2017 UC BattleBot Team

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by

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University of Cincinnati

College of Engineering and Applied Science

Mechanical Engineering Technology

2018 UC Battle Bot Team

The “Robostein”

Team Members and Responsibilities

Dr. Janet Dong – Advisor

Benjamin Schenck – Project Manager, Electronics, and Weapon Design

Nathan Hunt – Frame

Dan Schaefer – Armor

Reginald Glossett – Drive System

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT
Every year the University of Cincinnati requires all Engineering students to make/complete a senior design project that embodies the entire learning curriculum at UC and apply it to a real-world problem. Students working either solo or in a group must submit a problem they want to solve and then submit it to a committee of faculty who will evaluate each problem and deem whether the students can address the problem. A few projects such as the Baja, BUV, and Battlebots are outliers in the respect that there more of competitive problems but they require the same effort and problem solving as the "unique" and individual projects.

One of the competitive projects was the Battlebots and the goal of the Battlebot team is to design, manufacture/assemble, and compete a combat robot. These projects rely on the electrical, mechanical, and manufacturing skills/knowledge to succeed.

UC has had a competing Battlebot team since 2008. They have all been at the 120lb weight class though and my team received the unique opportunity to build a 220lb Battlebot which has never been attempted by UC before. My team wanted to have additional goals as well as the main one to build, design, and compete a Battlebot. We wanted to have a new design that hasn't been used by previous UC teams.

ACKNOWLEDGEMENTS

I would like to recognize a few amazing people who were critical to the process and were a guiding light. First, I would like to recognize Bill Culbertson from Bill Culbertson Remodeling who not only provided material but also dedicated time and energy to help us at various stages of the process. Second, I would like to recognize Chuck and Kris Black out of Chuck Black Race Cars in Independence KY who provided expertise, equipment, and material in the manufacturing of the frame and armor. Next, I would like to recognize Meyer Tool Inc. who provided equipment for use and Machintech who provided the armor. Lastly, I would like to recognize Dr. Janet Dong who supervised our project and helped us along. On behalf of my team we greatly appreciate everything you all have done for us.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

We are going to research, build, test, and compete in the 2018 BattleBot competition. We have been tasked to create a 220lb weight class BattleBot which has never been done at UC before. The project will be broken down into 4 sections: weapon, frame, drive system, and armor. The following teammates have the following responsibilities:

BACKGROUND

Scholars have been trying to decide when combat robotics competitions first took place in the US for years. Some scholars say that universities such as MIT and Caltech started it back in the 1970s while others say it started in 1980s in San Francisco. The first official sport competition for combat robotics was in 1994 when Marc Thorpe organized the first Robot Wars competition in San Francisco.

Previous years UC BattleBots include: Spinner design, Drum, and Flipper. Spinner design is a design where the defense is the best offence but the spinner can easily break. The drum design is the design that most used.

RESEARCH

SCOPE OF THE PROBLEM

The problem that our team will need to overcome is to win and defeat other battlebots at the competition. Also our team has the heaviest weight class (220lb) and it has never been done before by UC. We are treading new waters but with a heavy weight class we can incorporate a more powerful weapon system and can even put multiple weapons on it to help against the competition. So this is important that we do well as we are the first UC team to compete at this level and future classes of students will be looking to us for inspiration.

CURRENT STATE OF THE ART

a) **Weapon:**

There are many weapons that a BattleBot can utilize and the heavier the weight class the stronger the weapons need to be. We narrowed the choices from the 16 most common types and narrowed down to 4 different types.

Sawbot: a bot that has one or more toothed or abrasive disks that spin fast and cause minor damage to the bot. The biggest advantage that this bot has that it can do a lot of cosmetic damage, sparks, and sheet metal damage which can impress judges to give it a clear edge in close matchups. Sawbots' main disadvantage however is that they struggle in cutting through harder metals like titanium. Depending on how the blades/discs are rotating they can cause opponent to get top of Sawbot that can cause Sawbot damage or if they are rotating another way cause the Sawbot to flip over when colliding with other bot. Sawbot tends to have either a second blade/disc or a secondary weapon to make up for its disavantages.

Figure 1: Sawbot Example (Meggiolaro,2009)

Spearbot: A bot that has a long and thin penetrating weapon (hence spear) and it is usually pneumatically actuated. The weapon tip is usually sharp and is thrust outward at incredible speeds to puncture the other bot’s armor and cause massive damage to the other bot. The main problem with this design is that if the other bot is at a lower profile then the weapon is essentially useless. The other concern is that if the spear is stuck then the spearbot will be at the liberty of the other bot whether the other bot is able to abuse the situation or the spearbot got the other bot stuck too. A few people tried to implement a tethered spear (since projectiles are illegal) but often they switch back to the just the spear.

Figure 2: Spearbot Example (Meggiolaro,2009)

Hammerbot: A bot that has huge weapons on mounted on a (usually pneumatic) system. These huge weapons (most commonly a hammer) smash down on the tops of the opponent’s bots and cause huge amounts of damage to in most cases the second weakest spot on the bot with the first being the bottom. The main issues with this bot is that if the force of the hammer comes down fast enough, often can cause the bot to flip itself over if the weight is not compensated for the force of it. Also, the hammerbot has to turn fast enough to keep the enemy bot within the strike zone or else it will have trouble hitting its target.

Figure 3: Hammerbot Example (Meggiolaro,2009)

Launchers: A bot that has a mechanical lift built in that is capable of flinging the other bots into the air and letting gravity do the most damage to the other bots. Also, if the launcher manages to flip the bot over and incapacitates it, the launcher automatically wins the round. The main concern with this bot is that they have to have high pressure C02 containers inside the bot to power the main weapon and if the other bot manages to cause the C02 container to explode inside the launcher it will do massive damage to the launcher's internal workings. The launcher also must maintain high enough turn speeds to keep the other bot within the fling zone of the launcher.

Figure 4: Launcher Example (Meggiolaro,2009)

b) Armor:

The armor and the frame play hand in hand with each other. The actual design that we pick, it will be essential to pick the right type of material. There are a lot of different types of bodies and frame styles. We will be concentrating on 4 certain types. The wedge/saw bot, the spear style/Trojan, the launcher/flipper and finally the hammer style bot. First we will have to consider our defensive strategy and consider the weaponry secondly. Being able to withstand the blows of your opponent and survive is just as important to the battle as the attacks. In any instance we will need to reinforce the areas that would be susceptible to damage. Such areas would include the front and sides. Under which would house the vital components to the bot; the drivetrain, the brain to the electronics. We will want to reinforce all of these areas. **(2)**

There are many different materials we could choose from in making the armor. We have to consider what we are going up against. There are also many things to consider when dealing with the battle arena; there are saw blades that come from the floor which present issues with armor underneath the bot. Also, we will want to consider if we want to weld or bolt the armor together. If we weld the armor we will have to select a single material as with welding 2 types of material together will have flaws in its integrity. Some of the materials we will have to consider include, but are not limited to, wood, steel, aluminum, titanium, and Lexan. **(2)**

With wood, you wouldn’t think to use this as part of the armor but it does have it’s advantages. Now you wouldn’t want to use wood as a primary armor but if you use wood on the inside of the outer structure it can be used as a shock absorber to the heavier attacks.

Steel is widely used in the battle bot community. It is cheaper than most material for the amount that you can get. Steel has different strengths and is easily welded. Steel is also very strong and can take a beating whereas aluminum cannot. **(2)** One disadvantage to steel is that it is heavy. I am sure that we will not have to worry about this being that we are in the heavyweight class.

Aluminum is another option. I do not think we will consider this option as it is not as strong as steel and it is more expensive. It has its advantages when it comes to weight savings so it would only benefit us if we were in a lower weight class.

Titanium alloy is much stronger and lighter than steel. This would very costly for us to make our battle bot out of. Another disadvantage with Titanium is that it is hard to machine and weld. Two things that we are not looking for.

The last material for us to possibly consider is Lexan. Its popularity in the battle bot community is in the rising. **(2)** It is a high-grade form of polycarbonate. It is very light and also it is resistant to penetration from hammer blows or any type of strike attack. One disadvantage of Lexan is that it is easily cut, so any bot we face with a saw blade will be able to cut right through the armor. It is also expensive, but makes up for it with its versatility. **(2)**

Once we have come up with a concept to how our bot is going to look and perform, we will be able to come up with a material that we will utilize in the armor.

c) Frame:

Material:

Steel: Steel is would off the most bang for your buck when it comes to protection. Since we are building a 220lb bot I would suggest we go with steel as a primary defense and frame build. Steel is also easy to weld and moderate to machine. **Aluminum:** Aluminum is a durable lightweight substitute to steel. It is typically used in lower weight divisions but I think we can still use it for our bot. It is not as strong as steel but is a lot lighter than steel. However, that being said, aluminum does cost more than steel so we will need to keep that in mind for budget. Aluminum is moderate to weld and easy to machine. **(2)**
Titanium: The most expensive of the three materials, I recommend if we are going to use titanium we use it on very critical points only due to price. Titanium is stronger than aluminum but lighter than steel but is very hard to machine and weld. **(2)**
Lexan: A polycarbonate that is lighter than aluminum but still resistant to penetration. It is very flexible, good shock absorber, and makes it impossible to dent. It is expensive and can be cut easily so it would not be a good idea to put it on critical areas. **(2)**

Frame Type:

Spearbot: Different frame designs can be used for this one depending on how we want to do the spear. It can be a square, triangle, rectangle, etc. If we go with a retractable spear, triangle may be out of the question. Also I do not recommend we go with a round design.
Sawbot: As far as the saw bot goes for frame design, any shape will do except for possibly round. Round would present a difficult area of design due to lack of a flat face on the sides to mount anything.
Hammerbot: Hammerbot can be any shape as well. Looking up previous designs I have seen that most are square or rectangle in shape.
Launcher: With this style of bot I would say that a square or rectangle design would work best since its main weapon is going to be flipping a bot over. With all of these designs, I would recommend building an intense support frame since the weapons this bot could be facing can do a lot of damage and we don’t want it to crumble up like a tin can

d) The Dive system: the drive system for the robot is the most important part of designing the robot for combat. While we want to have a lethal weapon and strong armor, the robot's movement could be the factor that causes victory or defeat. How well the robot maneuvers, accelerate and steer can be a key weapon itself and if designed appropriately in line with the weapon function in mind could bode well for combat competition.

