2022-23 UC CEAS
12lb Combat Robotics Senior Design Team
BAKA BOT

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

Bachelor of Science

in Mechanical Engineering Technology

by

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Thesis Advisor: Dr. Janet Dong

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Problem Statement

Our team will design and build a 12lb combat robot to compete in a 2023 NHRL Competition. This project will be advised by Dr. Janet Dong. The competition requires competitors to build a robot that must disable opponents while protecting itself from attacks from said opponents. In addition, working with parameters that satisfy safety standard, weight, and cost. Through the engineering program at The University of Cincinnati, our team has the knowledge and experience to properly plan, build, test, and compete our BAKA BOT at the 2023 NHRL Competition on May 6th.

Research

Background of the Problem

In May of 2023, there will be a combat robotics competition hosted by the National Havoc Robot League (NHRL) in Norwalk, Connecticut. NHRL gives anyone the opportunity to form a team of 1 to 4 members to design and build a 3lb, 12lb, and/or 30lb combat robot that will compete in a tournament consisting of 3-minute rounds. The UC Combat Robotics Club is well known to compete at this event because prior students have built and competed their robots that they built for the club or for their senior design capstone project. Our BAKA BOT will be competing in the 12lb weight limit class. For this competition, some rules consist of having the robot be remote radio controlled, certain battery assemblies are required, and no hydraulic or combustion weapons are allowed. The rounds are also judged on three criteria: aggression, control, and damage. If no robot is defeated, it will come down to the judge’s decision. For more details on the rules of the building competition, see Appendix A (63). The University of Cincinnati and the UC Combat Robotics Club have given our team the opportunity to use this competition as our senior design capstone project.

Applicable Standards

Combat robotics technical regulations are outlined by Norwalk as Appendix A (63) in the references of our paper.

State of the Art - Frame

A combat robot's frame and armor are one of the most important aspects of the design considerations. It's extremely important to start with this and attempt to make it adaptable as it will develop and change over time with further developments. It is the main line of defense, storage for the drivetrain, support for the weapon, main source of weight where weight is limited, and much more. Typically, a few designs have proved successful in professional and college competitions which we will examine here.

Wedge Frame

One of the most common and easily designed frames, the wedge frame offers a simplistic but effective design. Wedge frames can be used as the weapon themselves but are commonly equipped with another weapon for additional damage. The main goal of the wedge is to be able to push and manipulate the competing robot into the boundaries of the arena or wherever the team would like. Scraping from underneath the opposing robot leaves it vulnerable and can at times even flip it rendering the victory to the wedge frame robot. However, this frame requires the driver to be skilled in driving to prove effective. It is also ineffective against another robot with a wedge design. Despite that a wedge design is possibly one of the best options in terms of simplicity and effectiveness for our purposes. [5][6]

Figure 1 – Hydra (2021) Battle Bots [10]

Full Body Spinners Frame

Full body spinners are more complicated but offer a certain wow factor for competitions and more importantly the judges. As a frame it is always circular with a weapon that rotates around the circumference of the frame. With a constantly spinning weapon, its best defense is its offense. Whenever another robot attempts to attack a spinner robot it is almost guaranteed to take damage. Therefore, the driver doesn’t have to be skilled to produce effective damage. However, this robot can quickly become self-destructive if a frame is not extremely strong. It is also difficult to design a sound spinning frame and it is next to impossible to repair or add other features. In a competitive scene where quick repairs/swaps may need to be made in between fights, a spinning frame may not be a viable option. [3][7]

Figure 2 – Captain Shrederator (2021) Battle Bots [8]

Box Frame

A box frame is a straightforward compact design capable of equipping most weapons. As the frame is a box it can adopt features from other frame designs and still be heavily armored. The largest design consideration is the armor. A large portion of the overall weight should be dedicated solely to its frame as the armor requirements are going to add the main source of weight. It is vulnerable from 3 directions and therefore needs to be able to take a beating. Most of the components will be tucked into the interior and will be hard to damage by another robot. [1][5]

Figure 3 – Minotaur (2021) Battle Bot [9]

Armor

Armor, while not immediately thought of as the most important aspect of the design, it is potentially one of the most vital aspects to the design. It must be able to defend the frame of the robot which provides the main support for the entire robot. Not only does it need to defend against several types of different weapons, but it also needs to be able to absorb the force from its own weapon. According to Newton's third law of motion, whenever one object exerts a force on another object, the second object exerts an equal and opposite on the first. Therefore, we need to consider the force we are exerting on other robots and act like we are exerting it on ourselves. [11]

Armor: Tank Armor

There are different methods of tank armor compositions that allow for extra defense that is worth mentioning. Sloped armor is what it sounds like, instead of a 90-degree vertical plane, it sets the outside armor at an angle to increase the horizontal width of the plating. This provides extra protection from impacting forces. In our case, slopping the outside armor is advantageous to save weight while simultaneously increasing the width of the plating. [12]

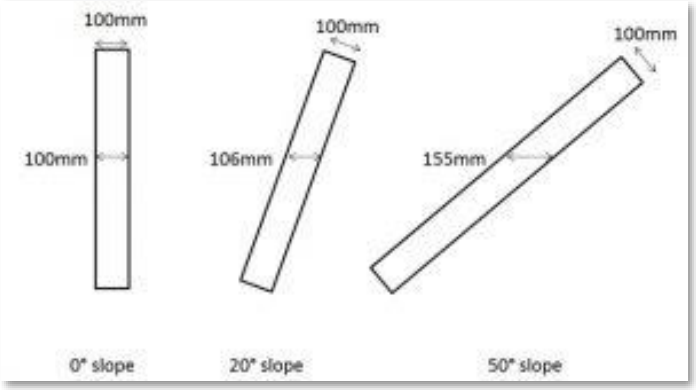


Figure 4 – Sloped Armor [12]

Another armor configuration method is spacing a second layer of armor to reduce the shockwave from the initial impact. This causes the impact to lose momentum and overall damage to the frame of the vehicle. A second layer would increase weight but does not necessarily need to be metal. For BAKA BOT, a composite material could be layered onto the outside to embrace the initial impact shock and reduce damage from each impact. [12]

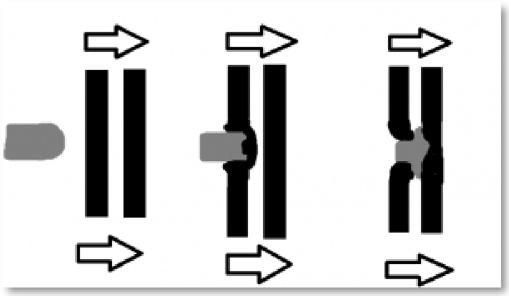


Figure 5 – Spaced Armor [12]

Common Material Types in Combat Robots

An ideal material type for armor needs to be lightweight but also provide a high level of hardness and toughness. It needs to be able to cover up and protect weak and critical positions within the drivetrain. Most likely, the front of the robot will need to be more heavily armored due to the nature of the fight. The most common armor material is aluminum, titanium, steel, and Lexan. [13]

Steel is one of the best materials in terms of protection for dollar purchasing. It is also one of the best materials for weapon designs as it is a very hard material and must be harder than the opponent’s armor to actually do damage. Steel is also an extremely easy material to mill and weld. However, steel is also very heavy. For only a square foot of quarter inch of 1018 grade it weighs just over 10lbs. While one of the most common materials used in framing, it is very heavy and must be taken into consideration for the overall design. [3][13]

Aluminum is also a great material for defense but is generally more expensive than other metals. While more expensive, it is also extremely lighter, a square foot of quarter inch of 6061-T6 grade weighs in at 3.53lbs. These huge weight savings make it the material of choice for most robots. Furthermore, it is easy to machine but more difficult to weld. Despite this, aluminum will likely be the main armor for our robot. [3][13]

Titanium alloy is the hardest of the three metals at a Brinell hardness number of 334. It has been gaining popularity among the higher budget builds in the professional scenes. The main problem with titanium is the expense because it is stronger than aluminum and also lighter than steel. It is the middle ground between aluminum and steel. It is also difficult to weld and machine. While not the most apparent option, it should be considered further in the concepts. [2][13]

Lexan is a high-grade form of polycarbonate manufactured by GE. While not a metal, it still provides a high amount of penetration protection and is lighter than aluminum. The flexibility of the material proves to be a good shock absorber. However, it is very expensive and is weak to cutting weapons. [13]

UHMW is an extremely tough plastic with high abrasion and wear resistance used in the previous years "DOOMBA" build. It is easy to fabricate and provides a durable surface that is also commonly used in guards or bumpers. UHMW creates a shock layer wherever it is layered making it a prime selection for BAKA BOT. [4][15]

State of Art – Weapon

Vertical Spindle Weapon

The vertical Spindle weapon is the most common and effective weapon used in combat robotic competitions. Its power is sourced on batteries, electric motors, etc. The weapon creates vertical movement that damages the competition's robot with any hit. However, the effectiveness of the hit varies depending on the size and sharpness of the blade. During Battle Bot season 1-5, the Nightmare's robot had an appearance showcasing its vertical spindle weapon with spinning discs [16]. This design has changed every year, but the performance of the robot has always been at the top for the vertical spindle weapon category. The advantages of using a vertical spindle weapon are the that it can damage the opponent from a wider range and the hits are more accurate. If wanted to be more powerful, multiple vertical spindle weapons can be added. The disadvantages of using this type of weapon are that it has to be made out of a strong material like steel and the weight of steel or materials like such can cause an issue with the materials for the frame and armor to be under the 12lb weight limit. [17]

Figure 6 – Nightmare [16]

Bar Spinner Weapon

Bar spinner or horizontal spinner weapon is a spinning weapon that rotates horizontally. This type of weapon is different from any spinning weapon as the shape is different. In most competitions, this weapon is shaped as a long rectangle or trapezoid with serrated/blunt tips for damage. One can think of this weapon's design as a lawnmower blade. The advantages of using a bar spinner weapon are that the weight for this is smaller than the vertical/disc spinner weapon. The weight is distributed better. If the size and power is balanced with the frame, there is a lower chance of getting flipped over by an opponent. The disadvantage of this weapon is that it is closer to the ground which can cause the robot to struggle to move on the arena. Since this type of weapon has to be dense, it would ultimately be heavier than the vertical spindle weapon option. [17]

Figure 7 – Tombstone [18]

