2019 UC MET Battlebot Team

15lb Combat Bot Design

A Baccalaureate Thesis Senior Design Report submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
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in partial fulfillment of the
requirements for the degree of

Bachelor of Science
in Mechanical Engineering Technology

by

Markus Cheslock
Justin Giese

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Thesis Advisor: Professor Janet Dong, Ph.D.

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University of Cincinnati's Battlebot Club provided funding towards purchased parts and knowledge towards the battlebot process and competition. The members of the battlebot team helped us with recommendations towards our design and to provide instruction on safety procedures within the competition. The club also provided the funding to purchase most of the components needed to complete our bot.

We are grateful to all of those with whom we have had the pleasure to work with during this project. Each person directly involved in this project has helped to provide personal and professional guidance to teach us the necessary knowledge in completing a fighting robot.

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Tables and Figures

Problem Statement

Our team will be competing in the Dayton held Xtreme Collegiate Clash 15lb combat competition. The competition has a list of rules and regulations that must be followed to compete, as well as safety guidelines that are set standard by the Fight Robot Association.

Our team will have the opportunity to design and manufacture the 15lb bot to compete in at the Collegiate Clash competition. Responsibilities for the designing a successful robot include the key areas of; Armor/Body, Weapon, Drivetrain, and Electronics. Markus will design the drivetrain and electronics. Justin will design the armor/body and weapon.

To design and build a successful combat bot, we will have to improve on previous and current designs through the defensive and offensive methods of robot combat.

Our team is split into two sub-teams. Our sub-team will develop the combat bot for the competition, while the other team will develop a test/combat arena for future competition uses. The team members designing the arena are Logan Jackson and Kialee Koch.

Research

Background of the Competition

Xtreme Collegiate Clash is a college only competition for combat robots that is hosted by Xtreme Stem. Xtreme Stem is a Dayton local organization that provides hands-on programs that engage students in Science, Technology, Engineering, and Mathematics (STEM) with a career path in manufacturing (1). Xtreme Stem is under the umbrella of the Ohio based company, Ohio Robotics Inc. ORI is a nonprofit organization dedicated to building a stronger and smarter workforce. The mission of ORI is to “provide workforce development initiatives that promote clear career paths in advanced manufacturing through science, technology, engineering, and math (STEM) disciplines that enhance critical thinking, leadership, and team-building skills.” (2)

The competition has posted a set of rules and regulations that states the requirements for each combat bot competitor. Within this document, the rules have limitations on the electronics and controls. The following information sections states these limitations. This information will reference the rules and regulation document within the appendix.

Commonly used weapon designs

Probably the first consideration for the design of a battlebot is the weapon. This is the part of the robot that will be doing all the destruction of other team’s robots. Throughout the various forms of battlebots over the years there have been multiple commonly seen weapon designs. These designs include crushers, drums, flippers, spinners, and ramps.

Crusher

This type of robot is meant to grab on to an opponent’s robot and then bend the frame and other components of the opponent’s robot. The advantages of the crusher are the ability to knock out your opponent’s bot with one well-placed shot as well as being able to add on more features (3). The disadvantages are you need a good driver and the robot could be difficult to maneuver with the additional weight.

Drums

Drum type robots work by using a heavy, spinning mass at the front of the robot. This allows the robots to do lots of damage to and can even throw their opponents (3). The advantages of a drum robot are they can do a lot of damage and you can build a sturdy frame. The disadvantage is the robot is hard to control because of the spinning mass at the front.

Flippers

The flipper type robot works by using a powerful arm to flip the opponent's robot. The advantage of this kind of robot is it is possible to take out your opponent in one shot depending the robot's configuration (3). The disadvantages of these robots are you need a good driver and your arm can be easily ripped off by other types of robots.

Spinners

Spinner type robots combine offense and defense into one function (3). This is done with their spinning weapon. To hit a spinner type robot, you are going to be hit by its weapon. The advantages of this kind of robot are the weapon is its offense and defense; and you don't need a skilled driver. The disadvantages are they can be self-destructive and are hard to design.

Ramps

A ramp style battlebot work by having a large ramp on the robot that is then used to drive your opponent's robot into the wall of the arena or any arena hazards (3). The advantages of ramp type robots are they have great defense and they are easy to design. The disadvantages are they do not have much offense and they require a skilled river.

Armor and Frame Research

The design of the armor and the frame of the robot will heavily affect how the robot functions. The frame shape will not only effect how we place internal components but how the robot will handle. The frame of the robot will need to be able to handle the weapon we choose for competition. The armor we decide on for the robot will need to be strong enough to take blows from weapons of other robots in our weight class but still be light enough, so we stay within our weight class. The commonly seen types of battlebot frames are a box frame and a spinning frame.

Box Frame

The box frame is a simple frame design that is very commonly seen in battlebot competitions. The box frame allows for multiple different weapon types such as a roller or ramp. This type of frame also gives plenty of internal room for components such as the drive train while still being able to stack on lots of armor (4). The main disadvantage of this type of frame is the vulnerability to being flipped. I f the wheels are placed underneath the robot it could be rendered immobile by a flipper or spinner.

Spinner Frame

The spinner frame is a complicated design with a weapon spinning around the entire outside of the robot. This type of robot can forgo have much armor of the frame in favor of putting its weight into a strong spinning weapon that will act as a weapon and armor at the same time (4). The main disadvantage of this kind of robot is it can lift itself off the ground if it hits a well armored robot.

Electronics and Controls

BattleBots are radio-controlled robots that use various electronics to provide wireless control and movement for the robot. Such electronics are; Transmitter, receiver, motors, electronic speed controllers, motor controller, batteries, and various electrical wires and connectors. Using the rules and regulations of the competition, the following background data will represent that various electronic components allowed within the competition.

Transmitters and Receivers

The control of the robot from the operator is made capable by a transmitter and the receiver. Transmitters are the controllers that the operator uses to give input signals to the robot. The signals sent from the transmitter are designated to channels. Depending on the number of channels and style of bot, there are multiple options for transmitters (5). There are transmitters that are available for drones, planes, cars and helicopters. The transmitter commonly used in battle bots is the flat style two joystick transmitter. These transmitters range from 4 channels to 14+ channels. The competition permits the use of two brand name transmitters, Spektrum(preferred) or Hobby King 2.4 GHz spread spectrum radio systems. The number of channels used is up to the competitor, but the competitor would need to at least use one channel for forward and reverse, one channel for turning, and one channel to activate a weapon, if used (5).

The receiver is the device that receives the signal from the transmitter and delivers the output to the robot electronics. Receivers range in the number of channels. Each channel on the receiver will have its own connecting point. Typically, the number of channels the transmitter has will match the number of channels in the receiver. Manufacturers will typically make their receivers only compatible to their transmitters, but some brands can be cross-compatible.

Electric Motors and Electric Speed Controllers

There are two types of electric motors: brushed and brushless. Both electric motors work by sending electricity through the copper windings that temporarily form a magnetic field that repels or attracts against stationary magnets (6). The force produced is converted into shaft rotation. The motors have two main parts; the rotor which is the rotating part, and the stator which is the stationary part of a motor. In a brushed motor, the copper windings are on the rotor, while the brushless has the windings on the stator, eliminating the need for the brushes (6).

Brushed motors are the original form of electric motors. They are the ideal choice for budget friendly project. Due to the low cost, the brushed motor is more commonly used in various store-bought radio-controlled vehicles. The brushed motors are run off DC power and allow for direct power to motor control. The use of and Electronic Speed Controller (ESC) allows for the control of the voltage going to the battery. With less voltage, a motor will spin slower. The Brushed motor ESCs are less complicated than the Brushless ESC (7). The disadvantages of the brushed motors are the need for maintenance due to the wearing parts within the motor. The motors also are less power efficient with averaging ratios around 75-80%.

Brushless motors are newer to the RC community. Although brushless motors get their power from DC power sources, the ESC used with a brushless motor converts the direct current into an articulating current. They offer longer life spans due to less wearing parts within the motor and create higher power ratios range from 80% to as high as 95%. Brushless motors are rated in a kV rating. The rating is a constant (k) multiplied by the voltage. the voltage from the battery is multiplied by the kV rating to give you a rotational speed in rpm (7).

Another common electronic used with robot vehicles are motor controllers. From the transmitter to the motors, without some sort of program controller, the motors will output at the given signal input. When a vehicle has one motor, the transmitter will give the control needed. If there are two motors to control the drive, the motors would either need to be on two separate channels to control each individually, or a motor control would need to be added in to control both motors with one channel. This is helpful for using one joystick on the transmitter to control the movements of forward, back, left and right. The controller uses software programming to manipulate input signals from two channels from the transmitter into one output channel to the motors, controlling two motors at various speeds to give a tank style movement. There are motor controls that can control more output motors from given input signals.

Batteries

Radio controlled vehicle batteries come in various types such as; nickel cadmium (NiCad), nickel metal hydride (NiMH), lithium iron phosphate and A123 (LiFePO4), and lithium polymer. The competition prohibits the use of lithium polymer due to fire and explosion hazards that come with damaged batteries (8).

Nicad batteries are one of the oldest forms of power source for radio-controlled systems and have been widely replaced by newer power sources. The advantage of these batteries are their low internal resistance and high currents, low self-discharge, and their ability to withstand lower temperatures. What makes these batteries less valuable are the fact that they are heavier than other battery types, suffer from memory/voltage-depression, and are considered environmentally unfriendly. The voltage-depression refers to a tendency for the batteries to lose capacity from being discharged only partially instead of fully. This can be avoided by allowing batteries to discharge to their safe amounts regularly (8).

Nickel metal hydride batteries are a form of battery that have been used to replace the nicad batteries. The early forms of NiMH batteries had problems within radio-controlled system, but with time have advanced to become a compatible source of power (8). NiMH have high capacities, no memory/voltage-depression effects, and are less environmentally unfriendly than the NiCad batteries. The problem with this battery type is their self-discharge rate over time is quicker than others, can be delicate with larger sizes, and tend to have less power capacity than what is advertised on them. These batteries require a process that allows their maximum capacity to be reached. This process can take quite some time (8).

Lithium iron phosphate batteries are the newest form of battery that take the safety and durability of nicads and adds the capacity and light-weight of a lithium polymer. LiFe batteries have high power to weight ratio, very low self-discharge rate, and have a higher durability to over-charging and discharging. These batteries are becoming the battery type that is the safest for all radio-controlled vehicle types (8).

Drivetrain

Combat robots use various styles of drive trains to send power to the wheels. Due to the combat robots using high rotational speed motors, the robot will typically utilize a speed reducer or gearbox to reduce RPMs and increase torque. After the gearbox, depending on the drive style the robot, a robot will usually incorporate a belt or chain drive. In some cases, a robot may use a drive shaft. Other robots can be direct drive from the reducer to the wheel, mounting the wheel straight to the shaft of the reducer.

Gearbox

Gearboxes are known as contained gear trains. The gearbox contains a series of integrated gears that are housed within a container. The boxes are built to size and come as a unit (9). The gearboxes can come in different combinations such as bevel gears, spiral bevel gears, worm gears and other planetary gear systems (9). The purpose of a gear box is to increase or reduce rotational speed and torque from the input to the output. Within a gear, the driving gear is coupled to the driving mechanism (motor) which connects to the next gear being larger or smaller depending on the desired output (10). The gearbox also reduces the inertia of a load from the motor. The square of the ratio is what the inertia is reduced or increased by (10). The gear box is usually used from the motor to the drive wheels to reduce the RPMs and increase torque. It is common to find between a 15:1 and a 20:1 reducer.

Belt

Belt drives are strips of flexible material that is looped between two or more pulleys on a rotating shaft. Belt drives offer smooth transfer of power between an input and output while offering a relief to hard shocks from the flexibility of the belt (11). Some of the different belt types are; Flat, Vee, Poly-Vee, Timing/Synchronous, and Vee Link Belts. The flat belt transfers power by friction of the belt over a pulley. The flat belt needs a tensioner to keep the friction high enough to spin the pulleys. This type of belt is susceptible to slippage. The Vee belt offers better power transfer than the flat belt (12). This belt usually is used in pairs or more to add strength. The poly-vee belt is a vee belt with multiple groves. Allows for the use of one belt with the same qualities as using multiple vee belts. The timing/synchronous belt has teeth on the interior of the belt that match with grooved pulleys. Provides limited slippage but can only be used in lower powered applications. Linked belts are belts that link together providing the ability to adjust the length of the belt and be easily installed (12). Commonly used in robots, the most likely used belts are the flat belts and timing belts. These belts transmit the needed power while allowing slippage during high impact cases.

Chain

Chain drives are like the belt drives but add more rigidity and remove the slippage. Chain drives utilize sprockets, which have numerous teeth, instead of pulleys (13). The sprocket is a toothed wheel that attaches to an input or output shaft. A key is used to lock the sprocket in place. The chain connects to two sprockets to drive from input to output (13). For combat robots, the use power transmission chains, which drives power from the input sprocket to the output sprocket. This type of chain is a standard general-purpose roller chain.

State of the Art

Weapon and Armor

There are many ways to design the weapon and armor for a battlebot. Some methods are more popular than others and start trends in the battlebot community. Below are examples of well-known and successful battlebots.

The robot shown in figure 1is named minotaur. It has a box frame, with two wheels, and a drum roller type weapon. This battlebot has become famous due to its success on the Battlebots tv show with a 10-3 record in two years of competing. This record can be attributed to its weapon and overall profile of the battlebot. Its weapon will often toss opponents on impact causing additional damage. Minotaur is also a shorter box frame battlebot making it able to take multiple hits and keep going. Another strength of minotaur is the battlebot is it can still move and attack after being flipped due to its two-wheel design.

Figure 1: Minotaur

The robot shown is figure 2 is another battlebot famous from the Battlebots tv show and that is Tombstone. Across three years of competing Tombstone has an impressive 15-2 record. This can be attributed to Tombstone being design around its large horizontal spinner weapon. The weight and speed of this weapon allows it to do high amounts of damage on each hit. Like Minotaur, Tombstone is a two wheeled design but it is vulnerable to flipping because its wheels are not large enough.

Figure 2: Tombstone

Electronics and Controls

With combat robots being popular in all locations nationally and internationally, there are hundreds, if not thousands, of unique variations to a combat robot out there. The following listed below are examples of common trends throughout the battlebot community.

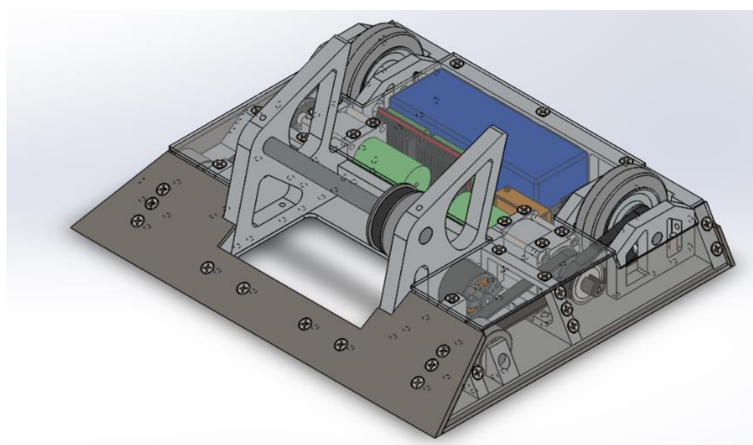


Figure 3: Lucas Grell's Battlebot

The robot in figure 1 to the right shows an example of a common drive style for a two-motor drive with belt drive. This option gives the advantage of using two motors to drive four wheels, along with adding a gear ratio (14). The ratio between the drive motors and the wheel will decrease the rotational speed of the drive wheel, while increasing the torque to the wheels. The weapon is controlled by a brushless motor to increase torque and rotational speed (14). The brushless set up is preferred for the weapon motor due to its single direction rotation and better power efficiency ratio. The drive motors are 1800kV brushless motors in line with Banebots 16:1 Gearbox. The power system is 4 A123 battery cells which outputs 13.2 nominal volts (14). This setup utilizes the power output for two drive motors and a weapon motor. The advantage to this design is high output torque and rotational speeds. The drawback to this design is the high cost for the brushless motors.

Figure 4: Team Toad: FrostBite 3.0

The robot in figure 2 utilizes the chain method to transmit power from the rear wheels to the front wheels. The rear wheels receiver power from one motor each. Each motor connects to a gearbox when connects directly to the wheel. The rear wheels have sprockets which chain drives to the front sprocket with a 1:1 ratio. The weapon is driven by a v-belt belt (15). The advantage of using the chain drive for this team is that it provides a more rigid power transmission from the rear wheels to the front wheels. The drawback of this design is the potential danger of losing the chain from a direct hit. Due to chains being brittle to high impacts, one hit from a weapon could shear the chain and leave the drive chain unbalanced.

The robot in figure 3 incorporates the direct drive method to provide power to the wheels by using two motors to connect directly to a gearbox reducer to the drive shafts (16). This method eliminates the possibility of losing power to the wheels by removing the belts and chains. The drawback of this method is that it only provides two wheels of motion and a reduction in traction. The weapon uses a belt drive that receives power from a single motor. The power for this robot uses a two-pack system, one for the weapon and one from the drive motors (16). This gives the advantage of having separate power draws from each system. If one power bank dies, the robot would still be able to function in one aspect, whether it be drive, or weapon.