Key factors to consider while designing the drive system are; the weight of each part, traction of the wheels, power of the motor, smoothness of the transmission and steering. Another factor is the weapon of choice, because depending on the weapon we choose, the way the robot moves is going to have to cooperate. These factors are crucial; our robot is intended to compete in the heavyweight division at 220 pounds. (Meggiolaro,2009)

There are several different types of wheels each having its own advantages and disadvantages. An important thing to consider with the wheels and their traction is the hardness of the rubber. There are two main steering types; Ackerman steering and differential. Our choice for drive are two-wheel, all-wheel and omni-directional drive. Motors and transmissions choices are; permanent magnet, shunt (parallel) and series motors which are all brush dc motors. We could use a brushless dc motor. Gear options are cylindrical, conical or worm. Belts or chains are options within the system. Also, flexible couplings and torque limiters. (Meggiolaro,2009)

END USER

We need to satisfy the requirements of the competition but we will be the end users.

Our requirements:

- 220lb weight class
- Must cost less than $20,000
- Use wheels (non-walking)
- Easy to fix on the fly
- Not to difficult to manufacture

Requirements of Robogames: (Meggiolaro,2009)

- Match length: 3 minutes
- Must be able to FULLY deactivate in under 60 seconds with manual disconnect
- Easily visible and controlled mobility
- Must use a radio system for control
- Some weapons such as explosives and electricity are not allowed
- Judges will score based on the following two categories:
- Aggression (how much time bot spent attacking other bot)
- Damage (how much physical damage done to other bot)

CONCLUSIONS AND SUMMARY OF RESEARCH

We narrowed down our options to four main weapon types: spear, saw, hammer, and launcher. Each has its own advantages and disadvantages that will be needed to be evaluated further to decide which will be the final weapon that will decide how the armor, drive system, and frame to be handled.

DESIGN

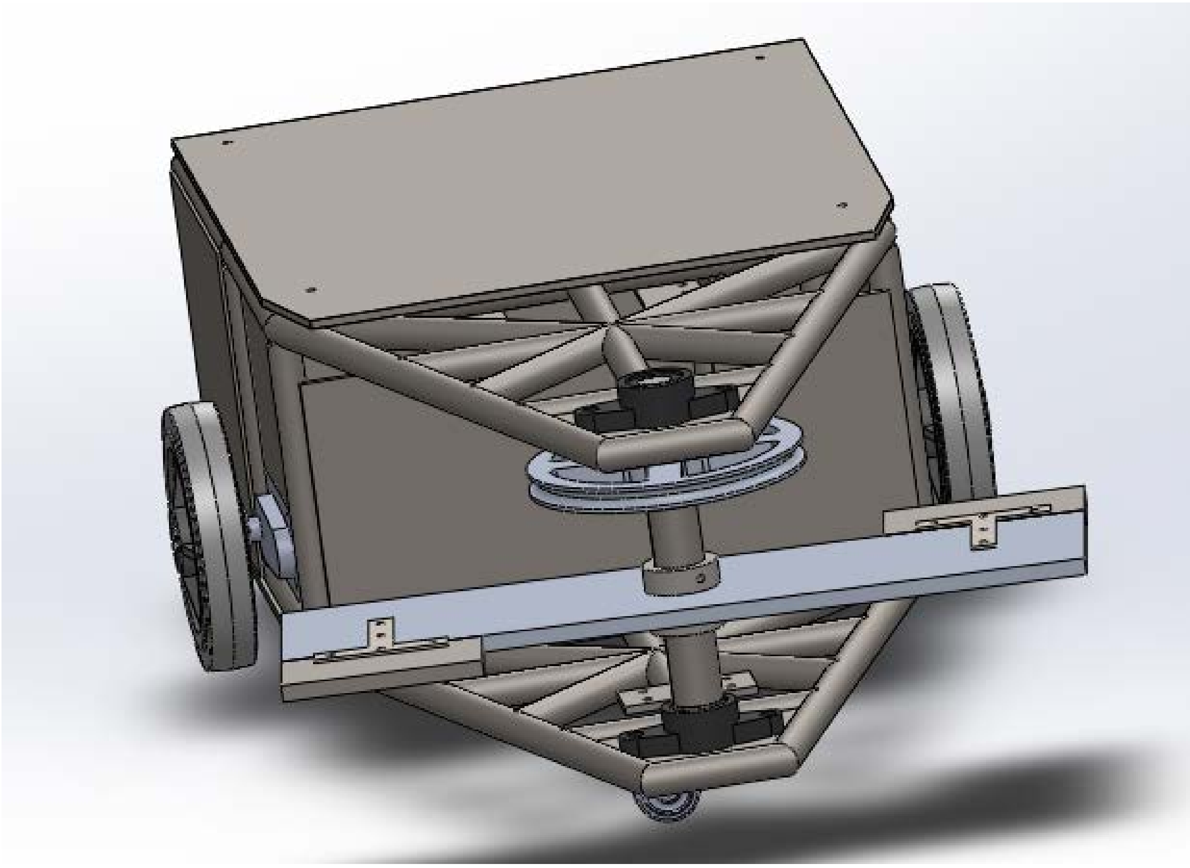


Figure 5: Complete bot

Decision for Bot Weapon

Choosing and designing the weapon for the battle is the most crucial part of the design process as the entire bot is defined by the weapon. One example would be the hammer bot where the body of the bot would need to be made long and wide enough to support the hammer. I believe that as a team it was important to choose a weapon first as certain weapons open or restrict other parts of the design.

As a team we poured through Youtube videos of matches in the 220lb class and researched into matchups. We saw bots like the Blacksmith and chomp which fought using a hammer or metal pick and we saw a few flaws with the design that became apparent. The hammer design calculations have to be very precise and if the hammer applies too much force the reaction force would cause the bot to actually flip itself over or if the hammer doesn't have enough damage it will just bounce off of enemy bot. Having many different bot heights in the competition would also make it really difficult to accommodate such a wide range of variables.

Another design that was considered was the saw blade design. The problem we saw with that one is that the it did a lot of cosmetic damage but not alot internal bot damage unless it was using one of the expensive rescue saw blades that can cost as much as the bot itself. Also we would have to have had many sawblades on hand as they would dull quickly and that would make the bot really expensive.

The launcher design was also considered but ultimately we threw out this design early in the process because of the expense of bot and the cost to repair component damage such as the hydraulic tubes. The spear design was also thrown out for reasons like the HammerBot as the other bot designs vary so much that it is hard to perfect the spear location where it will severely damage most robot types. Also, the spear also has the same problem as the launcher as it would be using hydraulic tubing to get the pressure it needs to go through 220lbs of BattleBot.

Ultimately we went with a horizontal blade concept. Horizontal blades are highly versatile as they can be changed out with a certain blades sizes for certain matchups and it can be easy to raise or lower the blade for certain matchups. Blades would be highly durable and inserts can be added to make the blades last for more matches with only needing to replace the inserts. Also bots like Tombstone and Last rites have really good track records against many matchups.

Design Process for Weapon (Horizontal Blade)

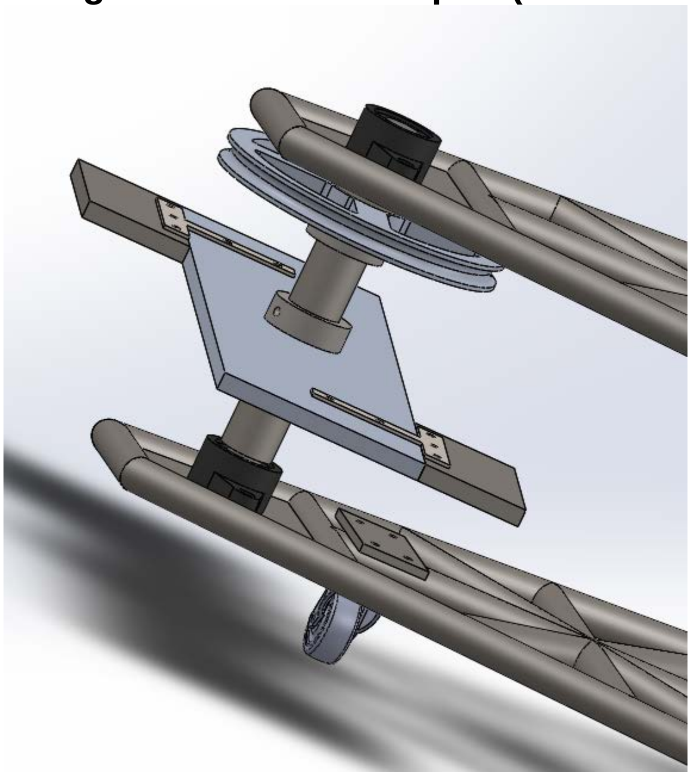


Figure 6: Weapon system

The weapon for the 220lb Battlebot this year will be the Horizontal Blade. With the horizontal blade we needed have a material that was strong without weighing too much. Stress analysis was needed to be performed on the blade to be able to insure the blade can take the impact. The design for the weapon was broken down into the following: material selections, shaft design, design of the weapon drivetrain, and motor selection.