Spinning Drum Weapon

The spinning drum weapon is a steam roller shaped weapon. During the Robot Wars, this weapon was the most uncommon, but it became more popular after Suicidal Tendencies, Blade, and Challenger 2 at Series 3. This weapon usually rotates vertically. The performance of the weapon depends on the speed and power of the weapon Son of Whyachi used this type of weapon on Battle Bot season 3 and 5. During season 3, this robot won the final match. The advantages of using a weapon type like this is that based on the Battle Bot competition data, this type of weapon has won different matches for the heavier weight limits. The disadvantage of this weapon is that to do any damage to the opponent, the robot has to be very close to the other robot. [18][19][20]

Figure 8 – Son of Whyachi [19]

State of Art – Drivetrain

Wheel Drive Methods

2-wheel drive is seen a lot when building smaller robots. These types of robots are a lot more agile, allowing them to quickly turn in place with little energy wasted. This is possible because each wheel is independent from the other. So they can spin in different directions to turn, or drive in the same direction to move forward/backwards. A professional robot example of a 2-wheel drivetrain is the Black Dragon (see *Figure 9* below). Their design has 2 wheels near the back and the front drags on the ground. This is done on purpose because when the weapon spins upwards, the reaction force when the weapon hits another robot is the front of the robot being pushed downwards. So having the front touching the ground allows the robot to be rigid and prevents the frame from bending/breaking. Another advantage of using 2 wheels is allowing the team to have more weight to work with in other aspects of the robot like the weapon. Wheels can weigh a lot, so when weight is a limit factor, using 2 wheels is a lot more efficient. [22][25]

Figure 9 – Black Dragon [22]

Multi-wheel drive is another popular option that is used in combat robotic competitions. This wheel configuration includes robots with 3 or more wheels. Normally robots have either 2 or 4 wheels, but there have been some robots that have had 3 or 6 wheels. This setup is more so used with bigger robots that weigh more needing more stability. An example of a 4 wheeled robot is Whiplash (see *Figure 10* below). It had a flipping weapon that required its base to be very sturdy and it weighed a lot, so 4 wheels was the best for this design. The main downside for 4 wheels is that the wheels take up a lot of the weight of the robot. So if the robot is under a weight limit, multi-wheeled drive may not be the best. Although, an advantage is that if one wheel is damaged, the robot can still function with one less wheel. Being able to drive around is huge in these competitions because that means your robot is still alive. Other advantages include being able to move faster in straight lines to gain more momentum, more stability, and it provides more tractions.[23][25]

Figure 10 – Whiplash [23]

Drivetrain Assembly

Chain drive is a good way of transmitting a powerful mechanical force to the wheels. This method is a cheap assembly that works well if maintained correctly. It uses a sprocket gear mounted onto the motor shafts and the wheel axles. Their main advantage is that they can exert a lot of power from the motors to the wheels all while being easy to replace/fix if the chains were to break. This is similar to bicycles. The main downside to this method is the chains require constant lubrication or else failure can occur. Also, chain drive requires more space within the robot's body. Lastly, the parts needed to use the chains, like the sprockets, can be very heavy. [25]

Belt drive is a very popular method used in competitions. This method is similar to chain drive but is a lot more lightweight. This system works by transmitting power through the use of a belt and pulley system instead of a metal chain and sprocket. This setup is very efficient which helps the motor's health from being overloaded. This is because the belt can slip if overloading were to happen. No lubrication is required but the belt material can break more easily than chains. Belt drive can also take up a lot of space within the robot's body. [25]

Gear drive consists of several gears directly intersecting each other to transmit power. Depending on how many gears are used, the motor power can be increased or decreased with the use of gear ratios. This drivetrain is the strongest and most reliable. Because the assembly is all metal and everything interlocks with teeth, there most likely won't be any failures. The main disadvantage of this method is that it can be very heavy and difficult to design perfectly. [25]

Motors on combat robots are usually outrunner motors. These motors are very compact and powerful when compared to other motors. Outrunner motors consist of a stator with coils and a rotor with permanent magnets attached to a ring or sleeve. The UC Combat Robotics Club recommends using these motors. This is because they produce more torque for the same volume size compared to inrunner motors. Inrunner motors have magnets that are usually attached to a shaft that rotate on the inside of the starter coil. This system is not as powerful as outrunner motors. In addition, because of the setup of outrunner motors, the outside shell spins too so that gives the builder more possibilities to where they can attach belts. For the compact size and mechanical power needed, outrunner motors are great for combat robots. [26]

Hub motor wheels are an alternative method that combines the wheels and the motors to become one component. This eliminates extra mechanical parts needed for a motor tension assembly. This setup has a brushless motor inside of the wheel that rides on a shaft. These wheels are normally used on electric skateboards. A con of these is that the initial torque is not the most powerful but because they are intended for people standing on a skateboard and riding it at reasonable speeds, these hub motor wheels can easily drive a 12lb robot. The main advantage of these is they will save a lot of weight and money. In addition, repairing the drivetrain setup will then become as easy as sliding the wheel off and sliding on a new one. [27]

Jake drive is the last assembly that will be mentioned. This assembly was brought to our attention by the UC Combat Robotics Club. It implements a custom molded wheel that has a ring and sun gear part of its shape on the inside. The motor and its gear are then slid between the ring and sun gear teeth which then allow the motor to have direct contact with the wheel. This saves weight by reducing the volume of the wheel, belts or chains are not needed, and it eliminates the gear on the wheel that is used in other assemblies. The con of this setup is that it can be unreliable at times. This direct contact with the motors and wheels can make the robots travel at very fast speeds and it is more inclined to break.

End User

Our team will create and design a 12lb combat robot funded and sponsored by the University of Cincinnati. It will then later be put to the test in the 12lb weight class where our team will drive and fight the combat robot. The fight will be filmed and uploaded to the internet for future reference and interest. By these specifications, the end user is the BAKA BOT design team, the University of Cincinnati, combat robot hobbyists, and future University of Cincinnati Combat Robotics teams.

Summary of Research

Our team will be constructing a 12lb combat robot to take to the NHRL competition next spring on May 6th representing the UC Combat Robotics Club. The robot will be put in competition against several other robots in a tournament style competition consisting of 3-minute rounds. BAKA BOT must follow the 12lb regulations set by Norwalk and will be judged on several criteria. One of the most important aspects to winning is constructing a strong frame with armor for extra protection. There are several different mainstream frame designs used in professional competitions that have proven to be effective. These include the box frame, wedge frame, and spinner frame. Each frame also comes with its own armor material. Steel, aluminum, titanium, Lexan, UHMW are all common material types in the professional setting. While there are advantages and disadvantages to each frame design and armor option, it is worth exploring concepts from each aspect. The most likely option will be to create a hybrid of several materials and frame configurations for our final combat robot.

The weapon type that we decide to use will depend on our frame design of the robot. Since we’re competing in the 12lb combat robot at the Norwalk competition, the design, size, and weight of the weapon has to fit all the standards mentioned on the Appendices section of this document. Since most of the weight will be from the frame and armor, the options of material for the weapon are more limited. We can base our options for the weapon based on the performance during the BattleBots competitions and on the survey for current and past BattleBots competitors that we will be conducting later this semester. Based on the research and discussions with my team, the best approach is the vertical spindle weapon as it's not dense, less expensive to manufacture, and is potentially better performing than the *2022 UC's BattleBots Doomba's* weapon design.

The type of wheel setup and drivetrain assembly is very important in combat robotic competitions because being able to drive around means your robot is still alive. Reviewing all the pros and cons of everything, our team will be utilizing a 2-wheeled hub motor system. These were chosen because we have a 12lb weight limit. So only using 2 wheels will help us use more weight in the frame and weapon. In addition, we are using a single vertical spinner weapon. So similar to Nightmare mentioned before, the front of our robot needs space to be touching the ground to help with the reaction forces for when our robot hits another robot. In addition, hub motors were chosen because it's a very lightweight solution eliminating any additional assembly needed for a motor. Atom #94 (see *Figure 11* below) is a good example of the general setup our BAKA BOT will look like but with only one blade and hub motor wheels. [27]

Figure 11 – Atom #94 [27]

Quality Function Deployment

BAKA BOT created a customer survey to prioritize various features to maximize customer satisfaction. From the sample size of 41 responses gathered, the team created a House of Quality with the engineering characteristics ranked and weighted based on the results from the survey. Upon completing the House of Quality (shown below), the team was able to rank the product objectives for future research.

Customer Features

- Total Costs
- Ease of use
- Weapon Design
- Weapon Size
- Weapon Motor Speed
- Total Weight
- Maneuverability
- Cool Design
- Safety

