2023-2024 University of Cincinnati

Combat Robotics Team "RoboCat"

Senior Design Proposal submitted to the

Department of Mechanical and Materials Engineering

College of Engineering and Applied Science

University of Cincinnati

In partial fulfillment of the

requirements for the degree of

Bachelor of Science in Mechanical Engineering Technology

by

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Problem Statement

Our battle bot will be a key bot on the University of Cincinnati's combat robotics team. The concept of combat robotics is based on the idea of designing a robot that is able to defend hits from other robots while effectively dealing hits to incapacitate the contestants in the ring with you. There is great importance of designing the optimal balance of rigidity of the robot and overall weight. Just like human combat sports, competition is divided into weight classes. We intend to design for the 12 lb. weight class and will showcase our robot at a series of events, including the NHRL event in Norwalk Connecticut. NHRL is the one of the world's most competitive combat robot leagues where some of the biggest names.

This project will allow us as a team to apply the theories we have been learning in the classroom and the skills we have been sharpening while on cooperative education rotations. It will allow us to showcase our critical problem-solving skills, apply design theories and concepts, apply robotic methods, budget and time management, working through team disagreements, and most of all it will showcase on a national level what the University of Cincinnati's MET program is capable of producing for possible future students.

Research

Background of the Problem

Beetleweight Combat Robot Design Handbook

The Beetleweight Combat Robot Design Handbook is a resource created by Peter Garnache of Repeat Robotics which provides years of knowledge and expertise on many bot-building topics. Although the handbook is specifically for robots in the 3-pound category, many of the principles remain the same.

Senior Design Report - VOODOO

"VOODOO" was a UC senior design project from the 2022-2023 academic year created by Brannon McGinn, Tate Mitchell, and David Peiro. The focus of our senior design will be to make considerable improvements to their design and thus, we will rely on this report to give us an in-depth understanding of the existing research, current bot design, and areas for improvement.

Senior Design Report - BAKA BOT

The "BAKA BOT" was a UC senior design project from the 2022-2023 academic year created by Ana Bartholomew, Brian Ross, and Kasey Shumard. Their report will be a helpful resource to reference in order to gain a deeper understanding of the design considerations we will make. Since the "BAKA BOT" varies significantly in its design from "VOODOO", it will provide an alternative solution to each problem and help to consider new design directions for our bot.

Miami University Battle Bot Senior Design Report

The senior design report created by Braden Bakenhaster and Nicholas Newton of Miami University in 2021 is a useful resource to gain a new perspective on the project. The UC reports mentioned previously will be beneficial of course, but will both be influenced by UC Battle Bot Club's culture and specific individuals. Referencing an external senior design team will help bring new ideas to the forefront of our design and consider new ways of solving this problem.

Applicable Standards

BattleBots has a main website where standards and rules can be located. In the rules section you can find four documents all focused on different areas relating directly to design & competition rules. The four sections are separated into the following named pdfs, BattleBots design rules, BattleBots tournament rules, BattleBots battery rules, and NHRL judge's guide. We should note there is a fifth document in this section titled "How to get on BattleBots," although this section won't be applicable to our senior design project. Everything on BattleBots website will be a good reference for general rules to keep our robot eligible for most competitions.

Although where our main focus needs to be is on the NHRL website, this is because we intend to compete in this combat league before the CEAS expo to discuss how we performed and what lessons were learned. The NHRL also has a rules and regulations section of their website, which is broken up into seven different areas. Those being, builder conduct policy, bot design rules, safety rules, event rules, fight rules, judging criteria, and finally a full rule book in pdf format. All of these sections will be crucial for our team to have a good understanding of in order to design, fabricate, and compete with a successful robot at the national NHRL event.

On top of these two resources we have to fall back on when concerned about strategy, design, or an application. We must also follow the University of Cincinnati College of Engineering and Applied Sciences rules, meaning how we go about fulfilling our senior project theoretically and physically. There are rules in place for academics and safety rules we must follow when machining or fabricating at Victory Parkway's Campus.

Technical regulations from NHRL for 12 lb. weight class [5]

- Compliance with all event rules is mandatory
- All bots must be at or below the specified weight for their weight class
- 12lb weight class multibots get a 3-pound weight bonus and non-wheeled bots get a 6-pound bonus
- The maximum weight of any single bot may not exceed 110% of the normal bot weight
- The bot(s) must fit into a 36 x 36 x 36-inch cube at the start of the fight
- All entrants must have an active weapon. Only the heaviest of the multi-bots must have an active weapon
- All weapons systems must have locks that stop their actuation. Weapons that move must have a lock that stops movement in all directions
- Weapons that primarily act by obstructing visibility are not permitted
- Electrical and shock weapons are not permitted, nor are electrical weapons that purposefully block radio signals
- Entanglement devices are not permitted
- Liquids expelled from the bot are not permitted. Liquids used as a fuel source are permitted.
- Combustion powered bots are permitted
- Fabric, foam, and other ablative armor are permitted
- Electrical systems cannot exceed 72 volts
- Batteries that charge inside of the bot are permitted if the bot measures less than 11 x 8 x 6 inches

- Bots must have an easily accessible master power cutoff in the form of a switch or removable link. The power cutoff must be accessible without disassembling the robot in any way. The power cutoff must be able to be deactivated in no more than 15 seconds.
- All robots are guaranteed a minimum of 20 minutes between fights

State of the Art

Weapon

Vertical Spinners

When it comes to choosing what weapon to use on the battle bot, there are multiple different weapon types that you can choose from. One weapon type is a vertical spinner, which is the most commonly used type of weapon on battle bots. A vertical spinner is a weapon type that operates on the x-axis and works in a simple fashion. Most vertical spinners are designed to rotate in an upward direction. This is to allow the weapon to penetrate and flip/lift the opponent. The bots that use vertical spinners usually locate the weapon in the front to allow for maximum power and stability while it is spinning. Weapons of this type are usually made of some sort of strong tool steel or some other strong steel to maximize its damage capabilities. Although vertical spinners are commonly used and pack a large punch, there are disadvantages to using them on a robot. Vertical spinners are only capable of contacting an opponent's robot at a certain distance. This means drivers need to be more experienced in order to get in close and land a hit to the enemy. Vertical weapons usually only have one, small point of contact that allows for damage to be dealt to the opponent. This only gives the driver one chance per revolution of the weapon to make solid contact. They also allow for the bot to have many attack points due to it having a smaller attack radius and due to its orientation.

A robot that utilizes a vertical spinner is the NHRL 12-pound competitor bot called, “Pramheda”. This bot is driven by Zach Knight and its weapon consists of a single-tooth vertical weapon. Pramheda’s weapon rotates about the x-axis of the robot, in an upward direction, like most vertical spinner bots. It has been able to find great success using a vertical spinner. Pramheda’s average fight time is around 88 seconds with an all-time record at 25-17, which makes the bot to be currently ranked #17 overall in the NHRL 12-pound class.

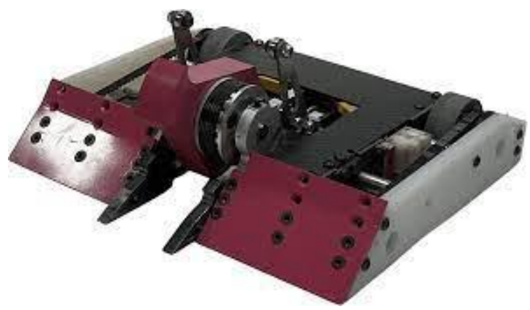


Figure 1.1: Vertical Spinner - Pramheda

Horizontal Spinners

Another type of weapon is a horizontal spinner. Horizontal spinners are another commonly used weapon type through battle bot history. These types of spinners rotate along the y-axis of a robot, can spin clockwise or counter-clockwise and are usually considered the most destructive and fascinating type of weapon. Horizontal weapons aim to make contact with the opponent and throw them off balance or send them flying across the arena. This weapon type is considered to be the most destructive because the orientation of these types of weapons allow the blade or size of the actual weapon itself to be larger than a vertical spinner. Weapons can be in the form of a blade, a "toothed" or "hooked" chunk of steel or in the shape of a sharp disc. Even though this weapon type is very efficient, it does have its vulnerabilities. When horizontal weapons make contact, they are sometimes susceptible to their own recoil which makes it hard for the driver to control. If it takes damage from its own recoil and becomes non-operational, the bot may lose the fight. These types of robots also have to consist of powerful batteries and weapon motors. This is because it takes a lot of energy to get one of the horizontal weapons to begin to rotate and to maintain its speed of rotation due to the larger weapon sizes.

The current #2 ranked NHRL 12-pound bot operates using a horizontal weapon. This robot is designed, built, and driven by a University of Cincinnati Graduate Student by the name of Jacob Hoffman. Maximizer's weapon is a large, 15mm thick Hardox 600 steel oval-shaped, single toothed weapon, which spins very fast and only leaves a small vulnerable spot on the robot's body for opponents to attack. The orientation and speed of the weapon allows this bot to land a nasty hit to all of its opponents. Its current overall record is 13-1.

Figure 1.2: Horizontal Spinner - Maximizer

<u>Drum Spinners</u>

The third type of common weapon type are drum spinners. Drum spinners are cylindrical-shaped weapons that spin horizontally or vertically. These types of weapons are commonly very bulky and are located at the front of a robot attached to the chassis. This weapon type usually rotates along the x-axis and is the entire width of the face of the bot since they are bulky. The drum spinners can be hollow or solid cylinders that consist of sharp teeth or one long blade/tooth on each side of the cylinder. These drums are usually made out of one single piece of steel. They are known for their powerful hits, giving the bot ability to flip over or to deal a great amount of damage to the opponents. This weapon type is very reliable since it is very secure to the robot's chassis, simple to imply, and has a compact design. Drums consist of disadvantages just like any other type of weapon. Due to their compact design, their attack distance and precision is much shorter compared to other weapon types. These drum spinners are also susceptible to their own recoil, similar to the horizontal sinner. Drum spinners can cause weight distribution and cause the bot to be unstable due to its bulky weapon size. These spinners are known to be more costly than the other types due to the complexity of its manufacturing.

The widely known battle bot known as “Minotaur” uses a drum spinner as its weapon. It is designed and operated by Team RioBotz on the tv show “Battle Bots”. Minotaur consists of a heavy, solid steel cylindrical drum spinner with a long, sharp tooth on each side. It delivers a powerful hit to its opponents due to its incredible high speeds of rotation. Its drum spinner is also known for its shear force power that it delivers to the opponents. Minotaur’s drum spinner has brought great success to the team, making the robot to be ranked within the top contenders on the show with an overall record of 25-10.

Figure 1.3: Drum Spinner - Minotaur

Drivetrain

<u>Belts</u>

The drivetrain can be one of a few different setups. The first type of drivetrain that can be utilized is a belt drivetrain. This type of drive system is very efficient and is cost-effective. Belts have a smooth and quiet operation that requires low amounts of maintenance and is easy to install. It contains only two main components, which are a belt and pulleys. There are multiple belt drivetrains that are able to be used, but the two main belt driven systems used on battle bots are open belt drive systems and crossed belt drive systems.

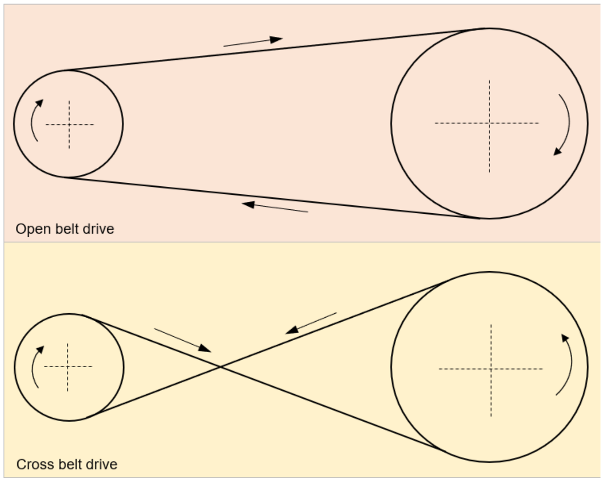


Figure 1.4: Open and Closed Belt Drive Systems

An Open belt system contains a belt that goes from the top of one pulley to the other without crossing. This means that the belt stays in the same plane through every rotation. This type has an angle of wrap between the belt and the pulley always below 180 degrees. Since the wrap angle is smaller, the power transmission capability is lower as well. Open belt systems have relatively shorter belts and usually have longer belt life since there is no rubbing on the belt itself through its rotations. The belt in an open belt drive does vibrate as the center distance in between the pulleys gets larger.

A crossed belt system contains a belt that crosses itself during operation starting at the top of one pulley to the bottom of another pulley. The belt bends in two different planes during each rotation and has an angle wrap always above 180 degrees. Since the angle wrap is above 180 degrees, the power transmission capability is higher than an open belt drive system. The crossed belt system usually consists of a longer belt length. Its belt is susceptible to more wear than open belt systems because it crosses between pulleys, making the overall shelf life of the belt short.

Chain:

Another common drivetrain system type is a chain driven pulley or mechanism. This drive system is driven by a chain attached to the top of one sprocket that rotates to the top of another sprocket in the same plane. The chain is rotated around by the teeth attached to each sprocket. Chain drivetrains are commonly used because of their ability to have high load capacities and to be very efficient. Chains also have the tendency to be able to last long due to their durability. Chains allow for low slippage while in motion and are very versatile. Chain driven systems contain two components, which are sprockets and the chain itself. This type of system can be very powerful and reliable, but it costs relatively more than other types and is a little more complex. Chain drivetrains require regular maintenance in order to stay operating smoothly. These types of system also generate more noise and vibration than the other drivetrain types. It is a much heavy drivetrain that has certain space requirements to be able to operate. The complexity of the system and the weight combines to make the system move slower if compared to other types of drivetrains.

Figure 1.5: Chain Drive System

<u>Gearbox</u>

A gearbox is a third type of drivetrain that many battle bots utilize. This system is a gear transmission drivetrain used to transmit power and motion. Many battle bots use this type of drive in their designs because it is a very compact design that gives you immediate power and torque while still maintaining a high efficiency. This type of drive system distributes its load evenly throughout its gears. It has a quiet performance noise and it gives the driver the ability to have good control on the speed and torque of the drive system. Gearbox drive systems are a little more complex than the other two systems. It contains components such as shafts, gears, and sometimes housings and casings. This drive system also requires a great bit of regular lubrication and maintenance. Although gearboxes are the most commonly used drivetrain on battle bots, there are still disadvantages to this type of drive. Overheating is an issue these gearboxes have while in operation due to friction. There are also limits to the gear ratios within the gearbox and the gears can be inefficient at low speeds due to the energy loss due to friction being higher than when it is in full operation. Gearbox drivetrains also tend to be more costly than the other two types of systems and in the event of a failure, they are much more complex to diagnose.

Figure 1.6: Gearbox Drive System

Armor/Frame

Many battle bots use some kind of armor to protect their brittle inside parts. There are many materials that are used on battle bot armor and frame components. Here are a few that are the most commonly used on many competing battle bots.

Aluminum is a widely used material for building frames and sometimes armor. Aluminum is a very light weight material that is easily shaped or formed into any shape that is desired. It is easily machinable and relatively cheap to purchase. It isn't the strongest material to get but it will provide some sort of protection. When aluminum gets hit by hard steel it shreds away instead of just cracking.

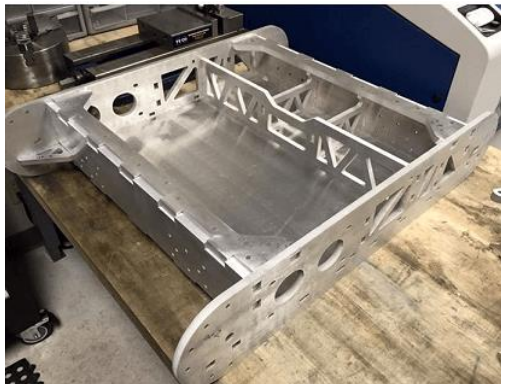


Figure 1.7: Aluminum Frame

Titanium is another commonly used material. Titanium is a hard steel that is very lightweight. It can take hard hits from other types of steels and still be fine to operate. There are some disadvantages to using titanium. It is more on the expensive side to purchase. Titanium is also harder to machine. Titanium is used for a lot of battle bot frames instead of aluminum because it doesn’t bend at all and will withstand many hard hits. Some other bots use it for armor, plows, and wedges on the outer surfaces of the bot for a strong, armored protection.

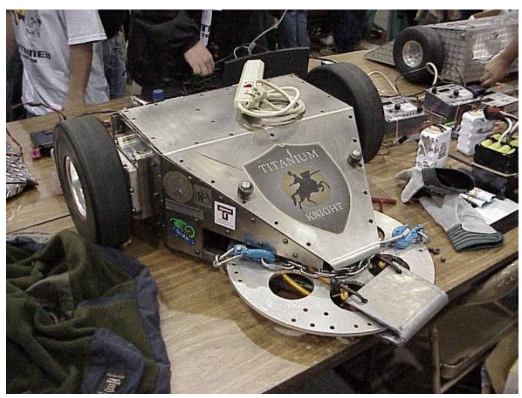


Figure 1.8: Titanium Frame

Another material is UHMW. This stands for Ultra-High-Molecular-Weight Polyethylene. This material is lightweight and is able to absorb a great amount of kinetic energy when it is hit. This attribute makes it a very suitable material for outer surface armor on a battle bot. UHMW is easy to machine and has a low friction coefficient on its surfaces, making them smooth, with some sort of lubricity. Many battle bots use this material for their inner structures such as body components or frame components.

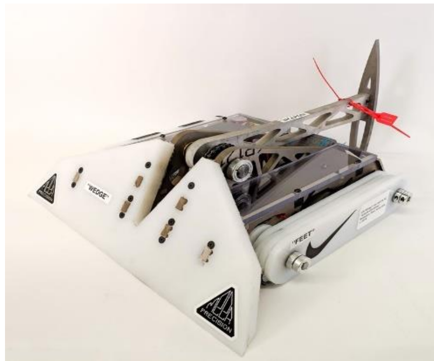


Figure 1.9: UHMW Frame

Wheel Type

There are a few different wheel types to use on a battle robot. Some types of wheels that can be used are rubber wheels, foam wheels, and crawler wheels/track wheels. Rubber wheels are the most commonly used type of wheel. They are cheap to produce or purchase and they are super reliable. They get good traction on the wood floors at the NHRL event, which allows for great maneuverability and driving control.

Figure 1.10: Rubber Resin Poured Wheels

Foam wheels are another cheap wheel type that are used on these battle robots. Since they are very lightweight style wheels, they help assist with weight reduction on the battle bots. They provide a soft landing for the bot when it gets hit and lands upright on its wheels. They maintain a great balance between traction and shock absorption when they are impacted. The disadvantages to using foam wheels are that the wheels themselves are very brittle. When in contact with hardened steel, they split very easily, possibly making the driver lose their drive controls. They don't have the best optimal traction when operating, especially on wood surfaces. The poor traction leads to poor maneuverability.

Figure 1.11: Foam Wheels - Spectroscope

Crawler wheel types, or also known as a track drive system are a third type of wheel base used on some battle bots. This type of wheel base is more complex than other types due to the number of components it uses. Tracks offer a great amount of stability and traction on wood flooring. They are able to take many more hits than other types of wheels since they usually are made from some type of metal and they distribute the force over a larger area. This type of wheel offers a large versatility when it comes to different terrains and they can maintain a larger carrying capacity as well. The disadvantages to using track style wheels are that the tracks can add a large amount of weight to the battle bots and they require a larger amount of maintenance than the other types of wheel. Tracks are usually more costly compared to foam and rubber wheels. Track wheels make the robot more susceptible to its opponents due to its tracks creating a large, exposed surface for flippers to get under or spinners to impact. They also force the robot to have a much larger turn radius, slowing down its maneuverability time.

Figure 1.12: Crawler Track Wheels – Bite Force

End User

The end user of our robot is going to be all members of our senior design team. Our team will design and create a 12 pound Battle Bot for a NHRL competition which will be sponsored and funded by the University of Cincinnati. One member will be expected to be familiar enough with the robot to drive the robot during matches. This means the robot must be easy to control so the driver is able to maneuver around opponents to deal maximum damage while avoiding attacks. In the case where the robot takes a significant amount of damage, all the team members need to be able to quickly repair and swap components in order to get the robot back for the next match. This means components will be as simple and modular as possible. We will mainly focus on research and surveys that will allow us to come up with the best design for our Combat Robot that will meet all of the competition requirements. By doing this we will be able to develop and fabricate a BattleBot which will allow us to defeat our competitors and stun event judges. As a team and as the end user of the robot, all members must follow the rules laid out in the NHRL rule book.

Summary of Research

Our project will be to design a combat robot for the 12-pound weight class and participate in NHRL competitions. To accomplish this goal, we have conducted extensive background research and considered state-of-the-art solutions. Drawing inspiration from these resources, we have a strong foundation on which to make informed decisions and ultimately, a successful combat robot. To inform our design process, we have gathered a wealth of background research, examining resources like the "Beetleweight Combat Robot Design Handbook," which, although aimed at 3-pound robots, offers principles for the sport of combat robotics that we can adapt to fit our larger robot. We've also closely examined senior design reports such as "VOODOO" and "BAKA BOT" from UC's 2022-2023 academic year, and other competing battle bots. These reports taught us design intentions, manufacturing processes, overall successes, and failures.

Our research has led us to investigate state-of-the-art combat robot weapons, with a focus on three common categories: vertical spinners, horizontal spinners, and drum spinners. Each type brings unique advantages and challenges, exemplified by bots like "Pramheda," "Maximizer," and "Minotaur." First, vertical spinners were examined and found to be heavy-hitting and able to transfer large amounts of energy to a singular area of your opponent. Horizontal spinners are the most destructive, due to their ability to house larger weapons. As a result of this, horizontal spinners require much more power to run and take longer to reach maximum speed. Drum spinners are a very commonly used weapon due to their simplicity. They deal consistent damage and reach maximum speed quickly. However, due to their small bite length and size limitations, drum spinners are not able to deal as much damage to a singular area as the other weapon types.

For the drivetrain of the bot, our team has investigated various options, including belt drives, chain drives, and gearboxes. Belt drives are very common in the sport of combat robotics since they can separate the loads applied to the bot from the motors themselves. This preserves components while still delivering maximum power. Chains transfer the motion of the drives from a distance and are very durable yet have increased weight. Oftentimes, the drives of a bot will be able to reach much higher speeds than desired of the weapon, so a gear box is used to convert these rotations into increased torque.

When it comes to the armor and frame, our research has revealed materials like aluminum, titanium, and UHMW are among the most common. Aluminum is lightweight, easy to machine, and readily available, making it the most common material for 12-pound robot frames. Titanium is also lightweight and incredibly strong, but higher costs and machining difficulties mean this material is used sparingly and only where necessary. The UHMW armor is excellent at absorbing the impact of an opponent's weapon and can be used to supplement the frame. Our robot's wheels are a critical component, and we've considered rubber wheels, foam wheels, and crawler wheels/track wheels. Rubber wheels are the most common type used in a combat robot due to their low cost and high traction. Foam wheels can be used to save weight of the bot, but they are less durable and provide less traction. Tracks are sturdy and provide great traction but are much heavier than the alternatives.

