$10.53
Weapon Studs/Set Screw	18-8 Stainless Steel Hex Head Screw (50 Pack)	Weapons	1/4"-20 Thread Size, 7/8" L	https://www.mc	1	$4.41	$4.41
Weapon Shaft	7075 T6 Aluminum Round Bar 3/8	Weapons	OD 0.375" X L 12"	https://www.mi	1	$7.52	$7.52
Wheels	BaneBots Wheel, 2-7/8" x 0.8", Hub Mount, 40A, Orange	Drivetrain	2.875" x 0.8"	http://www.ban	2	$2.45	$4.90
Wheels	BaneBots Wheel, 2-7/8" x 0.8", Hub Mount, 60A, Black	Drivetrain	2.875" x 0.8"	http://www.ban	2	$2.45	$4.90
Hubs, Wheels	T81 Hub, 4mm Shaft	Drivetrain		http://www.ban	2	$3.15	$6.30
Ball Caster	Recessed Flange-Mount Ball Transfer	Drivetrain	D21/32" x H27/32"	https://www.mc	1	$5.92	$5.92
Frame Material	UHMW Polyethylene Sheet 8" x 10" x 0.125"	Armor/Frame	L 10" X W 8" X 0.125"	https://www.fin	1	$6.24	$6.24
Frame Material	UHMW Polyethylene Sheet 8" x 10" 0.375"	Armor/Frame	L 10" X W 8" X 0.375"	https://www.fin	1	$12.13	$12.13
Armor Plate Material	Polycarbonate Sheet 1/8	Armor/Frame	L 8" X W 10" X 0.125"	https://www.fin	1	$6.75	$6.75
Armor Plate Material	Polycarbonate Sheet 1/16	Armor/Frame	L 8" X W 10" X 0.0625"	https://www.fin	1	$5.72	$5.72
Machining, Weapon Drum	4x Facing, 4x Drill & Tap, 1x Drill	Weapons		1819	1		$0.00
Machining, Weapon Shaft	1x Turning	Weapons		1819	1		$0.00
Battery to Charger Adapter	T-Connector to XT60 Battery Adapter Lead (2pc)	Electronics		https://hobbykir	1	$3.27	$3.27
Shipping, Banebots				http://www.ban	1	$8.75	$8.75
Shipping, Finger Tech				https://www.fin	1	$17.70	$17.70
Shipping, Robotshop				https://www.rob	1	$2.99	$2.99
Shipping, Midwest Steel Supply				https://www.mi	1	$10.00	$10.00
Shipping, Pololu				https://www.pol	1	$2.22	$2.22
Shipping, Mcmaster				https://www.mc	1	$5.99	$5.99
Shipping, Hobby King				https://hobbykir	1	$15.10	$15.10

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Project Management: Actual Budget