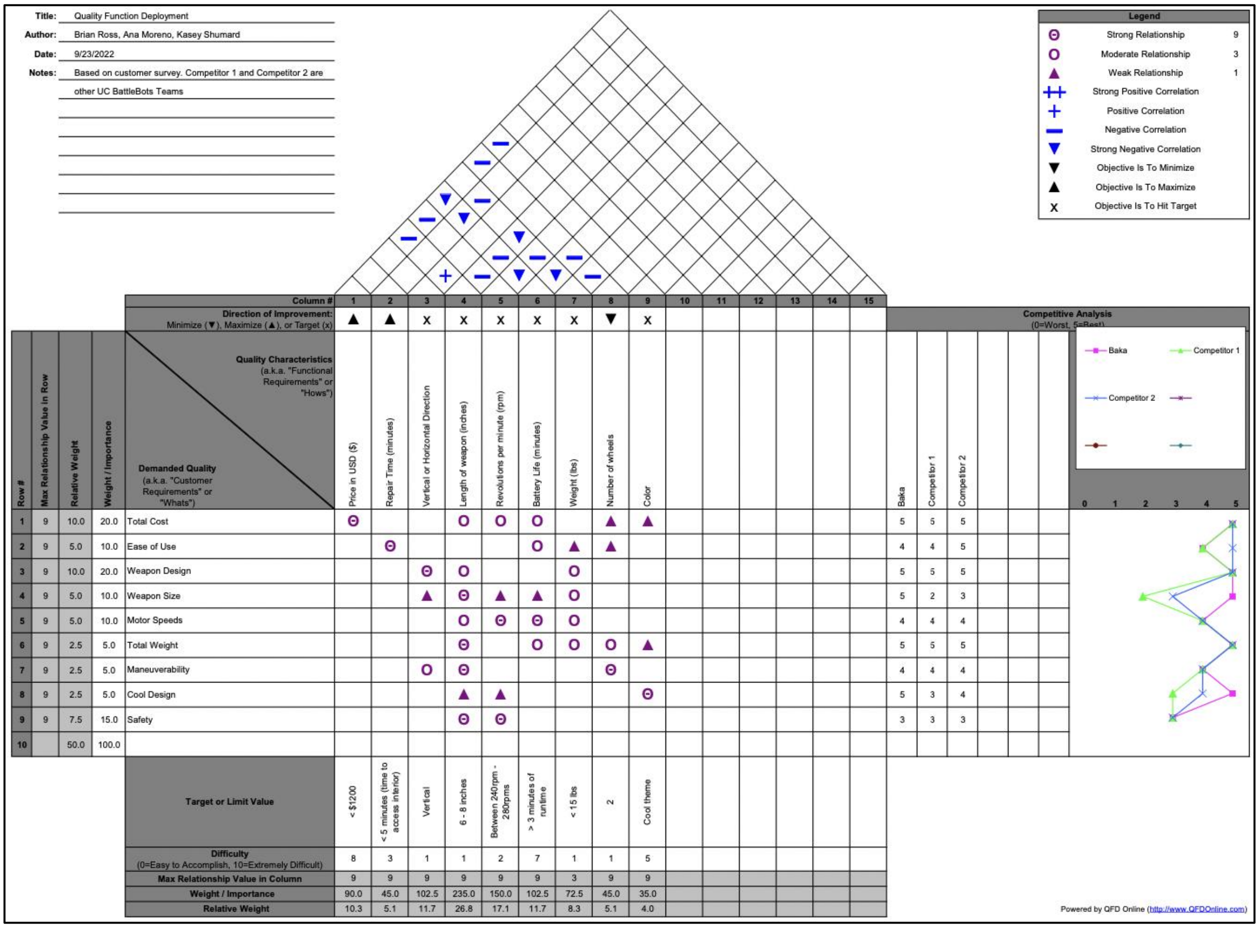
Engineering Characteristics

- Price in USD ($)
- Repair time (minutes)
- Vertical or horizontal direction (weapon)
- Length of the weapon
- Revolutions per minute (rpms)
- Battery life (minutes)
- Weight (pounds, lbs)
- Number of wheels
- Color/theme

Survey

Reference Appendix B (67) for survey template.

House of Quality



Title: Quality Function Deployment
Author: Brian Ross, Ana Moreno, Kasey Shumard
Date: 9/23/2022
Notes: Based on customer survey. Competitor 1 and Competitor 2 are other UC BattleBots Teams

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	

				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)					
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	x	x	x	x	x	▼	x												
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Price in USD ($)	Repair Time (minutes)	Vertical or Horizontal Direction	Length of weapon (inches)	Revolutions per minute (rpm)	Battery Life (minutes)	Weight (lbs)	Number of wheels	Color							Baka	Competitor 1	Competitor 2			
1	9	10.0	20.0	Total Cost	Θ			O	O	O		▲	▲							5	5	5			
2	9	5.0	10.0	Ease of Use		Θ				O	▲	▲								4	4	5			
3	9	10.0	20.0	Weapon Design			Θ	O			O									5	5	5			
4	9	5.0	10.0	Weapon Size			▲	Θ	▲	▲	O									5	2	3			
5	9	5.0	10.0	Motor Speeds				O	Θ	Θ	O									4	4	4			
6	9	2.5	5.0	Total Weight				Θ		O	O	O	▲							5	5	5			
7	9	2.5	5.0	Maneuverability			O	Θ				Θ								4	4	4			
8	9	2.5	5.0	Cool Design				▲	▲				Θ							5	3	4			
9	9	7.5	15.0	Safety				Θ	Θ											3	3	3			
10		50.0	100.0																						
				Target or Limit Value	< $1200	< 5 minutes (time to access interior)	Vertical	6 - 8 inches	Between 240rpm - 280rpms	> 3 minutes of runtime	< 15 lbs	2	Cool theme												
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	8	3	1	1	2	7	1	1	5												
				Max Relationship Value in Column	9	9	9	9	9	9	3	9	9												
				Weight / Importance	90.0	45.0	102.5	235.0	150.0	102.5	72.5	45.0	35.0												
				Relative Weight	10.3	5.1	11.7	26.8	17.1	11.7	8.3	5.1	4.0												

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

Figure 12 – House of Quality

Product Objectives

Scores are retrieved from the House of Quality. See *Figure 12* for more details.

1. Length of Weapon, 26.8
2. Revolutions per minute (RPM), 17.1
3. Vertical or Horizontal Direction, 11.7
4. Battery Life (minutes), 11.7
5. Price in USD ($), 10.3
6. Weight (lbs), 8.3
7. Repair Time (minutes), 5.1
8. Number of wheels (#), 5.1
9. Color, 4.0

Design Concepts

Three frame and armor concepts were 3D modeled based on the research in engineering characteristics, state of the art, and HOQ results. These concepts will help us determine the type of robot to finalize, develop, and eventually take to competition. They may not be the eventual production style robot but will help us gauge the one we want to go with.

Design 1: Wedge Frame

Our first concept is a wedge frame. Sitting at about 25 degrees, the ramp is meant to flip the opponent over rendering their entire robot useless. The overall length of the robot sits around 13 inches with the ramp taking up 7 inches of that space. It is 10 inches wide to cover a large area and to be able to incase the wheels behind a layer of shock loaded UHMW. This also leaves enough room for large wheels, electronics, and drivetrain motors. At only 3 inches in height, the compactness of the design should allow for our robot to easily bully other taller robots. A thin layer of clear plastic will then secure on top with screws for easy access to parts. The ramp will likely be made of hollowed-out steel, while the structure of the frame will be made of aluminum 6061. Due to the simplicity of the frame, the driver should have an easier time attacking the opponent while maintaining a safe defense from any side.

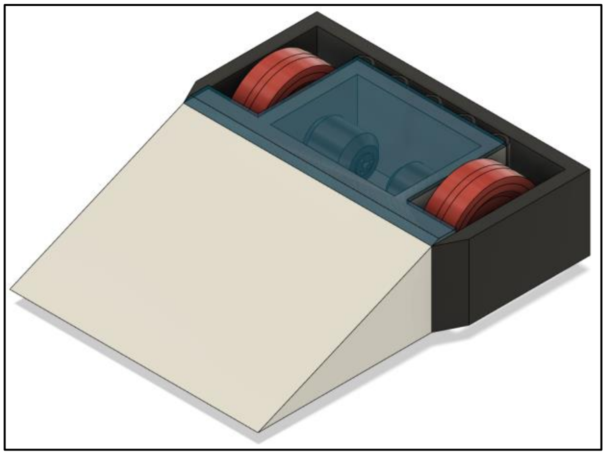


Figure 13 – Wedge Concept

Design 2: Box Frame with Drum Spinner

Our second concept design is a box frame equipped with a drum spinner. Equipped with 4 wheels, this concept should be able to move very quickly. There is one motor on each side driving a pulley system to act as the driving force for the wheels. There is then an internal motor near the front with a cutout space for another pulley to drive the weapon. Since the drum spinner is likely to made out of hollowed steel, it will act as not only a large weapon but an extremely strong shield. Like concept one, there will be a thin layer of plastic held in with screws for easy access to the electronics on the interior. The main weak area of this design is the back of it. There is nothing to defend itself from the rear so the driver should be aware of this and have plenty of practice maneuvering the robot before the competition.

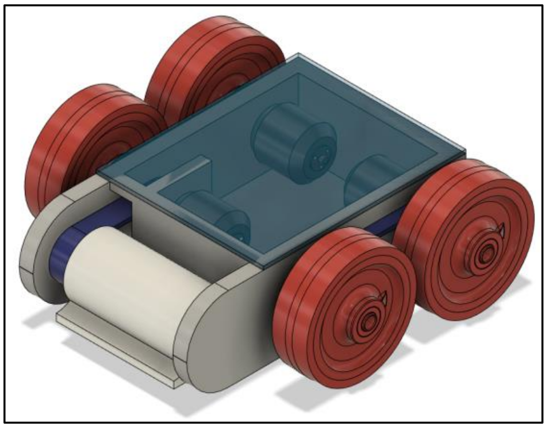


Figure 14 – Box Concept

Design 3: Hybrid (Box with Wedge)

Our third design is a hybrid of the first two concepts with space equipped with a vertical spinner. Sitting at nearly 12 inches wide and 10 inches in depth, this concept should act like a tank, slowly moving toward the target with the weapon constantly faced towards the opponent. It has space for direct drive motors on either side in a compact area. The main weapon shaft is driven by a pulley and belt to keep the fragile parts of the weapon concealed from any outside force. The weapon will be made out of steel and the frame out of aluminum 6061. With wedges on both sides of the robot, the driver can approach the opponent from either side and deal large blows to their robot. However, the side is extremely weak, so the driver needs to be cautious in their approaches to the opponent.

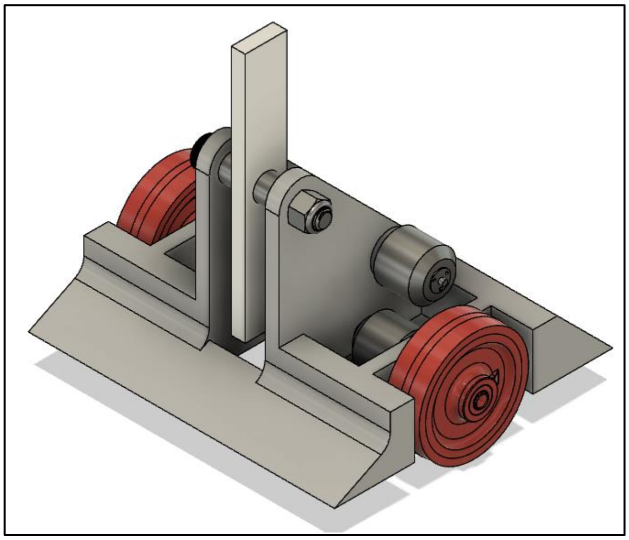


Figure 15 – Hybrid Concept

Design 4: Weapon Concept 1

In this concept, the weapon can be for vertical or horizontal position. However, this design is targeted as a vertical weapon. The weapon has a length of 8 inches and thickness of 0.5 inches. The weapon has extrusions that allow the driver to hit the opponents hard without sacrificing damage to the blade. The blunt endpoints are on both extremes of the weapon because if the robot gets flipped over, we still want the weapon to be able to deliver a blow. The weapon has a 3/4-inch shaft that connects to a bronze sleeve bearing. The bearing is fixed with two different hubs that go on each side of the weapon. Both hubs are secured by socket head screws and locknuts. Next to one of the hubs, a timing belt pulley is attached to the bearing. The purpose of the belt pulley is to connect to the belt and weapon motor, so that the weapon can freely rotate.