Weapon Blade Design

One of the important things to consider about the weapon blade was choosing the material for the weapon and the shaft. We needed the material of the blade and shaft to have a strength, stiffness, and Brinell hardness number all on the higher end of the spectrum. For the blade it was important the density scales inversely with the size of the blade as the material gets denser as to keep the blade overall constant no matter the material to make it very versatile. Also with a blade design stresses also affect the size of the blade. With our battlebot heavily reliant on sponsors we had to ensure that the blade would be properly designed for whatever material would be donated. The next table contains the materials that were considered for the blade. After material selection is performed we went ahead and calculated the different sizes of the blade to ensure that whatever material ended up being donated, we would have it calculated for that material to the right size. There are special stress calculations to be performed as well to ensure that the blade will not fracture inside out or outside in over time. The following figure shows the stress that will act on the blade. If the stress at point A is greater than the stress calculated at point B than the bar is able to be easily broken from the outside in upon repeated impacts and it is reversed if point B is significantly greater than the stress calculated at point A. The goal was to get the stress levels at point A and B to be close to being equal.

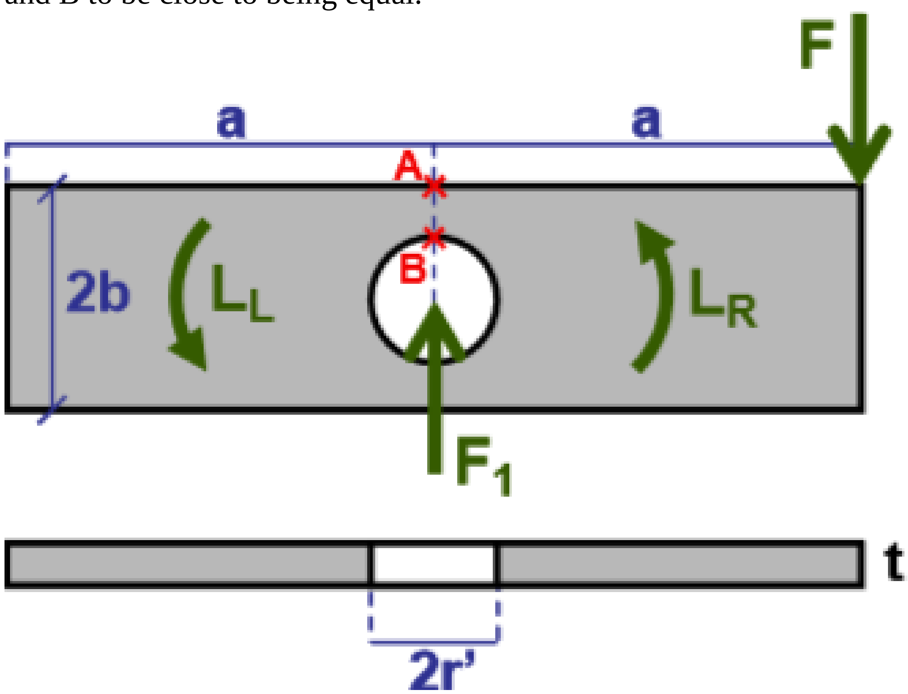


Figure 7: Weapon Blade Free-Body Diagram (Meggiolaro,2009)

Shaft Design

The shaft followed a very similar design process as the weapon blade. We selected 5 different materials and ensured that whichever shaft material gets donated that the design still works. We also chose the best material of the 5 if we were given a choice of material from sponsor or gave us money to purchase. After material was chosen the part was modeled in Solidworks. Stress analysis was then performed on the shaft to handle the max torque from the motor.

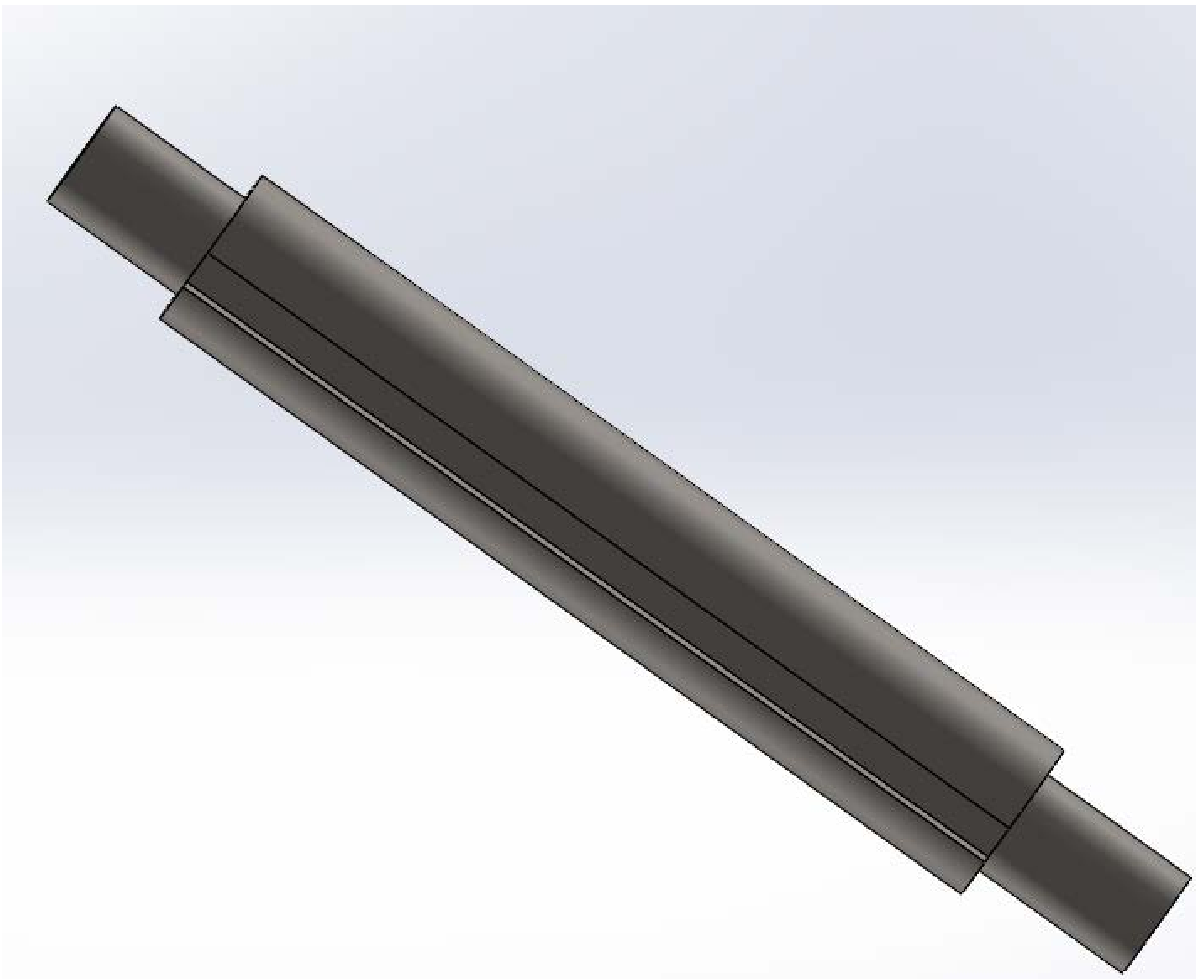


Figure 8: Weapon Shaft

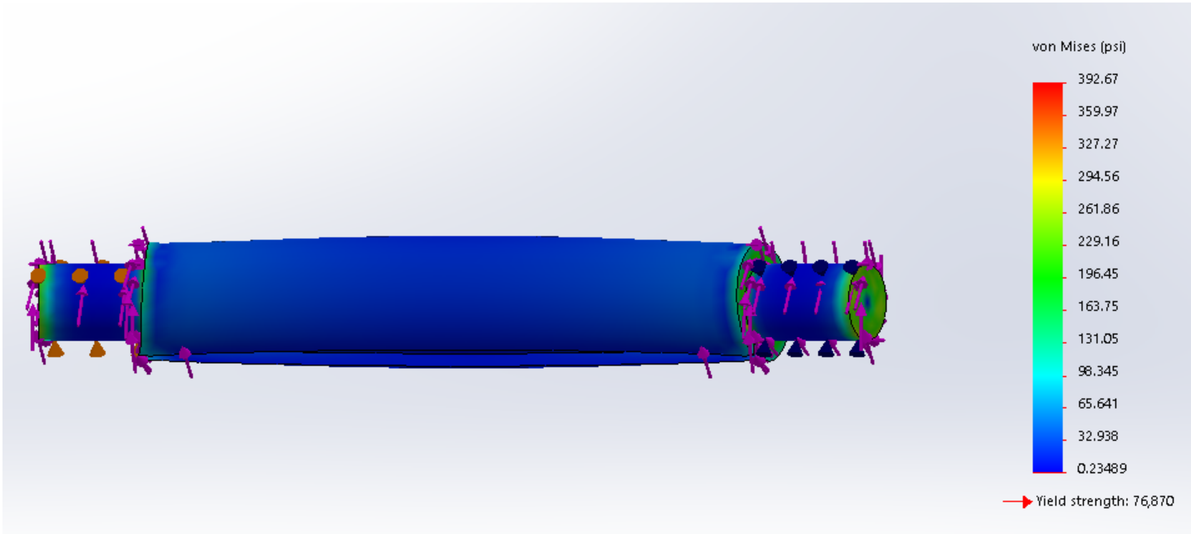


Figure 9: Weapon Shaft F.E.A.

Weapon Motor

For selection of the motor we researched and found a motor that is widely used motor, has seen use in Battlebots, and is able to take quite a bit of abuse. The motor we ultimately chose was the ME0708 PMDC Motor with a speed controller that has been rated to support this particular motor. The ME0708 can run 3700 RPM at 48V and has a max current of 330A for 2 min.