Quality Function Deployment

Customer Features

As a team we created a list of multiple applicable features we deemed important as the customers of our project. We then brought the list down to 10 key features to focus on and developed a survey to share with fellow combat robot builders. The survey was formatted in a manner in which questions prompted the respondents to rank the features importance on a scale of 1-10. From this survey we gathered X-Amount responses and were able to weigh each feature's importance. This was done by removing the outliers in gathered data and taking the average score of each response given relating to its respective feature. We then imported the collected data into a HOQ template.

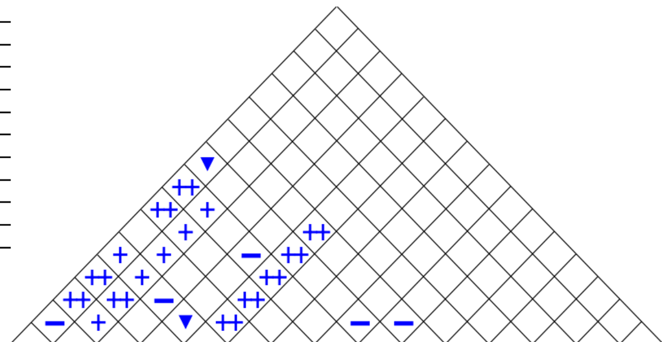
1. Safety
2. Weight Limit
3. Ease of Repair
4. Mobility Control
5. Budget Limit
6. Modularity of components
7. Armor strength
8. EDS strength
9. EDS speed
10. Component durability

Engineering Characteristics

1. Safety of handling and operating robot (Dimensionless)
2. Weight of robot in pounds and ounces (lb & oz)
3. Disassemble and reassemble time of robot (Seconds)
4. Time to move to a specified point in arena (Seconds)
5. Cost of robot United States Dollars ($USD)
6. Quantity of configuration possibilities
7. Armor Strength (yield characteristic of component material (MPa))
8. Yield strength of EDS material (MPa)
9. Tip speed of EDS (RPM)
10. Operating time or lifecycle of components (Seconds)

House of Quality / Interview with Sponsor

Title: RoboCat Senior Design HOQ
Author: Tyler Morris, Nicholas Scardicchio, and Eric Stachowiak
Date: 9/26/2023
Notes:



Legend

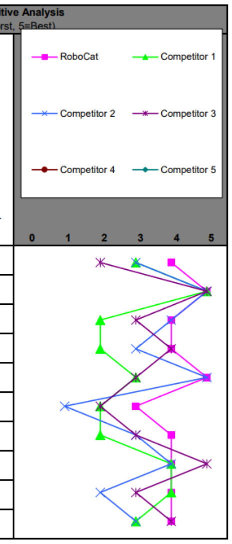
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Safe to Handle & Operate (Yes/No)	2 Pounds & Ounces (lbs & oz)	3 Assembly & Disassembly time (Seconds)	4 Time to move to a specified point (Seconds)	5 United States Dollars (USD $)	6 Configuration Possibilities (Quantity)	7 Yield Strength of Armor (MPa)	8 Yield Strength EDS (MPa)	9 Tip Speed (rpm)	10 Operating Time (Seconds)
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)										
1	9	10.5	0.1	Safety	Θ									
2	9	10.5	0.1	Weight Limit		Θ		O		▲		O		
3	9	21.1	0.2	Ease of Repair	▲		Θ							
4	9	10.5	0.1	Mobility Control				Θ						
5	9	10.5	0.1	Budget Limit		O			Θ					
6	9	10.5	0.1	Modularity of Components			Θ			Θ				
7	9	5.3	0.1	Armor Strength		Θ					Θ			
8	9	10.5	0.1	EDS Strength					O			Θ	O	
9	9	0.0	0.0	EDS Speed		Θ							Θ	O
10	9	10.5	0.1	Component Durability		▲	O		▲	▲				Θ
				Target or Limit Value		<15 Pounds	< 900 seconds	< 30 Seonds	1,700 USD	> 2 Possibilities	> 225 Mpa	> 1000 Mpa	> 8500 rpm	>360 Seconds
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	1	8	7	6	2	3	6	7	5	8
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9
				Weight / Importance	115.8	184.2	315.8	126.3	136.8	115.8	47.4	126.3	31.6	94.7
				Relative Weight	8.9	14.2	24.4	9.8	10.6	8.9	3.7	9.8	2.4	7.3

Columns 11–15 are blank.

Competitive Analysis (0=Worst, 5=Best)

Row #	Demanded Quality	RoboCat	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
1	Safety	4	3	3	2		
2	Weight Limit	5	5	5	5		
3	Ease of Repair	4	2	4	3		
4	Mobility Control	4	2	3	4		
5	Budget Limit	5	3	5	3		
6	Modularity of Components	3	2	1	2		
7	Armor Strength	4	2	3	3		
8	EDS Strength	4	4	4	5		
9	EDS Speed	4	4	2	3		
10	Component Durability	4	3	3	4		



Powered by QFD Online (http://www.QFDOnline.com)

Figure 2.1 House of Quality

Product Objectives:

Based on results from the survey sent to combat robot builders and the House of Quality. Weighted importance ratings have been determined and assigned to each engineering characteristic. The characteristic and its associated rating has been listed below. Moving forward this data will help drive the design choices and to help justify design decisions.

Formatting: Customer feature ***(Importance weight)***

Description

1. Ease of Repair **(24.4)**

a. Any component should be able to be removed and replaced including robot disassemble and reassemble times under 15 minutes

2. Weight Limit **(14.2)**

a. Our combat robot must be under 12 lbs. 0 oz. to compete

3. Budget Limit **(10.6)**

a. The total cost of all materials and labor required to build the robot including spare parts shall be no more than $1700.00

4. Mobility Control **(9.8)**

a. The combat robot should be able to move to any desired point in the cage within 30 seconds.

5. EDS strength **(9.8)**

a. Our energy deployment system must be fabricated out of a material with a minimum yield strength of 1000 MPa to deliver the strike force we anticipate

6. Safety **(8.9)**

   a. The combat robot should be safe to handle, safe to operate in the battle cage, and have the ability to have a successful EDS lock on it at all times other than when in battle.

7. Modularity of components **(8.9)**

   a. Our components need to be compatible with other combat robots' components on our University's team. Also, there needs to be at least 2 different possibilities of each component layouts within the combat robot.

8. Component durability **(7.3)**

   a. Most of the components should be able to last through at least 3, 2 minute fights.

9. Armor Strength **(3.7)**

   a. Our armor materials need to satisfy a minimum yield strength of 225 MPa to withstand anticipated strikes of opposing robots

10. EDS speed **(2.4)**

   a. Our energy deployment system should be able to spin a minimum of 8500 rpm at the tip of our EDS

Team Members and Responsibilities:

Tyler Morris:

- EDS Design and Assembly
- Fork Design and Assembly
- EDS Ear Design and Assembly
- Report
- Customer Features
- Manufacturing
- State of Art
- Operator

Nicholas Scardicchio:

- Drive Train Design and Assembly
- Drivetrain and EDS Calculations
- EDS Drive Design and Assembly
- Budget management
- Part sourcing
- QFD Report

Eric Stachowiak:

- Main Assembly Integration of Subassemblies
- Frame Design and Assembly
- Armor Design And Assembly
- Electronic Integrator
- Survey Management

Preliminary Concepts & Drawings

EDS:

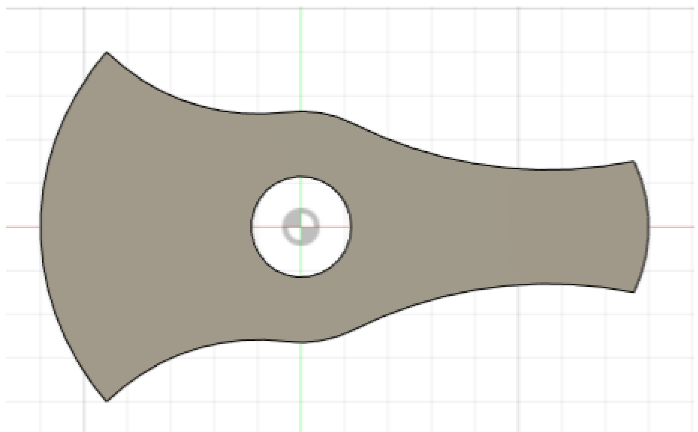


Figure 3.1 ax-shaped EDS

The first concept design is an ax-shaped EDS. This EDS is made from Hardox steel and is symmetrical, this allows us to attack opponents in clockwise and counterclockwise directions. It is ½ inch thick and has a diameter of 5.5 inches.

The benefits of this design are that it is completely symmetrical, making it easy to manufacture and relatively cheaper than a complex part would be. Since it is a single toothed EDS, there are many benefits that tags along with its functions. Single toothed EDS's give you greater ability of a high impact hit. All the energy is converted and transferred to the opponent all through this one tooth. Allowing the EDS to deliver harder hits. Also, single toothed weapons have a larger hit, also referred to as bite, on the opponents. This is based on factors such as the EDS speed and the number of teeth on the EDS. Since this EDS has only one blade and a high rpm speed, it can deal a great amount of damage each time it hits the opponent because it can only contact once every rotation. This allows the EDS to store up a large amount of potential energy before contacting the opponent.

The downfalls of a single tooth EDS is that it can only make one impact per rotation, limiting the amount of damage that could potentially be dealt to the opponent. Single tooth EDS have a smaller surface area of the teeth, giving it a less chance of making an impact on the opponent. They also are known to have limited range with only one tooth. The material of EDS gives this option a slight downfall because Hardox steel is expensive and hard to machine because it requires special tools to be able to cut the steel. This could become a big problem for last-minute changes and improvements to the EDS.

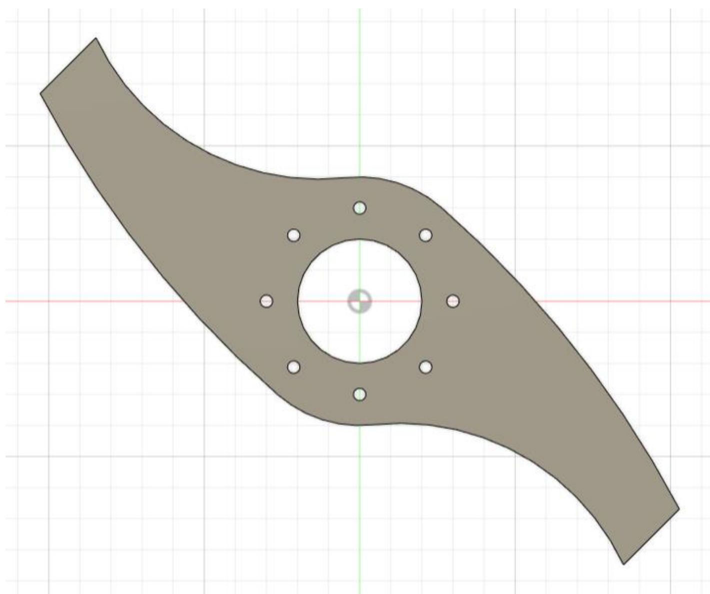


Figure 3.2 Dual Blade

The second concept design is a dual-bladed EDS. This dual-blade EDS is made out of Hardox steel and is also symmetrical, making it easy to get a center of mass calculated. It can attack opponents only in the clockwise direction. It is ½ inch thick and has a diameter of 4 inches.

The benefits of a dual-bladed EDS is that it has more opportunities to make contact with the opponents bot. This gives you the chance to repeatedly impact the opponent over and over again, adding up to a great amount of damage being dealt. EDS's that have dual blades have a greater durability because if they have one blade become dull or broken, it has another blade that may still be effective. Dual blade EDSs' have great energy efficiency because on how evenly the EDS impacts the opponent, allowing it to be easier on the EDS drive system and motor and not allowing strain on any of the parts.

Although a dual-bladed EDS has many advantages, there are some downfalls to these. Dual bladed EDS impactors have a slow rotational speed since it makes contact twice on every rotation This is because the double impacts do not allow the EDS to build up potential energy between hits. Also, a dual bladed EDS usually weighs more than single toothed blades. Since they weigh more, this means the EDS is limited in its capable diameter. They are usually much smaller in diameter than a single tooth EDS. Another downfall of a dual blade is that it is relatively more expansive and may be more complicated to machine, along with the fact that the center of mass for this EDS is harder to compute than a symmetric, single tooth EDS.

Drivetrain:

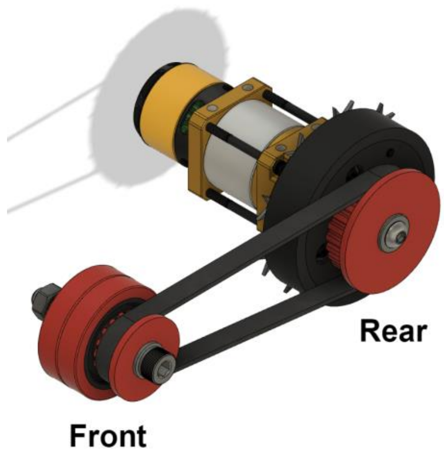


Figure 3.3 Pulley Driven Drivetrain Subassembly

Our preliminary drivetrain concept will create a four-wheel drive for the robot. The driving motor will be attached to a procured gear box which will create a 20:1 gear ratio. The output shaft of the gearbox will then be fastened to our rear wheels. The rear wheels will drive the front wheels via a premade XL-timing belt most likely procured from McMaster-Carr, along with premade toothed pulleys which will be bolted to the wheels. Figure 3.3 depicts this assembly, the driving motor and gear box are in yellow, the rear wheel is black and labeled in the image "rear" with the driving pulley (red) bolted on to it, the Front wheel is the red cylinder with the groove down the middle of it with its pulley attached by bolt.

Figure 3.4 Direct Drive

Another drivetrain concept would create a two-wheel drive robot. We would procure the same 20:1 gearbox as discussed in the previous concept, along with a combat robotics standardized motor to allow us to achieve our goal speed. We would then use epoxy poured wheels along with titanium cleats. The motor output shaft would feed into the gearbox, the gearbox output shaft would feed through the titanium cleats into the wheel.

Frame:

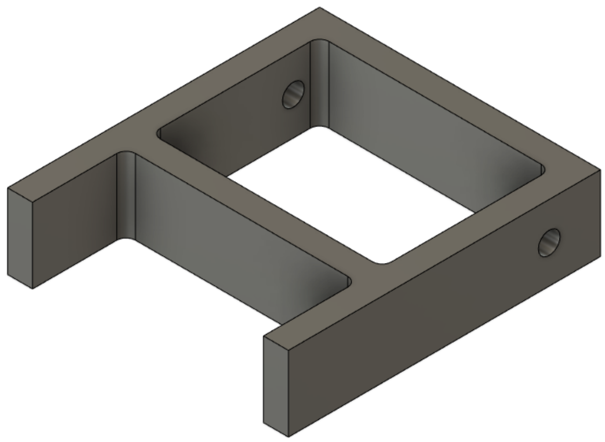


Figure 3.5 Welded Frame

A welded frame for a combat robot would offer several advantages. First, a welded frame provides exceptional strength and rigidity, making it well suited for absorbing the impact of heavy blows without compromising the crucial position or layout of internal components such as belts and pulleys. This sturdiness enhances the robot's durability, ensuring it can withstand intense battles. Another benefit would be the simplicity of the assembly which would require less hardware and reduce the bot’s overall weight. However, there are also drawbacks to consider. Welded frames can be time consuming and labor intensive to construct, which will in turn increase production costs. As well, a welded frame will be less forgiving when it comes to repairs and modifications. It would be impossible to replace destroyed sections of the frame and would need to be replaced entirely.

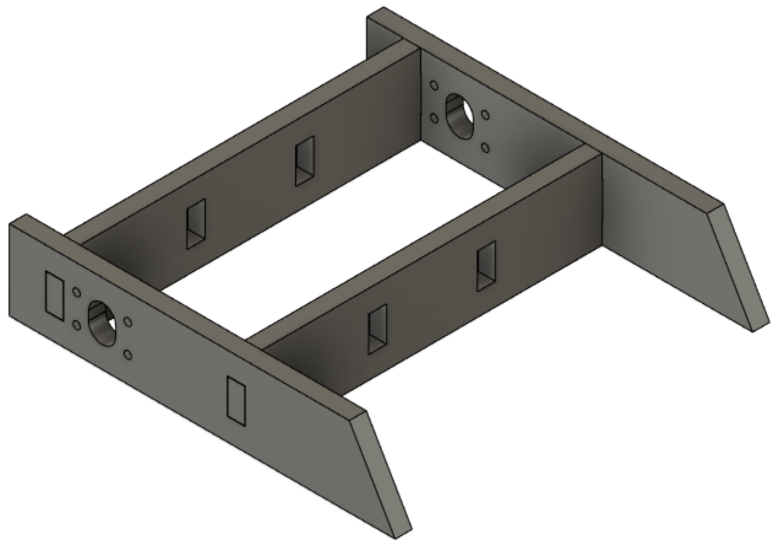


Figure 3.6 Segmented Frame

By using multiple segments to assemble the frame, the bot will be quicker, cheaper, and easier to assemble. Each segment is a water jet piece of aluminum with slots and tabs to provide positioning and added strength. In addition to slotting, each piece will be connected using hardware. Using a non-permanent connection will allow a single segment to be removed if it becomes damaged. However, this design will allow the frame to flex under extreme load and may be more likely to become warped and unusable. The added hardware will also increase the overall weight of the bot. Overall, this design is great due to its reparability, low cost, and shorter lead time.

Final Design Concepts & Drawings

EDS

EDS Stack:

Stack up assembly part selection (828g)

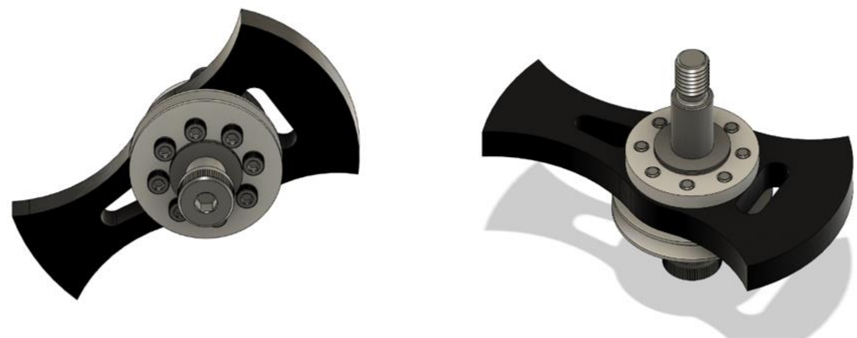


Figure 4.1.01 EDS Stack Up

The EDS stack up is a buildup of eleven components. The stack up is a mixture of custom designed parts by our team along with off the shelf components likely to be procured from McMaster-Carr.

The stack up is composed of:

- ⅝” Steel Shoulder Bolt
- 8x M5-1.00 fasteners
- 2x Needle Roller Bearings
- 2x Thrust Roller Bearings
- 2x ⅝” Washers
- Custom Aluminum 6061 Driven V-belt Pulley
- Custom Hardox Steel EDS
- Custom Aluminum 6061 Pulley Mount Plate

As mentioned above we decided to design the custom pulleys to allow us to run a v-belt as our timing belt which will drive our EDS. Due to the v-belt's characteristics being superior to a traditional toothed belt.

When it came to bearing selection, needle roller bearings best suited the robots needs. The driven pulley will be rotating around 13,000 rpm therefore we need a bearing capable of handling a very high speed.

$$(Kv \cdot V) \cdot \left(\frac{Driving\ dia\ in}{Driven\ dia\ in}\right) = EDS\ rpm$$
$$(970 \cdot 22.2) \cdot \left(\frac{1.16\ in}{1.93\ in}\right) = 12,932\ rpm$$

Figure 4.1.02 EDS RPM Calculation

Needle bearings are ideal for high-speed applications, as they offer low friction and reduced rotational inertia. Needle bearings are also generally used when there are space constraints, and a compact design is required. Due to our robot competing in a weight class, keeping our design as compact as possible is crucial for us to optimize our used weight. The needle roller bearings are set in the EDS and the driven pulley, this can be seen in the cross-sectional image figure 4.1.03.

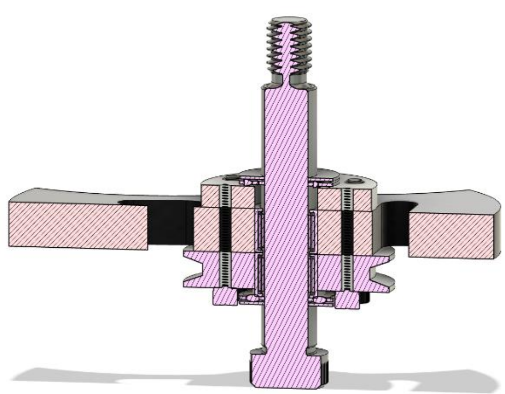


Figure 4.1.03 EDS Stack Cross Section

The ⅝ steel shoulder bolt was selected based from research and discussion from former senior design bot builders along with what is commonly ran in the 12 lb. weight class.

EDS Design:

The EDS is a symmetric, ax shaped ½ inch chunk of Hardox 500 steel. It has a diameter of 5.51 inches. It consists of a rake angle of 15 degrees at the toothed end and it has a minimum safety factor of 15. The moment of inertia for the EDS is calculated to be 0.024727 lb/ft^2. The EDS is designed so that it can be assembled inversely so that even if it gets flipped, it can still perform properly. It also allows it to flip it over during assembly if one end of the tooth gets damaged on one side during battles. It has one long, oval shaped cutout on the left, rear side of the body and one tear drop shaped hole on the right side of the body to get the center of mass at the dead center of the EDS. This allows the weapon to spin smoothly about its axis, which is the EDS shaft. The tear drop hole also allows for the weapon lock to go through it to lock the weapon in place during the competition.

During the design process optimization was done to the original EDS model. The first model of the EDS was an ax shaped. solid bodied with a center shaft hole and 8 pulley mounting holes. The issue with this design is that the weight was too heavy and the center of mass was not located in the center of the shaft through hole.

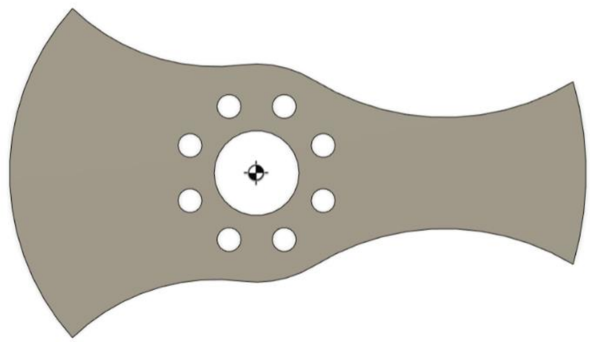


Figure 4.1.04 First EDS Model

It was decided that the EDS needed major optimizations in order to cut down unnecessary weight and to make the center of mass into the dead center of the shaft through hole. It was decided to added two oval shaped holes on each side of the shaft through hole, along the middle axis to keep it symmetric. The oval shaped hole on the left, rear side was vertical while the oval hole on the right side, the toothed end, was horizontal due to space limitations. After some trial and error on the oval hole sizes, the center of mass as located in the dead center and the EDS was much lighter, weighing 1.13 pounds.