This concept is inexpensive but could be potentially difficult to manufacture, as there are 3 holes and sharp extrusions. The disadvantages of this design will be making sure that the CNC or water jet program is perfect so that there are not multiple trials of creating this part. Creating sharp corners on the inside of the weapon as on the ends can be complicated. It also does not have an aggressive rake angle so impacts may not be able to dig into the opponent’s armor.

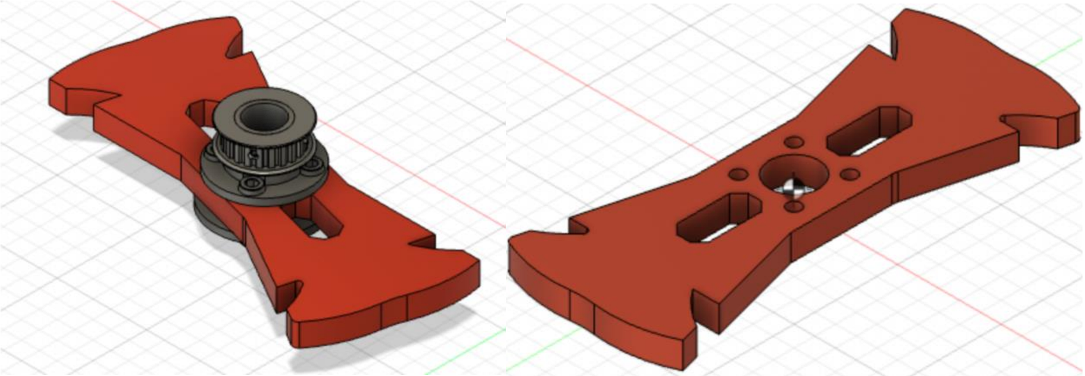


Figure 16 – Weapon Concept 1

Design 5: Weapon Concept 2

In this concept, the weapon's design is for a horizontal weapon robot. The weapon design is based on a circle with 2 ends for optimal hit. This design has various drawbacks as it's a horizontal weapon. Based on the customer surveys and communication with UC Combat Robotics Club, our BAKA BOT team will look into vertical weapon designs only. The diameter of this weapon is 10 inches, which is longer than concept 1. The design is unexpensive and easy to manufacture but doesn't have the final qualities we are looking for.

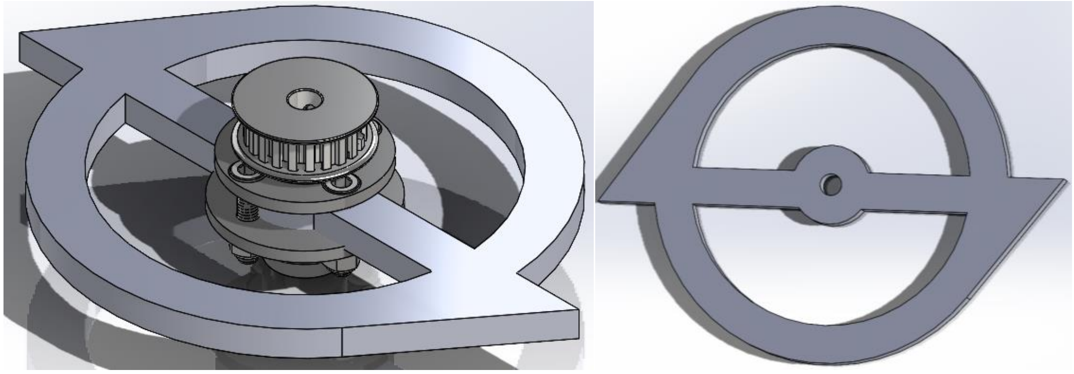


Figure 17 – Weapon Concept 2

Design 6: Weapon Concept 3

This concept is targeted for a vertical weapon direction, but it can be used for horizontal direction too. This concept is more expensive than concept 1 and 2 due to the complex geometry it could be difficult to manufacture. The disadvantages of this design will be ensuring that the manufactured part matches the CAD model. Furthermore, since this weapon has such an aggressive rake angle, it will take an extreme amount of damage during the battle and will most likely chip and or break.

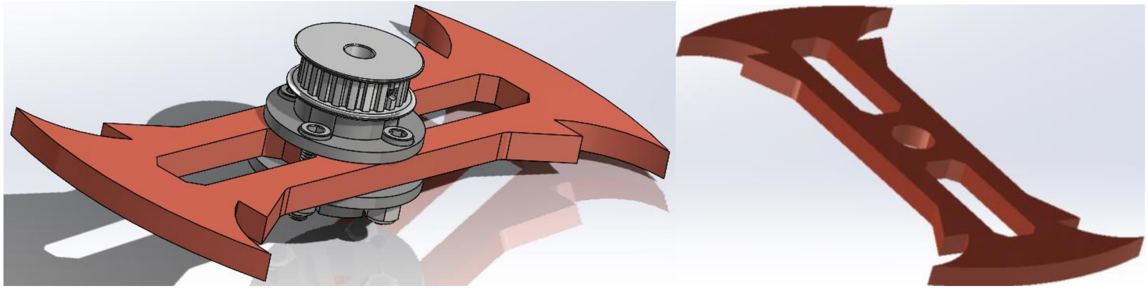


Figure 18 – Weapon Concept 3

Design 7: Drivetrain Concept 1 – Hub Motors

Figure 19 below shows hub motor wheels and how simple they are. For this drivetrain assembly, all that is needed is a shaft (exactly the same size as the shaft on the truck of a skateboard) to mount the wheels on. Then all you need to do is secure the wheels down and plug it into an esc and battery.

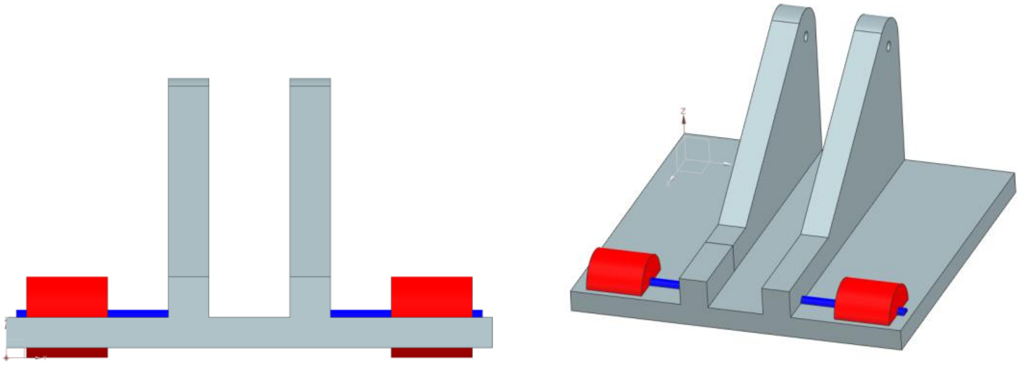


Figure 19 – Hub Motors Visual – Back and 3D View

Design 8: Drivetrain Concept 2 – Belt/Chain Drive

Figure 20 below shows the assembly of what a belt or chain drivetrain would look like. The red cylinders are the wheels, the green cylinders are the motors, the blue cylinders are the shafts for the wheels to ride on, and the black cylinders are the gears for the belts or chains (not shown) to drive on. In addition, there will need to be a tensioner added to the assembly (not shown). This is needed to make the chain or belt tight. This could be avoided by having the motor move in the horizontal direction and the user can pull the motor back to tighten the belt or chain.

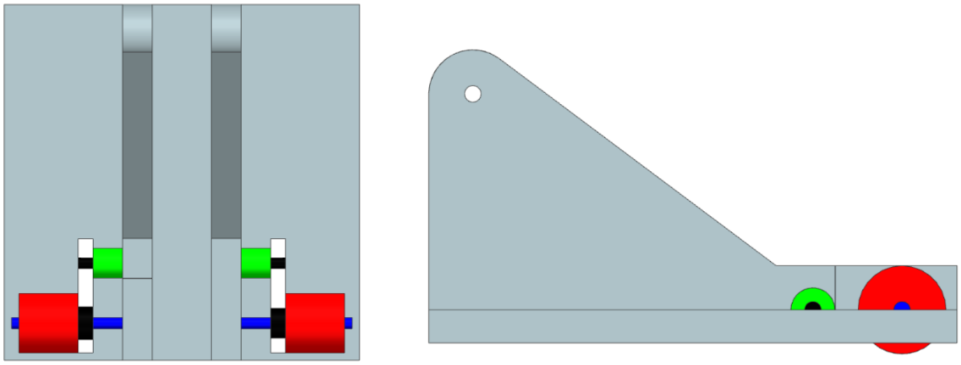


Figure 20 – Belt/Chain Drive Visual – Top and Side View

Design 9: Drivetrain Concept 3 – Gear Drive

Figure 21 below shows the drivetrain setup of a gear assembly. The red cylinders are the wheels, the green cylinders are the motors, the blue cylinders are the shafts for the wheels to ride on, the black cylinders are the gears attached to the wheels, and the purple cylinder is the gear attached to the motor. The two gears interlock each other with their teeth. This eliminates the belt or chain mentioned in concept 2.

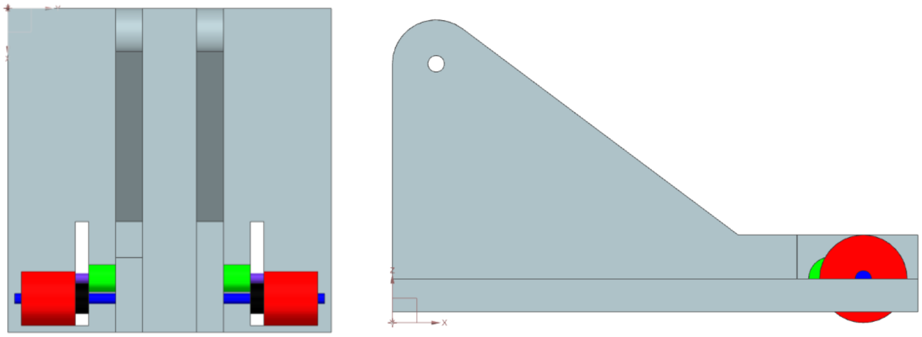


Figure 21 – Gear Drive Visual – Top and Side View

Design 10: Drivetrain Concept 4 – Jake Drive

Figure 22 below shows Jake drive, a unique kind of drivetrain. This assembly was brought to our attention by the UC Robotics Club. Essentially it uses a custom molded wheel that has a ring and sun gear teeth on the inside of the wheel (teeth not shown). This then allows the motor shaft gear to be inputted into the wheel and spin the wheel directly. This eliminates volume of the wheel, the wheel gear, and any belts or chains. This assembly is very lightweight and is highly reccomended by the UC Combat Robotics Club.