- Summary of Design:
  - Input: Electric Motor, 8 hp at 3700 RPM
  - Service Factor: 1.3 (Heavy Shock Loading)
  - Design Power: 10.4
  - Belt: 3VX610 V
  - Sheaves: Driver, 2in pitch diameter, 1 groove
  - Sheaves: Driven, 8in pitch diameter, 1 groove
  - Center Distance 22.50

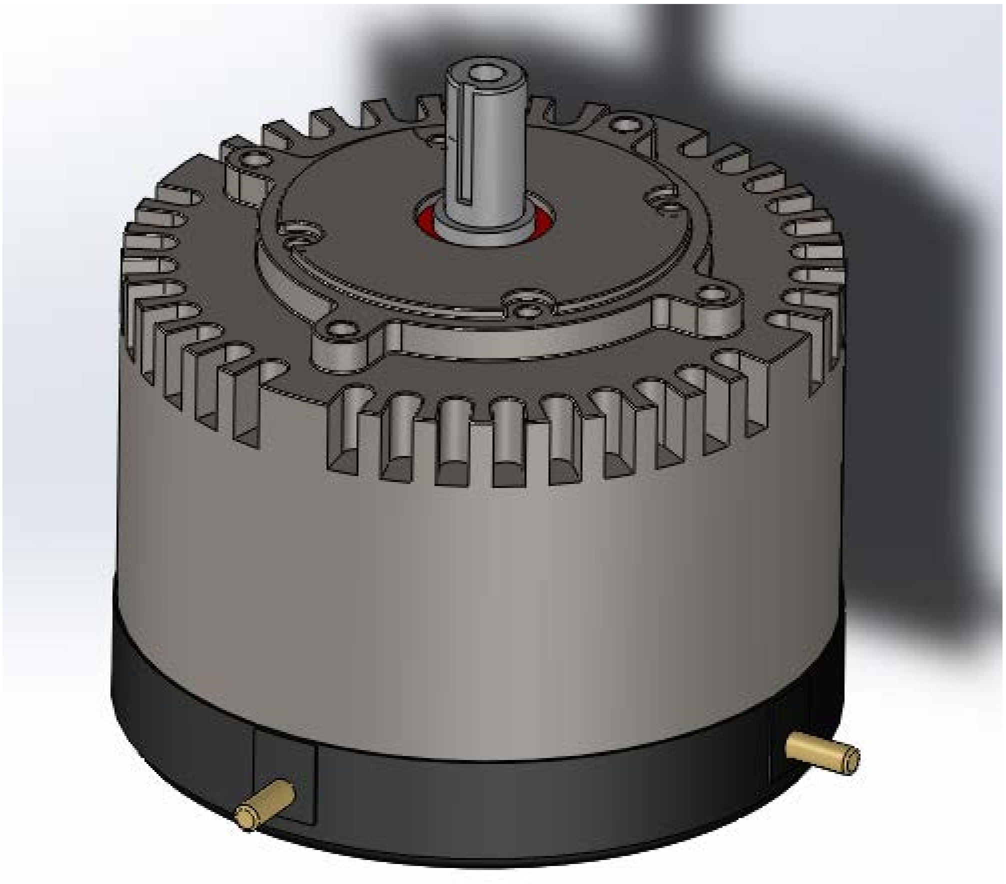


Figure 10: Design Weapon Motor

Weapon Drivetrain

For the weapon drive system it was decided that in order to cut weight that it would be best to use a V-belt system instead of the chains.

- Summary of Design:
    - Input: Electric Motor, 1 hp at 2600 RPM
    - Service Factor: 1.3hp (Heavy Shock Loading)
    - Design Power: 1.3hp
    - Belt: 3L610W
    - Sheaves: Driver, 2in pitch diameter, 1 groove
    - Sheaves: Driven, 8in pitch diameter, 1 groove
    - Center Distance 22.50in

F.E.A. was performed on the model and it showed that there is a pretty high concentration of stress at the T-brackets which

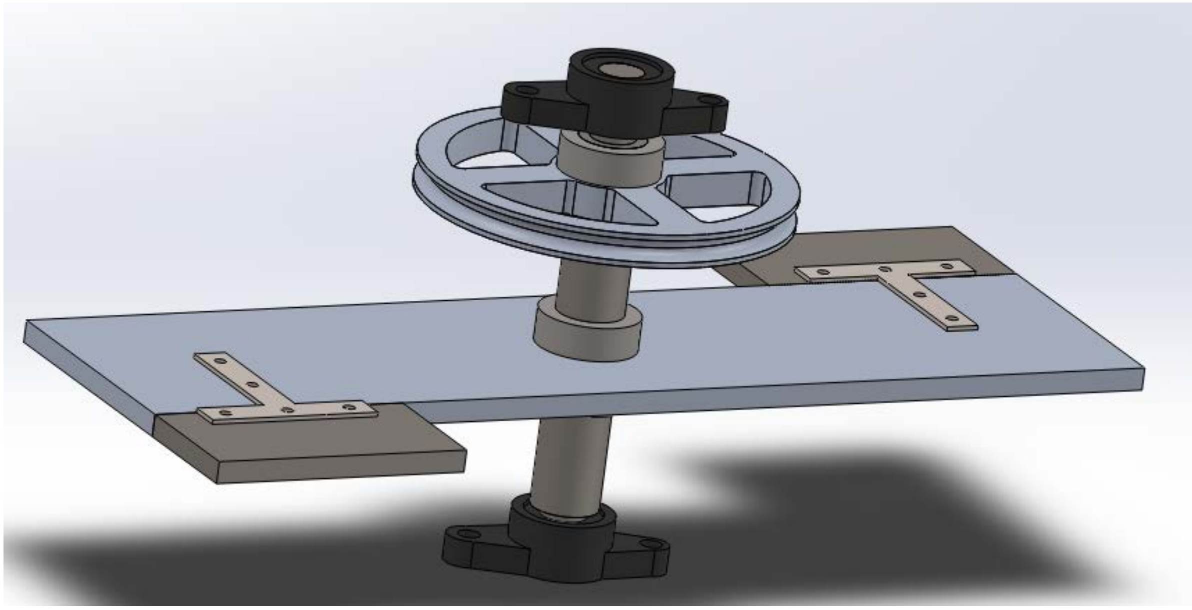


Figure 11: Weapon Drive System

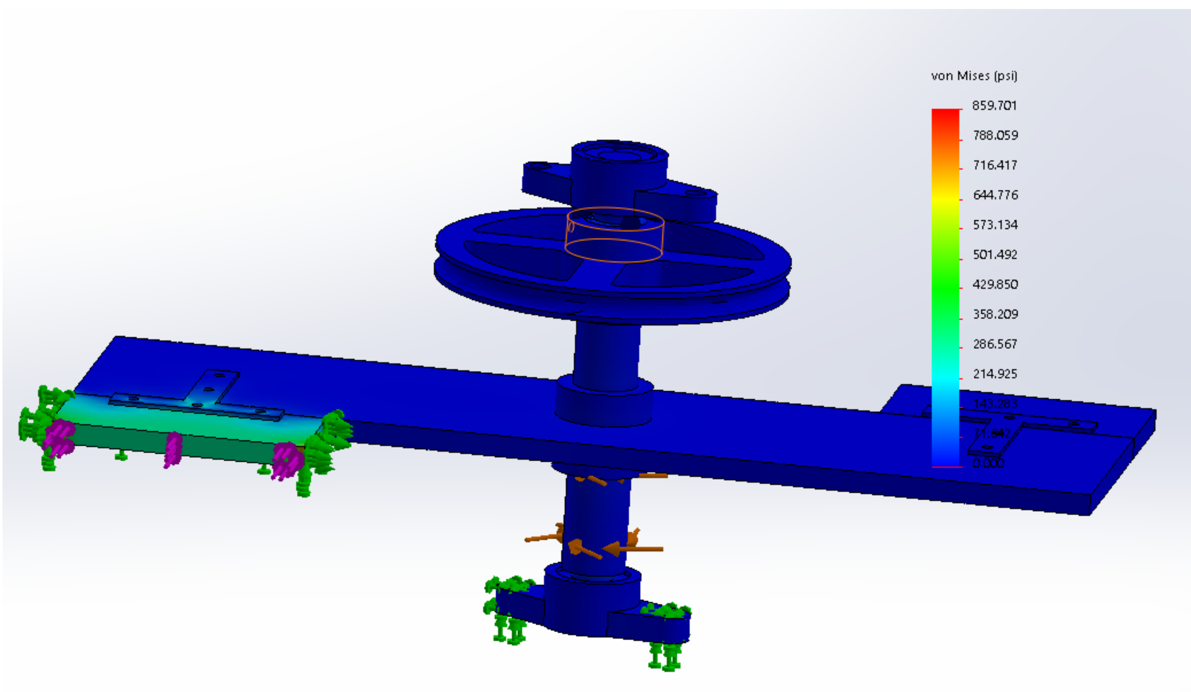


Figure 12: Weapon System F.E.A.

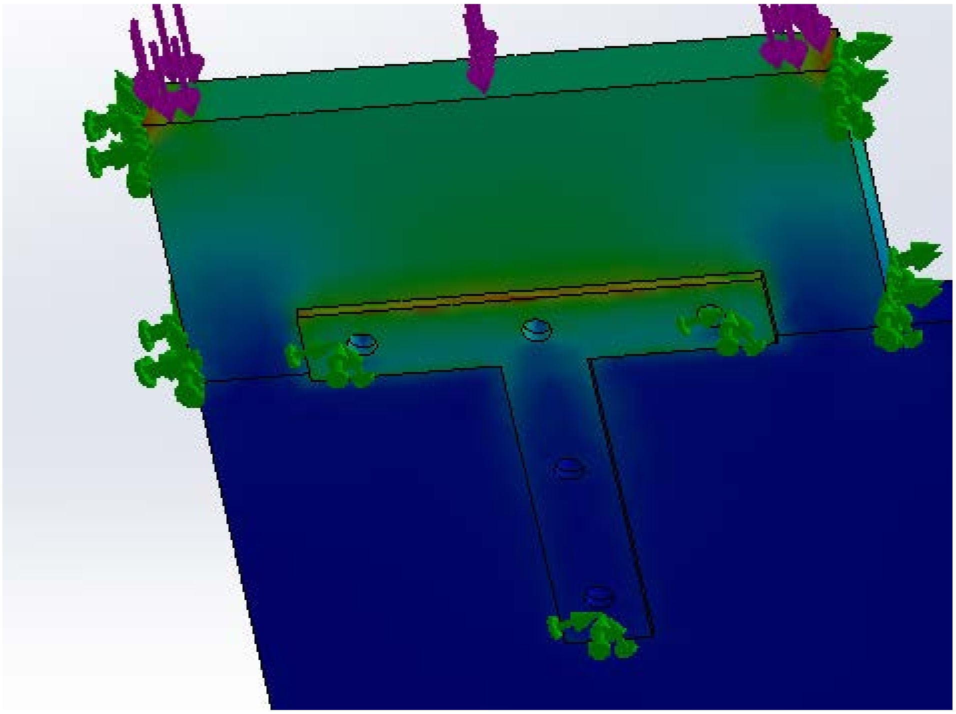


Figure 13: Weapon Blade F.E.A. Close up

Design of the Frame:

When designing the frame we looked at a four wheel design and six wheel design and using tacks instead of wheels before we decided on the two wheel design. But one thing all of those designs had in common. The frame design was going to be either a square or rectangle. The reason being is with research on bots similar to this the designs that were most successful were either square or rectangle so that is the design we decided to go with.