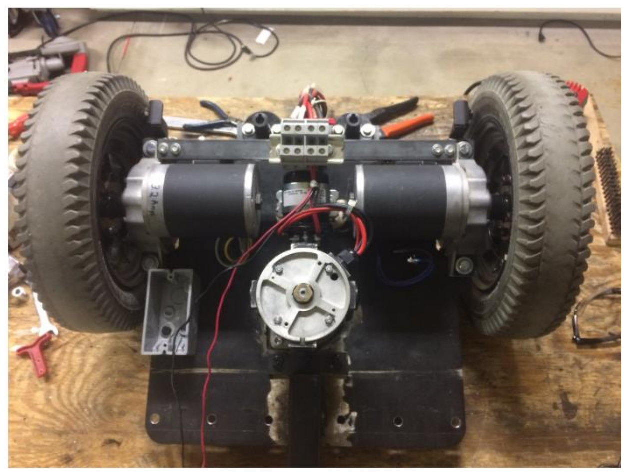


Figure 6: Reno Robot Club

Figure 5: Reno Robot Club

End User

Our customer is the Xtreme Collegiate Clash 15lb combat competition. The competition requires the design of a 15lb combat robot to compete. The design requirements must be met to compete and to please the judges. The goal of the competition is to not only disable the opponent, but to also gain points from other key aspects such as weapon effectiveness and armor durability. The competition wants the competitors to put on a satisfying show for the audience. Our team will design and manufacture a combat robot that will meet competition requirements and ensure victory.

Summary of the Research

The research for the combat robots has shown that frame design and weapon design often go hand in hand. This is due to needing an appropriately designed frame to accommodate you weapon. A box frame can accommodate most weapons but space for weapon and belt placement is needed. Keeping enough internal space for components such as motors and batteries is critical to the design of a battlebot as well. A fight can decided by a battlebot being unable to move so a battlebot that can still move and attack after being flipped is needed. This can be easily achieved with a two wheeled design and a weapon that is equidistant from the top and bottom of the frame.

For the electronics and controls design area, there are key aspects that allow the operator to maximize the efficiency of the control for the robot. Using power efficient motors such as the brushless motors to provide power to the wheels will increase torque and rpm while also decreasing power consumption. Utilizing gearboxes from the motors to the wheels will allow for high rpm motors to maximize torque outputs to the wheels. The use of a motor controller will help to provide control of the robot using one stick on the transmitter, while also providing weapon speed control. The drivetrain design works best when using belts or chains to transmit power from the motor to the weapon while increasing torque outputs for the weapon. With the combination of the proper electronics and drivetrain components, the combat robot control can have a very efficient system for movement.

Quality Function Deployment

Customer Features

Importance from greatest to least. Each feature is weighted to equal a total of 1. The customer features are weighted based on survey responses, interview responses, and personal preference.

1. Radio controlled mobility – (0.14)
2. Overall size – (0.13)
3. Indicator Lights – (0.12)
4. Flip capable – (0.10)
5. Radio controller type – (0.10)
6. Maneuverability – (0.09)
7. Armor strength – (0.09)
8. Weapon size – (0.09)
9. Maintenance – (0.07)
10. Battery type – (0.07)

Engineering Characteristics

- Weight (<15lbs)
- Weapon Speed (RPM)
- Impact force (lbf)
- Unit Speed (FPS)
- Assembly time (mins)
- Battery Life (mAh)
- Controlled Mobility (Y/N)
- Controlled Frequency (GHz)

House of Quality

				Engineering Requirements (units)														Customer Satisfaction Rating (0.00 - 1.00)		
		Importance value (1-10)	Importance wt.	Weight (lbs)	Weapon Speed (RPM)	Impact force (lbf)	Unit Speed (FPS)	Assembly time (mins)	Battery Life (mAh)	Controlled mobility (Y/N)	Controller frequency (GHz)									
	Customer Requirements			1	2	3	4	5	6	7	8	9	10	11	12	13	14	CP	A	B
1	Battey type	5	0.07	3	3		3		9	1									0.50	1.00
2	Maintenance	5	0.07	3				9											0.50	0.75
3	Weapon Size	6	0.09	3	9	9	3												0.35	0.75
4	Armor strength	6	0.09	3		9													0.50	0.70
5	Maneuverability	6	0.09	1		3	3		1	9									0.60	0.80
6	Radio controller type	7	0.10							9	9								0.50	0.90
7	Flip Capable	7	0.10	3			3			9									0.50	0.75
8	Indicator lights	8	0.12						3										0.35	0.80
9	Overall size	9	0.13	9		3	3	9											0.50	0.50
10	Radio controlled mobility	10	0.14				3			9	9								0.70	0.70
	Total Importance	69	1.00																5.00	7.65
	Engineering requirement importance			2.52	1	2.22	1.43	1.83	1.09	2.68	0.91									
Performance	Current Product																			
	2017 Battlebots club "Jeff"			3	3	3	2	3	1	3	1									
	Harry Botter			4	3	5	3	3	3	3	3									
	New Product Targets			3.5	3	4.5	3	3	2	3.5	2.5									

Table 1: House of Quality

Interaction Matrix																
		Engineering Requirements	Weight (lbs)	Weapon Speed (RPM)	Impact force (lbf)	Unit Speed (FPS)	Assembly time (mins)	Battery Life (mAh)	Controlled mobility (Y/N)	Controller frequency (GHz)	0	0	0	0	0	0
Engineering Requirements			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Weight (lbs)		1		3	3	3	3	3								
Weapon Speed (RPM)		2			3			-1	3							
Impact force (lbf)		3				3			1							
Unit Speed (FPS)		4						-3	3							
Assembly time (mins)		5														
Battery Life (mAh)		6							1							
Controlled mobility (Y/N)		7								3						
Controller frequency (GHz)		8														
0		9														
0		10														
0		11														
0		12														
0		13														
0		14														

Table 2: Interaction Matrix

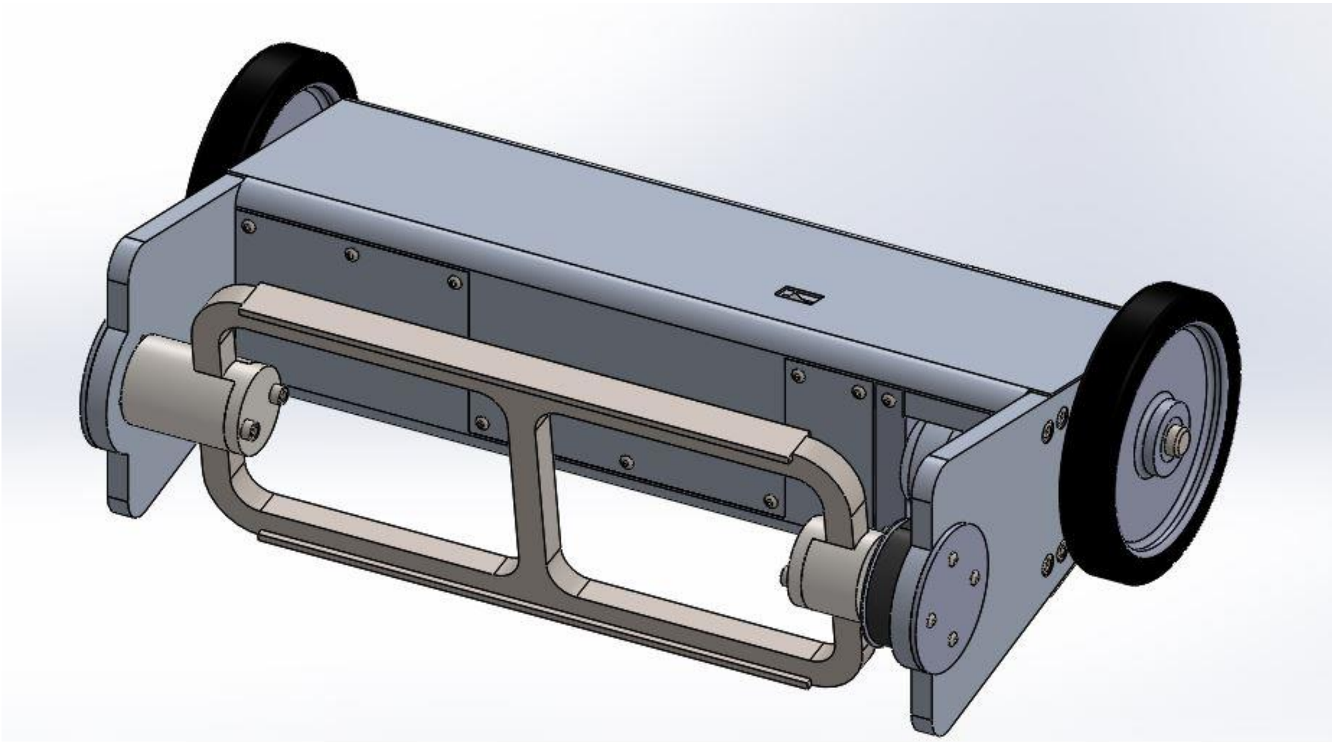
Product Objectives

The product objectives are ordered on priority of highest to lowest. For the objectives, the importance of each aspect needs to be addressed in the design to ensure a qualifying robot for the competition.

1. Radio controlled mobility
    a. Strong signal connection
    b. Correct frequencies
2. Overall size
    a. Cannot be over 15lbs
3. Indicator Lights
    a. Visible to show circuits have power
    b. Run in series with circuits

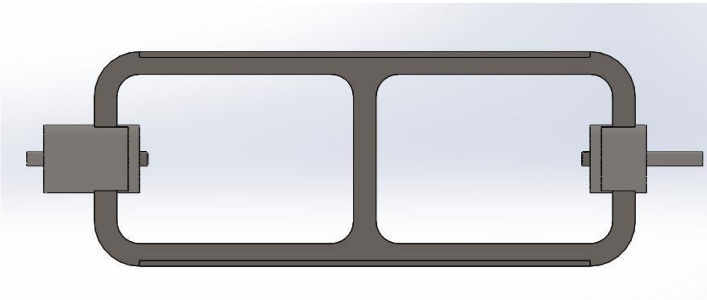
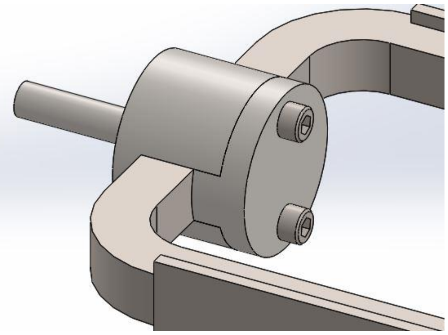
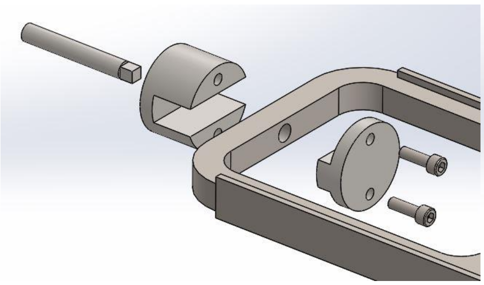
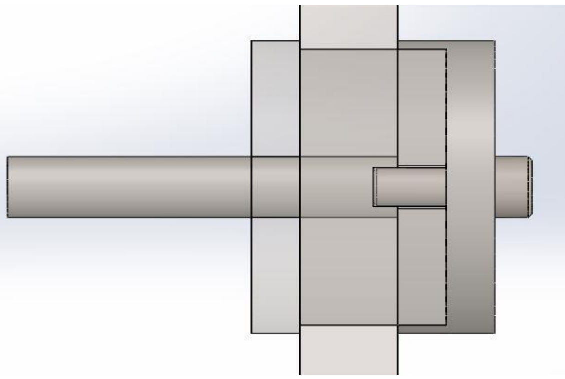
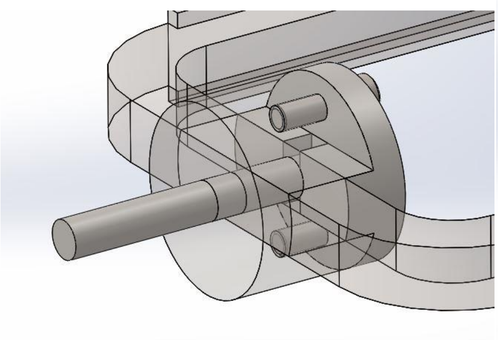
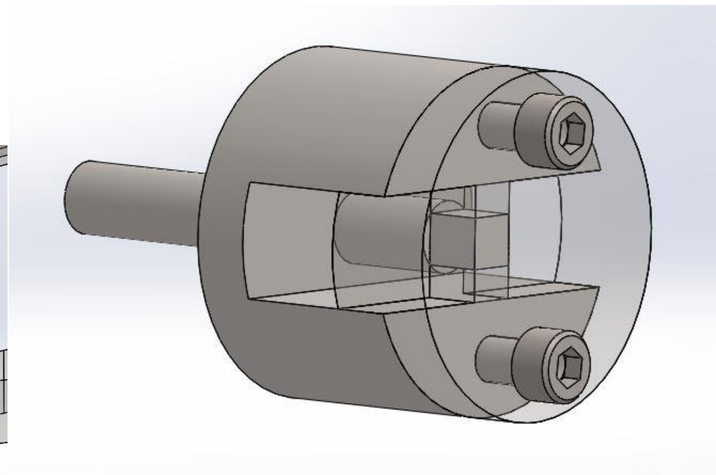
   c. Limit resistance
4. Flip capable
   a. Mobility from both sides of the robot
5. Radio controller type
   a. Spektrum transmitter
   b. Control all robot functions
6. Maneuverability
   a. Moves quickly
   b. Zero turn
   c. Directional
7. Armor strength
   a. Material type
   b. Material thickness
   c. Shape of armor
8. Weapon size
   a. The shape/style of the weapon
9. Maintenance
   a. Parts are swappable
   b. Can be disassembled/reassembled quickly
10. Battery type
   a. Cannot be LiPo
   b. Capacity
   c. Power

Design



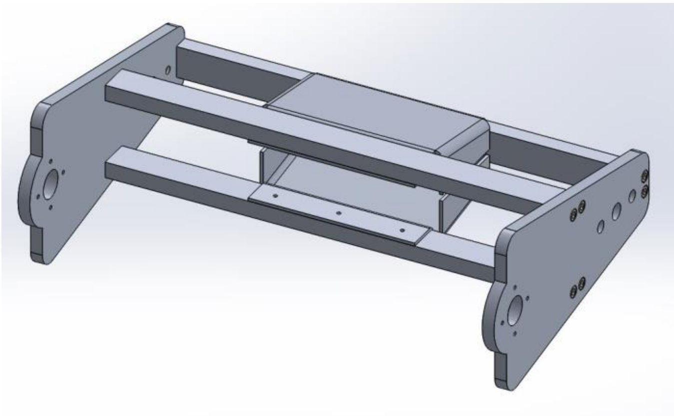
From our concepts and selection process (Appendix B), the design that we chose for our battlebot incorporates a high contact surface weapon with a wide face for an offensive attack. The weight distribution for our bot is mainly over the wheels which should allow for greater traction to the wheels. For chosen components, see Appendix A.

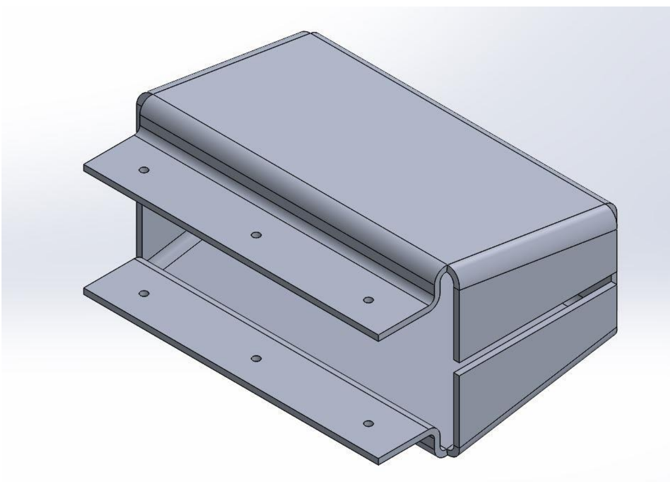
Weapon

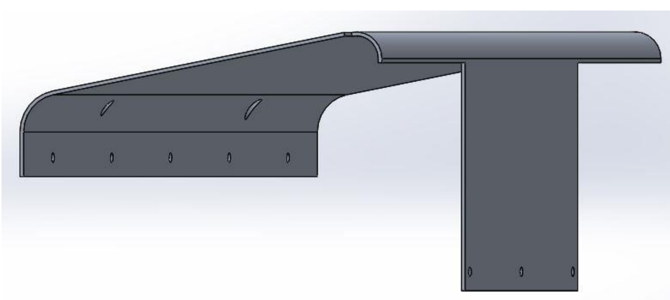
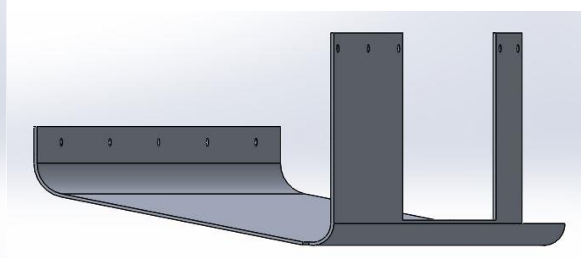







The weapon for our battlebot a vertical plate spinner with flared edges. This type of weapon will allow us to deal good damage on each hit as well a chance to throw our opponent. The flared edges give us an increased chance of hooking onto the opponent a throwing them. The shaft for the weapon will be attached to the weapon via a collar as shown above. This will allow us to easily and quickly disassemble the weapon assembly in-between matches if something were to break. For this reason, we have also decided to bolt the assembly together rather than something more permanent. The weapon and collars are made from 4140 steel and the shaft is made from 4340 steel.