Total Cost	Out of Pocket	Budget
$400.14	$60.14	$340.00

6	Description*	Qty.	Price Per Unit	Total
7	Wheels - BaneBots Wheel, 2-7/8" x 0.8", Hub Mount, 40A, Orange	2	$2.45	$4.90
8	Wheels - BaneBots Wheel, 2-7/8" x 0.8", Hub Mount, 60A, Black	2	$2.45	$4.90
9	Hubs, Wheels - T81 Hub, 4mm Shaft	2	$3.15	$6.30
10	Shipping, Banebots	1	$8.75	$8.75
11	Weapon Shaft Pulley - FingerTech S3M Timing Pulley 30T	1	$6.07	$6.07
12	Motor Pulley - FingerTech S3M Timing Pulley 15T	1	$4.64	$4.64
13	Belt, Timing - FingerTech S3M Timing Belt 201mm (67T) (60)	1	$3.03	$3.03
14	Frame Material - UHMW Polyethylene Sheet 8" x 10" x 0.125"	1	$6.43	$6.43
15	Frame Material - UHMW Polyethylene Sheet 8" x 10" 0.375"	1	$12.50	$12.50
16	Armor Plate Material - Polycarbonate Sheet 1/8	1	$6.96	$6.96
17	Armor Plate Material - Polycarbonate Sheet 1/16	1	$5.89	$5.89
18	Shipping, Finger Tech	1	$17.70	$17.70
19	Brushless ESC - Turnigy MultiStar 20A BLHeli-S Rev16 V3 ESC 2~4S (Opto)	1	$10.59	$10.59
20	LiPo Battery - Turnigy Graphene 1000mAh 3S 45C LiPo Pack w/XT60	2	$13.45	$26.90
21	LiPo Bag - Turnigy® Fire Retardant LiPoly Battery Bag (190x68x50mm) (1pc)	1	$2.95	$2.95
22	Battery to Charger Adapter - T-Connector to XT60 Battery Adapter Lead (2pc)	1	$3.27	$3.27
23	Shipping, Hobby King	1	$15.10	$15.10
24	Transmitter & Receiver - Turnigy T6A-V2 Mode 1 AFHDS 2.4GHz 6Ch Transmitter w/Receiver	1	$30.59	$30.59
25	XT60 Connectors - Genuine XT60 Nylon Connectors Male/Female (5 pairs)	1	$3.41	$3.41
26	Weapon Motor - Brushless - Turnigy 2815 EDF Outrunner 4000kv for 55/64mm	1	$13.69	$13.69
27	Mounting Hardware, Weapon Motor - 316 Stainless Steel Hex Drive Flat Head Screw	1	$3.91	$3.91
28	Bearing - Ball Bearing, Shielded, Trade Number R6-2Z, for 3/8" Shaft Diameter	2	$6.48	$12.96

6	Description*	Qty.	Price Per Unit	Total
29	Weapon Studs - 18-8 Stainless Steel Hex Head Screws (5 Pack)	1	$7.01	$7.01
30	Key, Shaft to Weapon - Zinc-Plated 1018-1045 Steel, 12" Long, 3/32" x 3/32"	1	$1.86	$1.86
31	Ball Caster - Recessed Flange-Mount Ball Transfer - Steel Housing, 0.625" Diameter Steel Ball	1	$5.04	$5.04
32	Self Tapping Screws - Phillips Rounded Head Thread-Forming Screws - for Plastic, 18-8 Stainless Steel, Number 0 Size, 3/8" Long	1	$12.69	$12.69
33	Drive Motors - Brushed Gear - 63:1 Metal Gearmotor 20Dx43L mm 12V CB	2	$21.95	$43.90
34	Motor Mount, L-Bracket, Pair, D20 mm - Pololu 20D mm Metal Gearmotor Bracket Pair	1	$6.95	$6.95
35	Mounting Hardware, Motor Mount - M3, Machine Screw	1	$0.99	$0.99
36	Shipping, Pololu	1	$2.22	$2.22
37	UBEC - RMRC 5A Power Regulator 5-6V UBEC	1	$5.99	$5.99
38	Shipping, RaceDayQuads	1	$3.56	$3.56
39	Brush ESC - Readytosky RC 20A Brush ESC Motor Speed Controller w/Brake for RC Car Boat Tank(2PCS)	1	$14.99	$14.99
40	Weapon Shaft - High-Strength 7075 Aluminum Rod 3/8" Diameter, 24" Long	1	$8.66	$8.66
41	Weapon Drum - High-Strength 7075 Aluminum Rod 1 3/4" Diameter, 6" Long	1	$27.46	$27.46
42	Duracell - CopperTop AA Alkaline Batteries - 8 Count	1	$6.99	$6.99
43	Brass Inserts 6-32 internal threads	4	$1.44	$5.75
44	Brass Slotted Flat Head Screw 6-32 Thread Size, 1/2" Long	8	$0.29	$2.33
45	18-8 Stainless Steel Slotted Flat Head Screws M2.5 x 0.45 mm Thread, 12 mm Long	4	$0.38	$1.50
46	16 Guage Wire	1	$0.50	$0.50

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APPENDIX D: TECH EXPO VIDEO

Video available in the UC repository.