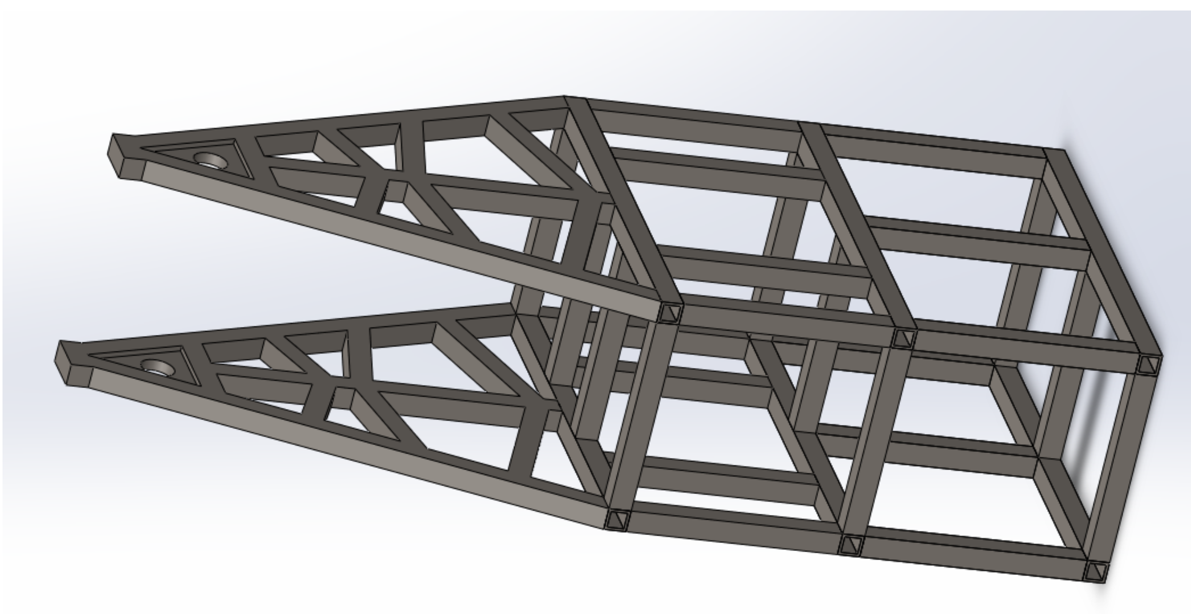


Figure 14: Initial Frame design

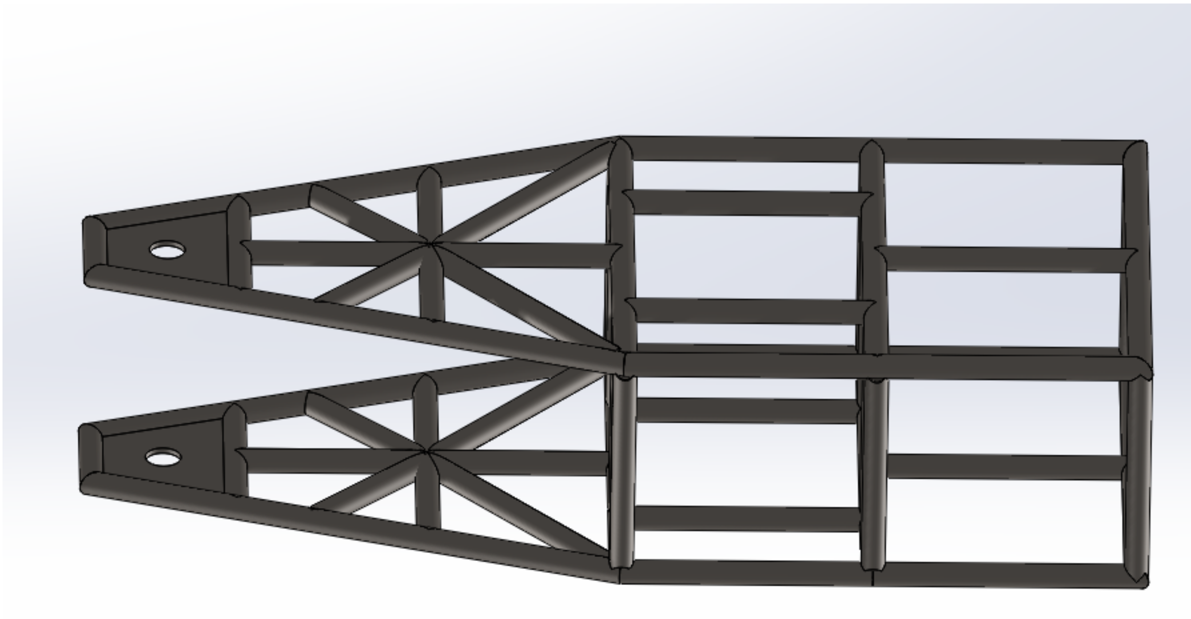


Figure 15: Final Frame Design

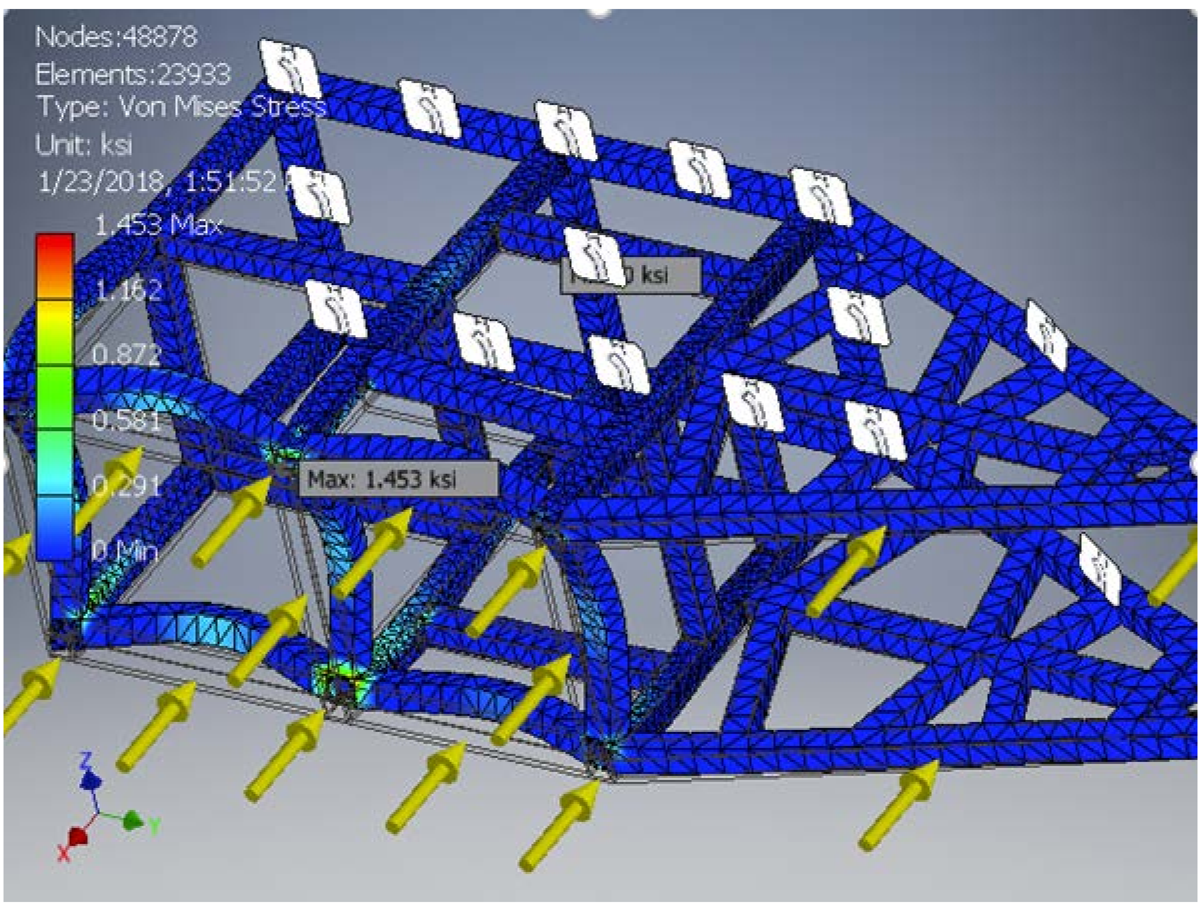


Figure 16: Frame under 1,000lb impact stress

Name	Minimum	Maximum
Volume	239.543 in^3	
Mass	67.9342 lbmass	
Von Mises Stress	0.00000786102 ksi	1.45256 ksi
1st Principal Stress	-0.151229 ksi	1.61237 ksi
3rd Principal Stress	-1.04977 ksi	0.262595 ksi
Displacement	0 in	0.000540677 in
Safety Factor	15 ul	15 ul
Stress XX	-1.04776 ksi	0.555384 ksi
Stress XY	-0.197452 ksi	0.211612 ksi
Stress XZ	-0.19182 ksi	0.17266 ksi
Stress YY	-0.71746 ksi	1.39389 ksi
Stress YZ	-0.525516 ksi	0.473017 ksi
Stress ZZ	-0.559002 ksi	0.529276 ksi
X Displacement	-0.000537461 in	0.000000175979 in
Y Displacement	-0.000181267 in	0.00000423923 in
Z Displacement	-0.000119279 in	0.000116442 in
Equivalent Strain	0.000000000236806 ul	0.0000438902 ul
1st Principal Strain	-0.0000000127297 ul	0.0000510951 ul
3rd Principal Strain	-0.0000366778 ul	0.000000272307 ul
Strain XX	-0.0000365908 ul	0.0000185918 ul
Strain XY	-0.00000853355 ul	0.00000914554 ul
Strain XZ	-0.00000829016 ul	0.0000074621 ul
Strain YY	-0.0000244965 ul	0.0000421842 ul
Strain YZ	-0.000022712 ul	0.000020443 ul
Strain ZZ	-0.0000185006 ul	0.0000177016 ul
Contact Pressure	0 ksi	1.43957 ksi
Contact Pressure X	-0.478236 ksi	0.501157 ksi
Contact Pressure Y	-1.27756 ksi	1.4243 ksi
Contact Pressure Z	-0.662846 ksi	0.620617 ksi