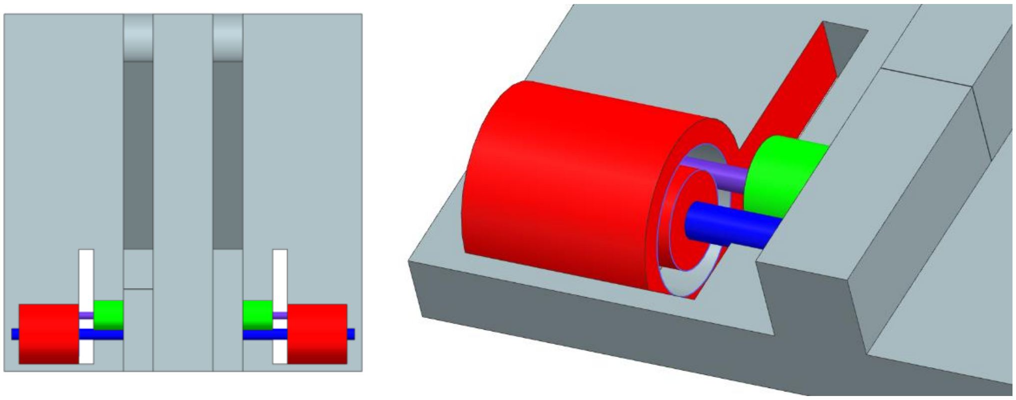


Figure 22 – Jake Drive Visual – Top and 3D View

Final Frame Design

Our final frame assembly consists of several types of materials and fastening. It was also designed to be able to work on its top and bottom in case it gets flipped over. The compartment is made from aluminum 6061. All these parts will then be welded together to create a secure and strong base for our electronics to be stored in.

The uprights and corner armor will be made from UHMW. This material is a sturdy and lightweight option even when compared to aluminum. Previously our uprights weighed near 2000 grams with aluminum but now with UHMW they weigh only 400 grams. An 80% weight reduction. UHMW is also very flexible and has a large elastic region meaning it will most likely not permanently deform under a high impact load. This is perfect for our application of combat robotics. The uprights will then be keyed into our aluminum compartment and secured using mounting brackets with locknuts and nuts.

The last material we are using is thermoplastic polyurethane (TPU). We can use this material in 3D printers and due to the soft nature of the material we can create a hinge cover for the back of our compartment. This creates easy access to our electronics to swap our batteries and make sure all the electronics are connected as we want.

All parts except the TPU hinge cover and the armor will be manufactured by a company called Send Cut Send. They have the capabilities to create all of the parts we need to assemble our robot frame. It is a cheap alternative with quick turnarounds on all of our parts. The only thing our team will have to do is tap a few holes, so the thread is in the correct orientation. The

TPU hinge cover will be 3D printed either at the Innovation Hub or on a personal 3D printer. Finally, the armor will be ordered and manufactured by our own team. We can order it as a flat sheet and create a plywood mold for the geometry we designed. By heating up the material it becomes very flexible so we can pound the heated UHMW into the mold with a mallet.

Figure 23 – Final Frame Design ISO Front and Back

Final Weapon Design

Our final weapon design consists of a 3/8” AR500 steel weapon with a 9” overall diameter. It will also be manufactured through Send Cut Send, to save time and money in manufacturing costs. This also allows for high precision and accuracy in our part. We chose AR500 because it is highly durable and resistant as it’s made of the same material as bulletproof armor. AR500 is also extremely common in the sport. It will be able to deal damage and retain its shape while attacking opponents. The vertical weapon will be driven by one 970Kv brushless motor and a belt pulley. With a 6s LiPo battery, our motor will run a tip speed of 192 mph. For this, our gear ratio is 3:1 with a designed MOI of 3180000 g/mm^2. All parts will be pressed onto a brass bushing to allow for free spinning motion. Calculations can be found in Appendix C (70).

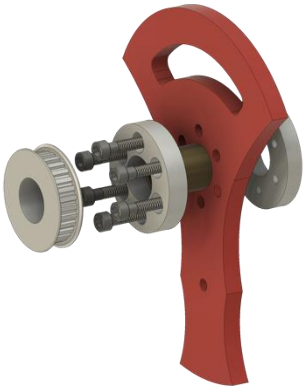


Figure 24 - Final Weapon Assembly

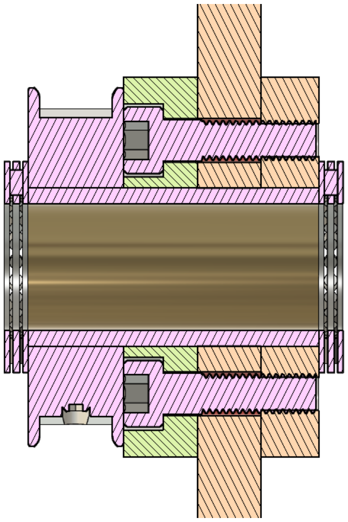


Figure 25 – Final Weapon Cross Sectional View

Final Drivetrain Selection

After reviewing the concepts, we considered using for the drivetrain, we decided to go with the electric skateboard hub motor wheels. Two of these wheels will be placed in the back of our BAKA BOT. The unique reason why we chose this drivetrain is because of how durable they are being skateboard wheels and the resulting simplicity that the drivetrain assembly becomes. If a wheel brakes during a match, the maintenance repair steps become as easy as taking off broken wheel, sliding on and screwing down the new wheel, plugging it in, and we are ready to go. In addition, the wheels having hub motors help us save space within our main back compartment for the other electronics.

Important specifications of the wheels are that they have a max speed of 1600 RPMs, weigh 1.41 lbs, have maximum current of 12 amps, are made of polyurethane and stainless steel, and have a diameter of 2.76 inches. As seen in our calculations in Appendix C (70), the maximum linear velocity will be 13.12 mph and the frictional torque is 14.9 in-lb per wheel. This is more than enough speed/power to propel our

12lb BAKA BOT around. The ESCs chosen for each wheel will be utilized to manage the speed control with our main remote control.

To use the wheels on our frame, we will be manufacturing a steel locking part. This steel locking part will be on the bolt for the wheel that slides into the square cutout on the side of the wheel (see *Figure 26* as a reference). Using this part is necessary because it will help lock down the middle cylindrical component (the hub motor) to allow the outer component (the actual wheel) to spin.

Figure 26 – Wheel Assembly Including the Steel Locking Part

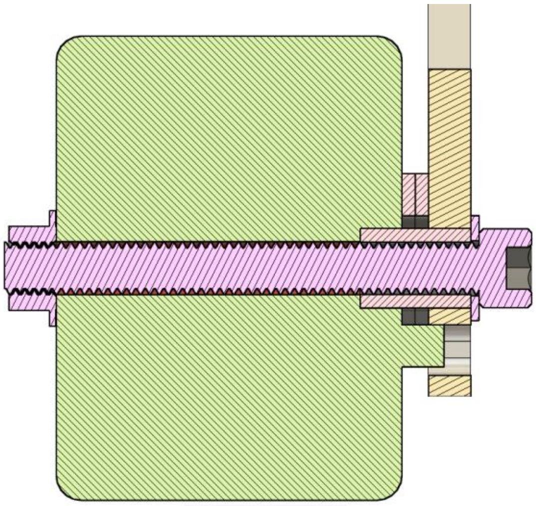


Figure 27 – Wheel Assembly Cross Sectional View

Final Electronics Selection

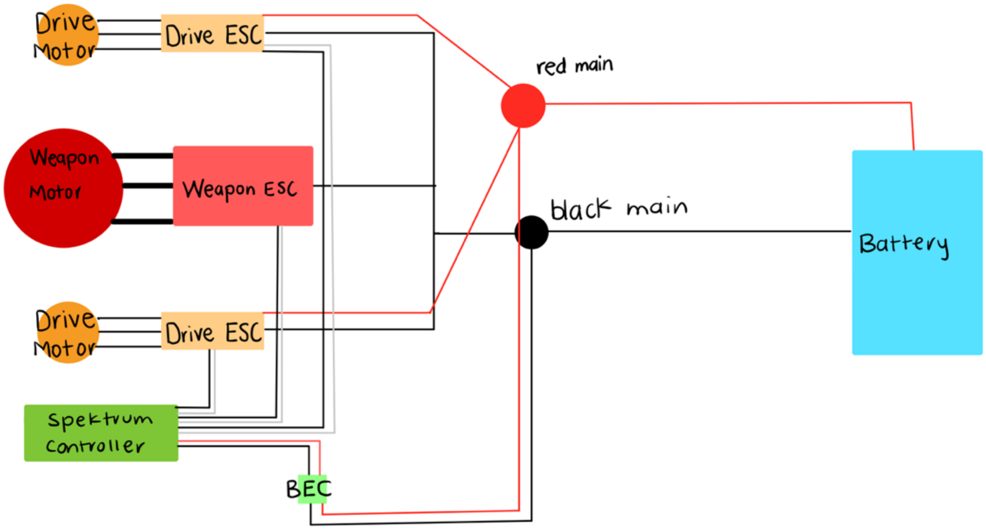


Figure 28 – Wiring Diagram

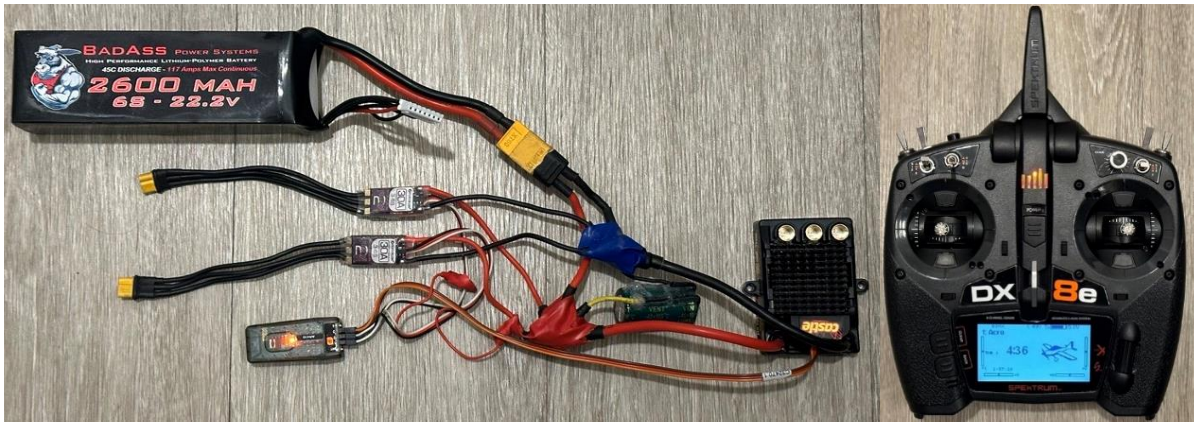


Figure 29 – Connected electronics along with the remote transmitter that will be used to control BAKA Bot.