Frame/Armor





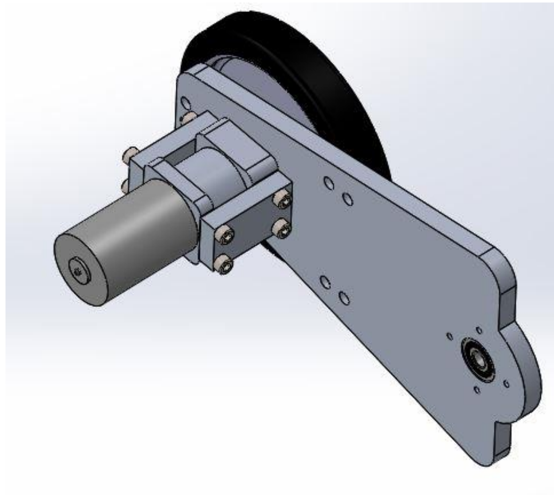



The frame consists of two side plates together with three crossbars between them. These crossbars are where we mount internal components such as the battery compartment as shown above. This frame is then wrapped in a shell. The shell is meant to prevent any particles or debris from getting inside the battlebot while the frame will act as the armor and absorb any hits we take. This is all bolted together for the same reason as the weapon. Without limited time between rounds if we need to swap out a battery, we need to be able to do it quickly. The frame is mad e out 7075-T6 aluminum and the shell is made out of 6061 aluminum.

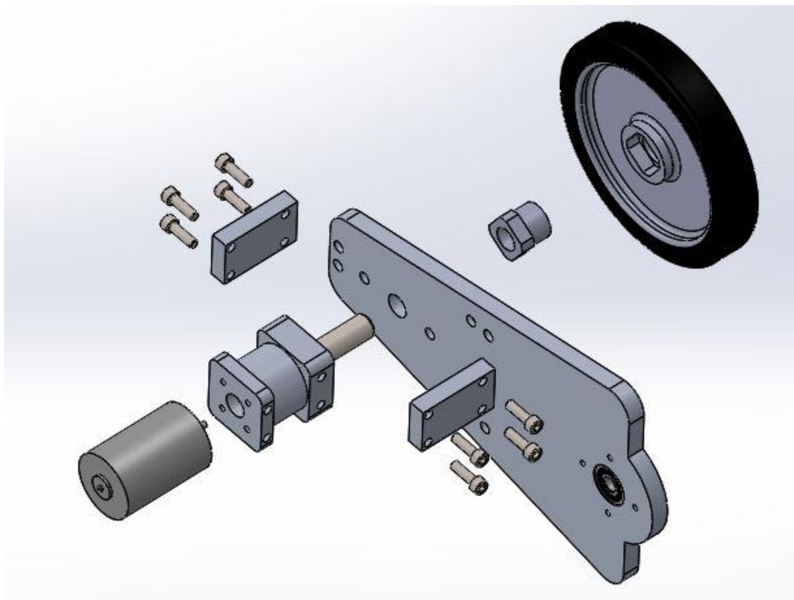
Drivetrain

Wheel Drivetrain

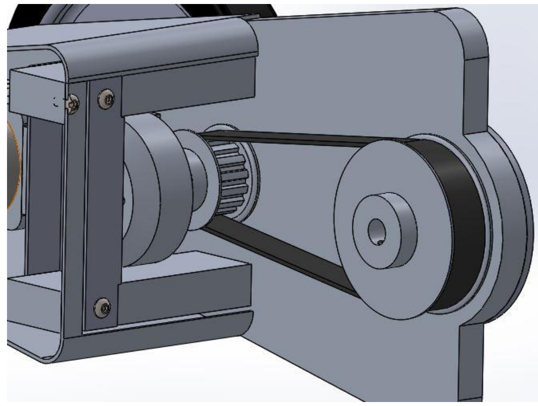
The drivetrain that controls the movement of the battlebot is accomplished using brushed motors and gearboxes. Our battlebot is designed using RS-540 sized motors that will be directly inserted into 20:1 gearbox reducer. This setup will allow for an efficient drive system at a low cost. Due to the nature of the combat bot, using parts that are easily replaceable and are cheaper is a high priority in the design process. For ease of assembly, the drives system was designed to allow for bolt together parts that can be easily disassembled and reassembled. Each drivetrain assembly is symmetric in design so that parts do not have to be specified between left and right. The parts that make up the drivetrain assembly are as followed:



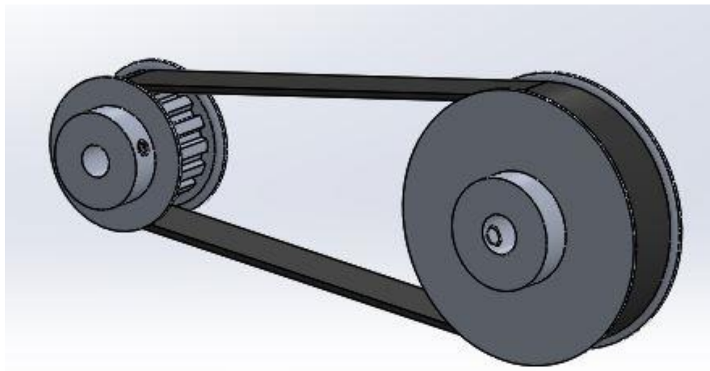
- Brushed motor
- Gearbox
- Gearbox mounting plates
- Hardware
- Side plate (frame)
- Wheel hub
- Wheel



Weapon Drivetrain



For the design of weapon power transmission, we implemented a belt drive system with the use of timing pulleys and belts. The timing belt assembly allows for a lightweight option for efficient power transmission from drive motor to the weapon pulley. The use of a belt also allows for slippage for high contact forces from the weapon, while providing a high output force to the weapon. The timing belt assembly is made up from the following components:

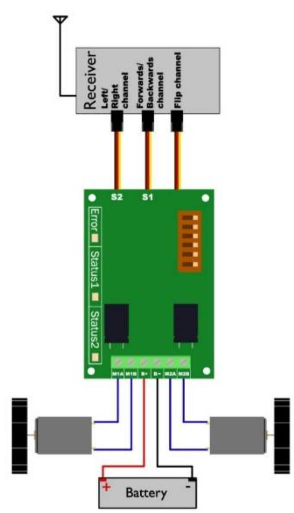


- Brushless motor
- Drive Pulley
- Timing Belt
- Driven Pulley

Electronics and Controls

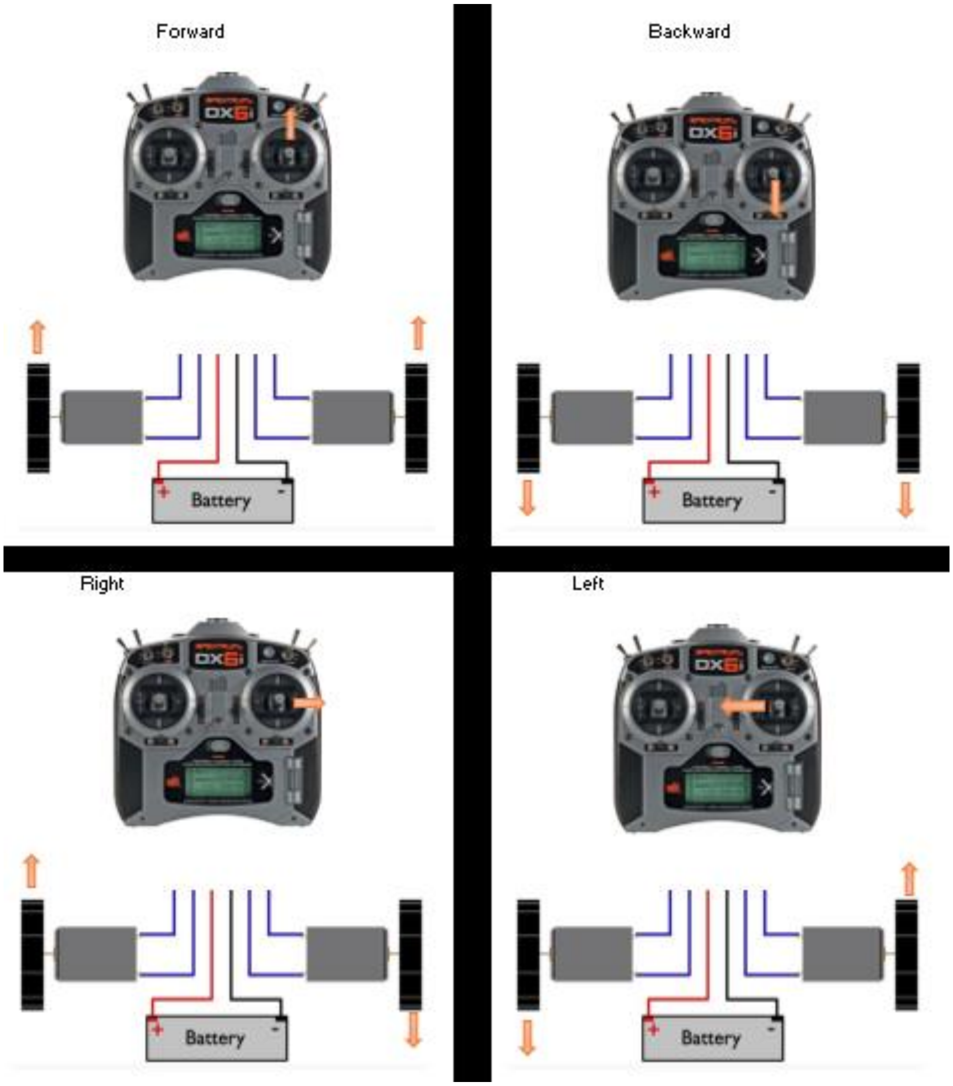
From the selection process, competition regulations, and feedback information from the battlebot club officers, most of our electrical parts will be donated from the battlebots club. The club is allowing us to use a transmitter/receiver (remote controller), batteries, and motor driver.

The motor driver is used to control two brushed motors for the drivetrain of the robot movement. For our design, our robot control will be modeled after a tank style, meaning that motor controller will need to mix the input controls of forward, backward, left and right to send the output controls to the two drive motors. The control components are as follows:

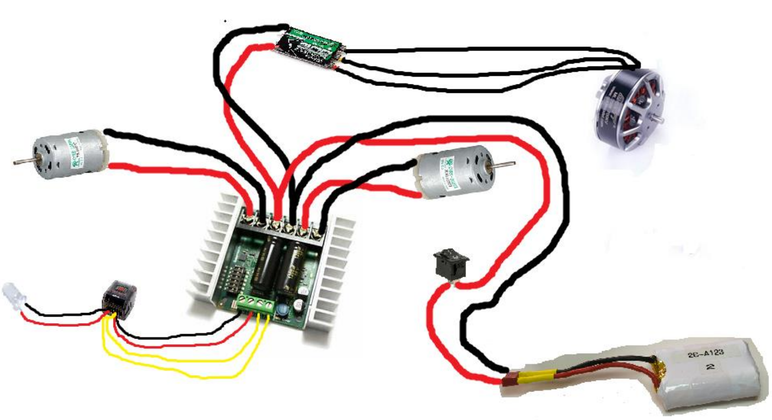


- Transmitter
- Receiver
- Motor controller
- Battery

The following diagram shows motor controller functionality:

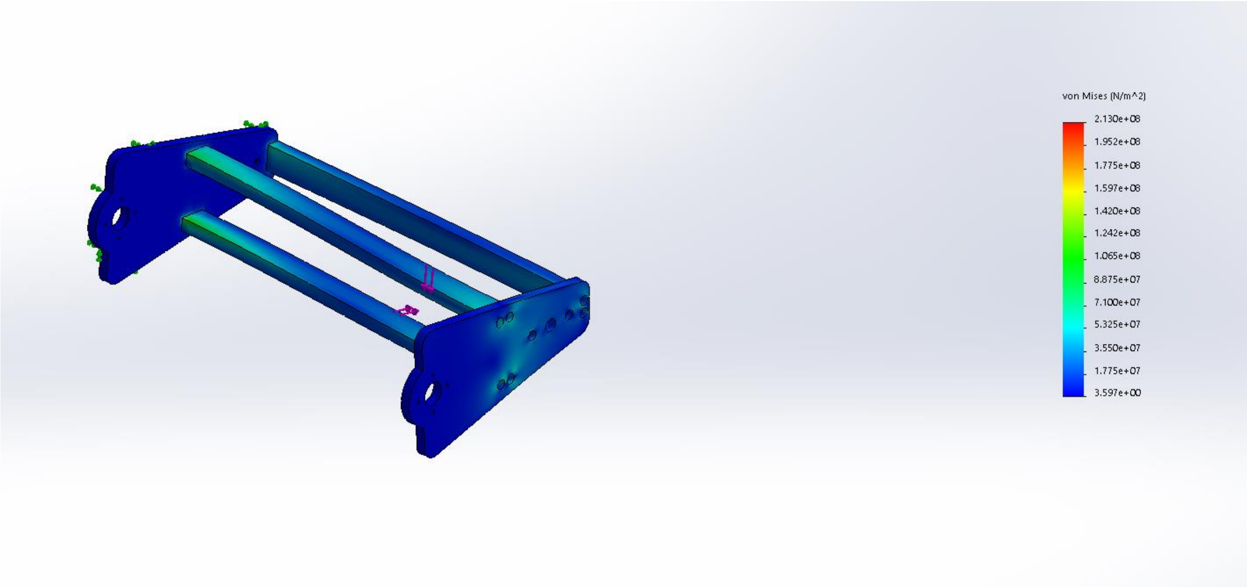


The following shows the diagram for the entire battlebot electrical components:



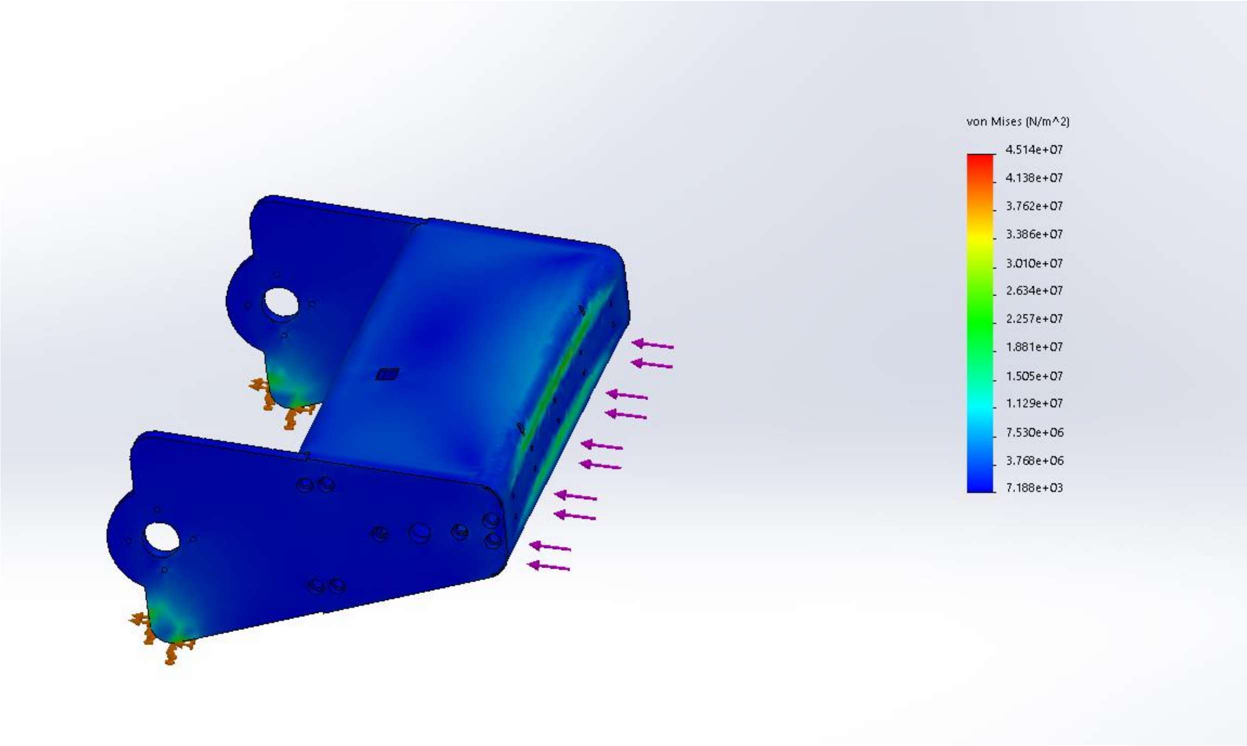
Stress Analysis

All our stress analysis was done using FEA in SolidWorks. Please note that the deformation for these stress analyses are exaggerated.