Table 1: Results of 1,000 lb frame stress test

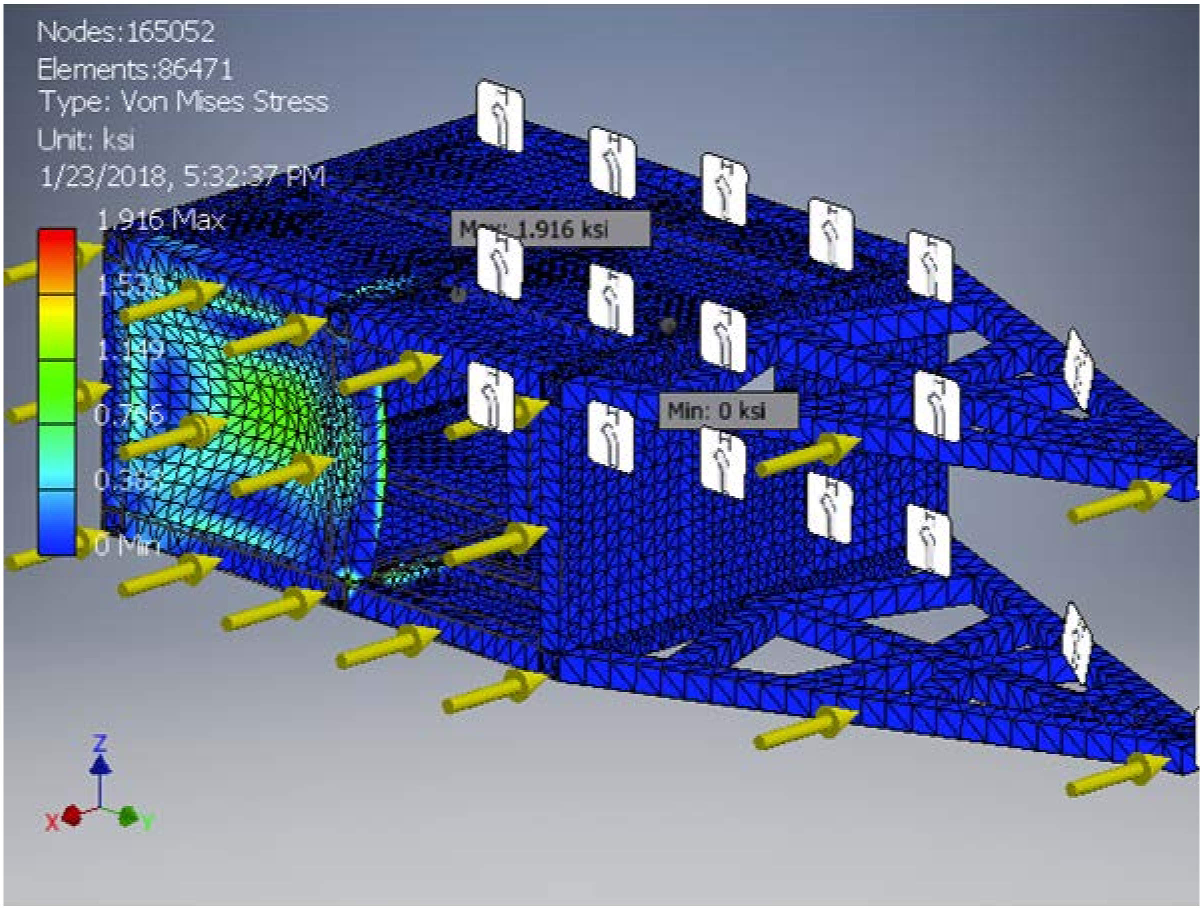


Figure 17: Frame w/ armor and 1,000lb impact stress

Name	Minimum	Maximum
Volume	572.263 in^3	
Mass	162.293 lbmass	
Von Mises Stress	0.000000707811 ksi	1.91558 ksi
1st Principal Stress	-0.50817 ksi	1.86684 ksi
3rd Principal Stress	-1.88465 ksi	0.345125 ksi
Displacement	0 in	0.00180041 in
Safety Factor	15 ul	15 ul
Stress XX	-1.88012 ksi	1.05611 ksi
Stress XY	-0.618333 ksi	0.533756 ksi
Stress XZ	-0.99702 ksi	0.854702 ksi
Stress YY	-1.4646 ksi	1.10618 ksi
Stress YZ	-0.68735 ksi	0.586513 ksi
Stress ZZ	-1.30298 ksi	1.39943 ksi
X Displacement	-0.00180022 in	0.0000937553 in
Y Displacement	-0.0002481 in	0.000107113 in
Z Displacement	-0.000426114 in	0.000384903 in
Equivalent Strain	0.0000000000310056 ul	0.0000569471 ul
1st Principal Strain	-0.00000302777 ul	0.0000609573 ul
3rd Principal Strain	-0.0000613938 ul	0.00000232892 ul
Strain XX	-0.0000611979 ul	0.0000345318 ul
Strain XY	-0.0000268585 ul	0.0000230681 ul
Strain XZ	-0.0000430895 ul	0.0000369388 ul
Strain YY	-0.0000369729 ul	0.0000344485 ul
Strain YZ	-0.0000297062 ul	0.0000253481 ul
Strain ZZ	-0.0000365267 ul	0.0000467019 ul
Contact Pressure	0 ksi	3.37537 ksi
Contact Pressure X	-1.65679 ksi	2.50647 ksi
Contact Pressure Y	-1.43468 ksi	1.3417 ksi
Contact Pressure Z	-1.82472 ksi	2.64619 ksi

Table 2: Results from 1,000 lb impact test of frame w/ armor

For the safety factor for the frame, it was decided to be a 15. As you can see from the results, that safety factor was never in any concern until the armor completely fails. At that point in time comes the risk of the frame failing if it is repeatedly hit in the same area with the same force.

For the component selection of the frame, it was designed to fit the critical parts in certain areas to best protect them, ease of access and in close approximation of other parts it works with. the furthest back section will be for the electronics and battery pack. It is put the farthest away from the designated danger area, or area that will receive the post punishment, since they are both very key parts in keeping the bot alive and running. In the forward section of the main body of the bot, the drive wheels are placed on each side while the weapon motor is placed in the center. There will be armor as well as reinforcements to help prevent an enemy attack from taking out the bots drive system or attack system. The main body will have tabs welded on the top side so the top armor plates can be removed so it is easy to replace damaged components or the battery pack. Finally, the part of the frame that is braced the most if the two forward arms on the robot. This is because this area is where the weapon blade is going to be mounted so it will have a high revolving force as well as receive the most impact or brunt of the force the enemy bot is putting out. there is no armor plating for as to save on weight.

DRIVE SYSTEM DESIGN AND ANALYSIS

Configurations

For the Drive system several options had to be taken into consideration. These selections come into real importance for competition and can be the difference between victory and defeat. For our bot maneuverability is of great importance so that lead us to choosing a wheel drive system versus walking legs or tank treads (which we were seriously considering at first). With wheels we had to consider whether to use a two, four, or six wheel system. We ultimately chose a two-wheel design, due to the necessity of being able to turn quickly to keep our opponent in front of us.

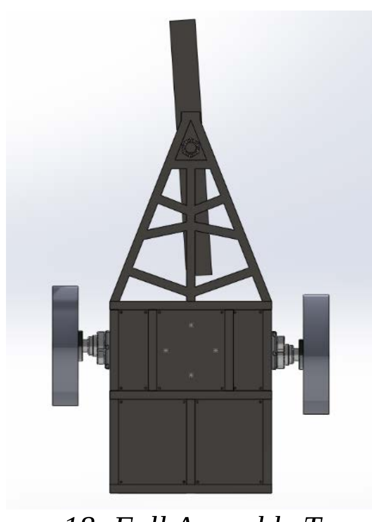


Figure 18: Full Assembly Top view

Motor

For our Drive system we selected to use two electric DC motors that would connect directly to our wheels. Between the many options of motor to choose from, we chose this option because of the simplicity it delivers to our design. In our initial design we selected to use the NPC-T74 motors from NPC Robotics. The motor was an improvement to the NPC-T64 motor that many bots similar to ours used. The specific motor brand also came with an attached gearbox, so we wouldn't have to make one on or purchase one separately. Due to a flaw in the design layout of all the motors and a lack of funding and accessibility we had to change and go with another set of motors.

We decided to use adapt two motors and gearboxes from a previous BattleBot project, 2011 team CATastrophe. The Motor is a S28-FP-150X MagMotor and gearbox was previously manufacture by the previously mentioned team. We did however have to adapt the output shaft of the gearbox to fit our application. The original shaft was not long enough so we machined new shaft and extended the shaft length (See Appendix A).