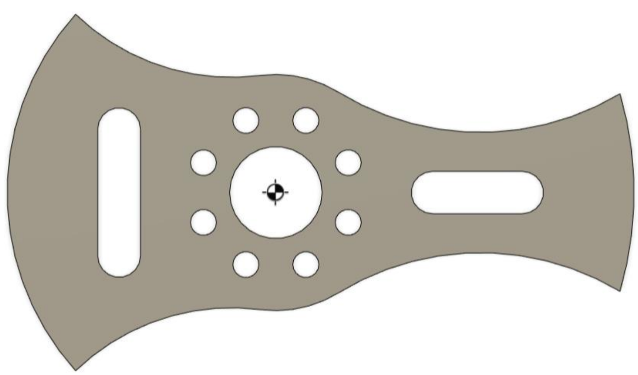


Figure 4.1.05 Optimized EDS

After the optimization of the first model was complete, a review of the affects it had on the moment of inertia and overall effectiveness of the EDS performance took place. After reviewing this design, it was decided that there could be potentially better optimizations done to the EDS to improve its moment of inertia, ultimately improving its efficiency of delivering a powerful hit. It was decided to take away more mass from the center area of the EDS, leaving more weight on the outer-most edges of the EDS. This would lead to an increase of efficiency, which also leads to an increase of the moment of inertia because removing weight from the center of the EDS leads to a lighter part, with the same amount of power being delivered. The left, rear side oval shaped hole was moved closer to the center of the EDS. Then the right-side oval hole, was changed to be more of a tear drop shaped hole, with the bigger end of the tear drop being closer to the center of the EDS. The results of this optimization was that the moment of inertia increased from 0.023943 lb/ft^2 to 0.024727 lb/ft^2. Although the moment of inertia was able to be increased with this optimization, the weight of the EDS went up slightly, now weighing 1.14 pounds. This weight gain ended up not affecting the assembly's total weight majorly, so it was not an issue.

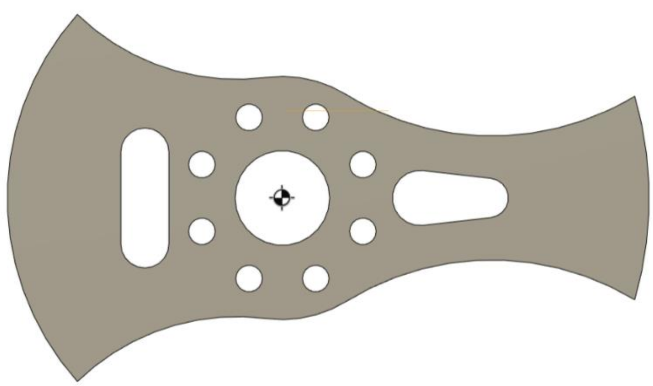


Figure 4.1.06 Final Optimized EDS

Dynamic test and FEA test:

In order to determine the force applied on impact at the end of the EDS when it makes contact with the opponent, the impulse needed to be determined by calculations and time of contact was needed to be determined. A dynamic simulation test had to be performed to find the time of contact with an opponent, since there is not a more accurate way of estimating the time of contact. The dynamic simulation was set up to be the EDS fixed with a pinned constraint and an in initial angular velocity to simulate it actively rotating. The item that was simulating the opponent was a 4.92 x 4.92 x 4.92 inch block of Aluminum. The EDS was set up to be close to the block but not touching, at a distance of 0.0004 inches. The simulation time was set for 0.0005 seconds, with 200 steps.

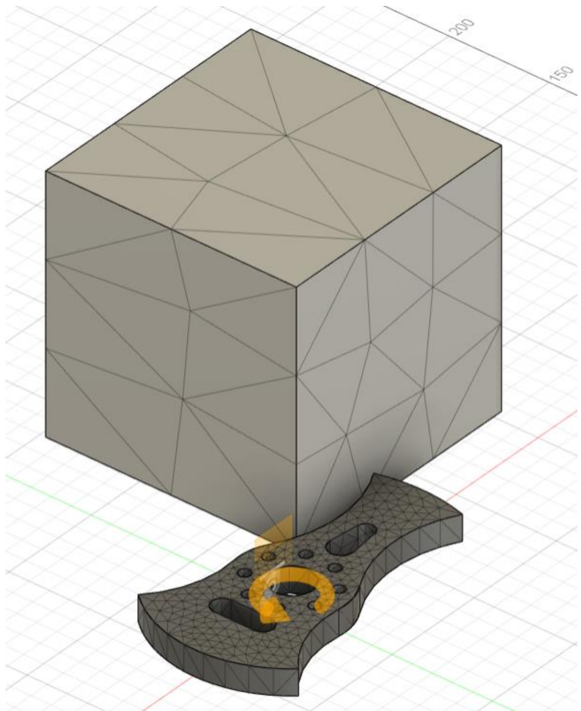


Figure 4.1.07 Dynamic Simulation Test Set-up

An animation of the simulation was resulted and was used to determined how long the EDS stayed in contact with the block, which is simulating an opponent in this case. The result was that the EDS contacted the block for 70 out of 200 steps. This was then multiplied by the run time of 0.0005 seconds, which gives the time of contact. To determine the impulse, calculations involving the angular velocity, moment of inertia, mass, gravity, and the height of the battle cage. After solving mass*gravity*height of cage, the change in angular velocity as the energy is transferred could be calculated. This led to being able to calculate the impulse. The calculated impulse is then divided by the time of contact to get the force applied on impact, which led us to performing FEA tests. The resulting force applied on impact came out to be 2331.43 Newtons, which is 524.13 pound-force.

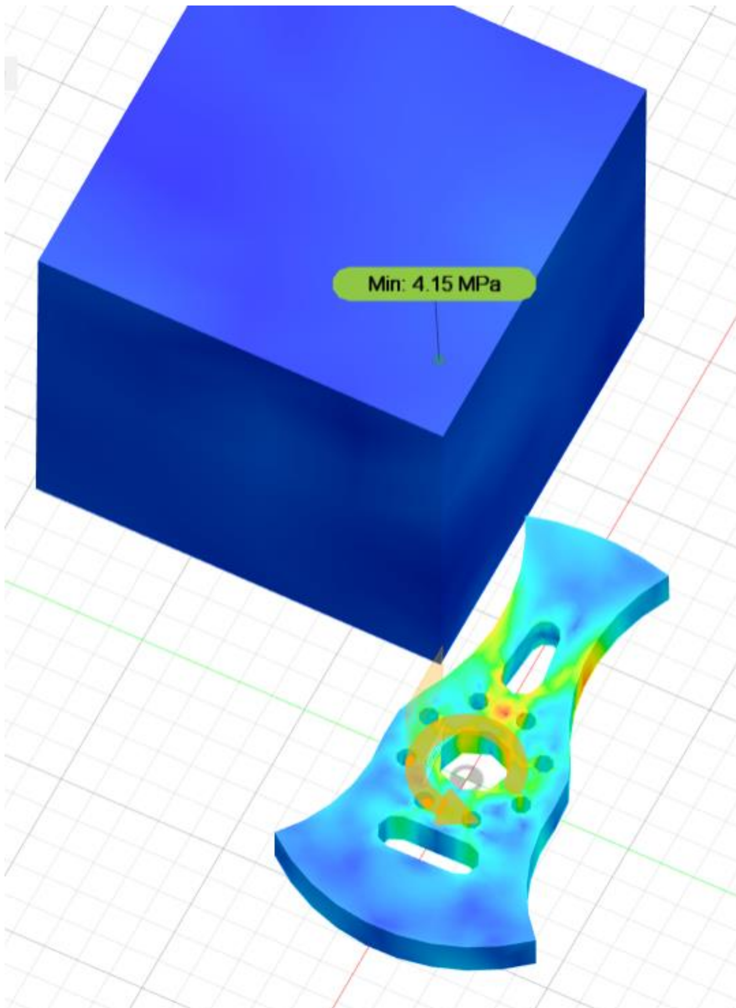


Figure 4.1.08 Dynamic Simulation Test Result

$$m * g * h = 5.4\, kg * 9.81 \frac{m}{s} * 3\, m = 160\, Joules$$

$$160\, Joules = I * w^2$$

$$\sqrt{\frac{160\, Joules}{0.001042\, kg/m^2}} = w$$

$$w = 391.86\, Radians/seconds$$

$$Impulse = I * w$$

$$Impulse = 0.001042 \frac{kg}{m^2} * 391.86 \frac{Radians}{seconds} = 0.408$$

$$Force = Impulse/Time$$

$$Time = \left(\frac{70}{200}\right) * 0.0005\, seconds = 1.75e^{-4}$$

$$Force = 0.408/1.75e^{-4}$$

$$Force = 2331.43\, newtons\; or\; 524.13\, pound\, force$$

Figure 4.1.09 Force Applied on Impact Calculations

Finding the resulting force that is applied on impact led to being able to perform FEA tests on the EDS to determine the safety factors of the part. The FEA test was performed with a force of 254.13 pound-force applied to the toothed end of the EDS since it is where it will contact the opponent. The results showed that the EDS had a safety factor of 15, which means it is very suitable to accept this amount of force and not be affected. The overall goal was to be above a safety factor of 8 with our design, which was easily exceeded since we are using Hardox 500 steel.

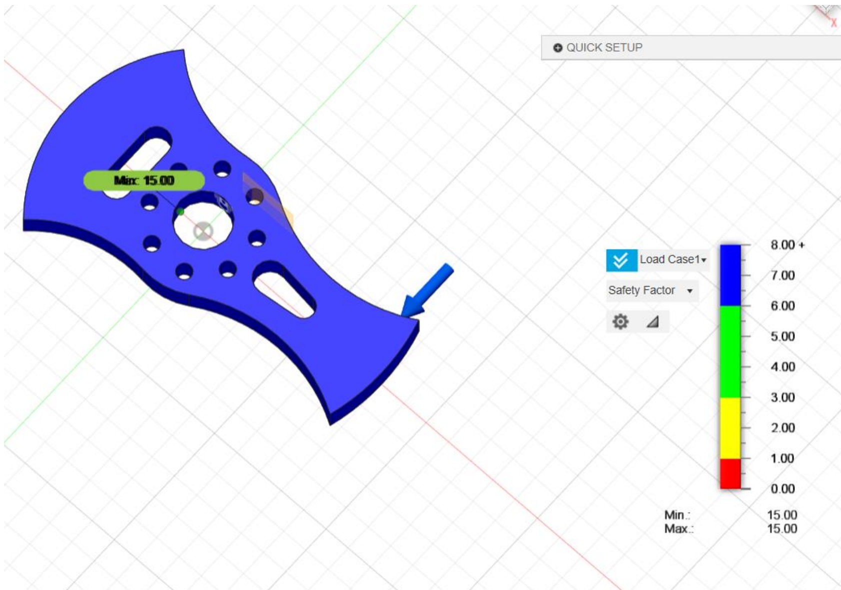


Figure 4.1.10 FEA Test on EDS With a Force of 254.13 Pound-Force

Ear Design:

On the battle bot, ears that have roller bearings were designed to mount on the uprights to be able to within the weight of the battle bot if it is flipped upside down during the fights. The roller bearing ears also allow for the EDS to not make contact with the arena floor, saving the EDS motor from possibly burning up inside. The roller bearing ears are designed out of Aluminum 7075. The ears are ⅛ inch thick and roughly 3.5 inches tall. It was decided to design them out of the Aluminum 7075 because of the material's tear-away properties. This will prevent the ears from bending inward after an impact, potentially causing an interference for the EDS while it is actively spinning. There is a different ear for each side of the bot because we wanted to add cutouts for a tear-away relief point when the ears take damages. The cutouts are 0.039 inch wide, 0.020 inch deep. The ears have a unique shape because of the mounting location, orientation, its use, and its interference with other components. The very bottom hole is used to mount to the upright. The middle, largest hole is made for the EDS shaft to go through the ears, which also helps assist the bottom hole in securing the ears. The middle oval shaped hole is used for the purpose of the EDS lock at the competition. The top hole is used to mount on the roller bearings at the top. The roller bearings allow the robot to be flipped and still have some free movement around the floor while also allowing the EDS to be spinning without making contact with the floor and potentially damaging the EDS motor. This is why they are called the ears of the robot because they stick up like animal ears, which are further than the highest point of the uprights and the EDS when it is in its topmost position.

Figure 4.1.11 Right Side Ear

Figure 4.1.12 Left Side Ear

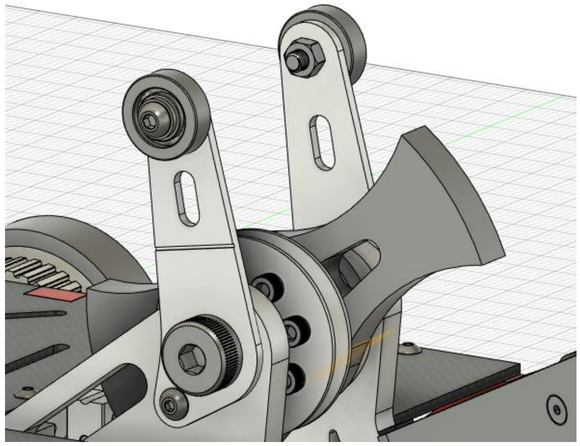


Figure 4.1.13 Ears with Rollers Assembled on the Uprights

Ear FEA:

A FEA test was also performed on the ears, much like the FEA test for the EDS. The ear FEA test was done to determine if the ears could withstand the impact force applied when the battle bot is sent flying in the air and landing on the ground, flipped upside down. For the FEA test, it is assumed that the bot lands on one ear and the full force is applied to that single ear. The force of impact with the ground is calculated by the potential energy equation since potential energy and kinetic energy are equal right before impact when an object is falling. The potential energy equation is mass*gravity*height. The weight of the bot is 12 pounds, which is equal to mass*gravity. The maximum height that the bot can be sent flying is 10 feet due to the competition cage size. The weight was multiplied by the maximum height, resulting in an impact force of 120 pound-force when the bot hits the ground. That force was then applied to the top of the ear in the FEA test to get the resulting safety factor of the design. Its minimum safety factor came out to be 14, which is excellent because our team's goal was to have a safety factor of 8 or more. This high safety factor means that the design is slightly over engineered, which leaves room for more weight reduction and part optimization if needed.

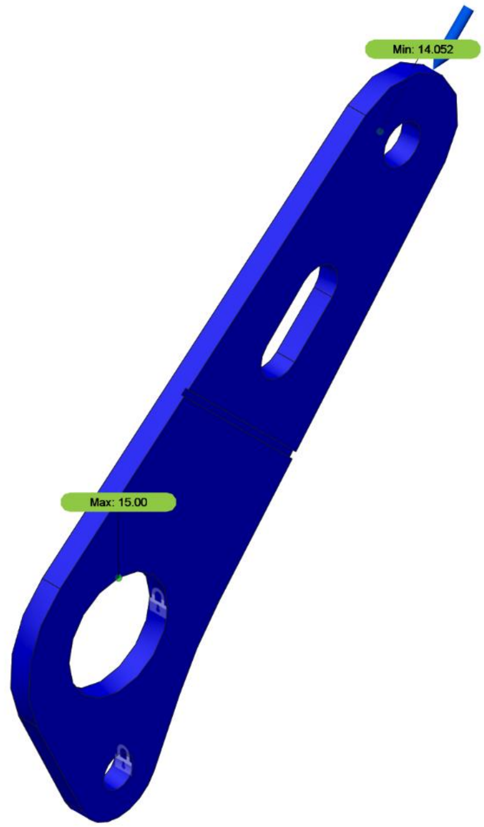


Figure 4.1.14 FEA Test on the Ears

$$W = m * g = 12\, pounds$$

$$h = 10\, feet$$

$$PE = m * g * h$$

$$PE = W * h$$

$$PE = 12\, pounds * 10\, feet$$

$$PE = 120\, pound - foot$$

$$PE = 120\, pound - force$$

Figure 4.1.15 Impact Force Applied to Ears After Falling

Drivetrain

EDS Drive

Overall System:

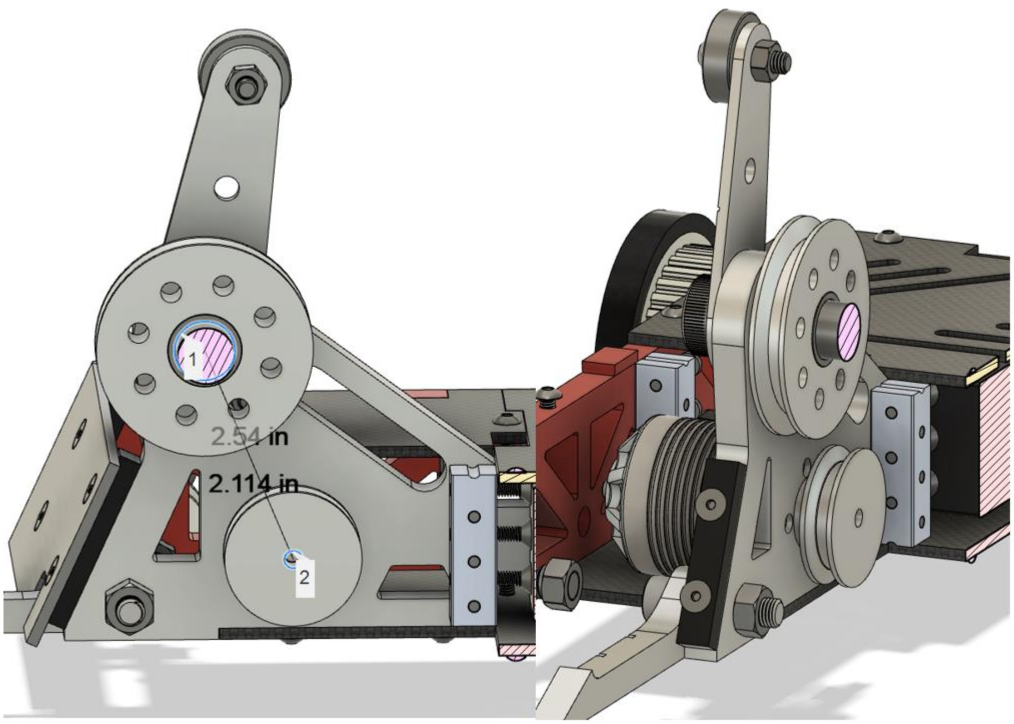


Figure 4.2.01 V-Belt Pulleys

The above images depict the drive system for our EDS (energy deployment system). The system is driven from custom V-Belt pulleys. We decided to design the custom pulleys to allow us to run a v-belt as our timing belt which will drive our EDS. V-belts are the superior timing belt of a toothed timing belt, they are seen on all the top performing combat robots. The main advantages of a v-belt which is appealing to a combat robot is the dampening effect and the tolerance to misalignment. V-belts are known for their ability to absorb shock loads which reduces the risk of damage to the pulleys along with the motor which is driving the pulley. Considering the application of the V-belt is on a combat robot where there will be strong shocks to the pulley system every time our EDS strikes an opponent. By implementing the V-belt we are increasing the life of our belt, pulleys, and EDS driving motor. The V-belt also provides a degree of flexibility which makes it forgiving to small misalignments.

The two key points in designing the pulleys were gear ratio and center to center distance. We approached this first by calculating the required gear ratio to achieve our goal EDS spin speed with standard team electronics. The required value for driving over driven is 0.53, or a gear ratio of roughly 2:1. The calculations below show the math to achieve this value.

$$(Kv \cdot V) \cdot \left(\frac{Driving\ dia\ (in)}{Driven\ dia\ (in)}\right) \cdot \left(\frac{EDS\ dia\ (in.)}{12in}\right) \cdot \pi \cdot \left(\frac{1}{5280}\right) \cdot 60 = Tip\ speed\ mph$$

$$(970 \cdot 22.2) \cdot (Driving/Driven) \cdot \left(\frac{5.51\ in}{12}\right) \cdot \pi \cdot \left(\frac{1}{5280}\right) \cdot 60 = 190\ mph$$

$$Driving/Driven\ (Required\ for\ goal\ speed) = 0.538$$

$$Driving/Driven\ (Actual) = \frac{1.16}{1.93} = 0.601$$

$$\left(\frac{5.51\ in}{12}\right) \cdot \pi \cdot 12{,}932 \cdot \left(\frac{1}{5280}\right) \cdot 60 = 212\ mph$$

Figure 4.2.02 EDS Tip Speed Calc

The next challenge was ensuring our pulleys were large enough in diameter to be capable of creating a wrap-around surface which would make an achievable center to center distance within the area of our EDS upright. The design was limited to a 10-inch (L) circumference v-belt. The below equation was used to determine our center-to-center distance on the pulleys. Our center to center was limited to 3 in. due to the geometry of our upright shape. We ended up selecting our driven pulley (D) to be 1.93 in. our driving pulley (d) to be 1.16 in.

$$C2C = \frac{L-1.57(D+d)}{4} + \sqrt{\left\{\frac{L-1.57(D+d)}{4}\right\}^2 - \frac{(D-d)^2}{8}}$$

$$C2C = \frac{10-1.57(1.93+1.16)}{4} + \sqrt{\left\{\frac{10-1.57(1.93+1.16)}{4}\right\}^2 - \frac{(1.93-1.16)^2}{8}} = 2.54\ in.$$

Figure 4.2.03 Pulley Center to Center Calculations

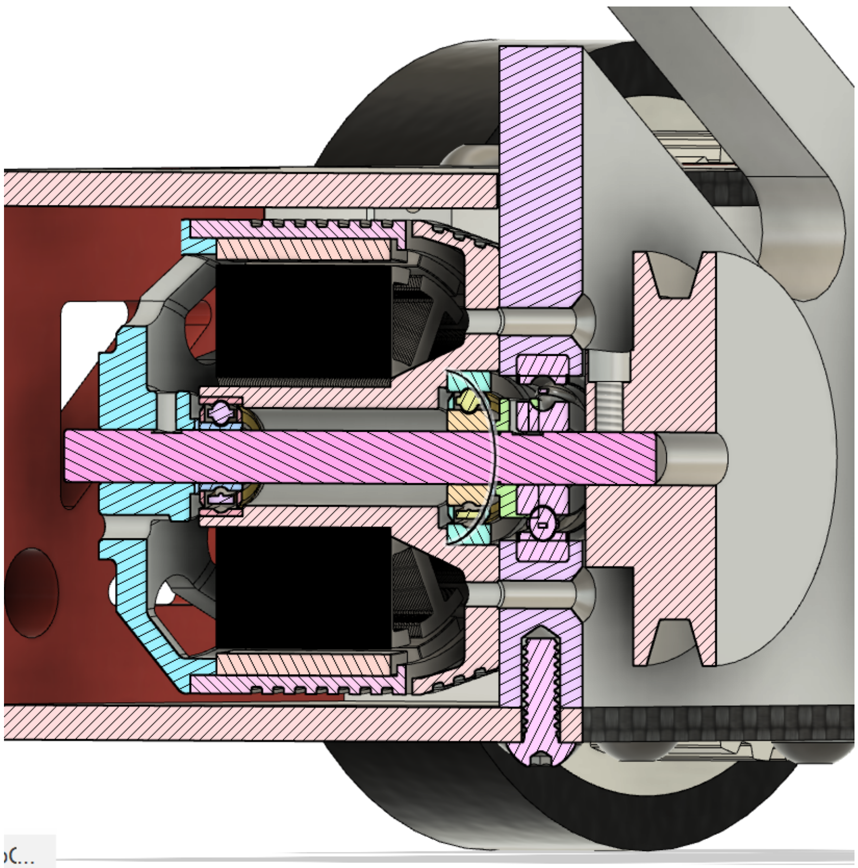


Figure 4.2.04 Cross Section of EDS Drive

When looking at a cross sectional view of the EDS drive system, the driveshaft of the motor was originally being cantilever loaded by the driving pulley at the end of the driveshaft. To maintain the structure of the motor drive shaft and avoid deformation over time a bearing has been placed on the driveshaft between the motor and pulley to give it additional rigidity and support.