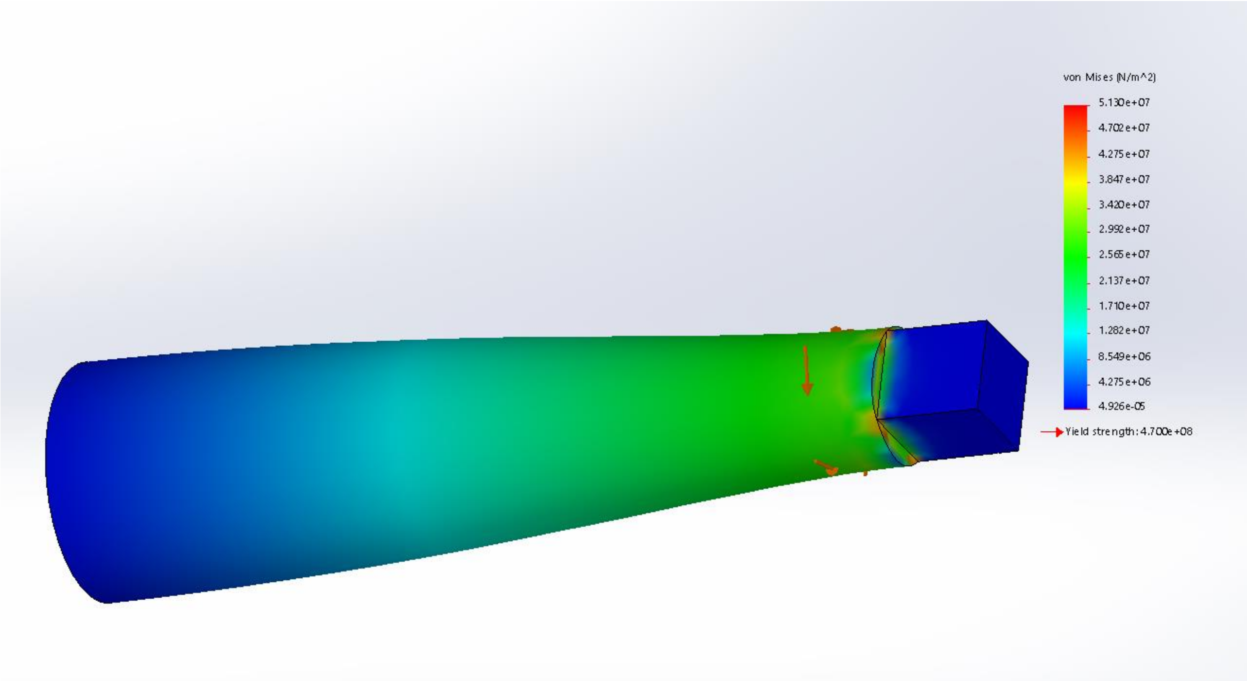
Frame

- Material is 7075-T6 aluminum with yield strength of 78,000 psi
- 200 lbf applied to side plate



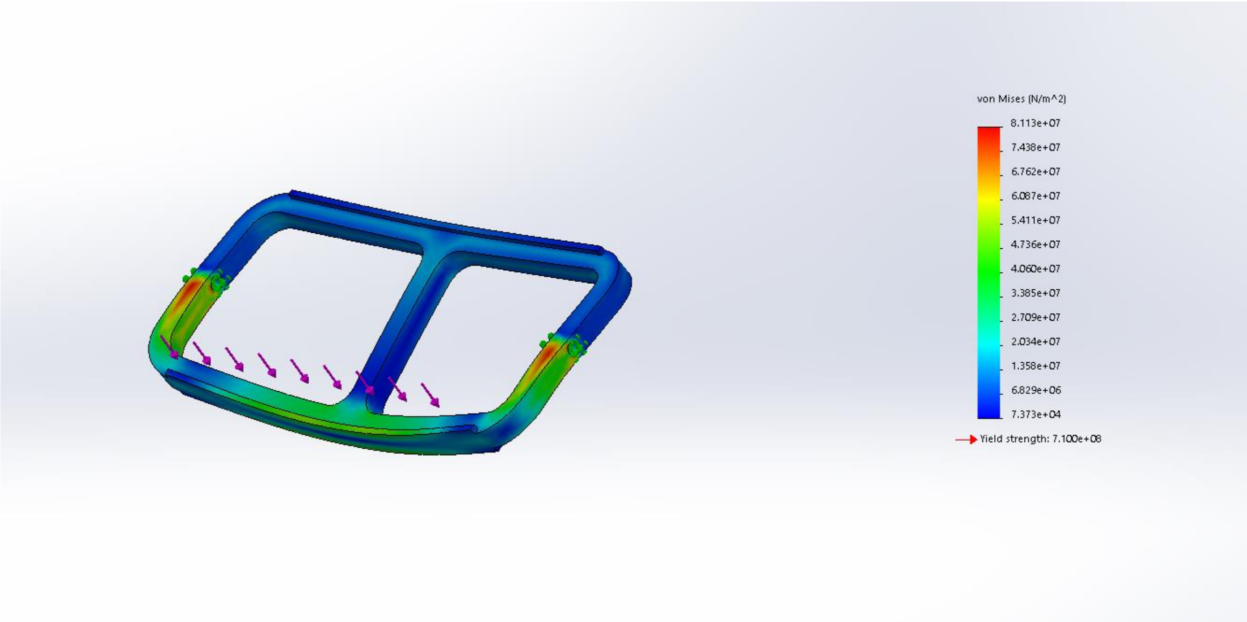
Frame with shell

- Material is 7075-T6 and 6061 aluminum with yield strength of 78,000 psi
- 200 lbf applied to the rear of the shell



Weapon shaft

- Material is 4340 steel with yield strength of 71,000 psi
- 20 lb-in torque applied to shaft



Weapon

- Material is 4140 steel with yield strength of 71,000 psi
- 200 lbf applied to the edge of the weapon

Calculations

Motor Calculations

Rated motor KV=700 rpm/volt

Rated Motor Amperage=28A

Rated Motor voltage=12V

$Rated\ Motor\ RPM = Rated\ Motor\ KV * Rated\ Motor\ Voltage * 0.7$

$Rated\ Motor\ RPM = 700 * 12 * 0.7 = 5880$

$Motor\ wattage = Motor\ Amperage * Motor\ Voltage$

$Motor\ wattage = 28 * 12 = 366W$

$$HP_m = \frac{W_m}{746}$$

$$HP_m = \frac{336}{746} = 0.45\ HP$$

$$T_M = \frac{HP_m * 5252}{RPM_R * 12}$$

$$T_M = \frac{0.45 * 5252}{5880 * 12} = 4.83\ in - lbs$$

Battery Calculations

$$Estimated\ battery\ usage = 3 * 20A * 3mins * 1000mAAmp * 60minshr = 3000mAh$$

Belt Calculations

Drive Pulley Diameter(D1) =0.955in

Driven Pulley Diameter(D2) =1.91in

$$v_b = \frac{\pi * D_2 * Motor\ RPM}{12}$$

$$v_b = \frac{\pi * 1.91 * 5880}{12} = 1470.11\ ft/min$$

$C = 3.721in$

$D_2 < C < 3(D_2 + D_1)$

$1.91 < 3.721 < 8.595$

Wheel

Max wheel motor rpm= 16500 rpm

Rated wheel motor rpm=14840 rpm

Wheel diameter=4 in

$\mu_s = 0.9$

Using gearbox with 20:1 ratio, R=20

$$Wheel\ Circumfrence = D * \pi$$

$$Wheel\ Circumfrence = 4 * \pi = 12.57\ in$$

$$RPM_{wheel} = \frac{RPM_m}{20}$$

$$RPM_{wheel} = \frac{14840}{20} = 825\ rpm$$

$$V_b = C * (\frac{\frac{RPM_{wheel}}{60}}{12})$$

$$V_b = 12.57 * \left(\frac{\frac{825}{60}}{12}\right) = 14.39\,\frac{ft}{sec} \approx 10\ mph$$

$$Wheel\ Load = \frac{w}{2}$$

$$Wheel\ Load = \frac{15}{2} = 7.5\ lb$$

$$F_f = \mu_s * wheel\ load$$

$$F_f = 0.9 * 7.5 = 6.75\ lb$$

$$T_w = F_f * R$$

$$T_w = 6.75 * \left(\frac{10}{2}\right) = 13.5\ in - lb$$

$$Input\ Torque = \frac{T_w}{R}$$

$$Input\ Torque = \frac{13.5}{20} = 0.675$$

Motors produce 2.04 in-lb of torque

Weapon Calculations

Drive Pulley Diameter(D1) =0.955in

Driven Pulley Diameter(D2) =1.91in

Weapon Diameter=4.75in

Weapon Weight=3.5 lbs.

Impact Duration=0.01 sec

$$R = \frac{D_2}{D_1}$$

$$R = \frac{1.91}{0.955} = 2$$

$$RPM_w = \frac{Mototr\ RPM}{R}$$

$$RPM_w = \frac{5880}{2} = 2940\ RPM$$

$$\omega = RPM_w * \frac{2\pi}{60}$$

$$\omega = 2940 * \frac{2\pi}{60} = 307.87 \frac{rad}{sec}$$

$$v_e = RPM_w * D_w * \pi * \frac{60min}{1hr} * \frac{1ft}{12in} * \frac{1\ mile}{5280\ ft}$$

$$v_e = 2940 * 4.75 * \pi * \frac{60min}{1hr} * \frac{1ft}{12in} * \frac{1\ mile}{5280\ ft} = 41.55\ mph$$

$$m = \frac{w}{g}$$

$$m = \frac{15}{32.2} = 0.47\ slugs$$

$$I_0 = mv_1 - mv_0$$

$$I_0 = (0.47 * 14.39) - (0.47 * 0) = 6.71\ lb * sec$$

$$I = I_0 * \frac{1ft^2}{144in^2}$$

$$I = 6.71 * \frac{1ft^2}{144in^2} = 0.047\ lb * ft^2$$

$$T_w = R * T_M$$

$$T_w = 2 * 4.83 = 9.66\ in - lbs$$

$$KE_w = \frac{I\omega^2}{2g}$$

$$KE_w = \frac{0.047 * 307.87^2}{2 * 32.2} = 68.56\ ft - lb$$

$$L_w = \frac{I\omega}{g}$$

$$L_w = \frac{0.047 * 307.87}{32.2} = 0.45\ ft - lb - sec$$

$$F_w = \frac{I(\frac{\omega}{t_i})}{\left(\frac{D_w}{24}\right) g}$$

$$F_w = \frac{0.047(\frac{307.87}{0.01})}{\left(\frac{4.75}{24}\right) * 32.2} = 225.03 lb_f$$

$$t_s = \frac{\mathrm{I}\omega}{T_w g}$$

$$t_s = \frac{0.047 * 307.87}{9.66 * 32.2} = 0.046\ sec$$

Fabrication and Assembly

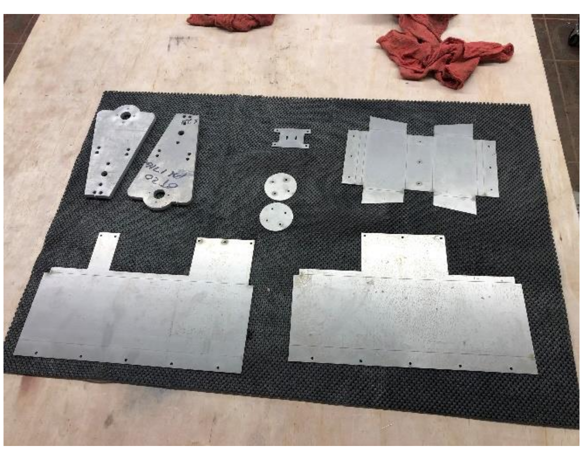
Fabrication

Water Jet

The waterjet was used throughout the fabrication process to cut out complex and precision parts. Water jet cutting is very useful given that it can cut up to 8 inches through anything that can be submersed in water. It gives a far superior cut quality to that of a plasma cutter.

The following parts were cut using the water jet:

- Side plates
- Weapon
- Sheet metal parts
    - Armor shell, top and bottom
    - Battery shell
    - Bearing covers
    - Weapon motor mount
- Gearbox mounts



Lathe

The lathe was used to fabricate cylindrical parts. Lathes are useful in the aspect that they turn parts about the center point of a circle.

The parts turned on the lathe are as follows:

- Weapon Shafts
- Weapon Mounts
- Weapon mount caps

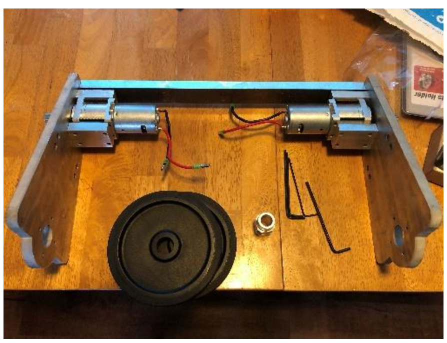
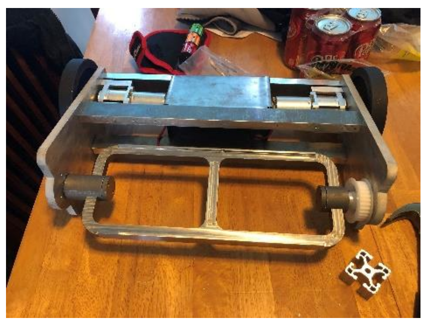
Vertical Mill

The vertical was used to machine parts to a given thickness or to drill holes at given locations. The usefulness of the vertical mill is its ability to be precise using the movable table on the machine. At University of Cincinnati’s Victory Parkway campus, they have a Bridgeport mill with a ProtoTrak two axis CNC attachment. This machine allows increased precision and automated machining processes. The parts machined on the Vertical Mill are as follows:

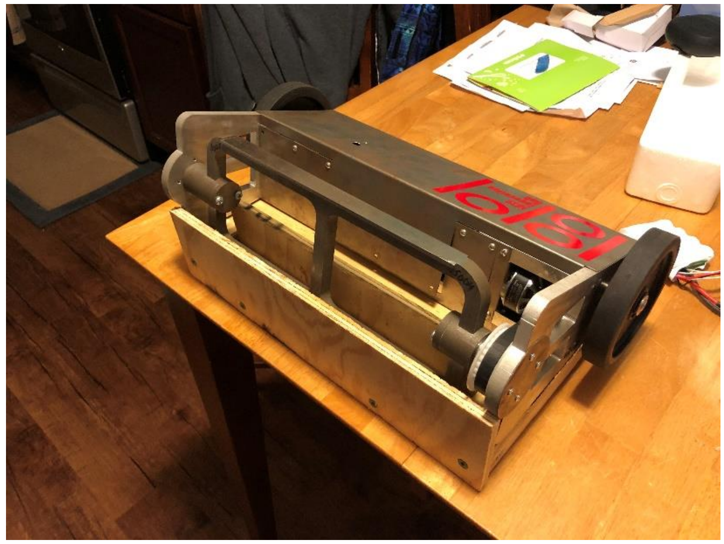
- Weapon Shafts
- Weapon Mounts
- Weapon Caps
- Frame Crossbars
- Weapon
- Side Plates
- Weapon Motor Shaft

Assembly

The assembly of the bot was done by the order of which we fabricated the parts. The bot was assembled and disassembled many times to ensure that the alignment of the parts being fabricated were fitting with the parts that were purchased. We found that the assembly of bot had to be done in an indirect way. We had to assemble the frame with battery mount in it to ensure alignment, then add on the armor to hold the frame rigid. Once this was done, we had to disassemble the side plates so that the gearboxes could be mounted. The mount mounts should difficulty due to tight tolerances that made it just about a press fit. Using the weapon shafts, the mounts could be aligned properly and hammered on. This became a permanent fit. From here the weapon motor was mounted with the pullies so that the tension of the belt could be determined. Once the bot was fully assembled, the wiring placement was initiated and completed. The photos below show the competition of the assembly and process.



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Assembly Tools

The following tools were used throughout the assembly process:

- Allen wrenches
- Combination wrench
- Screwdriver
- Flush cut pliers
- Needle nose pliers
- Snap ring pliers
- Mallet
- Scissors

Summary of Fabrication and Assembly

Throughout the machining process, we found that most of the parts that we designed were being machined easily. There were some parts that were quite difficult to figure out how to machine. For instance, the weapon through holes on the side that the shafts go through. It was difficult to come up with the right way to fixture the weapon so that we could drill the holes on the side to be centered. For the instances that we had difficultly, I would say that it was very helpful to have the machine shop instructors there for support and opinions. Throughout the entirety of the project, we found that we did not have to redesign any parts to make them fit. The only part we had to make adjustments to was the side plates, and that was to reduce the weight of our bot to meet the weight requirement. We ensured through the 3D CAD software that our design was going to be relatively around the end weight that we wanted it to be. After completely the assembly, we found that it was a few ounces over, but within a controllable amount.