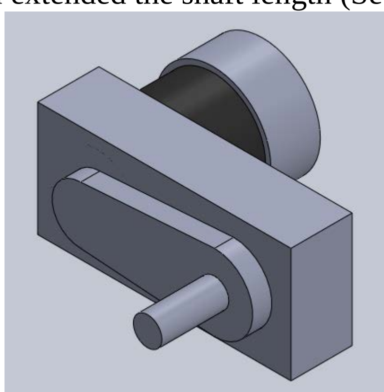


Figure 19: Model of 2011 BattleBot team Catstrophe, Motor and Gearbox

Wheel Selection

Our initial designs were to use two fourteen-inch flat proof tires. One of the ways to lose in competition is to get flipped over and unable to continue. The tires diameter size would have allowed us to be able to keep going whether we are flipped over or not. We went away from this design again due to funding restrictions and instead utilized two eight-inch diameter wheels. The tires on the wheels are a hard rubber material that'll allow us to take damage without the concern of going flat or being torn off the wheel hub. A caster wheel will be used in the back for balance.

Drive Assembly

For the overall drive system assembly, we still connected the drive motors and gearboxes to the wheel. A special bracket was welded to the frame so that the motors can be mounted in place. Electrically we used two 24V Nicon battery cells and a Thor 883 and Victor 88 speed controller, all of which were recycled from past BattleBot teams.

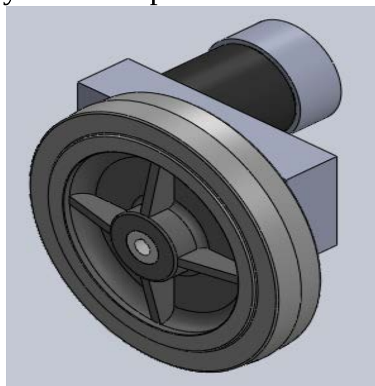


Figure 20: Model of Drive System

Fabrication

Figure _ : Frame Fabrication Image 1

Figure _ : Frame Fabrication Image 2

Figure _ : Armor Fabrication Image 1

Figure _ : Armor Fabrication Image 2

Weapon
The weapon blade was constructed out of high strength 2024 Aluminum ½" sheet. The hole in the center of the blade was cut out using a Wire EDM machine at Meyer Tool Inc. The little holes on the sides were just drill press out at Meyer Tool Inc.

Frame/Armor
The frame and armor were assembled at Chuck Black Race Cars in Independence KY. The tubing was welded together while the majority of the plates were welded on and 3 plates were bolted on.

Drivetrain

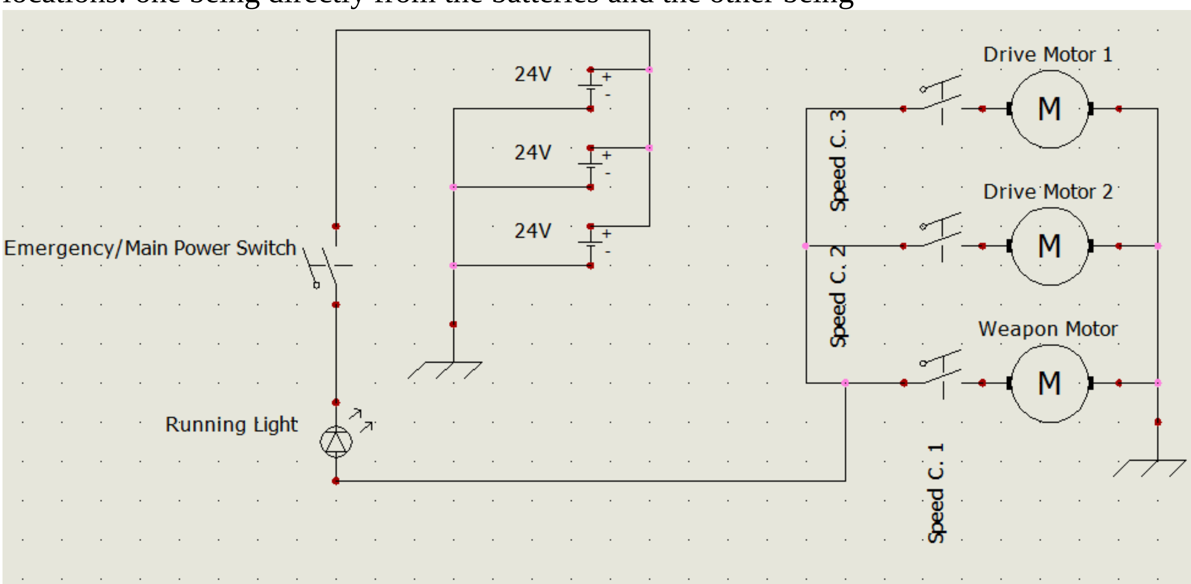
Testing

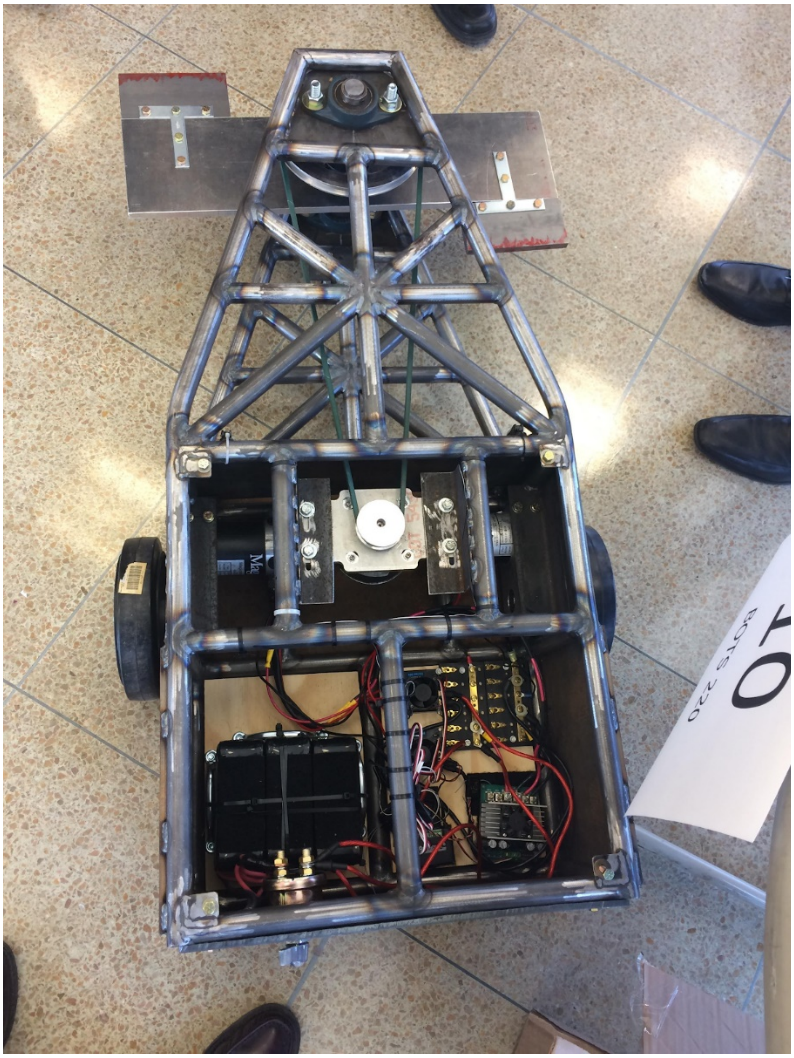
- Impact of weapon
- Weapon speed
- Battery life of weapon
- Battery life of drive system
- Turning speed
- Turning radius

- Top speed of bot
- Durability of weapon
- Location of test site: (parking lot) and will be filmed using a GOPRO

Electronics

The bot was wired using: 3 24V batteries, 1 Emergency/Main Power Switch, 2 Running Lights, and 3 speed controllers that will feed power to the 3 motors. The RC receiver receives power from the speed controller itself. For safety purposes the bot was grounded at 2 locations: one being directly from the batteries and the other being





Sponsors

- Chuck Black Race Cars: welding, fabrication equipment
- Bill Culbertson Remodeling: frame material, electrical support
- Machintech: armor

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

Proposed Budget

220lb BattleBot Budget (Seniors)				
Travel Expenses	Amount	Cost	Total Cost	Notes
Round Trip Plane Tickets to San Francisco from Indianapolis	4	$456.40	$1,825.60	Prices may change once final RoboGames date is set
Luggage Fee	4	$50.00	$800.00	
Hotel (for 4 nights)(Wednesday to Sunday)	1 Room	$149.00	$149.00	Prices may change once final RoboGames date is set
Car Rental (5 days rental)	1	$300-600	$600.00	Prices may change once final RoboGames date is set and based on vehicles available
Gas ($2.70 San Francisco Price as of 09/21/17)	1 Full tank of gas (16gal estimate)	$43.20	$43.20	Gas prices and cost will vary depending on vehicle gas mileage, gas tank size, and gas prices at time
Food				
Food (3 meals a day for 3 days and 1 dinner on Wed. and 1 breakfast on Sun.)	5 meals for 4 team members	$20 a meal	$500.00	
Team Expenses				
Team Shirts	4	$25.00	$100.00	Prices will change based on number of sponsors and are required by RoboGames
BattleBot Delivery to Robogames	1-2 Boxes		$1,967.00	Prices will vary based on box height, width, length, weight
Spareparts Delivery to Robogames	1-2 Boxes		$1,967.00	Prices will vary based on box height, width, length, weight
Total Estimated Cost of 220lb Battlebot Plus Spare Parts	1	$14,000.00	$14,000.00	Cost will change depending on design and material/labor and amount of spare parts
Team Registration for Robogames	1	$220.00	$220.00	There will be an additional fee based on the number of teammates beyond limit of 4 upon registering

			Team Total Cost	
			$22,171.80	

Actual Budget

Budget Item	Amount	Unit Cost	Cost
4130 Chromoly Square Tubing	32ft	Sponsored Material	Sponsored Material
Etek ME708 Weapon Motor	1	$525.00	$525.00
Controller KDZ 48400	1	$239.00	$239.00
NPC-T74 Drive Motors	2	$351.00	$702.00
Shaft Collars	4	$6.78	$27.12
14” Solid Rubber Tire	2	$87.94	$175.88
Adapter Hub	2	$20.00	$40.00
Vantec Speed Controller	1	$294.95	$294.95
1-1/2-12 Grade 5 Plain Castle Nut	2	$40.78	$81.56
		Total Unit Cost	Total Cost
		$1,565.45	$2,085.51

SCHEDULE, PROPOSED /ACTUAL

Proposed Schedule

- October 25, 2018: Settle on a Concept Design
- November 1, 2018: Send out Sponsor Letters
- November 8, 2018: Formulation and Basic Design Done
- November 29, 2018: 3D Models made and simulated
- December 13, 2018: Parts ordered
- January-March: Bot manufacturing and testing
- April: Competition

Actual Schedule

Week of January 29th- Order weapon and drive motors using the money allocated from the club. Also schedule frame assembly with the sponsor.