Driven pulley:

Figure 4.2.05 Driven Pulley

The design approach for the driven pulley was to keep the design as simple as possible in order to deliver an easily manufacturable part. Our two constraints were the profile of the V-belt and the shoulder bolt diameter which the pulley would sit on. In order to fasten the pulley to the EDS we designed a backplate with tapped holes. A set of 8 bolts will run through the through holes of the driven pulley, the EDS, and then be threaded into the back plate.

Driving Pulley:

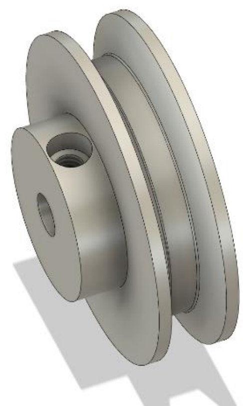


Figure 4.2.06 Driving Pulley

The driving pulley is to be made from 1 ⅝ in. Aluminum 6061 rod, having a 1.5 in. outer diameter, 1.16 in. dia. when considering the face which the belt is in contact with, and a 0.02 in. (5 mm) inner dia. for the motor drive shaft. There were a few possible options when designing the driving pulley, although this design allowed for the simplest manufacturing method. The part will be turned on the lathe, once the correct part geometry is achieved, the driveshaft hole (normal to the front face and depicted in figure 4.2.06) will be done with a drill press. Following the driveshaft hole, the countersunk hole will be drilled and then the set screw hole will be tapped. The countersunk feature is 5mm in dia. and 3mm deep, the thread pattern is for a M4x0.7 bolt.

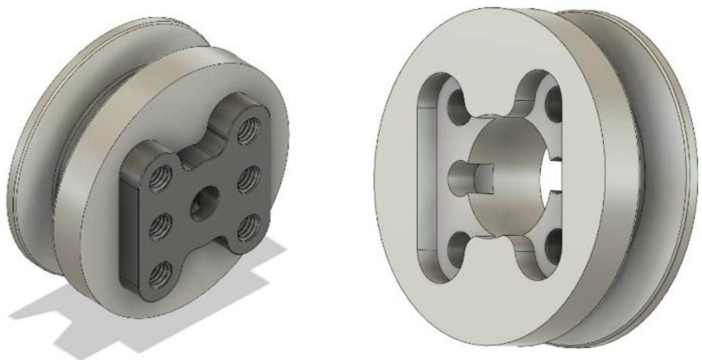


Figure 4.2.07 Old Driving Pulley

Initially the design was over complicated, this was due to how we had planned for fastening the driving pulley and motor drive shaft. We were going to procure a hub designed for 0.02 in. (5 mm) dia shafts, and machine out the hub geometry from the pulley allowing the hub to sit within the pulley (Figure 4.2.07). This design was clearly inferior to the integrated set screw design (Figure 4.2.06) Due to its complex manufacturing increasing cost and lead time, along with its overall weight being heavier. We were able to reduce the weight from 45 grams to 25 grams.

Wheel drive

Complete drivetrain assembly:

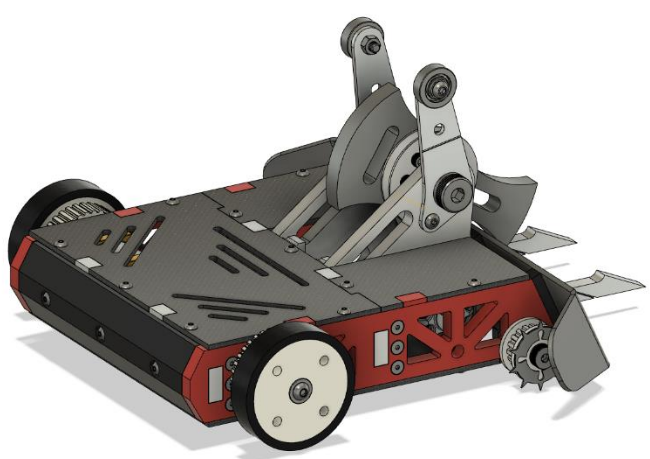


Figure 4.2.08

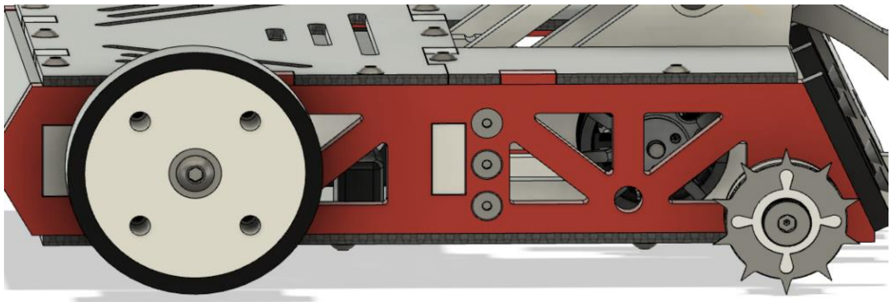


Figure 4.2.09 Drive Side View

The complete drivetrain system as a whole is built up from two sub-assemblies which will be further discussed below, those are the front drive module, and rear drive assembly. The rear will be driven by a Tempest 2814 motor which goes through the UCCR Goldiebox 20:1 gearbox and drives the rear wheel at an rpm of 945. That rear wheel has an integrated pulley which will drive a 19 in. circumference timing belt connected to the front module integrated pulley.

The goal capability in terms of speed was to drive the distance of the NHRL arena in 1,5 seconds, which equates to 7.23 mph.

$$\frac{16\,ft}{1.5\,sec} = \frac{12.8\,ft}{1\,sec} \cdot \frac{60\,sec}{1\,min} \cdot \frac{60\,min}{1\,hr} \cdot \frac{1\,mile}{5280\,ft} = 7.23\,mph$$

Figure 4.2.10 Goal Robot Speed Calculation

The calculations to verify that goal was achieved are shown below.

$$\text{Motor rpm} = Kv \cdot V = rpm$$
$$\text{Tempest motor output} = 850Kv \cdot 22.2v = 18,870 \text{ rpm}$$
$$\text{Gearbox produces 20:1 gear ratio}$$
$$\text{Final drive shaft speed} = 18,870 \div 20 = 943.5\, rpm$$

$$\text{Rpm} = \frac{(12 \cdot 5280) \cdot Speed\ (mph)}{\pi \cdot wheel\ dia\ (in.) \cdot 60}$$
$$\text{Speed (mph)} = \frac{\pi \cdot wheel\ dia\ (in.) \cdot rpm}{12in \cdot 5280\ ft} \cdot 60$$
$$\text{Actual Speed} = \frac{\pi \cdot 2.916in \cdot 943.5\ rpm}{12\ in \cdot 5280\ ft} \cdot 60 = 8.18\ mph$$

Figure 4.2.11 Robot Speed Verification Calculations

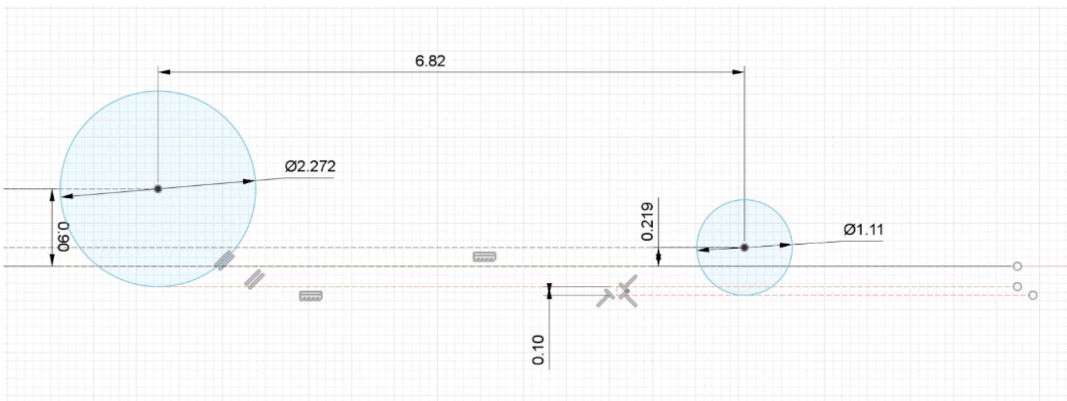


Figure 4.2.12 Wheel Center to Center Preliminary Sketch

The above image depicts how we determined where the front wheel should be placed in terms of the Z-axis on the side frame. We wanted our front wheel to be between 1/8 -1/16 of an inch below the floor so we went with 0.10 in. By drawing a line tangent from the bottom of the rear wheel and constraining it parallel to the X-axis we were able to represent where the arena floor will be. Then drawing a line normal to the floor 0.10 in. in length we knew where our front wheel must sit. We then took the measurement from the center of our front wheel and the base of our side plate to find out we need to have the center of the mounting hole 0.219 in. above the base of the plate. After finding that length we were able to calculate the center to center distance of the circles on the X-axis through Pythagorean theorem which came out to be 6.7855 in.

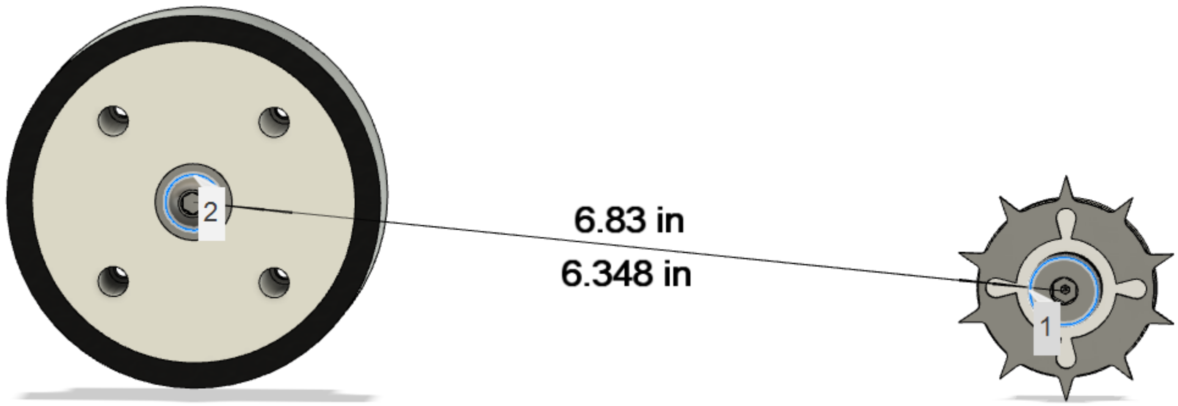


Figure 4.2.13 Wheel Center to Center Actual

The true center to center distance required was calculated using the known belt length (L) 19 in. the rear diameter (D) 2.72 in., and the front diameter (d) 1.11 in., and the center-to-center equation below.

$$C2C \;=\; \frac{L-1.57(D+d)}{4} + \sqrt{\{\frac{L-1.57(D+d)}{4}\}^2 - \frac{(D-d)^2}{8}}$$

$$C2C \;=\; \frac{19-1.57(2.72+1.111)}{4} + \sqrt{\{\frac{19-1.57(2.72+1.111)}{4}\}^2 - \frac{(2.272-1.111)^2}{8}} = 6.83\ in.$$

Figure 4.2.14 Center to Center Calculation

Front:

Front Module:

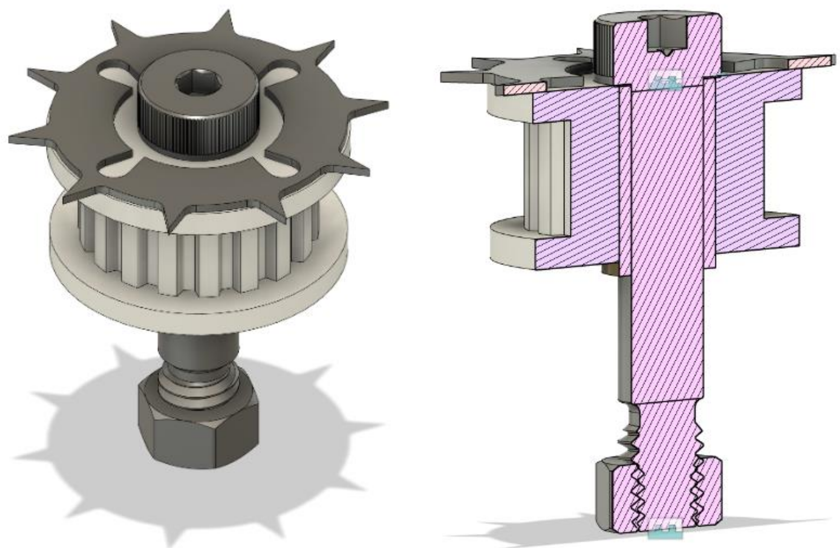


Figure 4.2.15 Front Drive Module

The front drive module was designed to be ultra simple, this was achieved by using a minimal amount of components effectively reducing complexity, costs, and weight. The module is compiled of a1 ¼ in. long and ⅜ in. dia. shoulder bolt, a ⅜ in. Ultra-Low-Friction Oil-Embedded bronze bushing, ⅜-16 nut, and custom titanium cleats 0.063 in. thick.

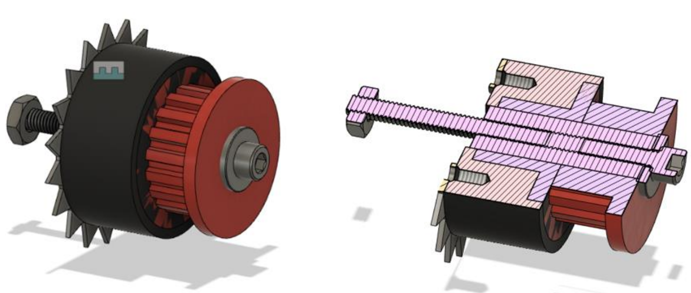


Figure 4.2.16 Old Front Drive Module

The original design used 8 different components, weighed 12% more, and used a greater volume. Which would have required the robots front armor to be elongated, resulting in higher robot weight and material costs.

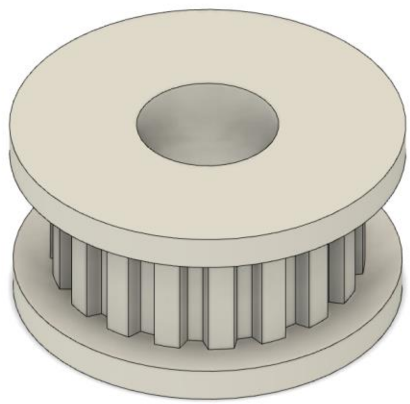


Figure 4.2.17 Front Pulley

The front pulley will be printed out of TPU, by printing the pulley on our own we are able to reduce weight and reduce costs. TPU pulleys have worked exceptionally well previously, there was no reasonable justification for wasting valuable budget on something that would increase our weight.

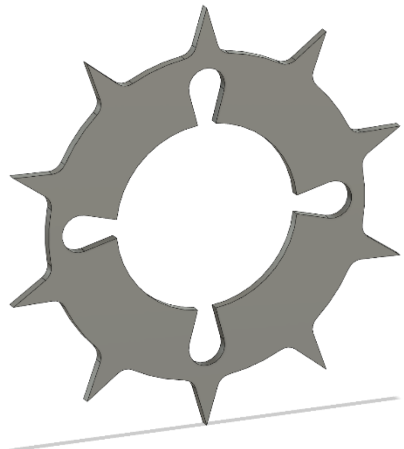


Figure 4.2.18 Cleats

The custom cleats will be laser cut out of titanium, they will be 0.063 in. thick. The cleats are only being run in the front, the reasoning for this decision came from observation of other competing 12lb robots. Due to our robot being powered from the rear, we want our front wheels to have better grip or traction to the floor, this will allow us to control turns better and overall increase our mobility.

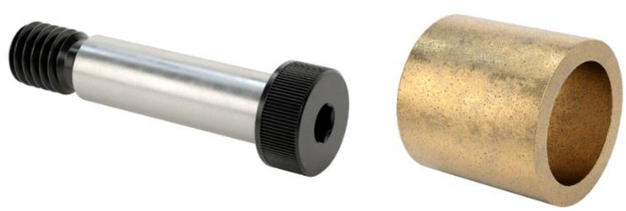


Figure 4.2.19 Front Axle Bolt & Bronze Bushing

The “axle” will be made out of a procured 1 ¼ in. long shoulder bolt with a shoulder diameter of ⅜ in. The reasoning for this sizing selection in terms of length was decided by staking the summation of the robot frame, and the required pulley thickness to be aligned with the rear pulley and capable of running the ⅜ in width belt. Shown in

Figure 4.2.20. The bronze bushing will sit in the pulley and around the shoulder bolt, effectively rotating the bushing around the shoulder bolt driven by the rear wheels.

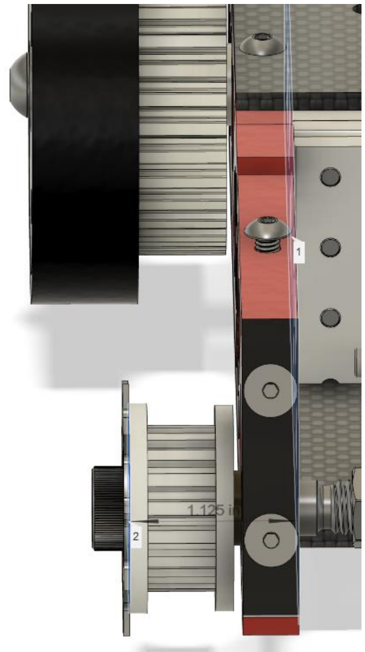


Figure 4.2.20 Drivetrain Alignment

Rear Module:

Rear Wheel:

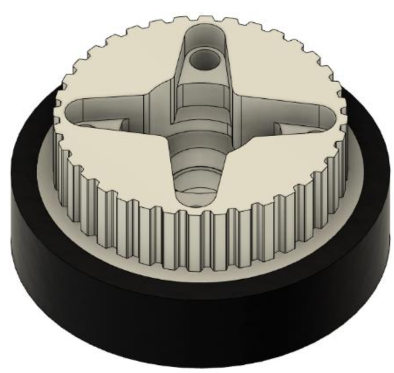


Figure 4.2.21 Rear Wheel & Pulley

The rear wheel will be a two-step process. First print the wheel and pulley (material in white in figure 4.2.21 out of TPU. The next step in the process is to pour the vita flex urethane around the wheel to form the "tire" around the wheel increasing the robot's traction. This is done by 3D printing a mold of the wheel to pour the vita flex urethane into and allow it to cure. The design of the rear wheel also changed throughout the development of RoboCat. Originally the rear system was compiled out of a hub, a wheel, a poured tire, and a pulley (Figure 4.2.22 shown below). The new system is able to integrate the wheel in pulley into one part, along with bringing the pulley being brought inside of the wheel reducing the likelihood of the belt being struck.

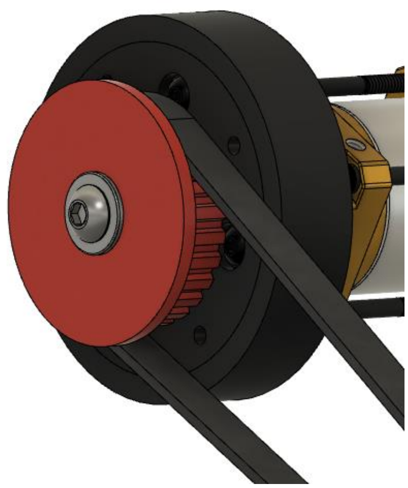


Figure 4.2.22 Old Rear

Rear hub:

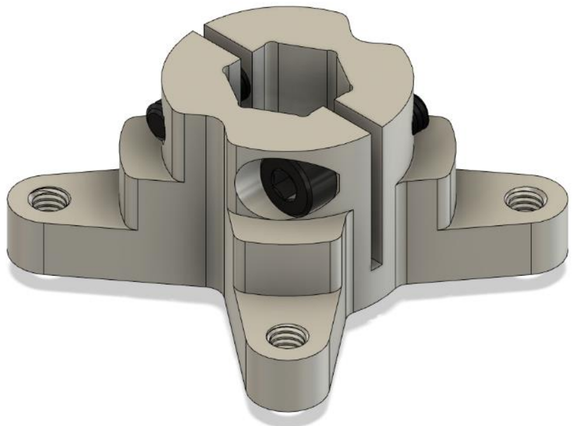


Figure 4.2.23 Rear Hub

The rear hub was selected based off of past University of Cincinnati combat robotics teams designs. The GoBuilda 12mm REX bore Hyper Hub is a heavy-duty clamping solution to fastening onto driveshafts. The dual pinch-bolts put a hold on the shaft and the extended length of the hub offers excellent surface contact with the shaft. This hub is balanced so that it can be used in high-speed applications without introducing vibrations. In addition to the standard threaded holes on the 16mm square pattern, the 1313 Series of Hyper Hubs also has shouldered arms which provide four additional holes on the 32mm square pattern. The shoulders have a 32mm diameter allowing the hub to nestle into parts which have a 32mm hole for a compact, low moment-arm setup.

Total Assembly:

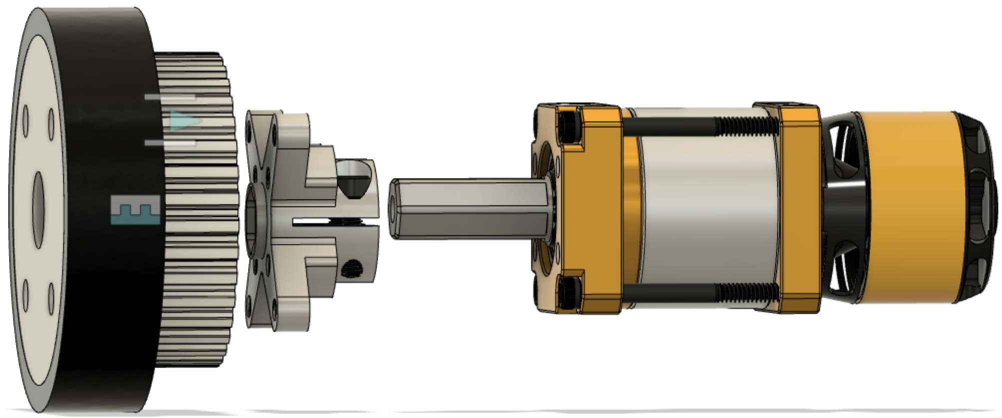


Figure 4.2.24 Rear Drive Module

The total assembly is depicted above in figure 4.2.24, the hub will slip onto the driveshaft of the UCCR-Goldiebox 20:1 gearbox and fastened via the set screws, The hub will be the fastened to the pulley integrated wheel using 4 bolts matching the pattern of the hub. A cross sectional view is depicted below in figure 4.2.25.