Project Management

Proposed Project Budget

Estimated Budget	
Item	**Cost**
Frame & Armor	$500.00
Weapon	$200.00
Electronics and Controls	$700.00
Drivetrain	$200.00
Tools and Other	$400.00
Total	**$2,000.00**

Table 3: Budget Table

Actual Budget

			qty	Price paid	Total (Tax Included)
7075-T651 AMS 4045	0.375 ALUMINUM PLATE	6" x 24"	1	$58.00	$62.06
7075-T651 AMS 4045	0.500 ALUMINUM PLATE	1" x 60"	1	$49.50	$52.97
Steel Sheeting			1	$0.00	$0.00
Weapon Steel			1	$4.67	$5.00
Shaft Steel			1	$5.61	$6.00
Weapon Mount Steel			1	$23.36	$25.00
drive	15T pulley		1	$5.60	$5.99
	30T pulley		1	$7.56	$8.09
	12in belt		1	$8.88	$9.50
Wheels			4	$4.25	$18.19
Hubs			2	$4.50	$9.63
Gearbox			2	$54.50	$116.63
Drive Motor			2	$12.99	$27.80
Weapon Motor			1	$28.96	$30.99
Drive Controller			1	$120.00	$128.40
Remote Controller/Receiver			1	$189.00	$202.23
Batteries			3	$30.00	$96.30
Wepon ESC			1	$0.00	$0.00
Hardware	Socket Head Cap Screw	1/4 - 20 x 5/8	1	$7.74	$8.28
	Socket Head Cap Screw	3/16 - 32 x 5/8	1	$10.28	$11.00
	Socket Button Head Cap Screw	1/8 - 40 x 1/4	1	$4.35	$4.65
Bearings	5/16 bore		2	$15.36	$32.87
switch			1	$0.00	$0.00
miscellaneous items			1	$30.00	$32.10
				Total	**$893.68**
		Out of pocket			**$241.92**
		Battlebot Club Contribution			**$651.76**

Key Milestones

Schedule

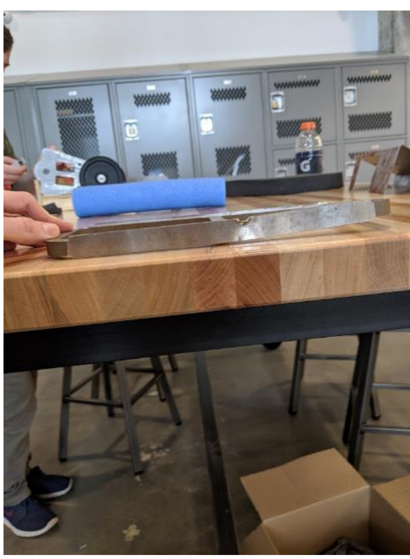
	8/27/2018	9/3/2018	9/10/2018	9/17/2018	9/24/2018	10/1/2018	10/8/2018	10/15/2018	10/22/2018	10/29/2018	11/5/2018	11/12/2018	11/19/2018	11/26/2018	12/3/2018	12/10/2018 Exam Week	12/17/2018	12/24/2018	12/31/2018	1/7/2019	1/14/2019 Classes Start	1/21/2019	1/28/2019	2/4/2019	2/11/2019	2/18/2019	2/25/2019	3/4/2019	3/11/2019	3/18/2019	3/25/2019	4/1/2019	4/8/2019	4/15/2019	4/22/2019	4/29/2019 Exam Week
Design 1																																				
Assign Responsibilties																																				
Design Draft																																				
Final Design Proposal																																				
Design 2																																				
Initial meeting with advisor																																				
Customer/Engineering Requirements																																				
Concept Design																																				
Concept Selection																																				
3D Model																																				
Parametric Design																																				
Bill of Materials																																				
Order Parts																																				
Design Presentation																																				
Design 3																																				
Machining																																				
Assembly																																				
Test																																				
Redesign & Retest (if needed)																																				
Combat Competition																																				
Tech Expo																																				
Project Presentation																																				

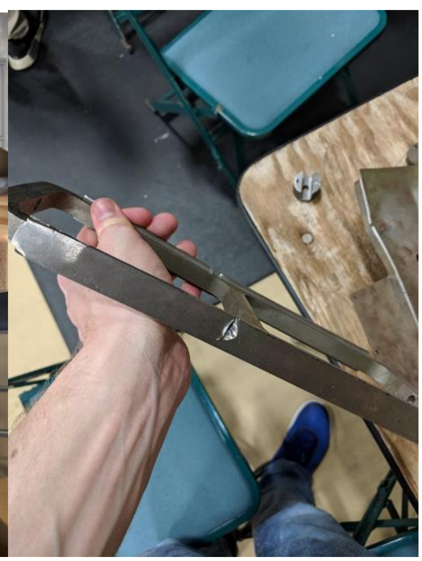
Table 4: Schedule outline

From Design 1 class through Design 2, the schedule was followed on track. During winter break, the initial plan was to start machining and assembly processes early on. The actual schedule that was followed was much more delayed than anticipated. From this delay, we were unable to do the endurance testing that we wanted to do. The completion of the bot was done on time for the competition. Unfortunately, the endurance testing will be done in competition.

Results

Before competition we needed to have our battlebot pass inspection to ensure it met all competition requirements. Our battlebot passed these tests and was able to move onto the competition the next day. In our first match we saw that the wheels had plenty of traction on the competition surface and we had full control of the battlebot. During this match our battlebot had multiple weapon to weapon hits with the opponent's weapon. This led to the weapon becoming warped and bending the shaft for the weapon as well. Because of this the weapon was not able to spin freely and the weapon motor could not produce enough force to spin it. As a result, we had to go the rest of the match without use of our weapon. The frame and armor held up well to the hits our battlebot sustained. There was minimal damage to the frame and the armor prevented any internal components from taking any damage.





Conclusion

Following our problem statement to design and manufacture a battlebot to compete in a competition, we were successful in designing a functional bot that passed all competition technical regulations. We were able to meet scheduled milestones to ensure that our bot would be completed by the competition deadlines. We found that our design was successful in key areas but unsuccessful in others. The battlebot wheel drivetrain allowed for successful maneuverability and our frame design allowed for the bot to take aggressive hits without failure. An area that was found to be unsuccessful is that our weapon was too thin for the material yield strength. Our competitor’s weapon was far superior to ours, causing significant damage during the battle. This senior design project has given us the opportunity to understand how robotic features can be used in destructive environments and that material selection and design is critical to the success of the battlebot.

Recommendations

Our recommendations for future builds are as follows:

- Start as early as possible. It helps to be done early so that proper testing and analysis can be done.
- Schedule fabrication processes early on and in order. If certain fabrication processes have time slots, these can fill up quickly. Knowing the entire process will help to schedule accordingly at one time.
- Purchase parts as early as possible. Having the purchased parts allows for the assembly process to be done quickly.
- Use instructors that know fabrication processes. They are instrumental in the success of the bot.
- Dial in the programming of the controller to you ensure maximum controllability
- Get involved with and seek assistance and advice from the Battlebot Club
- Practice driving the battlebot before the competition
- Be prepared for parts to be damaged and bring spares
- Make sure your weapon isn’t too thin as to prevent warping
- Ensure that your shaft is thick enough to handle head on hits with opposing battlebot’s weapons
- Plan for additional manufacturing time
- If your battlebot is overweight, take away material from non-critical areas

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16. Our Battle Bot. *Reno Robot Club.* [Online] Reno Robot Club, September 2, 2017. [Cited: October 8, 2018.] http://renorobotclub.org/our-battle-bot-build/.

Appendices

Appendix A: Parts and Sources

Drivetrain


Banebots P60 Gearbox: 1.5" Shaft, RS-540/550 Mount, 20:1 (No Grease)

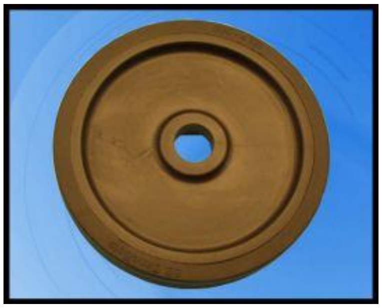
https://www.robotshop.com/en/banebots-p60-gearbox-20-1-no-grease.html?gclid=EAIaIQobChMIr8zUy7u54AIViYbACh1oUAJiEAQYASABEgIRGvD_BwE


Banebots RS-540 12V 17200 RPM Brushed DC Motor

https://www.robotshop.com/en/banebots-rs-540-motor.html

 T81 Hub, 1/2in Shaft

http://www.banebots.com/product/T81H-RS81.html

 BaneBots Wheel, 4-7/8" x 0.8", Hub Mount, 60A, Black/Black

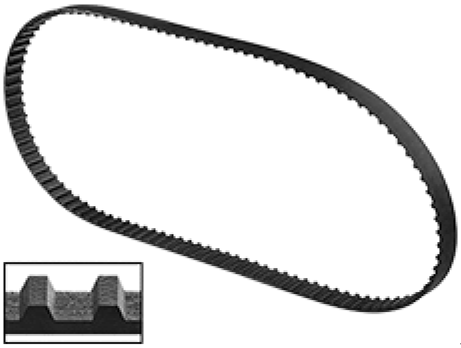
http://www.banebots.com/product/T81P-496BB.html

GARTT ML3508 700KV Brushless Motor

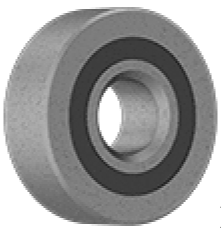
https://www.amazon.com/gp/product/B06W9HHDZW/ref=ppx_yo_dt_b_asin_title_o00__o00_s00?ie=UTF8&psc=1

 XL Series Lightweight Timing Belt Pulleys (15 & 30 Tooth)

https://www.mcmaster.com/pulleys

 XL Series Timing Belts (12in)

https://www.mcmaster.com/drive-belts

 High-Load Ball Bearing Trade No. 1605-2RS, Sealed, for 5/16" Shaft Diameter

https://www.mcmaster.com/2780t54

Electronics and controls

DX6e 6-Channel Mode 2

https://www.spektrumrc.com/Products/Default.aspx?ProdId=SPMR6650

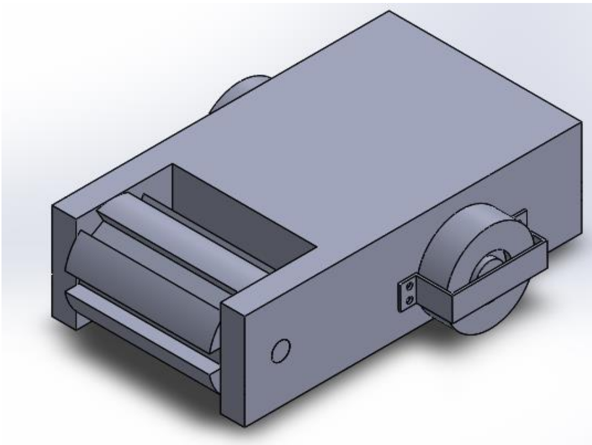
AR620 6 Channel Sport Receiver

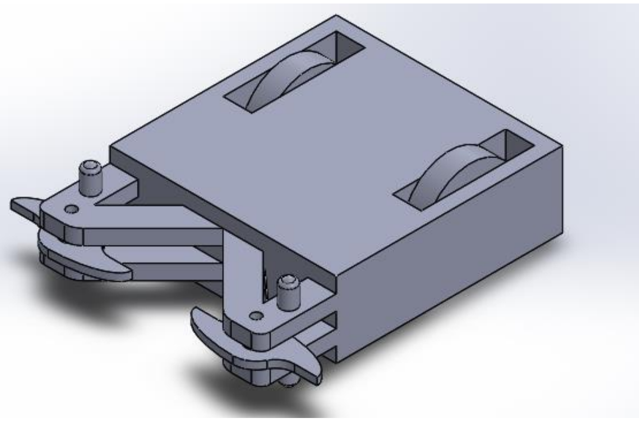
https://www.spektrumrc.com/Products/Default.aspx?ProdID=SPMAR620

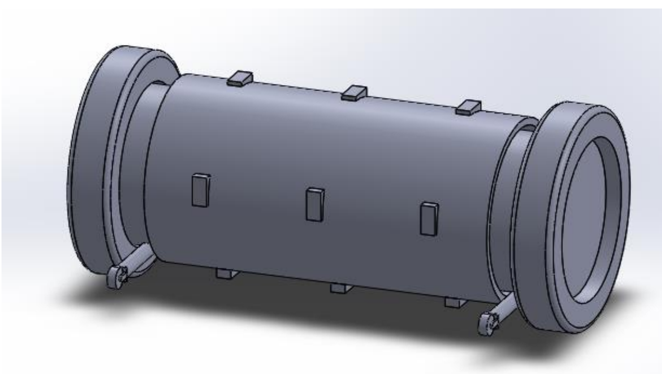
Sabertooth Dual 25A 6V-24V Regenerative Motor Driver

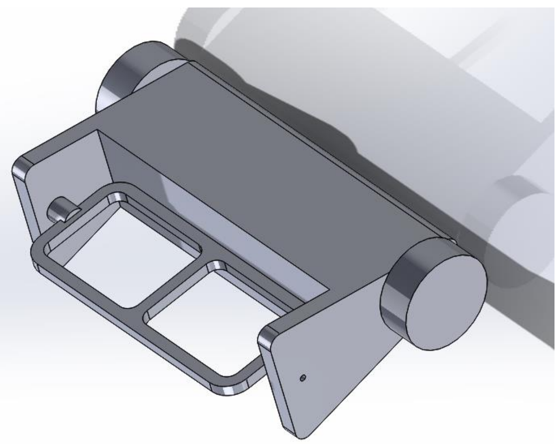
https://www.robotshop.com/en/dimension-engineering-sabertooth-2x25.html

Appendix B: Concepts and Selection Tables









Weapon Concepts							
		Horizontal Spinner		Drum Roller		Plate Spinner	
Criteria	Weight %	rating	weighted rating	rating	weighted rating	rating	weighted rating
Cost	0.1	2	0.2	2	0.2	2	0.2
Manuverability	0.2	1	0.2	1	0.2	3	0.6
Size	0.1	2	0.2	2	0.2	1	0.1
Rliability	0.25	2	0.5	3	0.75	2	0.5
Efficiency	0.1	1	0.1	2	0.2	2	0.2
Force	0.2	3	0.6	2	0.4	3	0.6
Ease of use	0.05	2	0.1	1	0.05	2	0.1
	100	n/a	1.9	n/a	2	n/a	2.3

Armor Material							
		Sheet Metal		Steel		Aluminum	
Criteria	Weight %	rating	weighted rating	rating	weighted rating	rating	weighted rating
Weight	0.15	2	0.3	1	0.15	3	0.45
Strength	0.25	2	0.5	1	0.25	2	0.5
Size	0.1	1	0.1	2	0.2	2	0.2
Cost	0.2	3	0.6	2	0.4	3	0.6
Manufacturability	0.1	2	0.2	2	0.2	3	0.3
Resilience	0.2	2	0.4	3	0.6	1	0.2
	100	n/a	2.1	n/a	1.8	n/a	2.25

		Drive system weapon					
		Chain		Belt		Gear	
	weight	rating	wt	rating	wt	rating	wt
Cost	10	1	0.217391	3	0.652174	2	0.434783
size	7	2	0.304348	3	0.456522	1	0.152174
reliability	6	3	0.391304	1	0.130435	2	0.26087
efficiency	7	3	0.456522	1	0.152174	2	0.304348
Torque	8	1	0.173913	2	0.347826	3	0.521739
ease of use	8	2	0.347826	3	0.521739	1	0.173913
	46		1.891304		2.26087		1.847826

		Drive Motor			
		Brushless		Brushed	
	weight	rating	wt	rating	wt
Cost	10	1	0.25	2	0.5
size	5	2	0.25	1	0.125
reliability	5	2	0.25	1	0.125
efficiency	5	2	0.25	1	0.125
Torque	7	1	0.175	2	0.35
ease of use	8	1	0.2	2	0.4
	40		1.375		1.625

		Weapon Motor			
		Brushless		Brushed	
	weight	rating	wt	rating	wt
Cost	5	1	0.121951	2	0.243902
size	10	2	0.487805	1	0.243902
reliability	5	2	0.243902	1	0.121951
efficiency	6	2	0.292683	1	0.146341
Torque	7	1	0.170732	2	0.341463
ease of use	8	1	0.195122	2	0.390244
	41		1.512195		1.487805

		Battery					
		NiCad		Nimh		Life	
	weight	rating	wt	rating	wt	rating	wt
Weight	10	1	0.217391	2	0.434783	3	0.652174
Size	8	1	0.173913	2	0.347826	3	0.521739
reliability	5	1	0.108696	2	0.217391	3	0.326087
efficiency	6	1	0.130435	2	0.26087	3	0.391304
ease of use	5	1	0.108696	2	0.217391	3	0.326087
	34		0.73913		1.478261		2.217391

Appendix C: Xtreme Collegiate Clash Technical Regulations

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

1. General
1.1. All participants build and operate robots at their own risk. Combat robotics is inherently dangerous. There is no amount of regulation that can
encompass all the dangers involved. Please take care to not hurt yourself
or others when building, testing and competing.
1.2. If you have a robot or weapon design that does not fit within the categories set forth in these rules or is in some way ambiguous or
borderline, please contact info@xtremebots.org. Safe innovation is always
encouraged, but surprising the event staff with your brilliant exploitation of a loophole may cause your robot to be disqualified before it ever competes.
1.3. Compliance with all event rules is mandatory. It is expected that competitors stay within the rules and procedures of their own accord and
do not require constant policing.
1.4. Each event has safety inspections. It is at their sole discretion that your robot is allowed to compete. As a builder you are obligated to disclose
all operating principles and potential dangers to the inspection staff.
1.5. Cardinal Safety Rules: Failure to comply with any of the following rules could result in expulsion or worse, injury and death.
1.5.1. Proper activation and deactivation of robots is critical. Robots
must only be activated in the arena, testing areas, or with expressed consent of the event personnel or its safety officials.
1.5.2. All robots must be able to be FULLY deactivated, which includes power to the drive and the weaponry, within 60 seconds by a
manual disconnect. (Removable link or Main Power Switch)
1.5.3. All robots not in an arena or official testing area must be raised or blocked up in a manner so that their wheels or legs cannot cause
movement if the robot were turned on. Runaway bots are VERY
dangerous. (We strongly suggest a custom designed block that ensures the robot will not be inadvertently dislodged from the block)

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

1.5.5. Weapon locking pins must be in place when weapon power is applied during a robot‟s power-on procedure. This includes all powered weapons regardless of the power source or weight class.
1.5.6. It is expected that all builders will follow basic safety practices during work on the robot at your pit station. Please be alert and aware of your pit neighbors and people passing by. Continued failure to follow safety directions could result in an individuals or the entire team disqualification for the event. (This includes and is not limited to wearing SAFETY GLASSES at ALL times while in the pit area.)
1.5.7. Any sharp-edged weapon must have the edge effectively covered until the bot is in the ring.