The weapon system for our robot includes one 970kV Brushless Motor equipped with its own Castle Sidewinder 25.2V ESC. The drivetrain system includes two hub motors with their own drive, Flycolor 30A ESCs. Both systems are powered by a 2600 mAh 6s LiPo battery that will be connected to a specktrum controller and back to the Castle Sidewinder BEC to control BAKA BOT's movement. See *Figure 28* above for a visual map of how everything is connected.

Model Assembly

Fusion estimates BAKA BOT to currently weigh 11.7 lbs without wiring and connectors. In which the missing 0.3 lbs will be taken up by these wires and connectors. We are under the 12lb weight limit for the competition. After assembling the robot in the future, weight will be further manipulated to make BAKA BOT combat ready. Our team made a laser cut wooden model at the 1819 Innovation Hub using the files of our 3D CAD model to ensure everything fits together (see *Figure 30* below). The model fit together perfectly so we are confident with the further steps of getting everything manufactured. In addition, this model shows the actual size of BAKA BOT and verifies that it fits in the required size limit of a 36-inch cube.

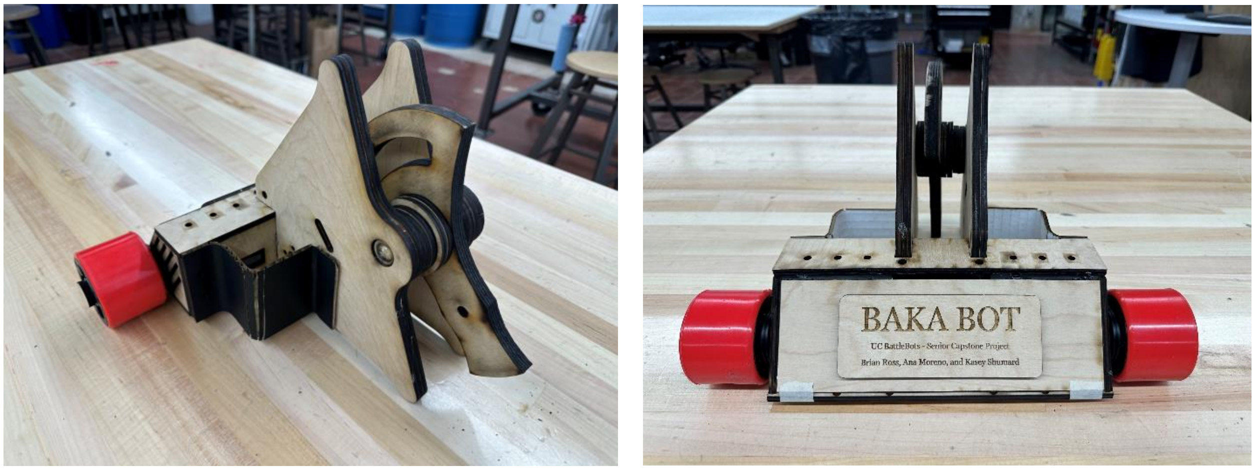


Figure 30 – Proof of Concept: Wooden Model

Safety Factors

To determine the safety factors of our design, we simulated forces on our armor, weapon, and the vertical uprights. These are the front faces components that are most likely to get hit. Looking at the figures below, there are little to no red areas. For the weapon, per our FEA analysis below in *Figure 31*, our weapon will only see minor chipping. This chipping does not represent a functional failure. For a failure, the weapon would have to bend 5/8th inches perpendicularly and hit one of the uprights which is very unlikely being that it’s made of AR500 steel. With all this in mind, our design has a lot of promise with staying intact after future hits during competition.

It should be noted that with the chaotic nature of combat robotics, our safety factor is extremely unpredictable. The infinite possibilities of weapon types, speeds, impact locations, and frame designs, the opponents we face can deliver an infinite range of impact types. So, the safety factor calculations below are values from a simple simulation of a generic hit or load on our parts.

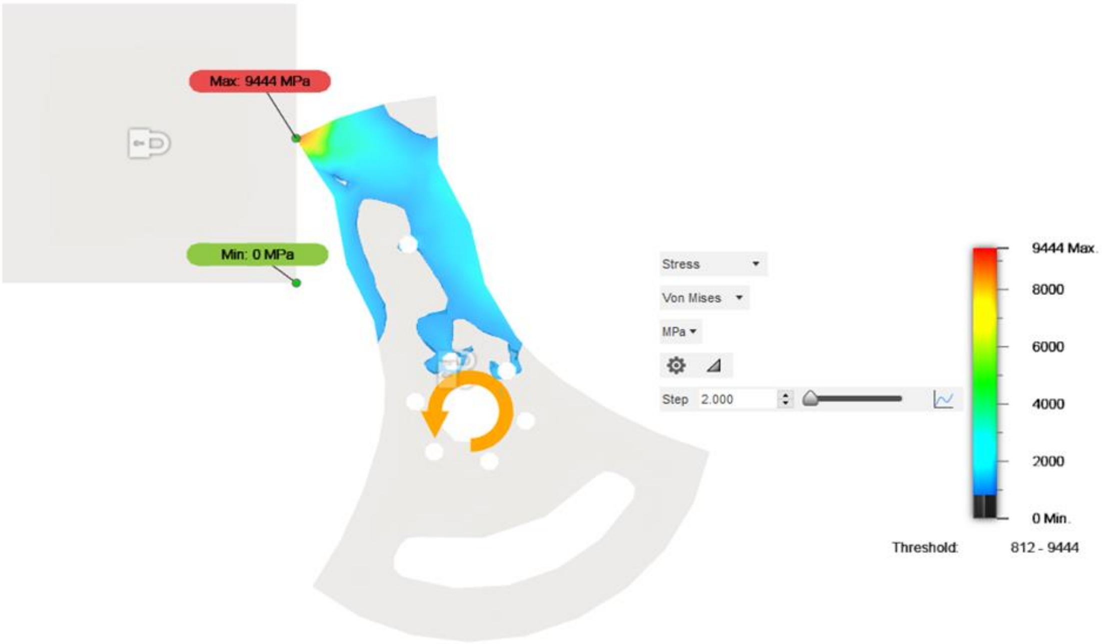
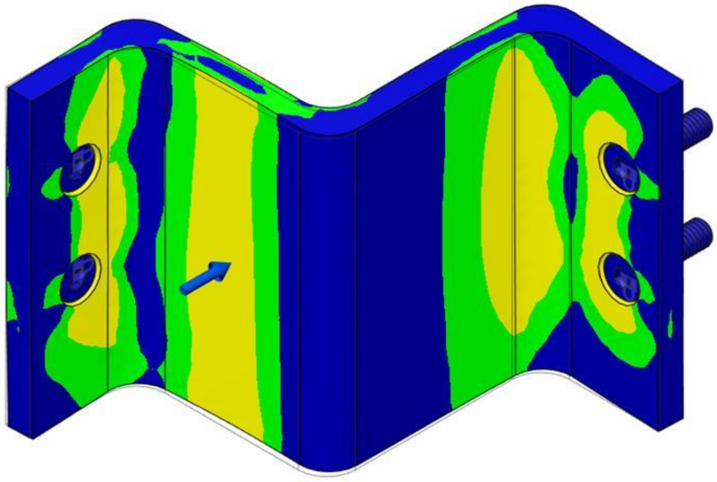


Figure 31 – Weapon FEA Analysis Showing an Impact at its Top Speed

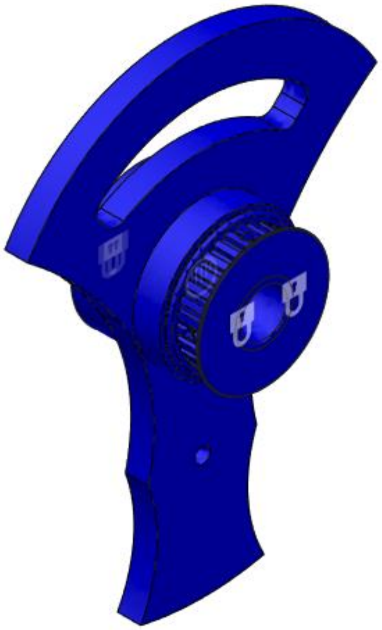


1000 N Load

Min safety factor = 2

Max safety factor = 15

Figure 32 – Safety Factor Impact Test of the Armor



1000 N Bearing Load

Safety factor = 15+

Figure 33 – Safety Factor Load Test on the Weapon Bearing

Component Fabrication

As previously mentioned, most of our parts were sent out for professional manufacturing to ensure high quality parts. It helped save our group time, money, quality, and any potential mishaps from our own manufacturing. These parts include the weapon, the UHMW uprights, all chassis aluminum components, and wheel spikes.

However, there are still parts that were too complicated or were unable to be made by send cut send and will be reviewed here. The parts created or modified include both weapon hubs, drivetrain square spacers, drivetrain custom washers, UHMW armor including mold, TPU hinge cover, lengthened weapon motor shaft, both weapon pulleys, and custom weapon forks. All relevant engineering drawings can be found in Appendix F (84).

Frame Machining

From the parts that we sent out for production, none of them had to be machined by our team. Everything was done professionally. The only thing we needed to do was weld the aluminum 6061 together to assemble our metallic compartment. Due to the aluminums high thermal conductivity, tough oxidized layer, and tendancy for burn through we looked to professional help. An experienced machinist walked us through prep work, different welding seam options, and set up.

To start we cleaned the outer layer of the aluminum with sandpaper and Acetone to get rid of the outside oxidized layer of the aluminum. This helps provide a cleaner and stronger weld. Once all of the aluminum was cleaned and prepped, Mr. Cokley walked us through how he planned on welding the compartment together. Once the plan was established, we down the initial set up for welding. Before the TIG welder was even turned on, we used a torch to eliminate the moisture from the aluminum. Moisture in a weld can cause hydrogen to be absorbed into the weld metal ultimately reducing the welds strength and potentially causing a failure. Finally, Mr. Cokley welded the final product together while showing us exactly how to do so. The welding process took an entire weekend to complete and we couldn’t be happier with the result.