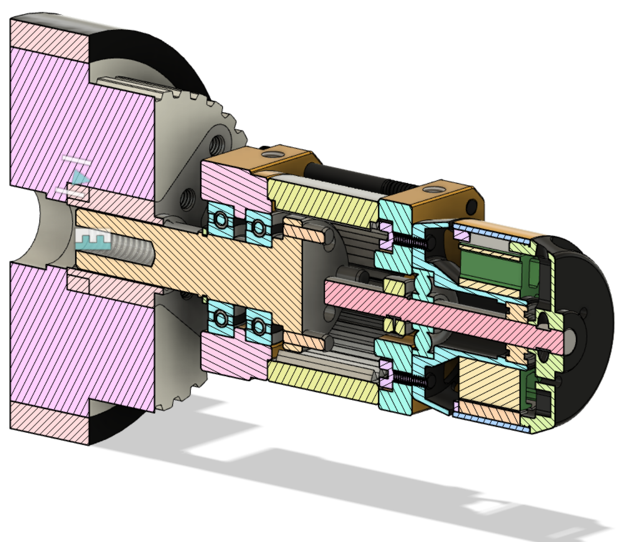


Figure 4.2.25 Rear Drive Cross Sectional View

Frame & Armor

Frame:

The frame of the robot is constructed using ⅜ inch thick aluminum 6061 members. This specific alloy was selected due to its increased ductility while maintaining a high strength. Ductility in the frame is critical to allow incoming hits to be absorbed into the material instead of likely shattering it. Each section of the frame is slotted together using rectangular holes and protrusions. At each of these corners, six screws connect the two pieces together by making use of a nut strip. In past designs which made use of slotted frame connections, nut strips were not used, and the screws were instead threaded directly into the sides of each member. Implementing nut strips is a more ideal connection method for two reasons. First, this will simplify the manufacturing of each frame component. Each section of the frame will be laser cut from a single aluminum sheet and only features along a single vertical axis will be created prior to being received. Additional features along other axes, such as drilling and tapping into the side of the frame, would need to be completed separately. By using nut strips, each screw will have a clearance hole laser cut into the frame members to easily locate the threads within the nut strip. The second improvement pertains to assembly and disassembly between combat. If a member of the frame were to receive a high impact force during combat, the connection screws could potentially bend and be nearly impossible to remove. Nut strips allow each frame member and its respective screws to remain separate so that they could be removed individually.

1/8’’ carbon fiber paneling is located on the top and bottom of the robot. Carbon fiber is a low weight, high rigidity material which will improve the frame’s ability to withstand high lateral forces. Each panel is located using rectangular features precut in the frame and panel. This will simplify the additional manufacturing processes of drilling and tapping connection holes since the paneling will be easily set in the correct position. The top paneling specifically is divided into three sections, referred to as “main cover”, “front left cover” and “front right cover”. The purpose of this is to allow for quick access to the robot’s internal components if only a single area is required. This will also allow for replacement parts to be independent of one another. If the front right cover becomes damaged, it can be replaced for a lower cost. Lastly, the main cover includes cut out slots to improve the heat transfer within the bot, reducing the risk of overheating internal components.

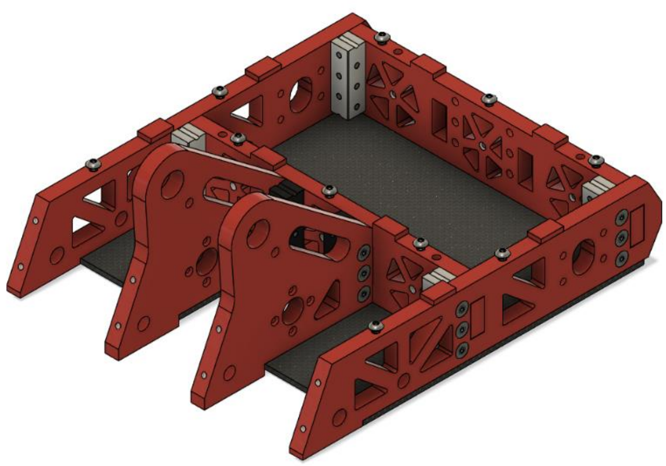


Figure 4.3.01 Frame Assembly without Covers

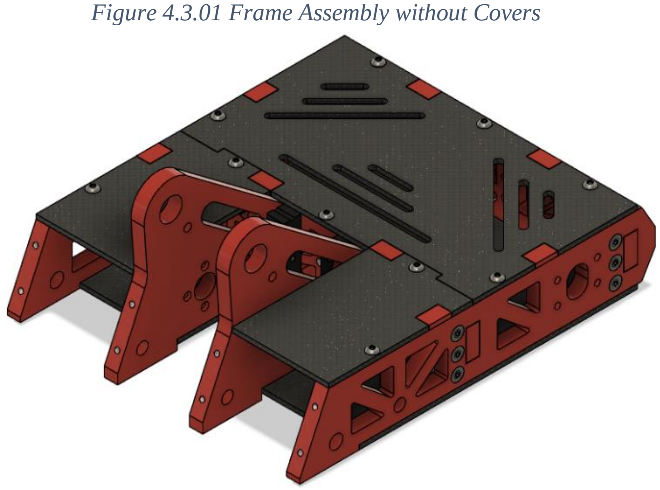


Figure 4.3.02 Frame Assembly with Covers

The bot is protected from forward facing impacts by using two 0.125'' AR500 steel wedges. The wedges are designed to deflect hits up and away from the bot and to shield the front drive wheels which are located behind the bent feature. Hardened steel has extremely high strength properties but will be more difficult to machine as a result. Previous bot designs have shown that careful consideration of part clearance and laser tolerance during the design phase of the robot will prevent machining complications during assembly. The wedges were designed with generous clearance to prevent these issues. To minimize the damage resulting from rear impacts, the bot is fitted with a 3d printed TPU armor block. TPU is a very cheap and soft material which will allow the bot to absorb an incoming hit and easily be replaced if needed between fights.

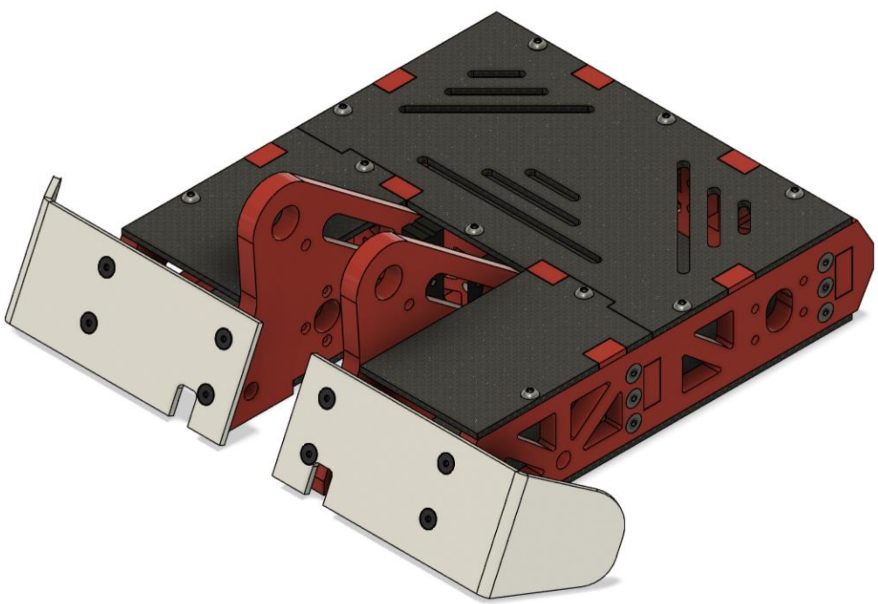


Figure 4.3.03 Wedges on Frame

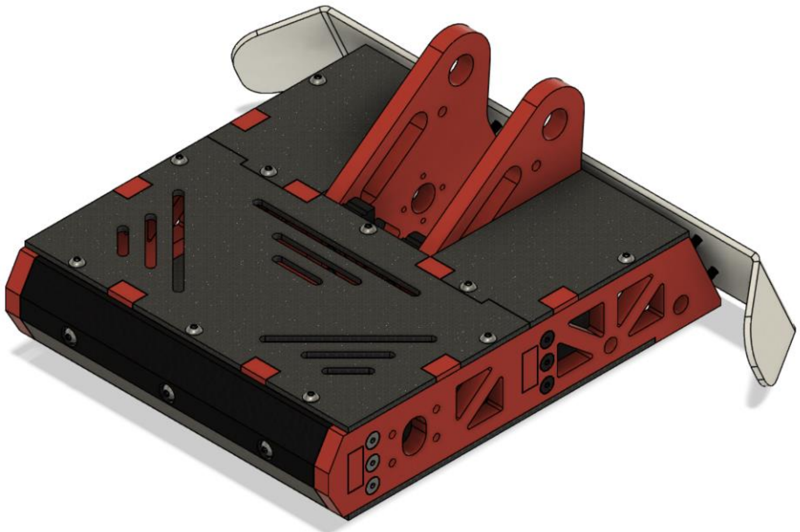


Figure 4.3.04 Rear Armor

Frame Weight Optimization and FEA

The robot's frame adds a significant portion to its overall weight. Optimization of the frame was conducted to remove unnecessary material from low stress areas while still maintaining a large factor of safety. To begin this process, the estimated force acting on the EDS uprights because of the EDS itself were calculated in the EDS design section. The load of approximately 524 pounds is divided between two unoptimized EDS uprights and the resulting stress was simulated. As shown in *Figure 4.3.5*, the unoptimized upright has a minimum safety factor of 15. The actual safety factor is higher but is capped at 15 due to the limitations of the program. The low stress areas shown were targeted for weight reduction. After material was removed, the simulation was repeated using the same variables and the results are shown. These changes reduced the weight of each upright by 22%, or 0.2-pounds total, while maintaining a minimum safety factor of 14.88.

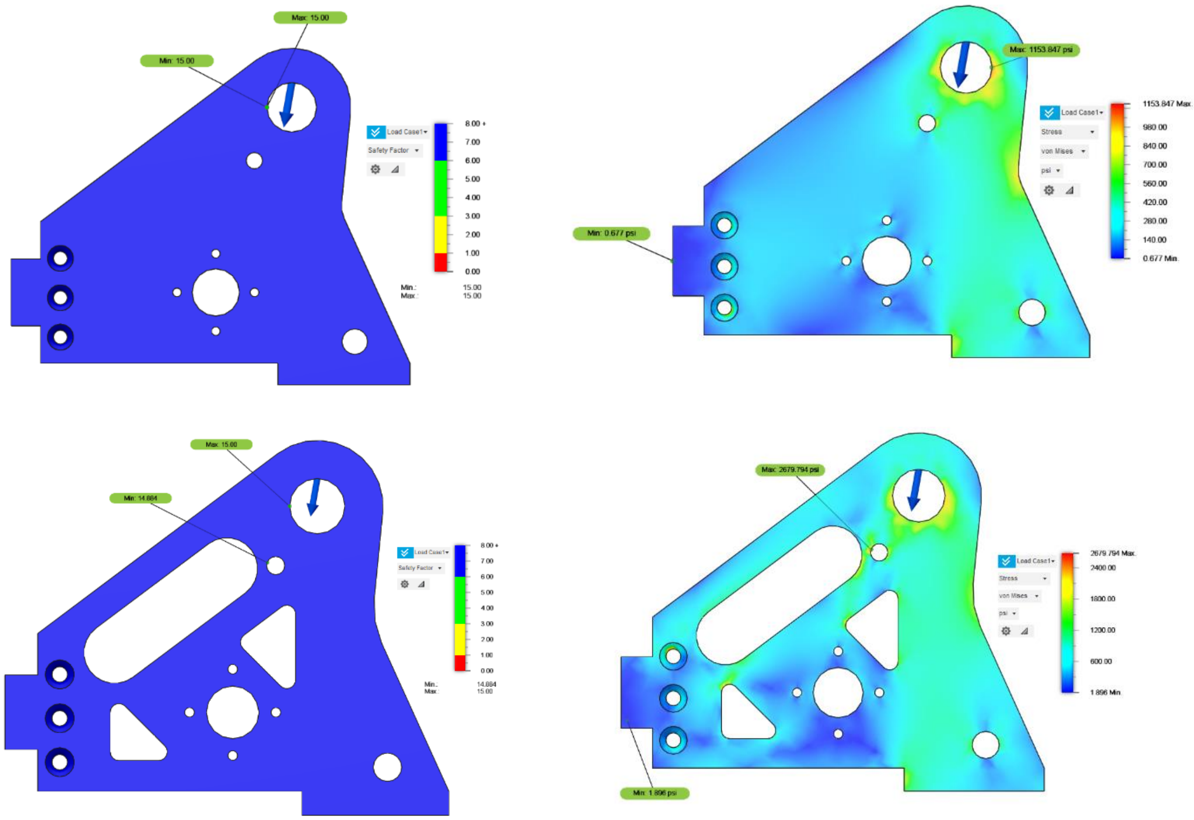
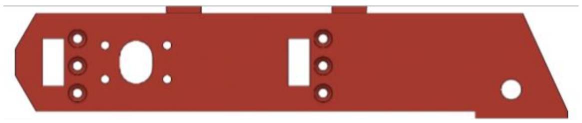
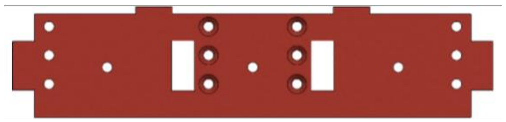


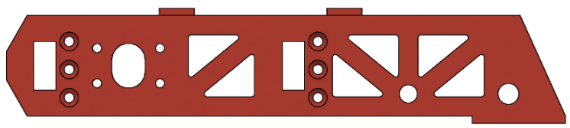
Figure 4.3.05 EDS Upright Stress Analysis

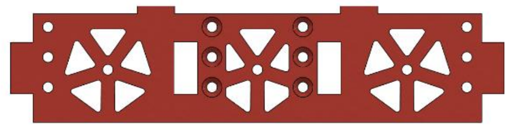
The robot's horizontal frame members were also optimized to improve the overall weight. However, size and placement of the optimizations were much more heavily dependent on the existing cut outs on the frame. The holes for drivetrain components and frame connections define where additional weight can be removed. As a result, the material removed is shown in *Figure 4.3.6*. By doing this, a total of 0.36 lbs. of material was removed from the bot. Stress simulations were conducted on the rear frame member under loading conditions consistent with opponents using both horizontal and vertical spinners. *Figure 4.3.7* shows that after weight optimizations and using an applied load of 225 lbs., the members have a minimum safety factor of 2.7 and 3.3 respectively. The value of this load has historically been used to estimate the force transferred to the robot's frame from an opponent. However, the actual value will vary significantly depending on specific opponents.





0.602 lbs. *0.497 lbs.*

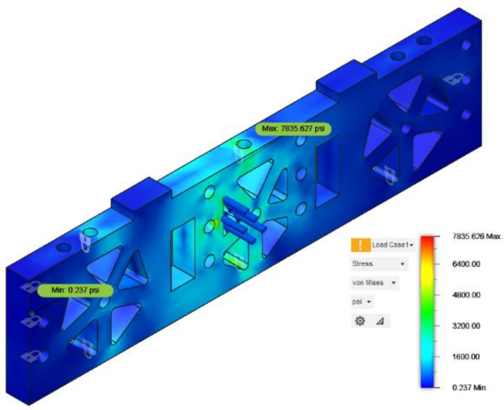




0.510 lbs. *0.409 lbs.*

15.3% reduction, 0.184 lbs. saved **17.7% reduction, 0.176 lbs. saved**

Figure 4.3.06 Frame Members Weight Reduction



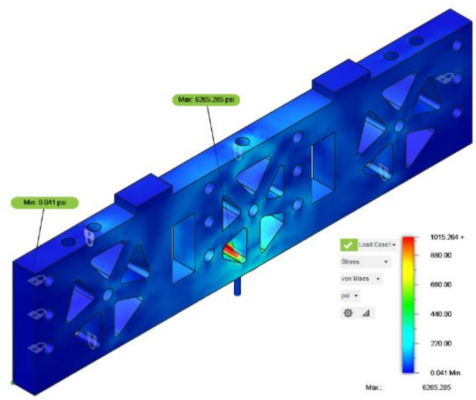


Figure 4.3.07 Frame Members Stress Analysis

The final simulation was conducted to examine the stress and displacement of the front armor wedges. Since the wedges are located closely to the front drive wheels, it is important to consider any displacement that may occur from an impact. This is done to prevent binding of the front wheel. *Figure 4.3.8* shows that given the assumed load of 225 lbs., the wedge has a safety factor of 2.87 and a maximum displacement of 0.112'' toward the front wheel. This value is acceptable and will not cause interference between the two components.

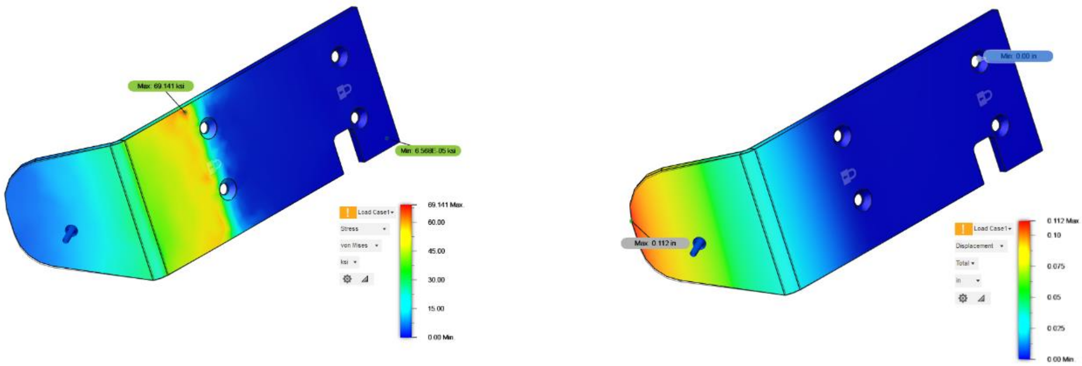


Figure 4.3.08 Wedge Displacement Analysis

Fork Design:

The front forks are designed to be manufactured out of Aluminum 7075, similar to the ears. This material was chosen because of its material properties. Like previously stated in the ear design description above, Aluminum 7075 has more of a tearing/shredding action instead of bending action when it is impacted. The forks are 4.33 inches long and have a thickness of ⅜ inch. They have two- 0.08 inch wide slots cut out of them on one of the surfaces throughout the body of the forks. The cut-out slots act as relief points for the desired tear-away locations. The idea behind this design is that it allows the forks to take damage and still function properly. When impacted, the forks are designed to tear away at a relief cut point, leaving another sharp, angled edge similar to the original edge. Many battle bots use forks similar to this design, but without the cut-outs. This design is a new twist to the typically used fork design within the battle bot industry, so it is hopeful that it works very well and becomes a new industry standard.

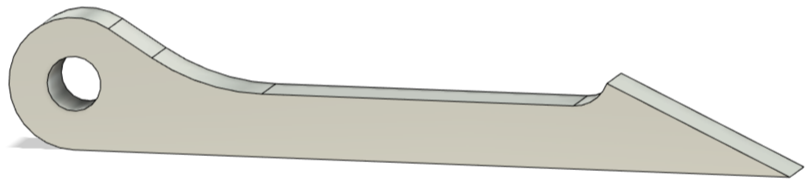


Figure 4.3.01 Fork Design without Cut-outs

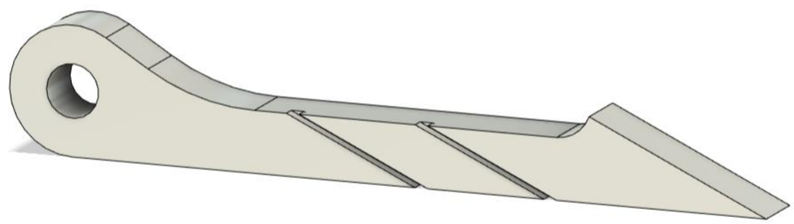


Figure 4.3.02 Fork Design with Cut-outs

Electronics

Receiver
Spektrum AR410 4-Channel RC Sport Receiver, Black:

Figure 4.4.01 Controller Receiver

The Spektrum AR410 air receiver is a full-range, 4-channel sport receiver with DSMX/DSM2 compatibility and a compact footprint. The AR410 also features an internal antenna design that delivers installation ease and includes a higher-level of durability and convenience while maintaining full-range performance. The compact, simple, and high performing design makes it a perfect fit for the RoboCat. The receiver is also low cost in comparison to similar products which keeps the budget for the design in good shape.

Motors
EDS: BadAss 3520-970Kv Brushless Motor

Figure 4.4.02 EDS Motor

Drive: Tempest 2814-850Kv Brushless Motor

Figure 4.4.03 Drive Motor

The BadAss 3520-970Kv Brushless Motor and Tempest 2814-850Kv Brushless Motor were selected due to a few factors. Brushless motors typically have a higher power-to-weight ratio compared to brushed motors. Brushless motors are generally more efficient than brushed motors because they don't rely on physical brushes to transfer electrical energy. Brushless motors have fewer moving parts, which can contribute to increased durability. Brushless motors can achieve higher rotational speeds (RPM) compared to brushed motors. This is advantageous in battle bots where quick and precise movements are crucial. Brushless motors generate less electromagnetic interference. The combination of high-power density, efficiency, durability, and precise control makes brushless motors the superior option.

ESC

Electronic Speed Controller is a critical component in the design of the battle bot, providing precise control over the motor's speeds and direction. It enhances the overall performance of the robot while offering protection features to prevent damage to the motor and battery.

Drive ESC:

Figure 4.4.04 Drive ESC

The Flycolor Francy 2 BLHeli_32 3-6S Dshot ESC was selected due to its compatibility with the selected battery and drive motors. The ESC is also part of the University of Cincinnati combat robotics electronics kit, meaning the part will be interchangeable with spares at a low cost.

EDS ESC

Figure 4.4.05 EDS ESC

Sidewinder 8TH ESC was selected due to its compatibility with the selected battery and EDS motor. The ESC is also part of the University of Cincinnati combat robotics electronics kit, meaning the part will be interchangeable with spares at a low cost.

Battery:

Figure 4.4.06 Battery

6S Lipo Battery 22.2V 130C 1550mAh TATTU R-Line. Has been selected as the standard battery for the University COmpabt Robotics team for the 2023-2024 season. The battery offers high power density at a economical price making it a good fit for the team.

Project Management

Project Budget Limit

After reading multiple past senior design reports over battle bots we began to get a sense of how much each area of our combat robot will cost. Outside of the senior design reports, we discussed with other builders in the bot building community, mentors of our club who have previous experience, and discussion amongst our team who all have bot building experience to generate an estimated cost including materials and labor. We have estimated our budget to be $1,665 to cover all required costs for the year.