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

3. Mobility
3.1. All robots must have easily visible and controlled mobility in order to compete. Methods of mobility include:
3.1.1. Rolling (wheels, tracks or the whole robot)
3.1.2. Non-wheeled: non-wheeled robots have no rolling elements in contact with the floor and no continuous rolling or cam operated motion in contact with the floor, either directly or via a linkage. Motion is “continuous” if continuous operation of the drive motor(s) produces continuous motion of the robot.
3.1.3. Shuffling (rotational cam operated legs)
3.1.4. Ground effect air cushions (hovercrafts)

4. Robot control requirements:
4.1. Tele-operated robots must be radio controlled via 2.4GHz Spread
Spectrum radio systems.
4.2. Tethered control is not allowed.
4.3. Radio system restrictions for this event with corresponding weight and or weapon restrictions:
4.3.1. Radio systems that stop all motion in the robot (drive and
weapons), when the transmitter loses power or signal, are required for all robots. This may be inherent in the robots electrical system or be part of programmed fail-safes in the radio.
4.3.2. All robot radio systems must be Spektrum (preferred) or Hobby King 2.4 ghz spread spectrum radio systems. No other radio systems are allowed.

5. Autonomous/Semi-Autonomous Robots: Any robot that moves, seeks a target, or activates weapons without human control is considered autonomous. If your robot is autonomous contact league personnel.
5.1. Autonomous robots must have a clearly visible light for each autonomous subsystem that indicates whether or not it is in autonomous
mode, e.g. if your robot has two autonomous weapons it should have two
“autonomous mode” lights (this is separate from any power or radio indicator lights used).

5.2. The autonomous functionality of a robot must have the capability of being remotely armed and disarmed. (This does not include internal
sensors, drive gyros, or closed loop motor controls.)
5.2.1. While disarmed, all autonomous functions must be disabled.
5.2.2. When activated the robot must have no autonomous functions enabled, and all autonomous functions must failsafe to off if there is
loss of power or radio signal.
5.2.3. In case of damage to components that remotely disarm the robot, the robots autonomous functions are required to automatically disarm within one minute of the match length time after being armed.

6. Batteries and Power
6.1. The only permitted batteries are ones that cannot spill or spray any of their contents when damaged or inverted. This means that standard
automotive and motorcycle wet cell batteries are prohibited. Examples of
batteries that are permitted: gel cells, Hawkers, NiCads, NiMh, dry cells, AGM, LIon, A123 LiFe Nano Phosphate. Lithium Polymer batteries (LiPo) are prohibited (Fire and explosion hazard exists when incorrectly charged, shorted, or punctured). If your design uses a new type of battery, or you are not sure about it, contact info@xtremebots.org.
6.2. All nominal onboard maximum voltages are limited to: 24 Volts for
15# class robots for this league. (It is understood that a charged battery's initial voltage state is above their nominal rated value)
6.3. All electrical power to weapons and drive systems (systems that could
cause potential human bodily injury) must have a manual disconnect that can be activated within 15 seconds without endangering the person turning it off. (E.g. No body parts in the way of weapons or pinch points.) Shut down must include a manually operated mechanical method of disconnecting the main battery power, such as a switch (Hella, Whyachi, etc) or removable link. Relays may be used to control power, but there must also be a mechanical disconnect. Please note that complete shut down time is specified in section 1.5.
6.4. All efforts must be made to protect battery terminals from a direct short and causing a battery fire. All Robots must have a separate light per circuit that is easily visible from the outside of the robot and shows that its circuit‟s power is
activated. LED‟s and fiber optics are good, low power options for this.

7. Pneumatics
7.1. All 15# robots must use Low Pressure Air systems. (LPA)
7.2. Pneumatic systems on board the robot must only employ non- flammable, nonreactive gases (compressed air or disposable CO2
cartridges are permissible).
7.3. Example diagrams of typical pneumatic systems:
7.3.1. 15# class robots - CO2 based systems, see attachment below
7.4. Pneumatic system refilling process:
7.4.1. You must have a safe way of refilling the system and determining the on board pressure.
7.4.2. The maximum pressure that may be stored or used for the 15#
class robot is 150 PSI or less. The maximum total volume of pressurized gas is 8 cubic feet at standard temperature and pressure.

7.4.3. All components must be used within the specifications provided by the manufacturer or supplier. If the specifications aren't available or
reliable, then it will be up to the Safety Official to decide if the component is being used in a sufficiently safe manner.
7.5. You must have a safe and secure method of refilling your pneumatic system. All LPA systems must have the standard Schrader valve for
refilling; all CO2 systems must use single use tanks.
7.6. All pneumatic components on board a robot must be securely mounted. Particular attention must be made to pressure vessel mounting
and armor to ensure that if ruptured it will not escape the robot. (The
terms 'pressure vessel, bottle, and source tank' are used interchangeably)
7.7. All pneumatic components within the robot must be rated or certified for AT LEAST the maximum pressure in that part of the system. You may be required to show rating or certification documentation on ANY component in your system.
7.8. All pressure vessels must be rated for at least 120% of the pressure they are used at. (This is to give them a margin of safety if damaged during a fight.) It is not permissible to use fiber wound pressure vessels with liquefied gasses like CO2 due to extreme temperature cycling.
7.9. All primary pressure vessels must have an over pressure device (burst/rupture disk or over pressure 'pop off') set to no more than 130% of that pressure vessels rating. (Most commercially available bottles come
with the correct burst assemblies, use of these is encouraged)
7.10. If regulators or compressors are used anywhere in the pneumatic system there must be an (additional) over pressure device downstream of the regulator or compressor set for no more than 130% of the lowest rated component in that part of the pneumatic system.
7.11. All pneumatic systems must have a manual main shut off valve to isolate the rest of the system from the source tank. This valve must be
easily accessed for robot deactivation and refilling. It must also be out of
any danger areas.
7.12. All pneumatic systems must have a manual bleed valve downstream of the main shut off valve to depressurize the system. This bleed valve
must be easily accessed for deactivation. This valve must be left OPEN
whenever the robot is not in the arena to ensure the system cannot operate accidentally.
7.12.1. It is required to be able to easily bleed all pressure in the robot before exiting the arena. (You may be required to bleed the entire
system if it is believed that you have any damaged components.)
7.13. All pneumatic systems must have appropriate gauges scaled for maximum resolution of the pressures in that part of the system.
7.14. If back check valves are used anywhere in the system you must ensure that any part of the system they isolate can be bled and has an
over pressure device.
8. Hydraulics
8.1. Robots in the 15# class are NOT allowed to use hydraulics.

9. Internal Combustion Engines (ICE) and liquid fuels.
9.1. Robots in the 15# class are NOT allowed to use ICE.

10. Rotational weapons or full body spinning robots:
10.1. Spinning weapons that can contact the outer arena walls during normal operation must be pre-approved by the event. (Contact with an inner arena curb, or containment wall is allowed and does not require prior permission.)
10.2. Spinning weapons must come to a full stop within 30 seconds of the power being removed.

11. Springs and flywheels
11.1. Springs used in robots will use the remaining rules in this section.
Safe operation, good engineering and best practices must be used in all systems.
11.2. Any large springs used for drive or weapon power must have a way of loading and actuating the spring remotely under the robots power.
11.2.1. Under no circumstances must a large spring be loaded when the robot is out of the arena or testing area.
11.2.2. Small springs like those used within switches or other small internal operations are exempt from this rule.
11.3. Any flywheel or similar kinetic energy storing device must not be spinning or storing energy in any way unless inside the arena or testing area.
11.3.1. There must be a way of generating and dissipating the energy from the device remotely under the robots power.
11.4. All springs, flywheels, and similar kinetic energy storing devices must fail to a safe position on loss of radio contact or power.

12. Forbidden Weapons and Materials. The following weapons and materials are absolutely forbidden from use:
12.1. Weapons designed to cause invisible damage to the other robot. This includes but is not limited to:
12.1.1. Electrical weapons
12.1.2. RF jamming equipment, etc.
12.1.3. RF noise generated by an IC engine. (Please use shielding around sparking components)
12.1.4. EMF fields from permanent or electro-magnets that affect another robot‟s electronics.
12.1.5. Weapons or defenses that stop combat completely of both (or more) robots. This includes nets, tapes, strings, and other entanglement devices.
12.2. Weapons that require significant cleanup, or in some way damages the arena to require repair for further matches. This includes but is not limited to:
12.2.1. Liquid weapons. Additionally a bot may not have liquid that can spill out when the robot is superficially damaged.
12.2.2. Foams and liquefied gasses
12.2.3. Powders, sand, ball bearings and other dry chaff weapons
12.3. Un-tethered Projectiles (see tethered projectile description in Special Weapons section 13.1)
12.4. Heat and fire are forbidden as weapons. This includes, but is not limited to the following:
12.4.1. Heat or fire weapons not specifically allowed in the Special Weapons section (13.1.1)
12.4.2. Flammable liquids or gases
12.4.3. Explosives or flammable solids such as: DOT Class C devices

Gunpowder / Cartridge Primers
Military Explosives, etc.

12.5. Light and smoke based weapons that impair the viewing of robots by an Entrant, Judge, Official or Viewer. (You are allowed to physically engulf your opponent with your robot however.) This includes, but is not limited to the following:

12.5.1. Smoke weapons not specifically allowed in the Special Weapons section (13.1.1)

12.5.2. Lights such as external lasers above „class I" and bright strobe lights which may blind the opponent.

12.6. Hazardous or dangerous materials are forbidden from use anywhere on a robot where they may contact humans, or by way of the robot being
damaged (within reason) contact humans.

13. Special weapon descriptions allowed at this event:

13.1. Tethered Projectiles are allowed at these events, and must be no longer than 3 feet.

13.1.1. Heat, Smoke and Fire are not allowed at these events.

Appendix D: Survey Sample

Customer Survey

Battle Bot

This survey will be used to prioritize various features to maximize customer satisfaction. The following survey will assess your opinion on battle bot styles for a 15lb combat robot competition.

How important is each feature to you in a Battle bot?

Please circle the appropriate answer. 1 = Low 5 = High

Initial Investment Cost	1	2	3	4	5	N/A
Efficiency	1	2	3	4	5	N/A
Weapon Size	1	2	3	4	5	N/A
Ease of use	1	2	3	4	5	N/A
Maintenance	1	2	3	4	5	N/A
Armor strength	1	2	3	4	5	N/A
Maneuverability	1	2	3	4	5	N/A
Overall size (width)	1	2	3	4	5	N/A

How satisfied are you with current Battle Bot units?

Please circle the appropriate answer. 1 = Low 5 = High

Initial Investment Cost	1	2	3	4	5	N/A
Efficiency	1	2	3	4	5	N/A
Weapon Size	1	2	3	4	5	N/A
Ease of use	1	2	3	4	5	N/A
Maintenance	1	2	3	4	5	N/A
Armor strength	1	2	3	4	5	N/A
Maneuverability	1	2	3	4	5	N/A
Overall size (width)	1	2	3	4	5	N/A

What is the maximum value you would be willing to invest in a Battle Bot?

Cost in dollars	0-50	50-100	100-500	500-1000	1000+

Appendix E: Survey Data Table

Survey Response	1	2	3	4	5	6	AVG	Wt. Imp.
Overall size (width)	3	5	2	4	2	2	3	0.1
Efficiency	3	2	3	3	4	4	3.17	0.11
Ease of use	4	4	3	4	2	3	3.33	0.11
Weapon Size	3	4	5	5	3	2	3.67	0.12
Maintenance	4	5	2	5	4	2	3.67	0.12
Armor strength	5	4	4	5	3	3	4	0.13
Initial Investment Cost	5	5	5	4	4	4	4.5	0.15
Maneuverability	5	5	5	5	4	5	4.83	0.16
							30.17	1
cost	1000+	1000+	100-500	100-500	50-100	0-50		

Table 5: Survey Response Table

Appendix F: Interview Q&A

Interviewee: Jacob Woeste, Battlebot Club Co-President

Q: What is a typical budget for a 15lb bot and what can be done to reduce cost and funding?

A: last year's bot was Between $1500-$2000. The costliest areas came from the frame and armor for price of the materials. Shopping at local shops for materials can reduce the cost of materials. Getting sponsorships will help fund the cost on top of the allotted amount of around $1500 from the battlebot club

Q: What have you seen to be successful weapon types?

A: Rotary weapons have shown to be the most effective within the competition. Drum or disk style rotatory weapons that lift the opponent while pushing your bot down towards the ground. Flipping the opponent is the goal.

Q: What armor styles have you found successful?

A: Polycarbonate seems to be the best armor material due to it being lightweight and durable.

Q: What dimensional sizes is best for 15-pound bot?

A: The bot that we have made through the club is 15in wide by 15in long by 8in tall

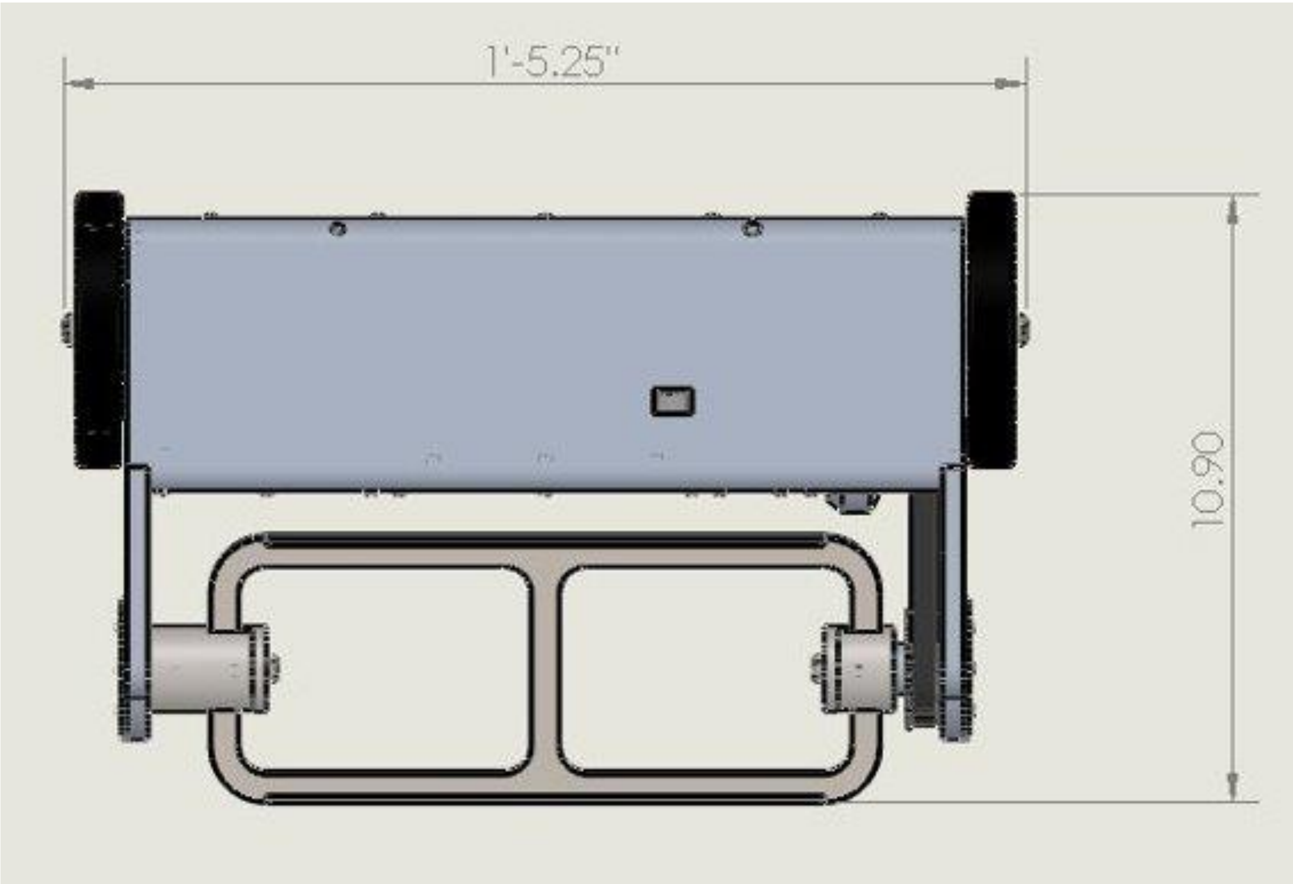
Q: What is the weight distribution for the bots?