Figure 34 – Sanding down the oxide layer

Figure 35 – Cleaning parts with Acetone

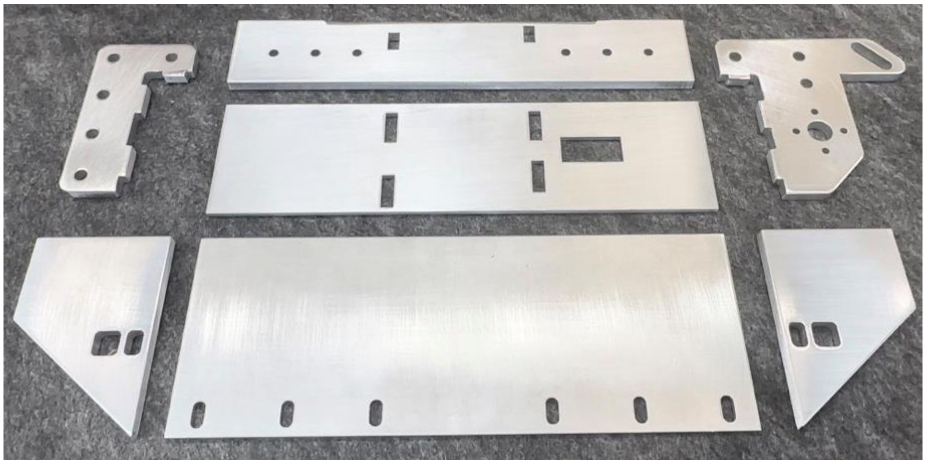


Figure 36 – Cleaned parts

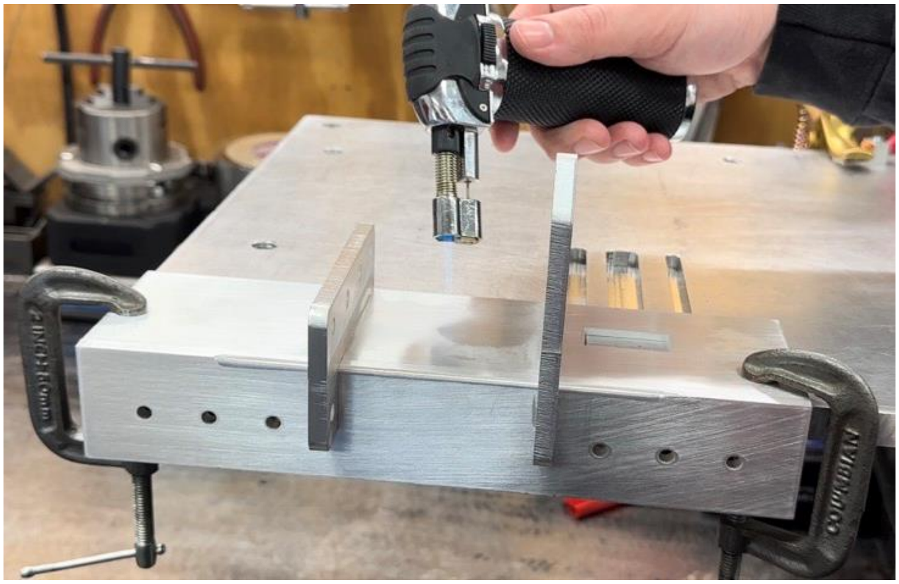


Figure 37 – Removing moisture

Figure 38 – TIG welding

Figure 39 – Clamped setup to ensure no offsetting during the welding.

Figure 40 – Final product

Drivetrain Machining

For the most part our drivetrain design was plug and play. We expected to be able to machine one part (square spacer) and drive perfectly. However, after testing the drivetrain when installed on the frame of our robot, we realized we needed to create some custom washers to fit onto the hub of our wheels but around the wiring connecting to the electronics. Both parts were manufactured at the victory parkway campus.

There were several steps to creating the square spacer necessary to operate our drivetrain. Using a mill, we took a piece of 0.5” x 0.5” square steel stock and machined down the edges to match the inner dimensions of the wheel square. We then stood the stock up on its long edge to drill a 5/16” hole down the entire piece. Then we cut our part per length on the horizontal band saw. Finally, using the belt grinder, we rounded the edges and made it a perfect fit.

The custom washers were relatively easy to produce. We bought standard washers with the correct outer diameter of 1.25”. At victory parkway, we then punched the correct inner diameter of 0.625” on the center of the standard washers. Finally, we used a vertical band saw to cut out a section of the washer to make room for the wire.

Figure 41 – Milling outer edge for correct width/height and to ensure it’s perfectly flat.

Figure 42 – Drilling 5/16" hole

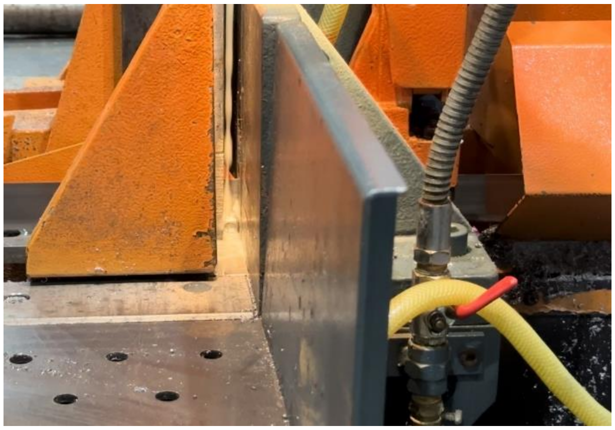


Figure 43 – Cutting stock to length

Figure 44 – Rounding the edges

Figure 45 – Punching washer for correct ID before cutting on the vertical band saw.

Weapon Assembly Machining

Manufacturing parts for our weapon assembly was our biggest task. It had the most parts with the most complexity. We machined a brass bushing, two pulleys, and two weapon hubs from scratch.

To create the weapon hubs, we used cylindrical aluminum stock with an outer diameter of 2.25". On the lathe, we drilled and reamed a 15/16" hole to be able to fit onto the brass bushing. Then, using the CNC mill, we programmed the mill to drill press six M6 clearance holes the entire length of the cylindrical stock at a 1.5" diameter. Keeping the same programming, we drill pressed counter bores into the same side to create room for the screw heads. Afterwards, we used a tapping bit to create threads for a secure connection when assembled. Finally, we took the part back to the lathe and cut sections to the correct lengths.

Our other main components (pulleys and bushing) were simpler to make as they only required one process per part. Our pulleys both were drilled out using the lathe to match the correct diameter of the shaft/bolt they were attached to. The small pulley to 5mm and the large pulley to 15/16". We had to use metric on our small pulley due to the preassembled weapon motor using metric units. For the bushing, we used the lathe to cut it down to the correct length. It came in a stock size of 2" and we machined it down to 1.72".

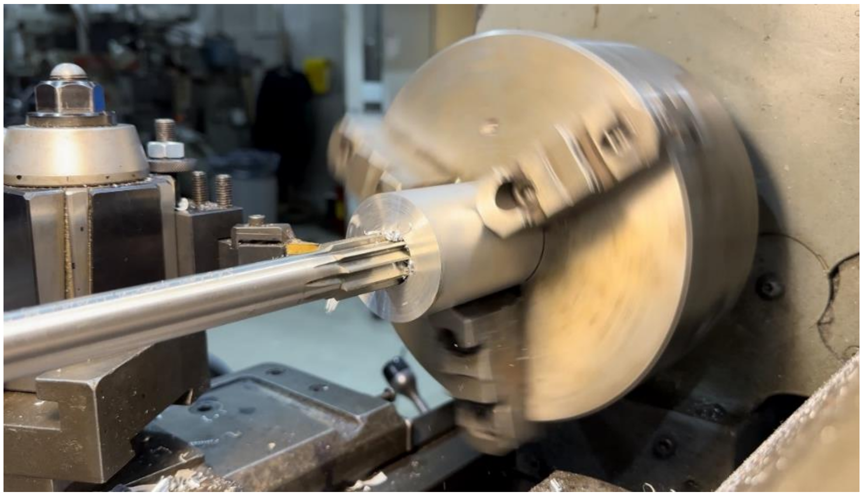


Figure 46 – Drilling out and reaming 15/16” Hole

Figure 47 – CNC drill pressing screw holes and counterboring for screw heads

Figure 48 – Tapping for M6 Screws

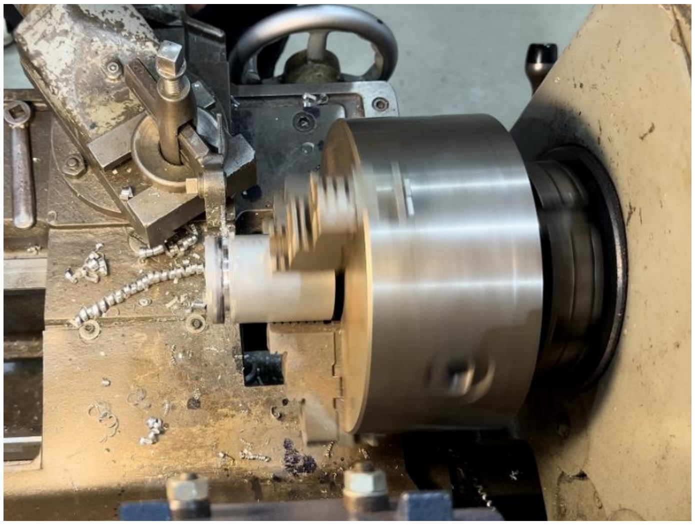


Figure 49 – Cutting hubs to designed length

Figure 50 – Drilling on lathe for correct ID on pulleys

Figure 51 – Final press fit assembly

Soldering the Electronics System

Our team utilized the soldering table at the 1819 Ground Floor Makerspace to solder all our electronics. This process only took one day. The drivetrain ESCs and the hub motor wheels all needed new connectors/plugs. The weapon ESC and weapon motor needed new connectors as well. Once everything was soldered and had the correct connectors/plugs, BAKA BOT is now capable of operation.