RoboCat BOM				
Group	**Component**	**QTY**	**Unit Cost**	**Total Cost**
EDS				
	EDS Motor Support Bearing	1	$17.48	$17.48
	Driving Pulley Set Screw	1	$11.01	$11.01
	EDS Pulley Mounting Bolts	1	$5.74	$5.74
	EDS	1	$45.00	$45.00
	EDS Shaft	1	$8.51	$8.51
	EDS Needle Bearing	2	$6.83	$13.66
	Thrust Roller	2	$3.91	$7.82
	EDS Belt	1	$9.02	$9.02
Movement				
	Front Axle Bolt	2	$8.28	$16.56
	Front Bushing	2	$1.14	$2.28
	Front Pulley	2	$0.00	$0.00
	Front Cleats	2	$15.00	$30.00
	Rear Wheel	2	$0.00	$0.00
	Rear pulley	2	$0.00	$0.00
	Rear Wheel Hub	2	$12.00	$24.00
	Timing Belt	2	$9.98	$19.96
	Drive Gearbox	2	$120.00	$240.00
Body				
	Frame Center Wall	2	$30.00	$60.00
	Frame Side Wall	2	$30.00	$60.00
	Front Cover	2	$10.00	$20.00
	Main Cover	1	$20.00	$20.00

Figure 5.1 RoboCat BOM "Top Half"

	Bottom Plate	1	$25.00	$25.00
	Frame Uprights	2	$25.00	$50.00
	Front Armor	2	$20.00	$40.00
	Nut Strip	3	$9.99	$29.97
Electronics				
	Controller Reciever	1	$35.00	$35.00
	EDS Motor	1	$75.00	$75.00
	Battery	1	$48.00	$48.00
	Drive ESC	1	$21.00	$21.00
	Drive Motor	2	$37.00	$74.00
	EDS ESC	1	$130.00	$130.00
Spares				
	Controller Reciever	0.5	$35.00	$17.50
	EDS Motor	0.5	$75.00	$37.50
	Battery	1	$48.00	$48.00
	Drive ESC	1	$21.00	$21.00
	Drive Motor	1	$37.00	$37.00
	EDS ESC	0.5	$130.00	$65.00
	Frame	1	$170.00	$170.00
	Cover Plates	1	$65.00	$65.00
	EDS	1	$45.00	$45.00
	Front Armor	1	$20.00	$20.00
			Total Cost:	**$1,665.01**

Figure 5.2 RoboCat BOM "Bottom Half"

Prototype & Fabrication Plans

The prototype will be first made from a cheap material, such as cardboard or Styrofoam, to see what the bot looks like to scale and what tolerances/clearances we should consider adding or removing. Then we plan to build a model prototype out of 3d printed plastic to get a better representation of how things will mate and function when we go to the final design. The final design will be a combination of manufacturing techniques. We plan to outsource parts, along with machining on our own at the 1819 lab. Any 3d printed parts will be printed on our own along with the molding of our own set of drive wheels.

The parts that we plan to outsource are the weapon drive motors, wheel drive motors, the Hardox steel EDS, the drive belts, the armor, and the carbon fiber top and bottom pieces.

The parts we plan to machine in house at the 1819 lab are the frame components, custom pulleys, the titanium cleats, the aluminum ears, the aluminum forks, and the UHMW pieces.

We plan to pour our own urethane wheels, and to do our own 3D printing on all printable components within our design to reduce labor costs.

All bolts and bearings are planned to be purchased at McMaster-Carr.com.

We plan to start outsourcing and machining right before and after winter break. This is to allow us to start the building process in early spring.

Testing Plan

To test our prototype, we will do a few different individual tests to make sure all components work properly. We plan to do a drive system test, an EDS spin up test, battery test, assembly and disassembly timed tests, an evaluation of safety, weight test, and FEA tests.

The drive system test will pertain to setting up a small obstacle course. We will take a timer and time how long it takes to maneuver through the course and we will evaluate the ability to have total control of the prototype. We plan to be able to move to a specified point in less than 20 seconds. We will also check for belt slippage and traction control.

We plan to do a safe and quick spin up of the EDS system to make sure it works smoothly and properly. We will check for the time to reach a max spin up speed and time for the

EDS to stop moving when powered down. We will inspect the belt for tension and slippage during the spin up. We want a max tip speed of at least 8500 rpm but this will be determined by calculations during the testing. We also will be keeping an eye on if the EDS is spinning on center and that it is not off balance.

The battery test will be a simple test. We will test the life of the battery and performance of the battery while doing the spin up test and maneuverability test. We will have all components running at the same time to make sure the battery can handle the power of all components at the same time. We will test the time it takes to charge the battery and how long it takes to insert and remove from the robot.

The assembly and disassembly time test will be relatively simple as well. We will take turns fully assembling and disassembling the prototype and timing ourselves. Each of the three of us will assemble and disassemble the prototype three times and record the times. We will average our assembly times and then we will average our disassembly times. According to those results, we will further discuss if we need to improve anything to cut down the times. Ideally, we are looking to be able assemble and disassemble the robot fully in 900 seconds or 15 minutes.

The evaluation of safety is an easy evaluation. We will inspect the prototype for sharp edges and we will inspect the wiring to make sure they are safe and that there are no spots for potential sparking or arcing on other metal components. The results will be in a format that is as simple as a yes or no/ safe or not safe.

The weight test will also be a simple evaluation. We will take a scale that has a very high precision and place the prototype on it after it is fully assembled. We need it to be at or under 12 pounds. Depending on the weight, we will discuss what further actions will be needed. If the robot is over 12 pounds we will need to figure out which components can be optimized to reduce weight, while maintaining the strength of the component. If we are underweight, we may discuss adding additional items, such as armor, to add to the durability and overall strength of the prototype.

The last type of test we will do is the FEA tests. We will run FEA tests on the frame components, armor components, and the EDS. These tests will tell us where the strengths and weaknesses are in our components. It will show if they will be durable enough to not deform under force or torque and it will tell us if they will be suitable for our prototype. The results will tell us if we need to make any reinforcement corrections to components throughout our design and it will test us where we can optimize certain components in our prototype design.

Key Milestones

The milestones below have been set based on the requirements of the UC Combat Robotics Club, NHRL Competition, and the UC Senior Design schedule. A more detailed schedule will be developed as due dates are posted on canvas along with more dates are finalized within the UC Combat Robotics Club. The club has successfully delivered multiple senior design projects over the years, so these unconfirmed dates are neither alarming nor concerning to the group.

Schedule		
Event	**Start Date**	**Deadline**
Preliminary CAD Models	09/04/2023	10/18/2023
Senior Design I Proposal Submission	09/04/2023	10/10/2023
Senior Design II	10/10/2023	12/4/2023
Budget Proposal	NA	11/04/2023
Prototype Design	9/6/2023	12/1/2023
Final Proposal Submission	10/10/2023	12/04/2023
Presentation to UC Faculty	12/04/2023	12/04/2023
Submit Designs for Fabrication	12/06/2023	01/03/2024
Procurement	12/06/2023	01/03/2024
3D Print Components	01/03/2024	01/06/2024
In House Machining	1/10/2024	1/31/2024
Electronics Assembly	02/01/2024	02/10/2024
Assemble RoboCat	02/10/2024	02/17/2024
Testing & Tuning	02/18/2024	02/24/2024
Drive Practice	02/25/2024	03/01/2024
Travel & Compete	02/30/2024	03/02/2024
Finalize Report & Prep for Expo	03/04/2024	04/09/2024
Present at CEAS Expo	04/09/2024	04/09/2024

Figure 6.3.01 Key Milestone Dates

Manufacturing & Assembly

Frame Manufacturing

Figure 7.1.01 Frame Assembly

The assembly of RoboCat is separated into three main sections, and one of those sections is the frame and armor. Once our 3/8th in. thick Aluminum 6061 sheet was received, the waterjet cutting process could begin. The frame was compiled out of two side pieces, two uprights, a rear piece, and a center piece running perpendicular to the frame sides. To give the frame additional rigidity we procured nut strips which were used in six separate locations. We selected a ½ inch hole pattern with #10-32 threads. An image of the nut strip, and nut strip locations (in green circles) are depicted below.

Figure 7.1.02 #10-32 Nut Strips

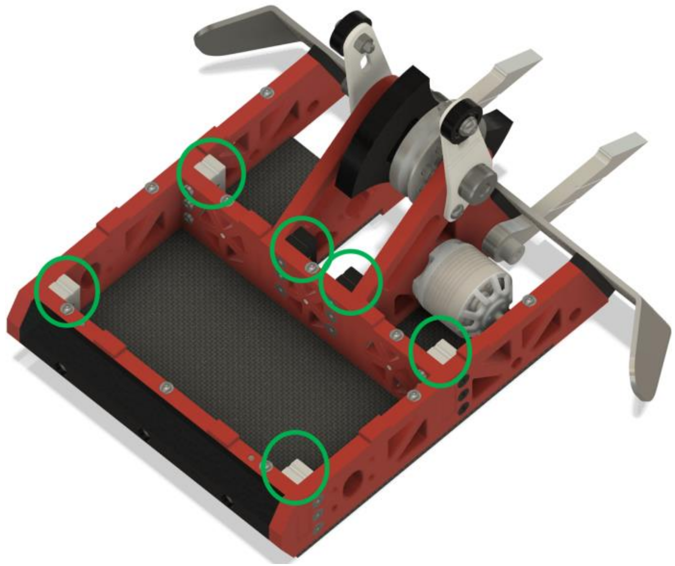


Figure 7.1.03 Nut Strip Locations

These frame pieces were then sandwiched with a carbon fiber bottom plate, and a compartmentalized three section top plate. Two AR500 steel plows were then fastened to the front of the frame.

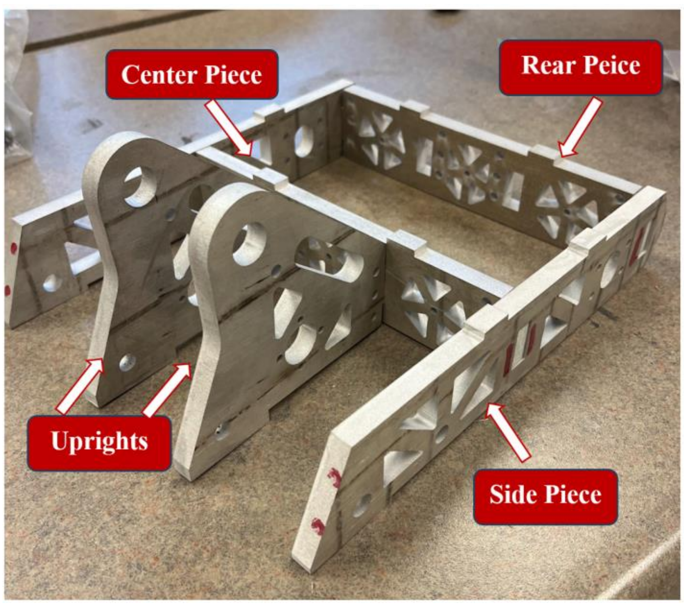


Figure 7.1.04 Frame Component Callouts

Of course, like any brand-new product, mistakes missed in the model will arise in the physical prototype. After receiving the parts from the water jet, we noticed missing features on our components. The tabs on the rear piece and center piece which were supposed to slot into the side pieces were not captured during the file conversion. The through holes for where our nut strips would be fastened to were also missing. The threaded holes along the top and bottom faces of our frame components which allowed the top and bottom plates to fasten to the frame were missing. Along with the threaded holes in the front of our battle Bot which would allow for the plow/front armor to fasten to the frame. We then sent the frame side piece files back to the waterjet updated with tabs included. We salvaged the remainder of the frame components and drilled the through holes in ourselves. The image below depicts where the through holes were missing with pink marks on the part. We used a standard drill press at the Victory Parkway Campus to drill our missing features.

Figure 7.1.05 Missing Holes on Frame

After drilling the appropriate sized pilot holes to fasten the carbon fiber plates to the frame we used a manual tap to tap the holes to our desired thread. This is shown in the image below.

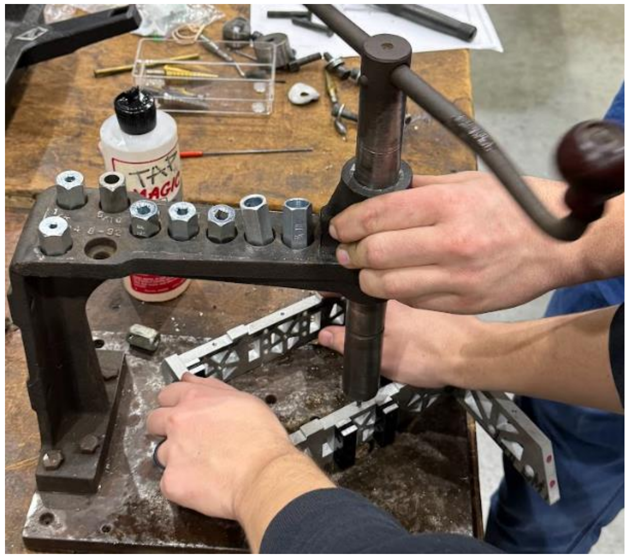


Figure 7.1.06 Tapping Threads

Once we machined all the missing features our raw frame looked like the image bellow.

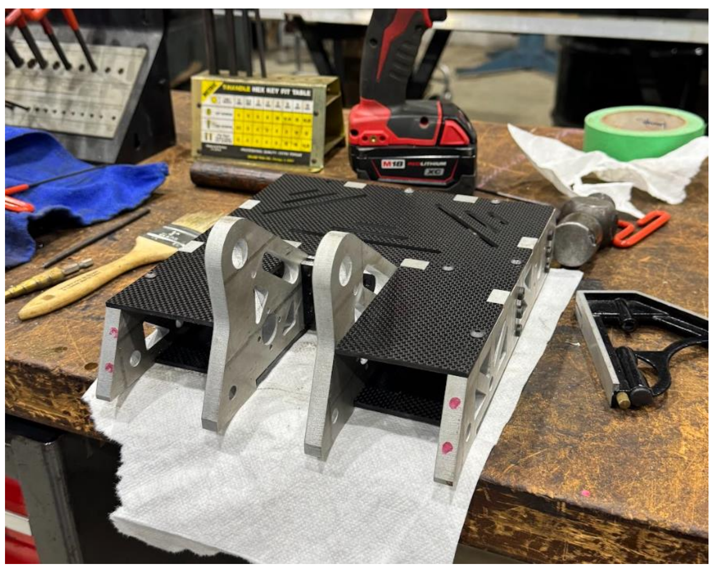


Figure 7.1.07 Frame & Carbon Fiber Plates

The last step of completing the frame assembly was attaching our armor. Our armor consisted of two AR500 Steel front plows, and a back plate 3D printed out of TPU plastic. Our front plows were also fabricated on a waterjet meaning they arrived as a flat plate. To achieve the part geometry, we designed for, which was a 52 degree bend we would need to heat the plows up. Once the plows were heated to a high enough temperature, we manually bent the steel to the desired 52-degree angle. The bent plows are depicted in the image below. An image of the 3D printed TPU backplate armor is also shown.

Figure 7.1.08 Plows & Rear Armor

Upon completion of the frame and armor assembly we gave RoboCat an aesthetic finish by powder coating our aluminum components with a nice University of Cincinnati red. The armor components were done in black, with the plows powder coated and the TPU printed in black plastic. After assembling the painted frame, we added decals to our robot to resemble the university of Cincinnati bearcat, the iconic University of Cincinnati claw logo, and a custom RoboCat logo. The goal of our color scheme and decal choices was to resemble the University of Cincinnati in a presentable fashion.

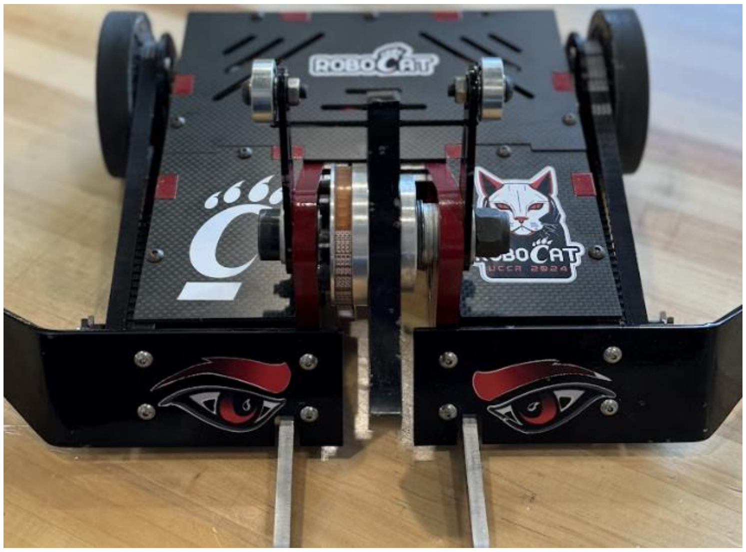


Figure 7.1.09 RoboCat Finished with Decals

EDS Stack Up & Drive Assembly

The EDS stack up and drive were simple in terms of assembly and manufacturing. The reason for this was due to the amount of off-the-shelf components this section included. Outside of the custom V-belt pulleys, pulley backplate, ears, and the EDS itself we procured the remaining components.

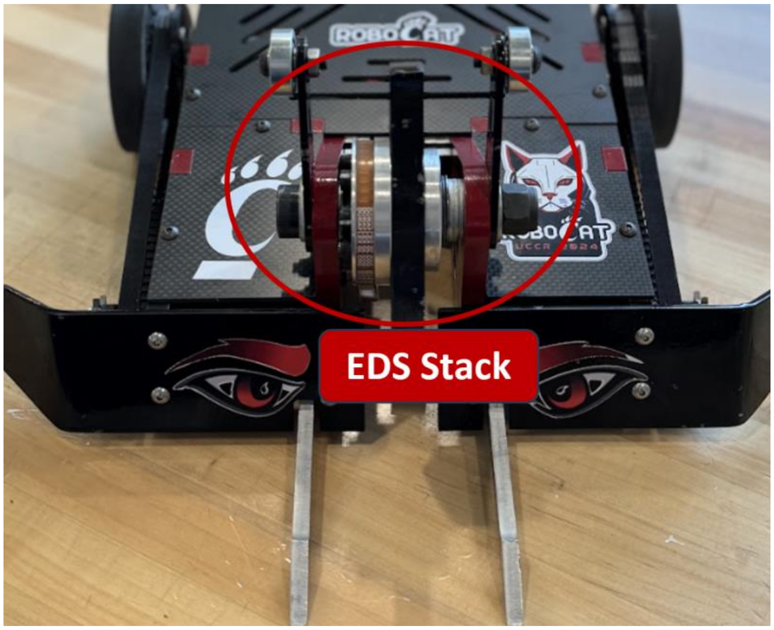


Figure 7.2.01 EDS Stack

The stack consisted of a series of bolts, washers, thrust roller bearings, needle roller bearings, a shoulder bolt custom designed v-belt pulley, pulley backplate, and a locking nut.

Figure 7.2.02 EDS Assembly

The 5/8th in. shoulder bolt functioned as an axle for the EDS to spin about. The Shoulder bolt sat on the needle bearings, the needle bearings were press fit into the driven pulley and the EDS. The pulley was and EDS were bolted to a custom back plate with eight M5 bolts. Sandwiching the pulley and back plate were thrust roller bearings followed by washers. This allowed for reduced friction and a higher rotational speed. Upon receiving the v-belt pulleys from the 1819 innovation hub machine shop we noticed they were out of tolerance per the drawing. Due to time constraints, we did not have time to have another set machined, we were able to go up a belt size and switch to a cogged belt vs the original idea of a V-belt. This change in belt length allowed us to run all our original components. Had this not worked we would have needed to redesign our EDS mounting location on the upright to reduce the center-to-center distance of the pulleys driving the system. The image below depicts the pulleys and the calculation of the center-to-center distance required.

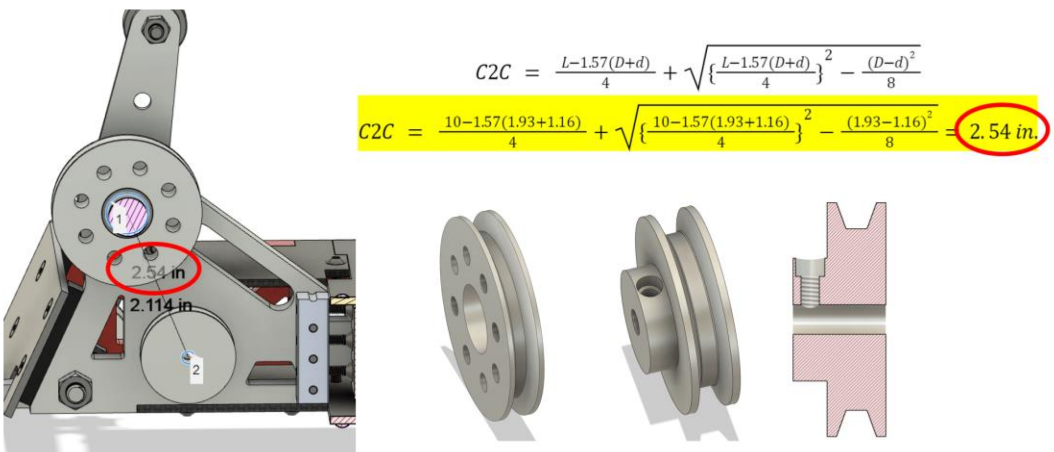


Figure 7.2.03 EDS Pulley Locations

Drivetrain Assembly

The drivetrain for RoboCat consisted of two rear drive modules, two front drive modules, and two timing belts integrating the systems. Each rear module was built up from a Tempest 2814 brushless motor, custom 20:1 gear box, goBILDA hub, custom TPU printed wheels with integrated pulley teeth, urethane poured tire, and the required fasteners.

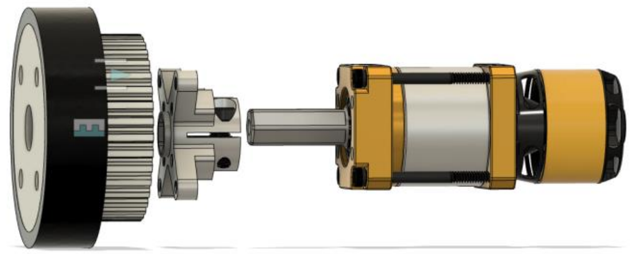


Figure 7.3.01 Rear Drive Module

An issue we ran into when assembling the rear module was that the cavity in the wheel did not have the correct geometry to allow the hub to sit in the wheel properly. This was due to a user error when creating the cad file for the wheel. Due to this being a 3D printed component it was both cheap and quick to remodel and print. Allowing the project to stay within our budget and not delaying deadlines. Another issue the team ran into was the sizing of the output driveshaft from the Tempest brushless motor. The diameter of the shaft was to large for the pinion gear of the gear box. This put the project timeline at risk, the team had to use the tools available to produce a solution. We disassembled the motors and gearboxes to extract the motor driveshaft. Upon the driveshaft extraction we reduced the diameters using a lathe at 1819 innovation hub.

Figure 7.3.02 Disassembled Gearbox & Motor

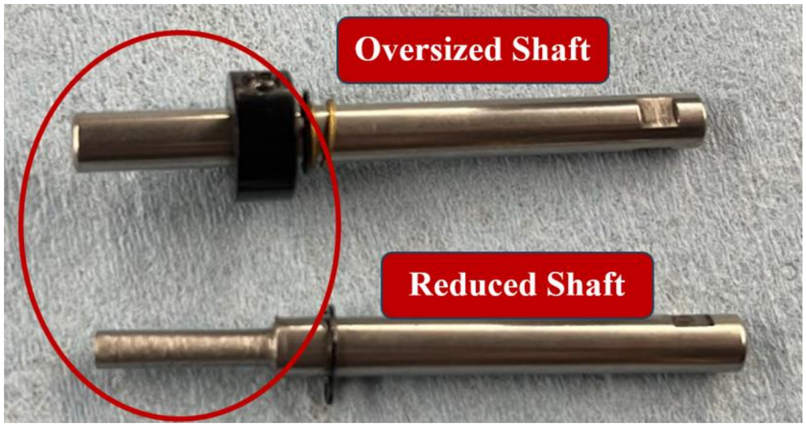


Figure 7.3.03 Before & After Lathe Operation

After reducing the shafts to the correct size, we press fitted the pinons on the reduced shafts using an arbor press and reassembled the motor/gear box module. The driveshaft diameter reduction did not end up hindering performance or causing any issues in competition.