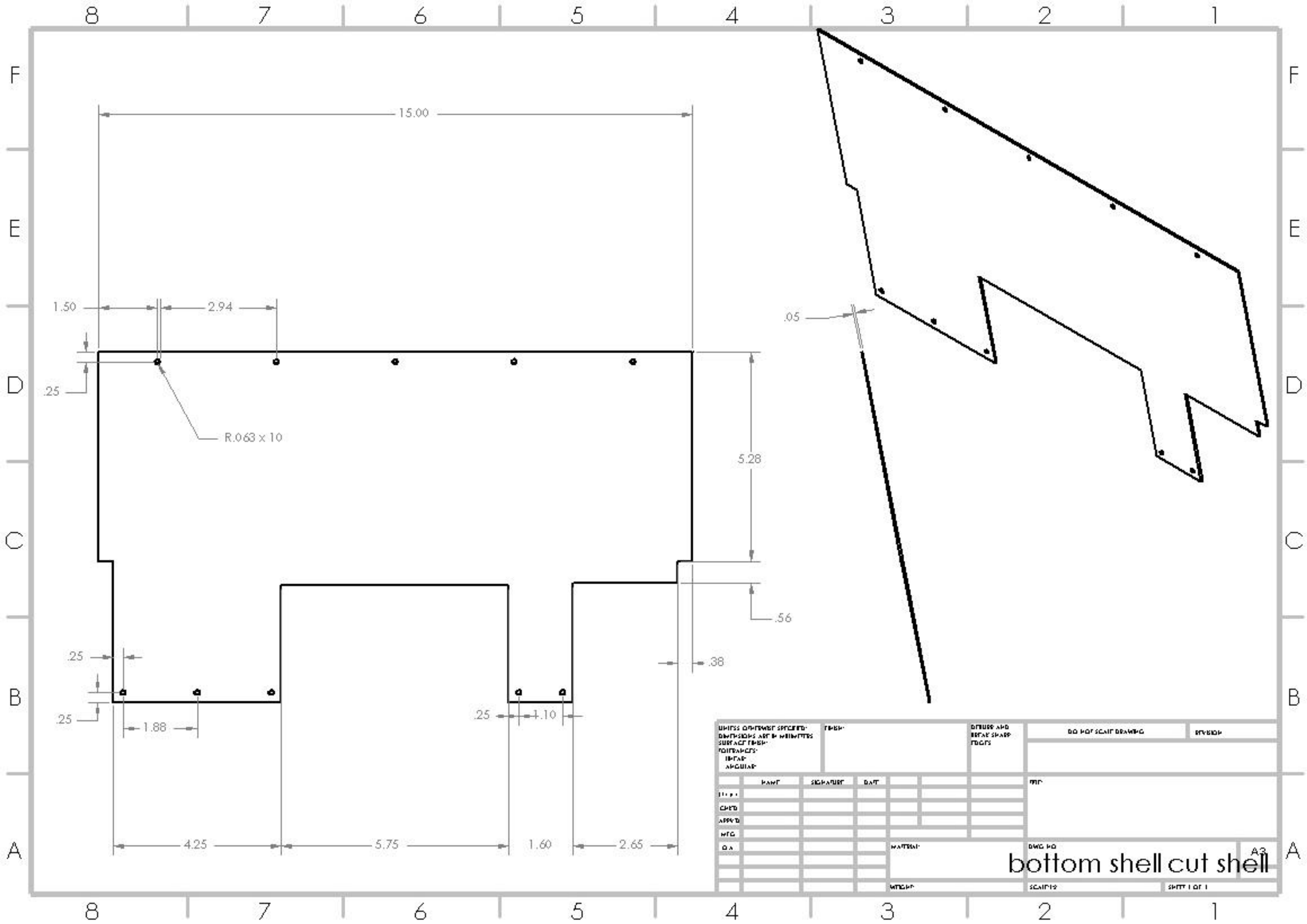
A: The bot should be split into thirds with the following key areas; weight and weapon, frame and armor, and electronics. The weapon itself is usually only around 1 or 2 pounds.

Q: Any other recommendations you can make for a successful bot?

A: Design a bot that has mobility on both sides in case it is flipped upside-down. Make sure you have a battery that can handle the amount of time within the 3-minute rounds. Lithium ion batteries tend to be the better type of battery to use. Lastly, Sabretooth brand motor controllers seem to be a successful brand for using in a battlebot.

Appendix E: Mechanical Drawings

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.25
R.063 x 10
5.28
.05
.56
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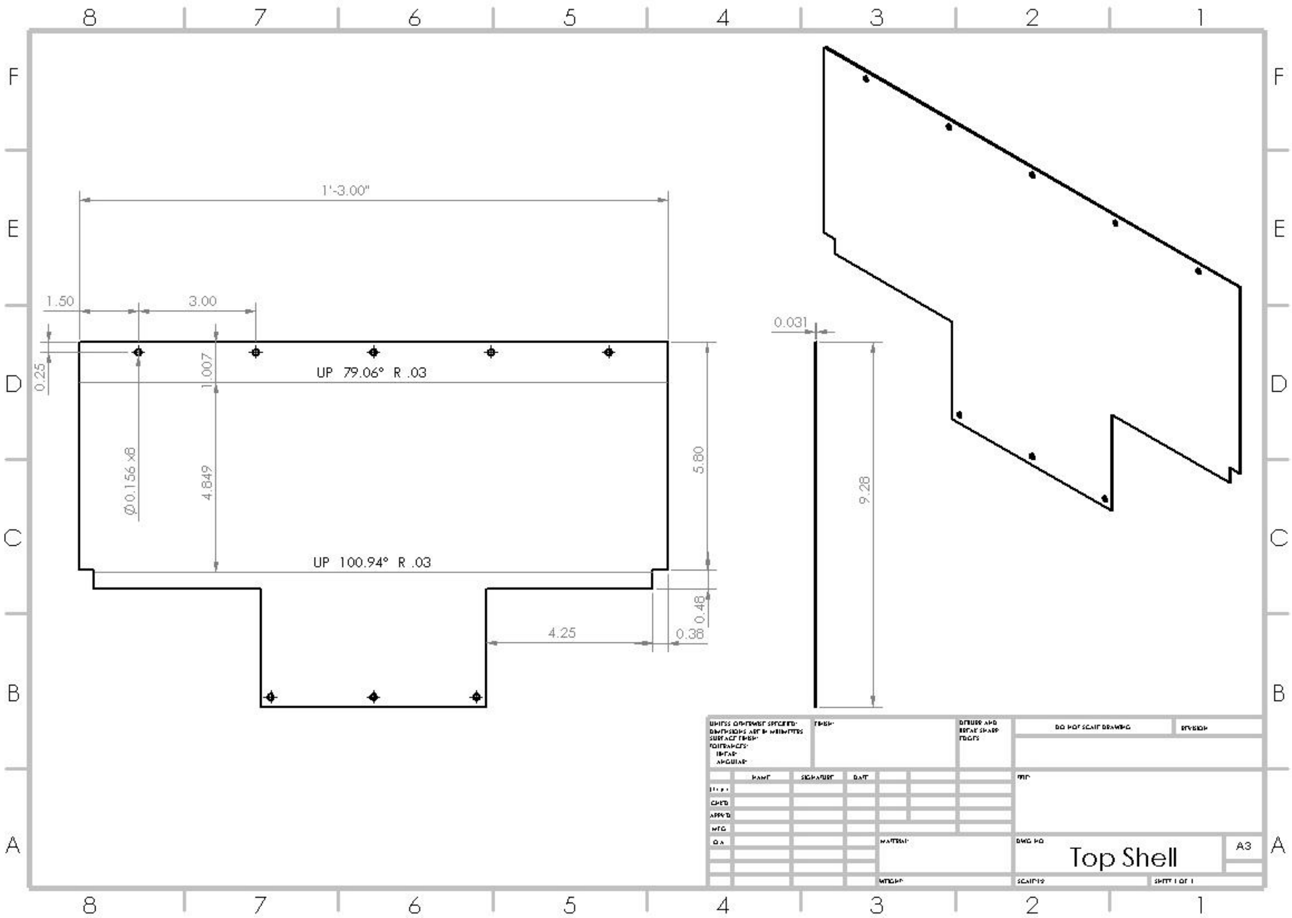
2.65
bottom shell cut shell
A3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3.00
0.25
1.007
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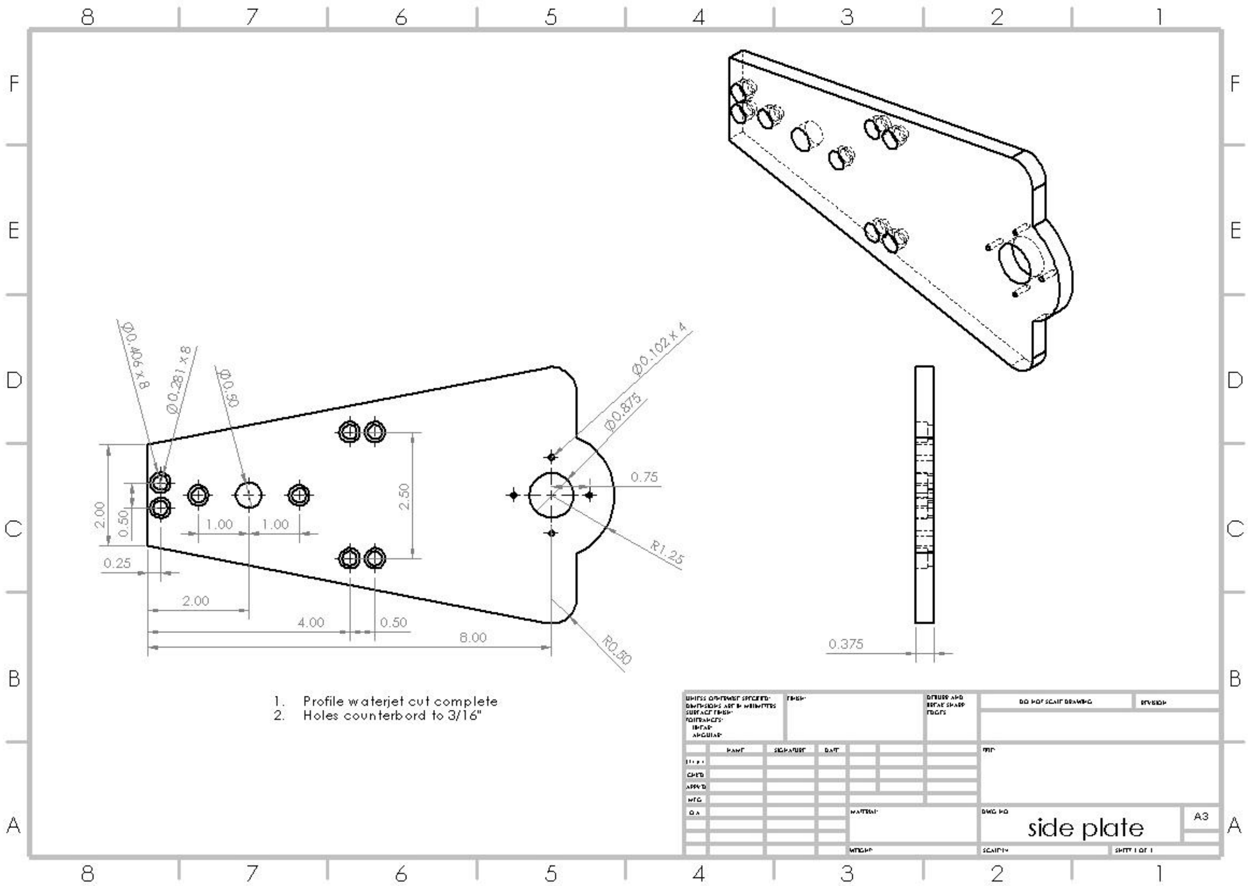
0.031
9.28
Top Shell
A3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Ø0.102 x 4
Ø0.875
0.75
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R0.50
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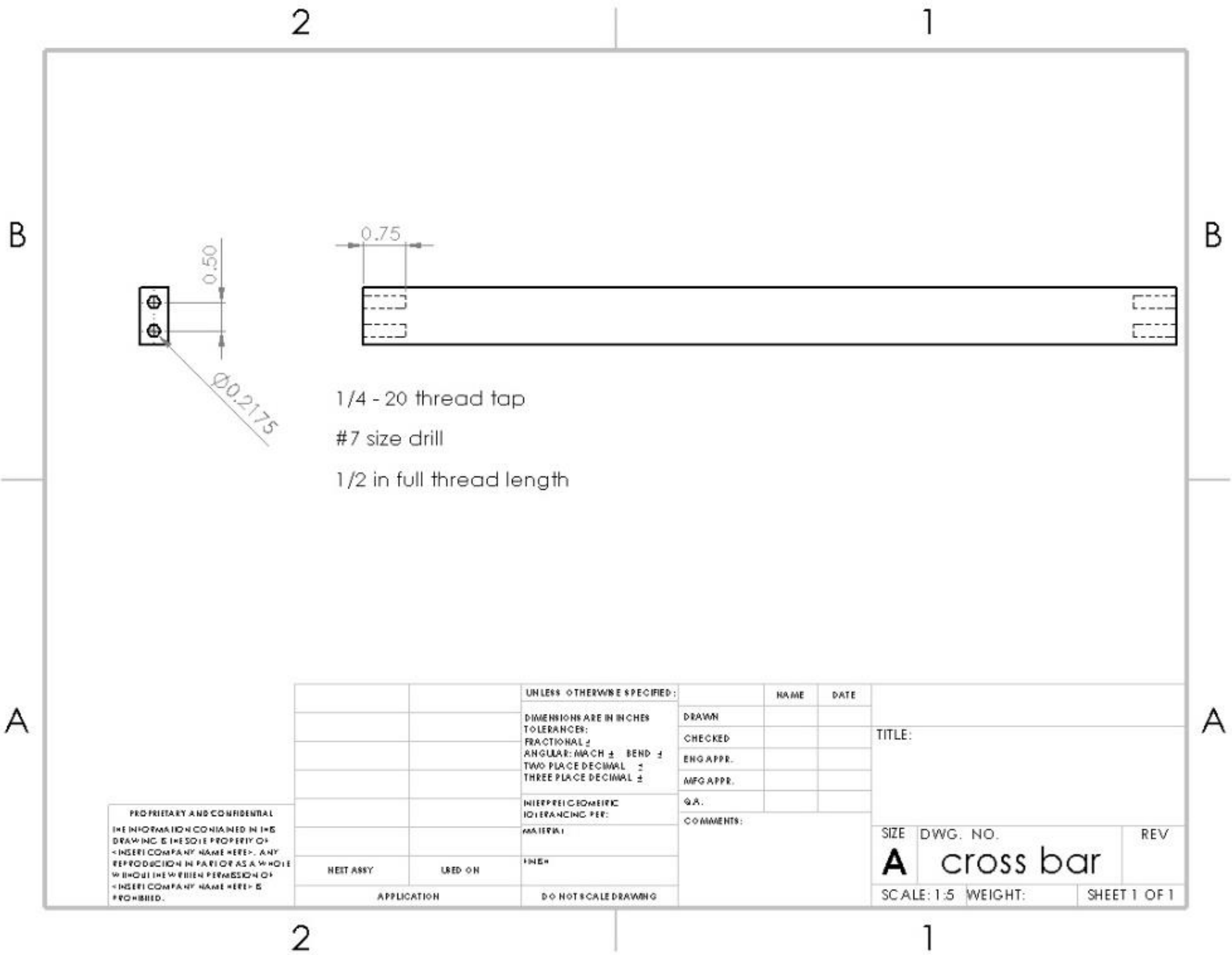
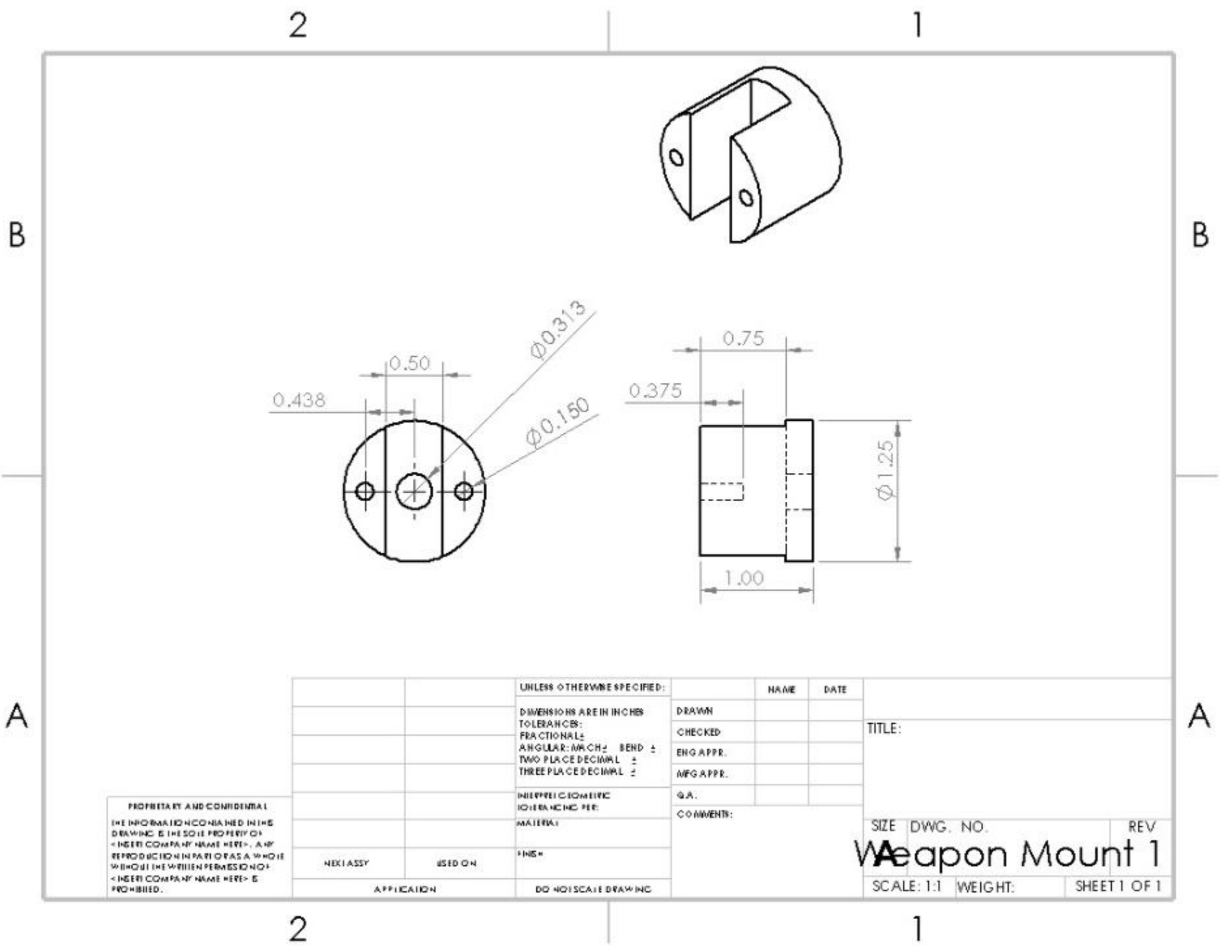
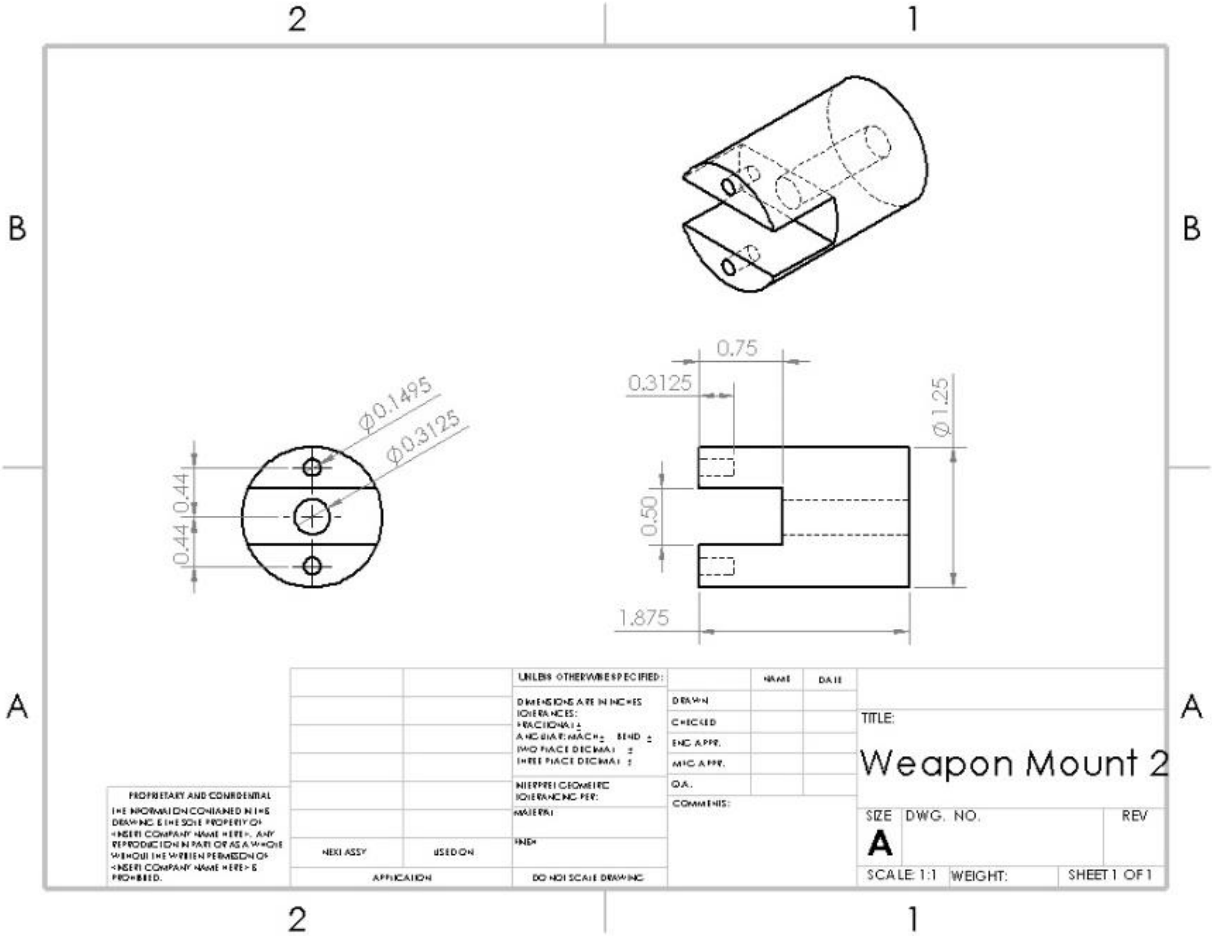
0.25
1.00
1.00
2.50
2.00
4.00
0.50
8.00
0.375
1. Profile waterjet cut complete
2. Holes counterbord to 3/16"
side plate
A3