By the end of February- Have frame assembled, drive system mounted, battery packs made

Week of March 1st- Begin wiring of system and connection to the controllers as well as finishing up Weapon assembly

Week of March 5th- Begin testing and record testing with a gopro

Week of March 12th and 19th- Make any required changes and retest

FUTURE RECOMMENDATIONS/PLANS

Due to scheduling conflict with Graduation ceremony and the competition we decided that after we graduate we will compete in a competition at a later date. Before the competition we are going to make some improvements to the bot. Here are the changes to each component I want to make:

Weapon System:

- Have a double sheave system to help prevent slippage
- Have more than one blade made with different designs to fit the blade to the enemy bot
- Possibly make a shroud around the pulley for protection

Drive System:

- Have bigger wheels mounted so it can be operated right-side up or upside down
- Have two ball bearings mounted to bot (one on top and one on bottom) instead of the caster
- Get motors that mounted parallel to the side of bot to conserve space

Frame:

- Save money and build a second spare frame

Armor:

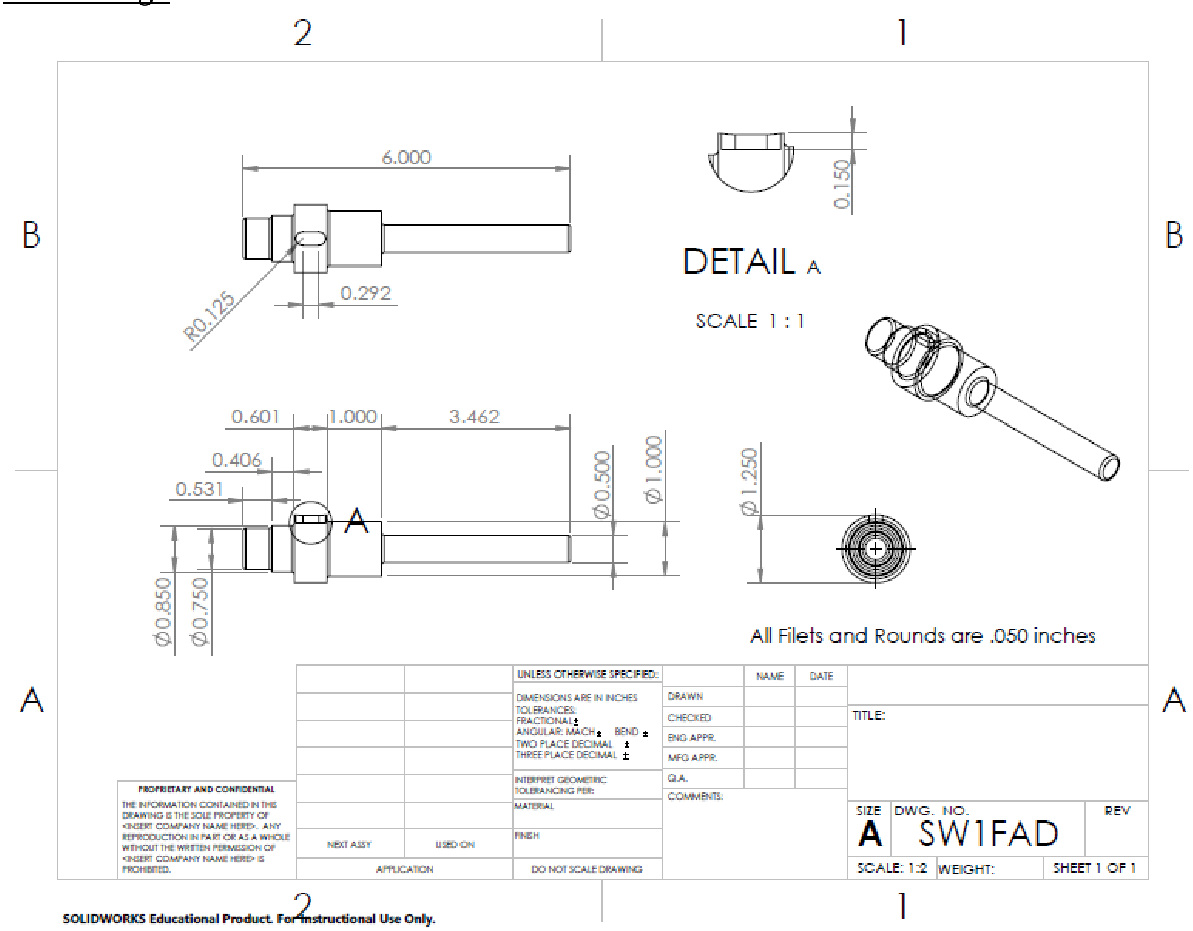
- Swap the AR400 top plate with a lighter material such as Aluminum
- Create a skirt or shroud around wheels to protect them as they are currently the weak spot of the bot

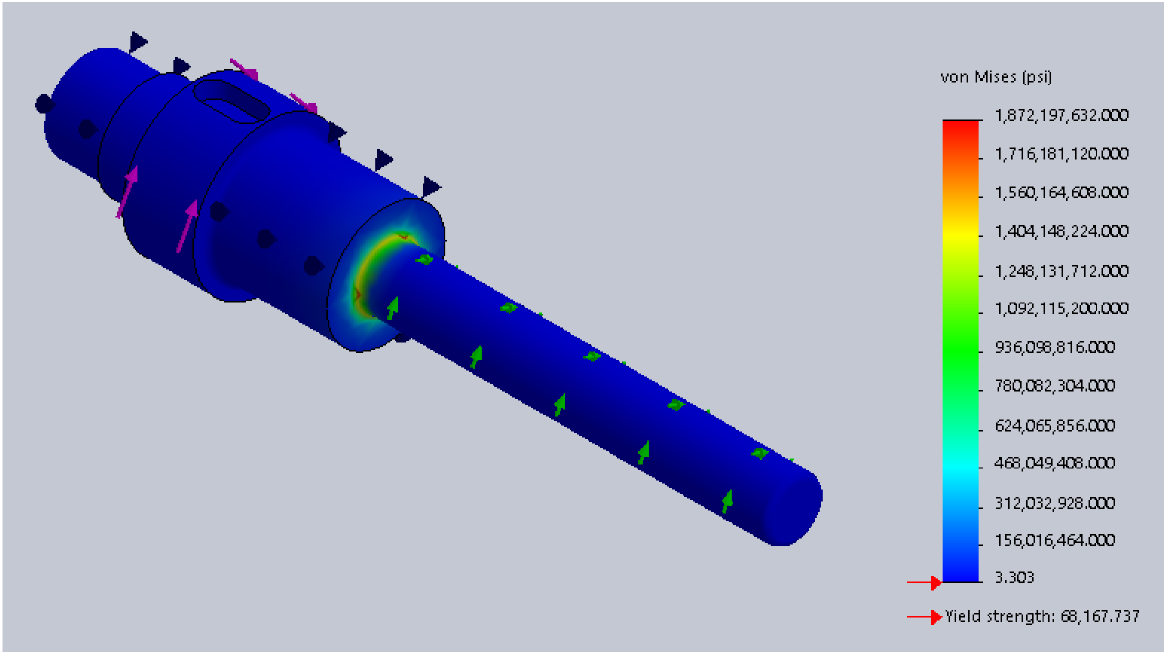
Works Cited

1. Meggiolaro, Marco Antonio. RioBotz Combat Tutorial. *Robogames.* [Online] March 2009. [Cited: October 1, 2017.] https://www.riobotz.com/riobotz-combot-tutorial.
2. Battle Robot Construction Tips. *LOGANBOT.COM.* [Online] LoganBot.com, August 2002. http://www.loganbot.com/bot_tips.html.

APPENDIX A

Shaft Design




von Mises (psi)
1,872,197,632.000
1,716,181,120.000
1,560,164,608.000
1,404,148,224.000
1,248,131,712.000
1,092,115,200.000
936,098,816.000
780,082,304.000
624,065,856.000
468,049,408.000
312,032,928.000
156,016,464.000
3.303
Yield strength: 68,167.737

APPENDIX B

Speed Calculations

Gearbox speed reduction:

$$RPM_f = \frac{RPM_i}{Reduction} = \frac{245}{20} = 12.25\ RPM$$

Maximum speed of BattleBot:

$$A_{wheel} = \pi r^2 = \pi \times 7^2 = 153.94\ in^2$$

$$Max\ speed = A_{wheel} \times RPM_f = 153.94\ in^2 * \ 12.25\ RPM = 1885.74\ in/min$$

$$Max\ speed = 1885.74 \frac{in}{min} * \frac{60min}{1hr} * \frac{1mile}{63360in} = 1.79\ mph$$

Design Torque:

$$\tau_D = Weight_{bot} * D_{wheel} = 220\ lbs \times 14\ in = 3080\ in - lbs$$

Design Horsepower:

$$HP_D = \frac{(\tau_D * RPM_f)}{5252} = \frac{(3080 * 12.25)}{5252} = 7.18\ hp$$