The front drive modules consisted of a shoulder bolt acting as an axel, lubricated bronze bushing, custom 3D printed TPU pulley, custom titanium cleats. The titanium cleats were designed to give RoboCat more traction and allow for better control, these parts were cut on a waterjet by an external supplier. The fasteners which were selected for joining the cleats and pulley were not enough to hold the components together. To add rigidity, the team elected to use epoxy to secure the fasteners. This turned out to hold up extremely well in competition.

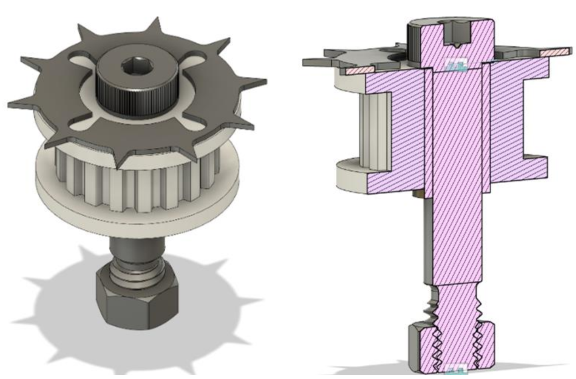


Figure 7.3.04 Front Drive Module

Product Testing

When assembly of the bot had finished, we began to implement our testing plan as previously illustrated in its respective section above. Several of our planned tests were not able to be completed in Cincinnati due to UC's safety restrictions. These are any tests which involve spinning up the EDS. Therefore, the dangerous tests were completed in a safe and controlled environment at the NHRL competition. All other tests were conducted within the UC Combat Robotics club room.

The first test was an electronic test. After all components, except for the EDS motor, had been connected to each other and the controller, the bot was turned on. The controller was used to determine that it was receiving signal from the bot and that the wheels were functioning properly. It was important to ensure that the wheels had been wired to the drive ESC properly so that they rotated in sync and in the correct direction. After this test was completed successfully, all final components of the bot were placed within the assembly and set on a scale. The weight test is crucial because the bot would not be able to fight if it did not fall below the 12 lb. weight restriction. Since we were diligently monitoring the weight of the bot in CAD and through manufacturer spec sheets, the bot weighed in at 11.99 lbs., making this test a success.

Now that the final state of the bot was achieved, we began to conduct our assembly and disassembly tests. Each member of the team fully assembled and disassembled the bot, and all times were averaged to find the results. For a complete assembly, the average time was 15 minutes and 27 seconds. The average disassembly time was 14 minutes and 42 seconds. The NHRL competition only guarantees 15 minutes to rebuild your bot between fights, so it was important to fall below this time when making repairs. Although the average assembly time is higher than 15 minutes, this time is for a complete assembly time. It is much more likely that only a small amount of components will require replacement in between fights, so a complete assembly will not be required. As a result, we considered this testing result a success.

The next three tests were all completed at the NHRL competition since they required full electrical connections, including the EDS motor. First, the EDS was powered on to its maximum speed for two minutes. After the timer had stopped, the weapon was powered down using a fail-safe procedure. While the EDS was running, the bot was examined for excessive vibrations which would indicate an imbalance in the EDS stack up. This effect was not seen by our team, and this test was considered successful. Immediately following this test was the mobility test. This involved maneuvering the bot around the arena to determine the speed and control of the bot. The driver made quick turns and rapidly accelerated to determine if the bot would tip or lose contact with the driving surface. This test showed that the bot was able to manage these intense movements during the fight. Also, the bot was timed as it went from one end of the arena to the other. Our goal for this test was for the bot to go from one end to another (distance of 16ft) in under 1.5 seconds. The actual value for this time was measured to be 1.3 seconds and therefore the test was a success. Lastly, immediately after conducting the previous two tests, the battery level was measured to ensure that a single charge would last an entire fight. The battery was measured to have approximately 50% charge after these tests and would, therefore, be able to last a full 3-minute fight.

Conclusion & Recommendations

Lessons Learned

There were many important lessons learned during this senior design project. Several of the lessons learned were from when we finished the battle bot and competed at the competition in Norwalk, Connecticut. Some were learned in the process of assembling. One of the first lessons that were learned was to not fully depend on the reliability of the 3D CAD software. Just because it says it can fit or says it is a certain weight, does not always mean that it truly will be those things. In the CAD file, we had four times the required space for the battery and all the wires inside the body of RoboCat. When we were assembling it, we found out that the space was more limited than we originally planned. Fortunately, we were still able to fit all the electronics inside the space allotted. Also, in the CAD model, our weight was almost one pound under the 12-pound limit we had designed around. After assembly of the robot, we weighed in just shy of twelve pounds. Another lesson that we learned was to not trust anyone's accuracy without double checking yourself before paying. Due to time constraints, we had to have a pulley lathe machined by an employee at UC's 1819 building. After we received the part and assembled onto our battle bot, we noticed that our original EDS belt did not fit on the pulley. We went directly to our instincts and checked measurements on the part with calipers. The part ended up being larger than we needed and the V-belt groove was out of tolerance. This mistake required us to buy a larger belt for our battle bot.

The other lessons learned were brought to our attention after the competition. One of those being to always account for all shear stress locations. Prior to the competition we had thought we accounted for all the possible shear stress locations on our robot when being stuck by the opponent. We found out that we failed to account for a hit on the corner of our front plows and the amount of shear stress that would move through our four front bolts. During one of our battles, both of our plows was struck on the corners and the bolts immediately sheared off, causing us to lose the battle.

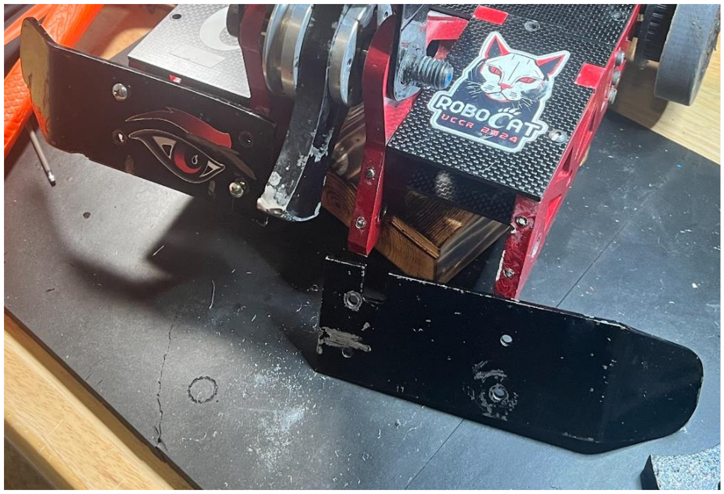


Figure 8.1.01: Sheared-off Plow Bolts from Battle

This also led us to realize that you always need to account for the worst possible damage when fighting battle bots. Even when you don't think a part will fail, there is always a possibility. We never thought that our plow would fail causing us to lose but we got proved wrong in less than 3 minutes. One of the last lessons learned during our time in Norwalk was that when we evaluated the robot without a drivebelt we found that it didn't have quite the drive power compared to operating with the belt. We originally designed the battle bot to be able to drive well with and without the drive belt. This was to allow us to not worry about damage to the belt during the fight. Knowing that our bot did not operate well with no belt, we tried to keep the belts away from the opponents, but unfortunately during one of our three battles, the opponent hit our belts and we lost much drive/pushing power, resulting in us losing.

Future Recommendations

The above lesson learned during the project gives us the ability to recommend work ideas and tips for future versions of RoboCat. One of the main recommendations would be to attach the front plows differently. They need a stronger connection that can withstand high stresses to prevent them from shearing. After looking at the damage, we would recommend using nutstrips, like what we used for connecting the frame pieces. This would give a sturdy connection for the plows to the frame and would withstand harder hits and shear forces. The nutstrips worked well in keeping our frame well connected, so that is why we think they would be a good choice for the front. Another future recommendation would be to shred some weight on the battle bot, making the availability to use large diameter bolts/screws. This would also help with increasing the force that can be dealt to the battle bot without parts shearing and breaking off. We used many small screws that were fine threaded in our assembly, and we now feel that we should have used larger, course threaded screws and bolts to ensure stronger connections. Course threaded screws/bolts tend to be heavier duty and can withstand much more stress, while also not hurting the internal threads. The thread life and condition were also major things we needed to pay attention to because all our parts were aluminum.

Continuing with future recommendations, we feel that additional side armor should be added to the battle bot. This stems from the belt drive system not working as we hoped. When the belt was destroyed by the opponent, our driving power decreased heavily. If the future design were to have side armor protecting the belt, the robot would not need to worry about the opponent taking out its drivebelt during the fight. This is why we feel that this addition to RoboCat would be beneficial. The last recommendation that we feel is necessary to RoboCat for future designs is to build multiple of the same robot for competition. Since this was our senior design project and funds allocated to us by the club, we were only able to create one physical model of the battle bot. We had spare parts, but not enough for a whole new robot. When arriving to coemption, we found that the successful and experienced builders either had enough spare parts for a whole new robot or they had already made a second duplicate model of their robot. This immediately put us at a disadvantage. After our fights, we had too much damage and too little time to completely rebuild to continue battling. Other competitors had other robots ready to use for their next fight while they fixed the one that was damaged when they had extra time.

Conclusion

Overall, our team feels that our senior design battle bot project was a success. We were able to come up with a design, manufacture, assemble, and compete within the time frame of roughly 7-8 months. This project was a faster turnaround than many other senior design projects. This was because our competition was in early March and not later in the school year. We feel that it was a success because aspects of our design performed just as we planned. We had less problems than we expected to have during our manufacturing and assembling processes. All the minor problems that did show up, we were able to fix them right away with ease. We were able to stay under budget as well during the whole project, which was a huge bonus since we had limited funds to deal with throughout the club since there were many groups making senior design battle bots. Another reason that we feel our project was successful was because we were able to compete in the competition on March 2, 2024, in Norwalk, Connecticut with a battle bot that performed just as we wanted it too. Everything thing worked well on the battle not leading up to the rights, which was one of our ultimate goals. Our other main goal was to win at least one fight, out of the two guaranteed fights. We ended the competition with a record of 1 win and two losses, which unfortunately did not place us into the main tournament bracket. We performed better and worse than fellow classmates who also competed at the event with their senior design project. After the fight we were able to conclude what worked well and what did not. Which led to us figuring out why certain things failed and thinking of ways to improve those problems in future designs of this project. So, in the end, our team is happy with the results of our project and its success. We are also pleased with our design skills and our ability to discover the issues our project had and workable solutions to those issues. We would recommend anyone to give this senior design project a try when they are at the point in their college careers!

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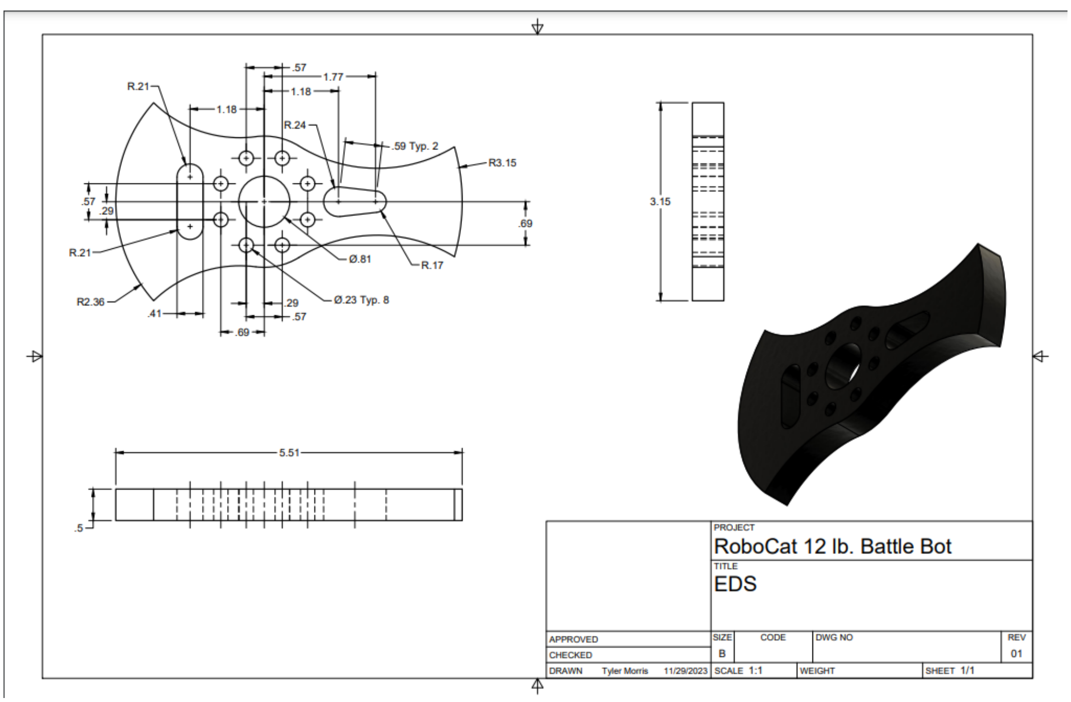
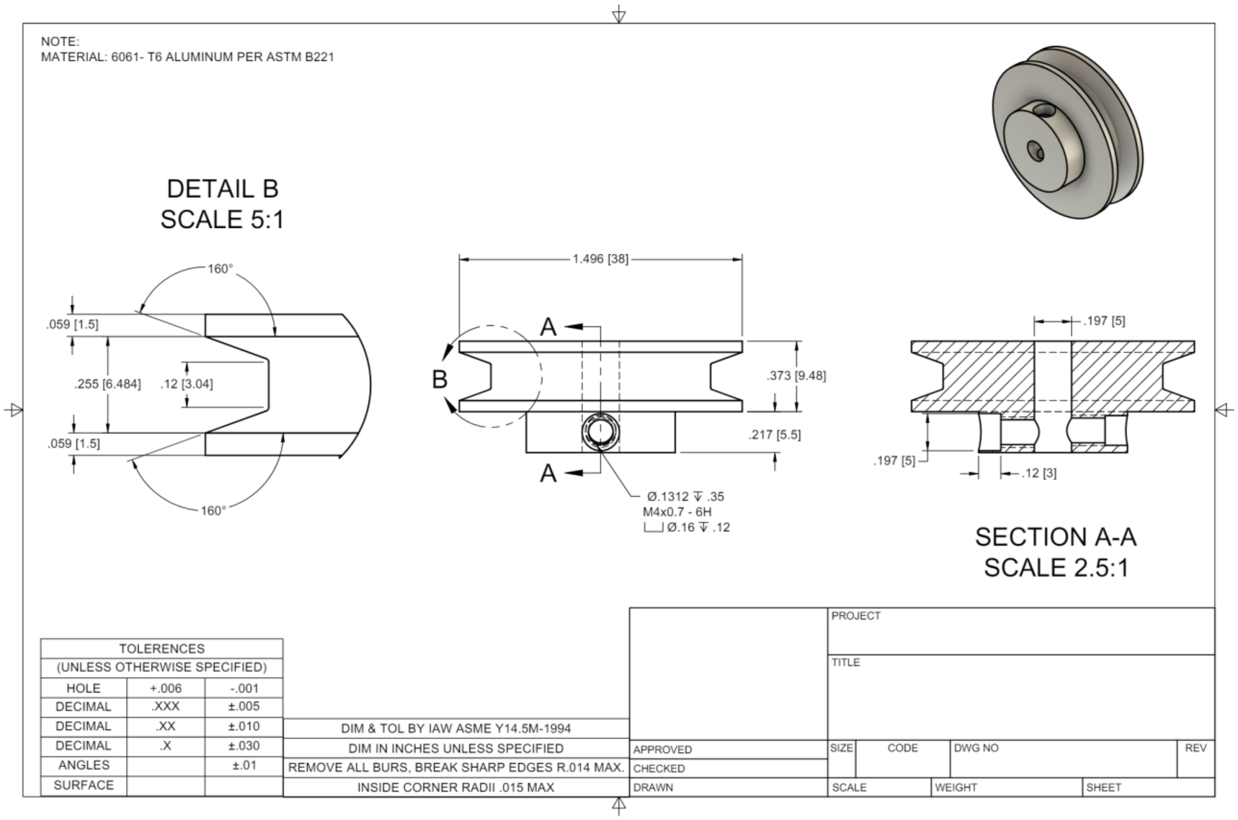
Appendices

EDS Drawings:



Driving Pulley:



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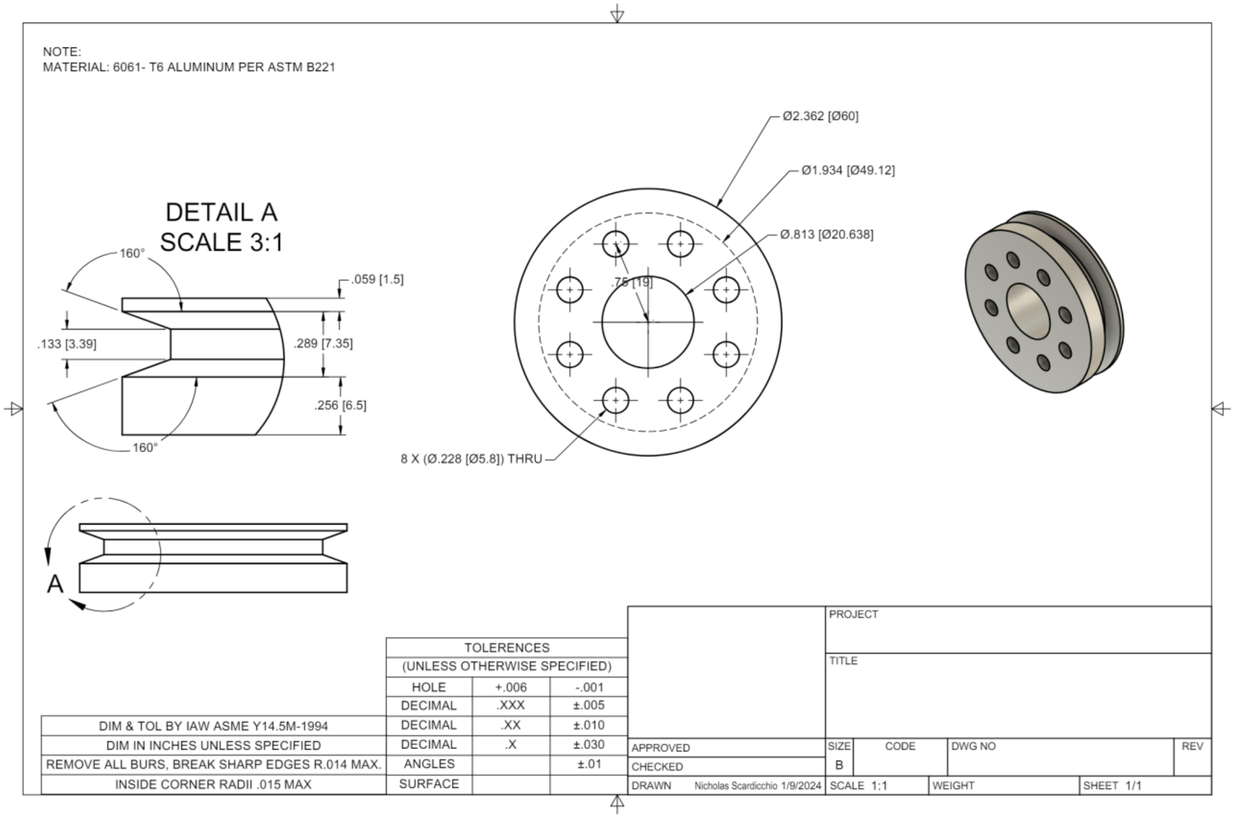
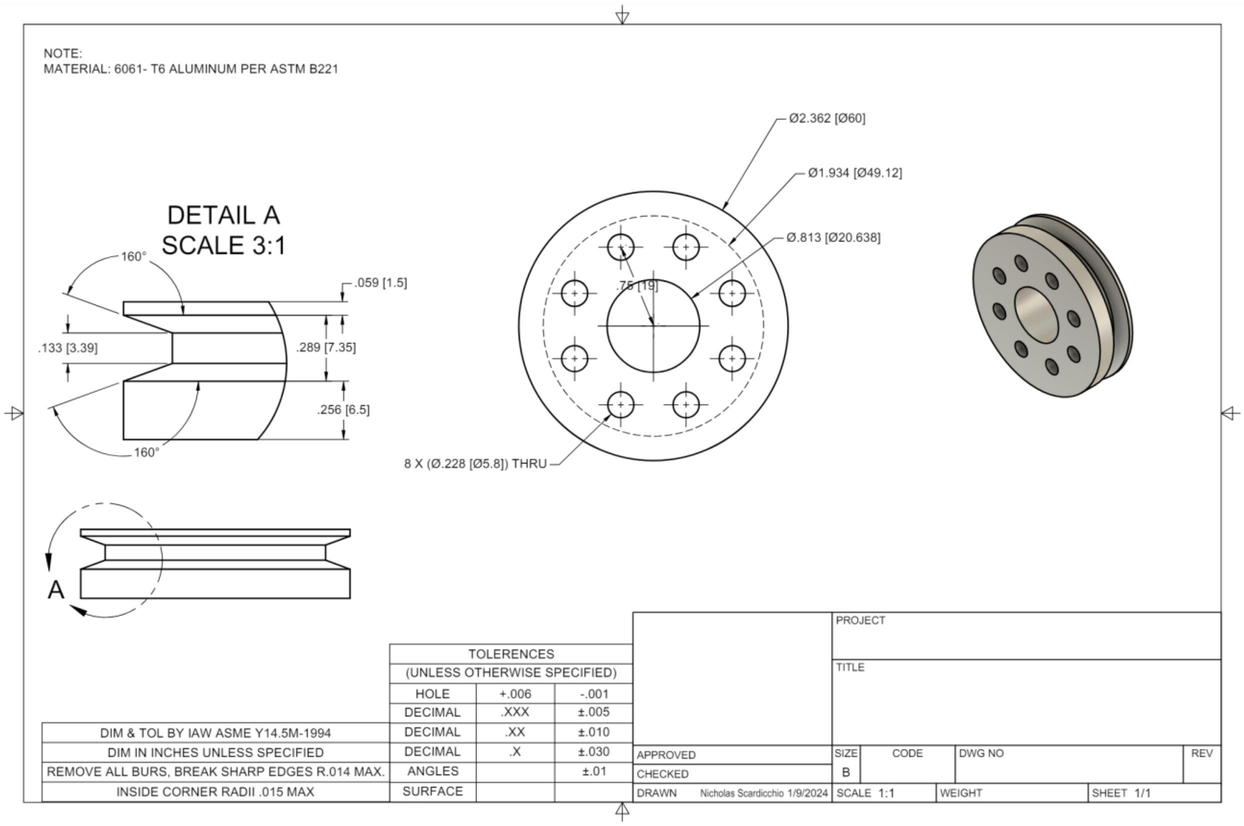
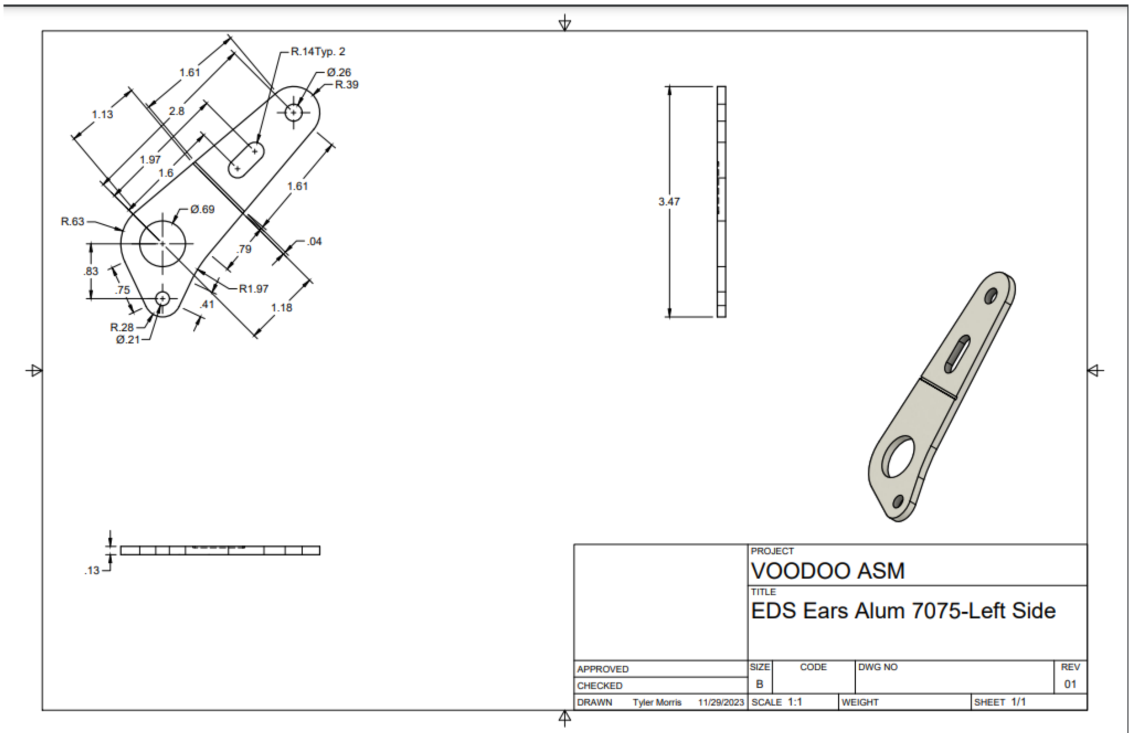