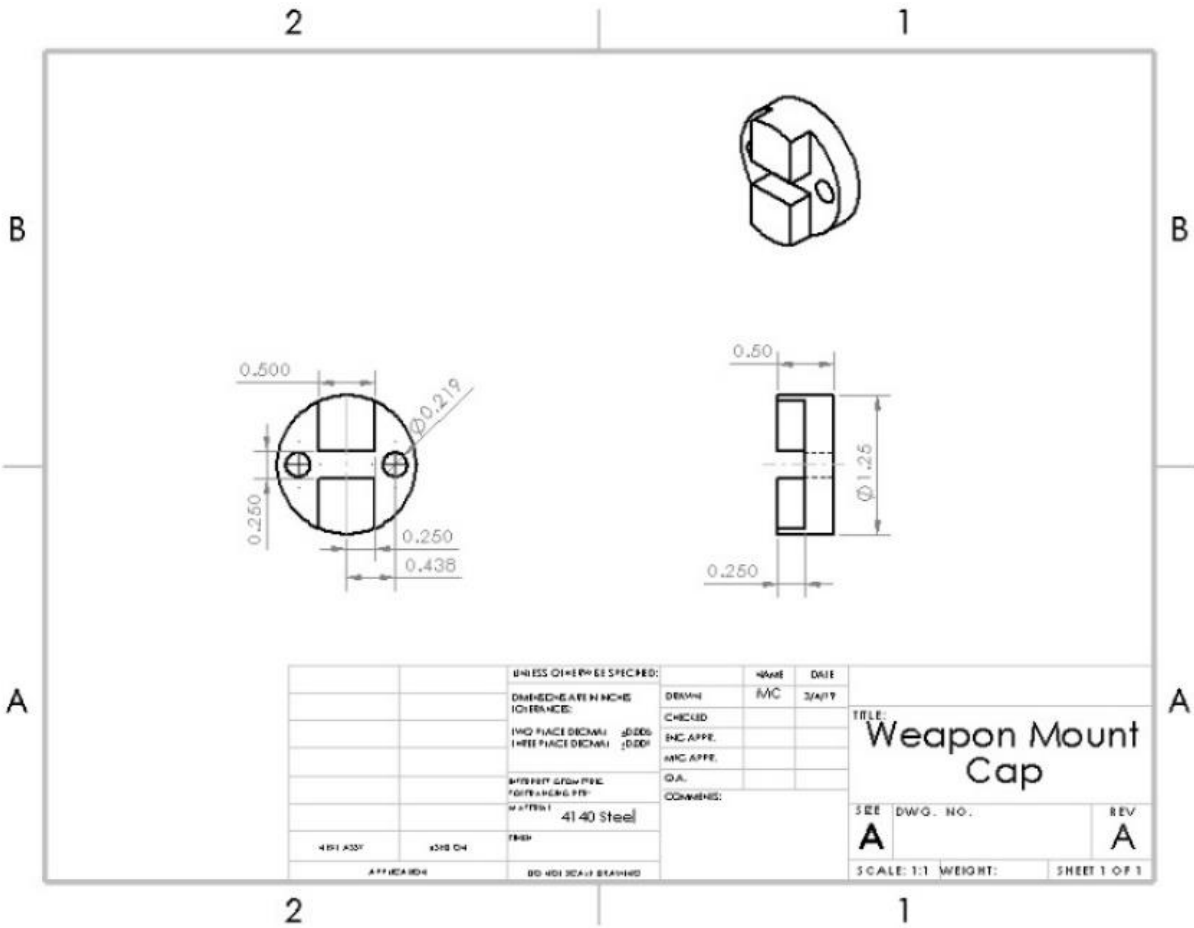

0.75
0.50
Ø0.2175
1/4 - 20 thread tap
#7 size drill
1/2 in full thread length
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
SIZE
DWG. NO.
REV
A
cross bar
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1

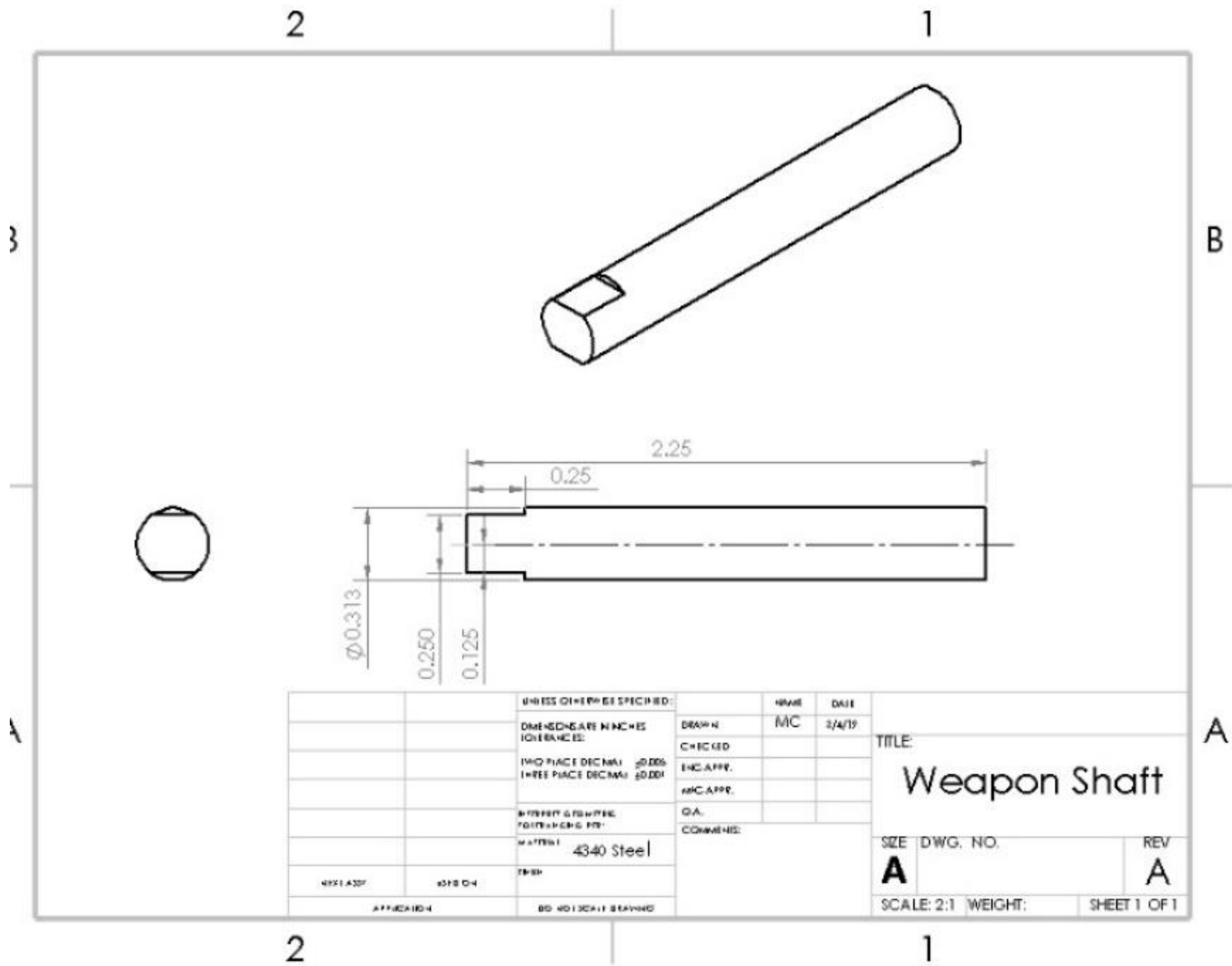


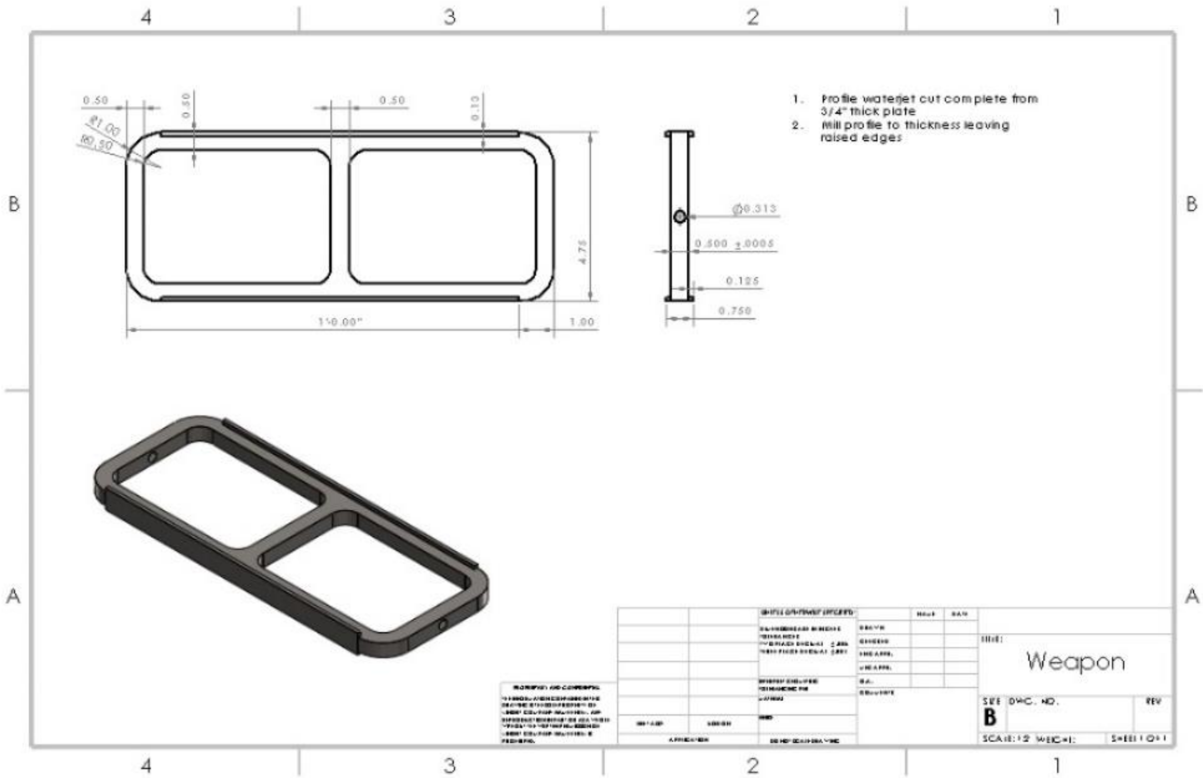
2
1
B
A
Ø0.313
0.50
0.438
Ø0.150
0.75
0.375
Ø1.25
1.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
Weapon Mount 1
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL



2
1
B
A
Ø0.1495
Ø0.3125
0.44
0.44
0.75
0.3125
Ø1.25
0.50
1.875
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Weapon Mount 2
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL


2
1
B
B
A
A
0.500
Ø0.219
0.250
0.250
0.438
0.50
Ø1.25
0.250
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
NAME
DATE
DRAWN
MC
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
41 40 Steel
DO NOT SCALE DRAWING
TITLE:
Weapon Mount
Cap
SIZE
DWG. NO.
REV
A
A
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
2
1


2
1
B
A
2.25
0.25
Ø0.313
0.250
0.125
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.001
MATERIAL
4340 Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
MC
3/4/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Weapon Shaft
SIZE
DWG. NO.
REV
A
A
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1



0.50
0.50
0.50
0.13
R1.00
R0.50
4.75
1.00
Ø0.313
0.500 ±.0005
0.125
0.750
1. Profile waterjet cut complete from 3/4" thick plate
2. Mill profile to thickness leaving raised edges
TITLE:
Weapon
SIZE
B
DWG. NO.
REV