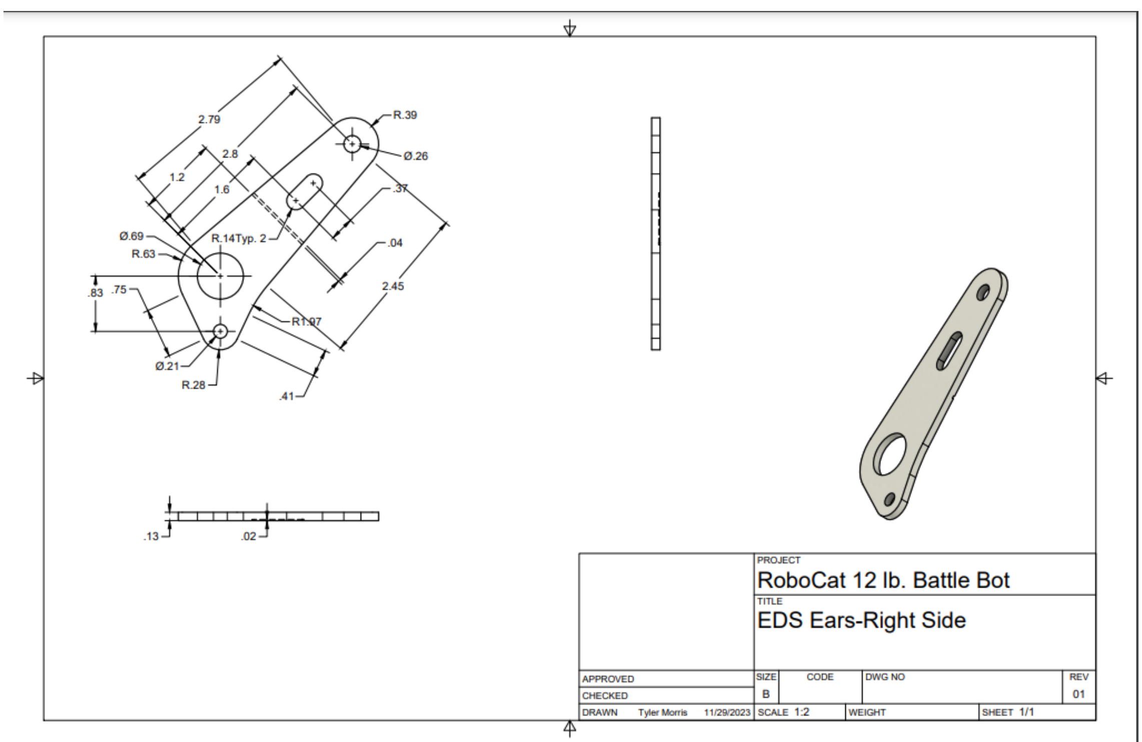
	TOLERENCES (UNLESS OTHERWISE SPECIFIED)		
	HOLE	+.006	-.001
	DECIMAL	.XXX	±.005
DIM & TOL BY IAW ASME Y14.5M-1994	DECIMAL	.XX	±.010
DIM IN INCHES UNLESS SPECIFIED	DECIMAL	.X	±.030
REMOVE ALL BURS, BREAK SHARP EDGES R.014 MAX.	ANGLES		±.01
INSIDE CORNER RADII .015 MAX	SURFACE		

Driven Pulley Back Plate:

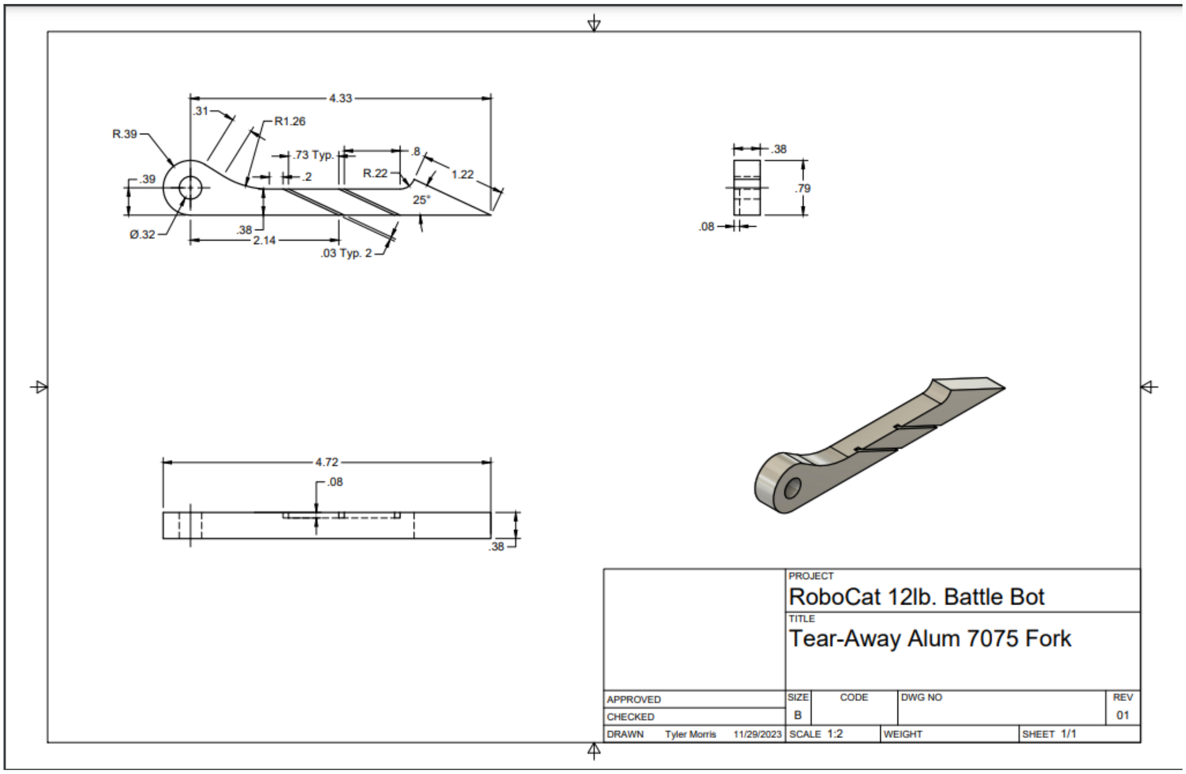


Ear Drawings:

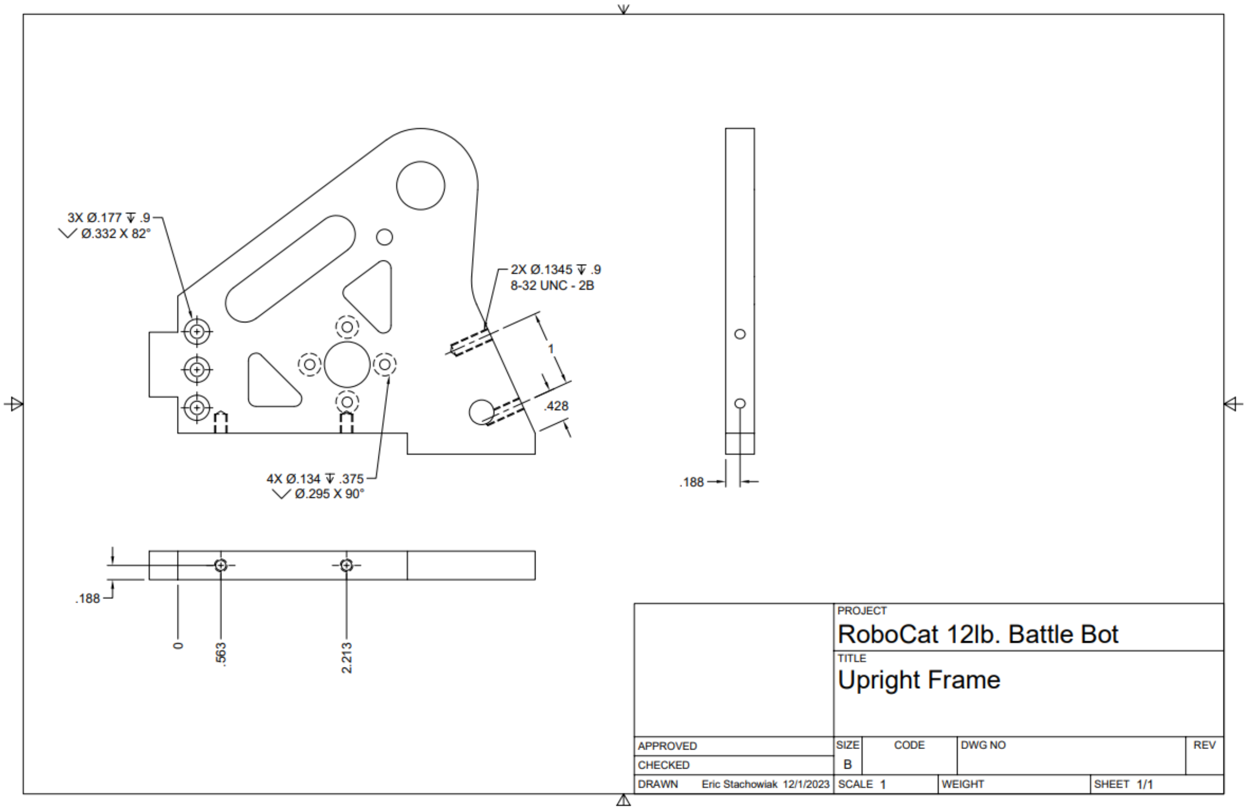


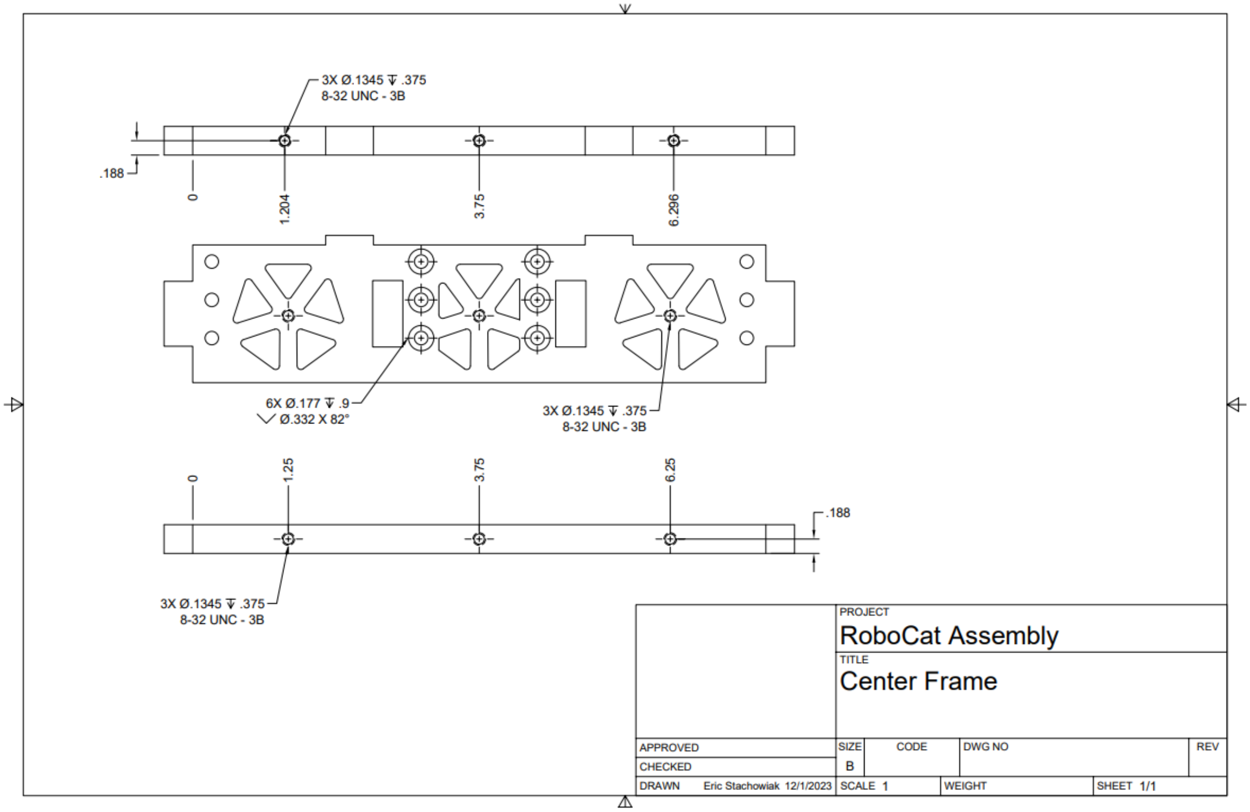


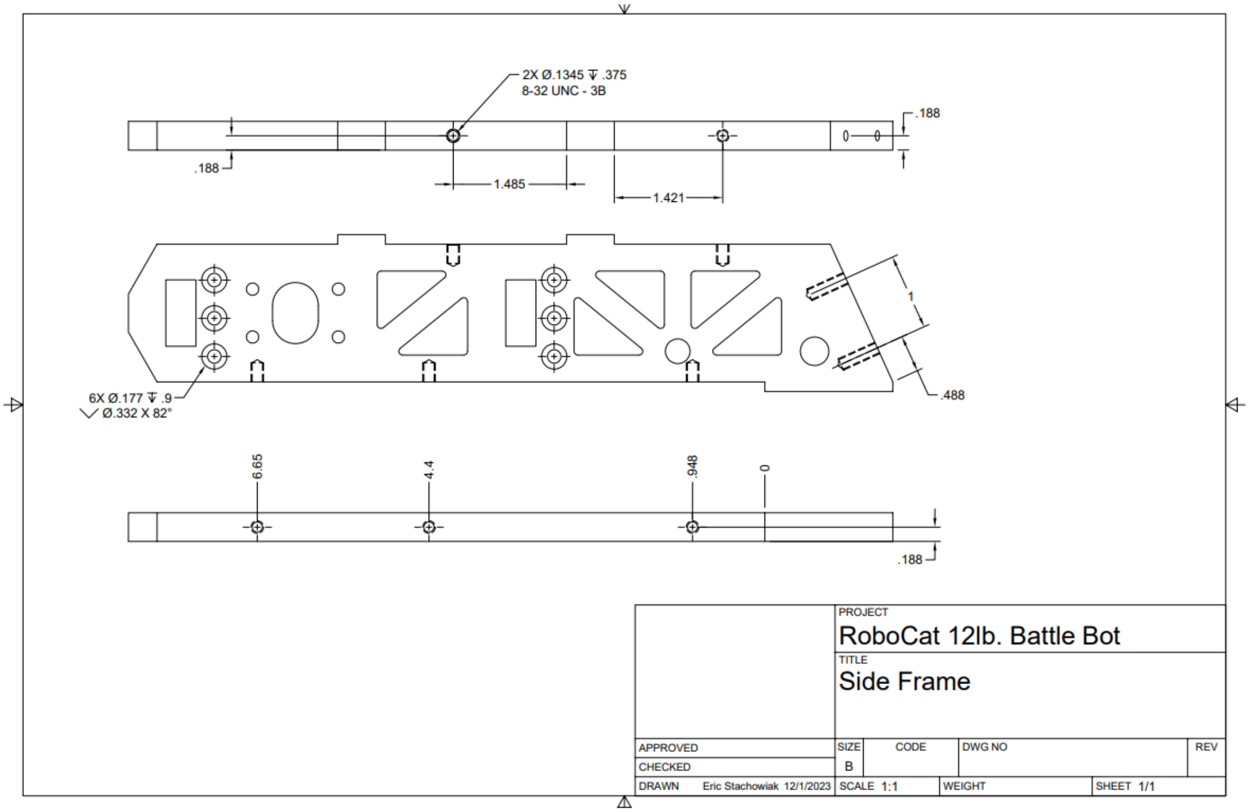
Fork Drawings:



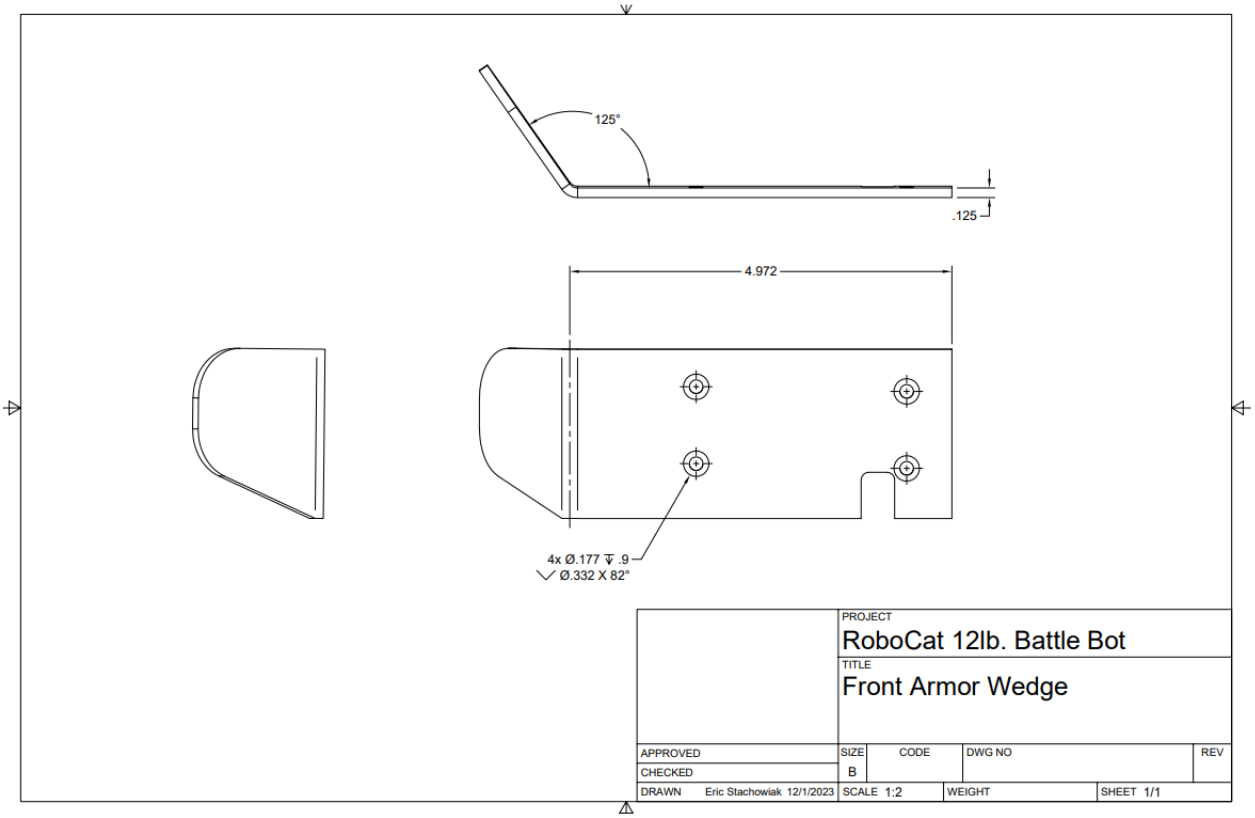
Frame Drawings:




3X Ø.1345 ↧ .375
8-32 UNC - 3B
.188
0
1.204
3.75
6.296
6X Ø.177 ↧ .9
⌵ Ø.332 X 82°
3X Ø.1345 ↧ .375
8-32 UNC - 3B
0
1.25
3.75
6.25
.188
3X Ø.1345 ↧ .375
8-32 UNC - 3B
PROJECT
RoboCat Assembly
TITLE
Center Frame
APPROVED
CHECKED
DRAWN Eric Stachowiak 12/1/2023
SIZE B
CODE
DWG NO
REV
SCALE 1
WEIGHT
SHEET 1/1



2X Ø.1345 ↧ .375
8-32 UNC - 3B
.188
.188
1.485
1.421
1
.488
6X Ø.177 ↧ .9
⌵ Ø.332 X 82°
6.65
4.4
.948
0
.188
PROJECT
RoboCat 12lb. Battle Bot
TITLE
Side Frame
APPROVED
CHECKED
DRAWN Eric Stachowiak 12/1/2023
SIZE B
CODE
DWG NO
REV
SCALE 1:1
WEIGHT
SHEET 1/1


125°
.125
4.972
4x Ø.177 ↧ .9
⌵ Ø.332 X 82°
PROJECT
RoboCat 12lb. Battle Bot
TITLE
Front Armor Wedge
APPROVED
CHECKED
DRAWN Eric Stachowiak 12/1/2023
SIZE B
CODE
DWG NO
REV
SCALE 1:2
WEIGHT
SHEET 1/1