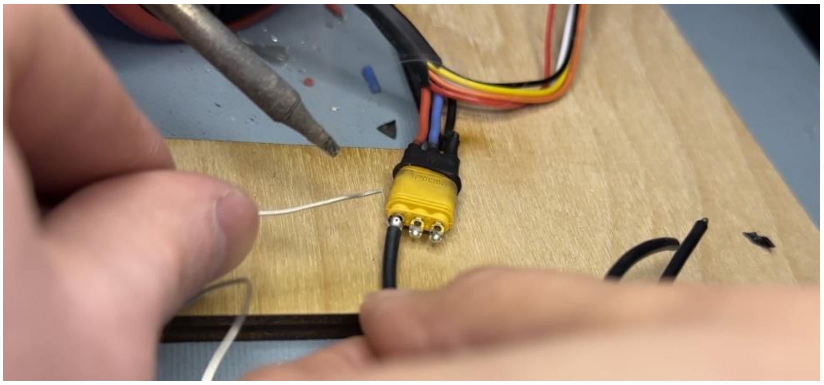


Figure 52 – Soldering example showing the wheel to ESC male/female connectors.

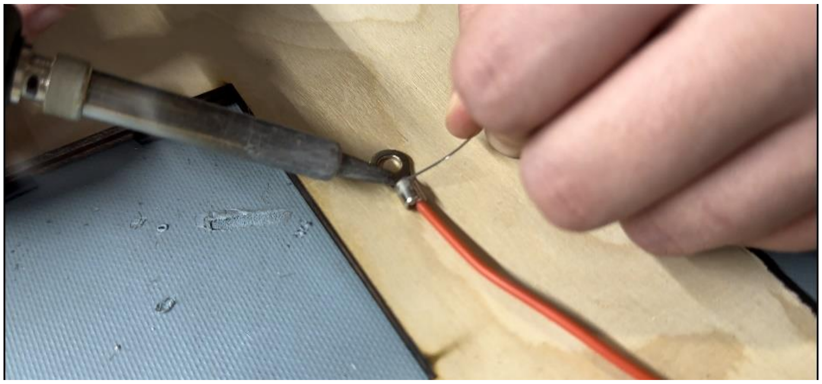


Figure 53 – Soldering example showing the addition of eyelet connectors.

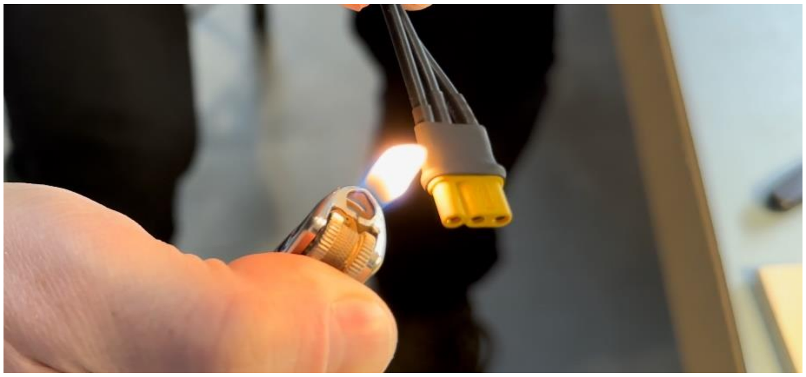


Figure 54 – Heat shrinks were used to ensure strength and safety within the system.

Other Fabrication

Our last fabricated parts include our armor/armor mold, our extended weapon motor shaft, and the upright forks. To protect our motor, we needed to mold UHMW armor to fit around the outside of the motor. We exported DXF files from fusion to import into the computers at the 1819 Ground Floor Makerspace to create laser cut layers for our mold. We then used pins to align all of the layers and glue them together with wood glue. Once the glue was done drying, we took the UHMW stock we had and placed it in an oven at 260 degrees Fahrenheit for an hour. The melting point for UHMW is 270 degrees. So, we purposely made the material as close to a liquid without becoming one, so it was easily formed in the mold. We were able to easily push and clamp it into the mold as seen below in *Figure 57/58*. After about 10 minutes in the mold, we took our newly formed armor over to VPC. Finally, we used the vertical band saw to cut off the excess material and drilled holes for mounting. See *Figures 55 – 59* below for reference.

The weapon motor shaft on the ordered motor was too short for our assembly requirements. Therefore, we had to take apart the brushless motor and swap out the stock shaft for a longer one. The shaft we used was a 4140 hardened steel with a length of 89.5 millimeters overall, which was perfect for our application (see *Figure 60*). A dremel was used to shave down flat spots for the set screws within the motor and pulley.

The last part we created was our handcrafted weapon forks (see *Figure 61*). These polycarbonate spring loaded forks were hand cut on the vertical band saw and drill pressed. The forks allow us to ram into our opponent and scoop them off the ground into our weapon.

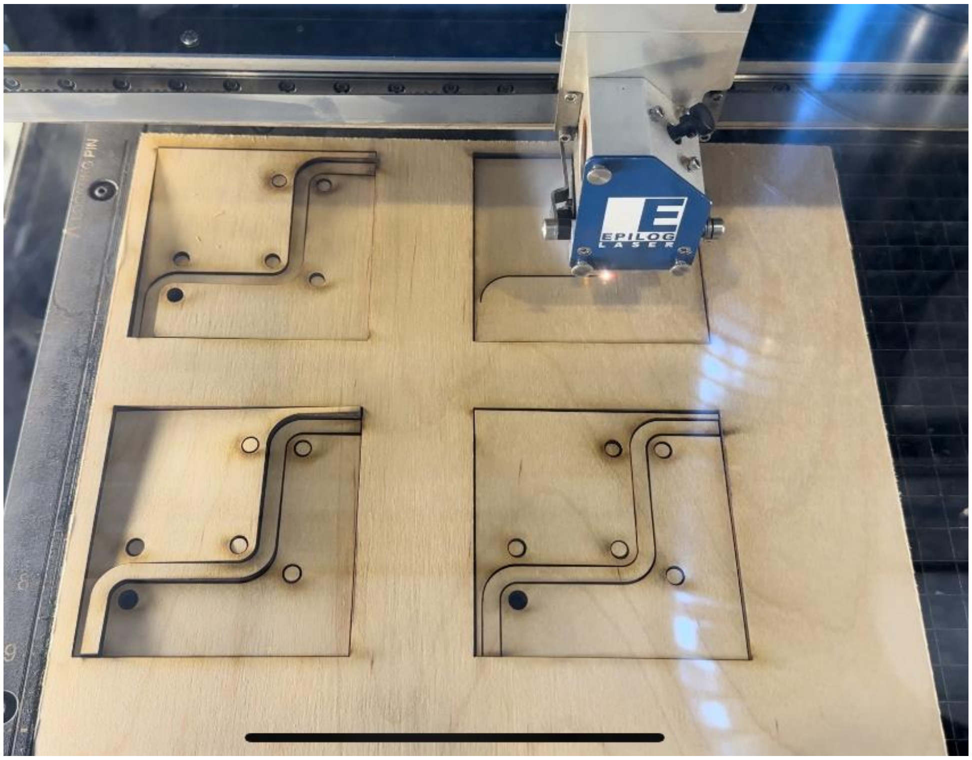


Figure 55 – Laser cutting mold layers

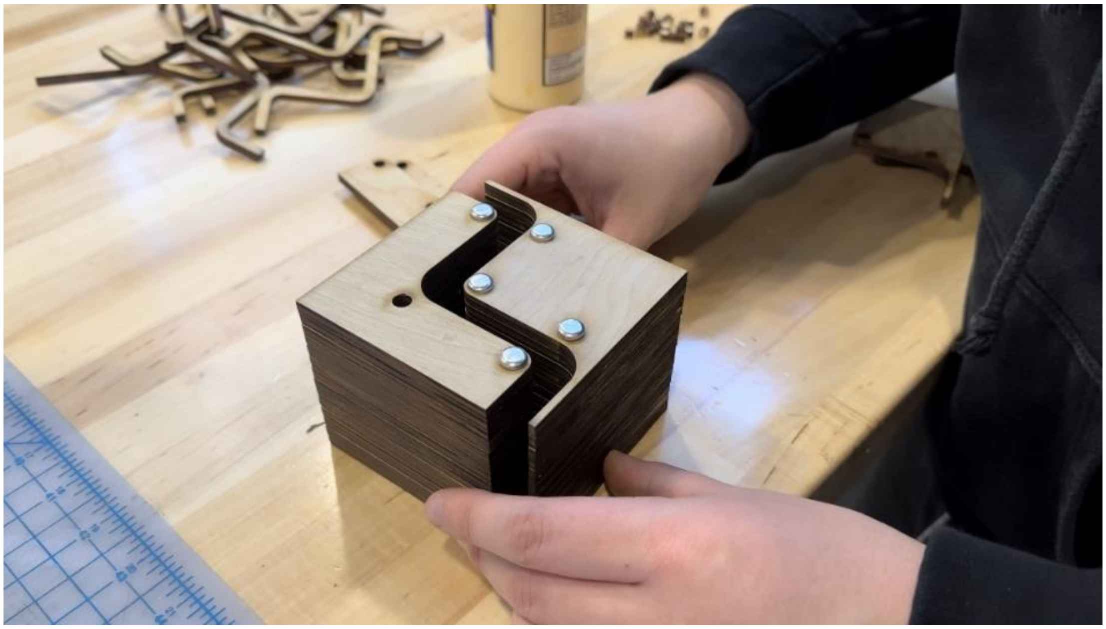


Figure 56 – Assembled mold

Figure 57 – Pressing UHMW to desired shape at 10 degrees below its melting point.

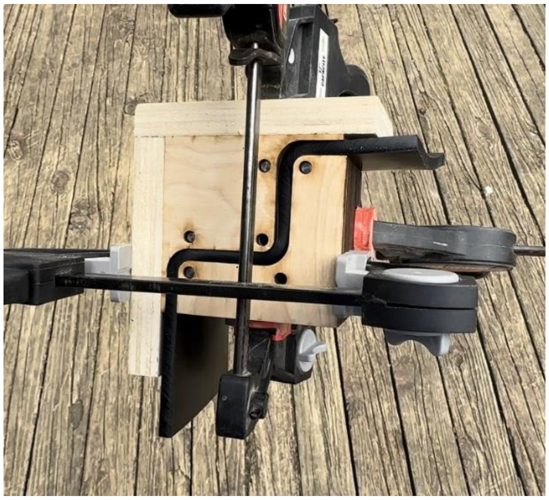


Figure 58 – Clamped UHMW for cooling

Figure 59 – Cutting off excess material before drill pressing holes for connection points with the uprights and chassis.

Figure 60 – Extended weapon motor shaft

Figure 61 – Hand cut polycarbonate forks using a vertical band saw and drill press.

Assembly Steps and Process

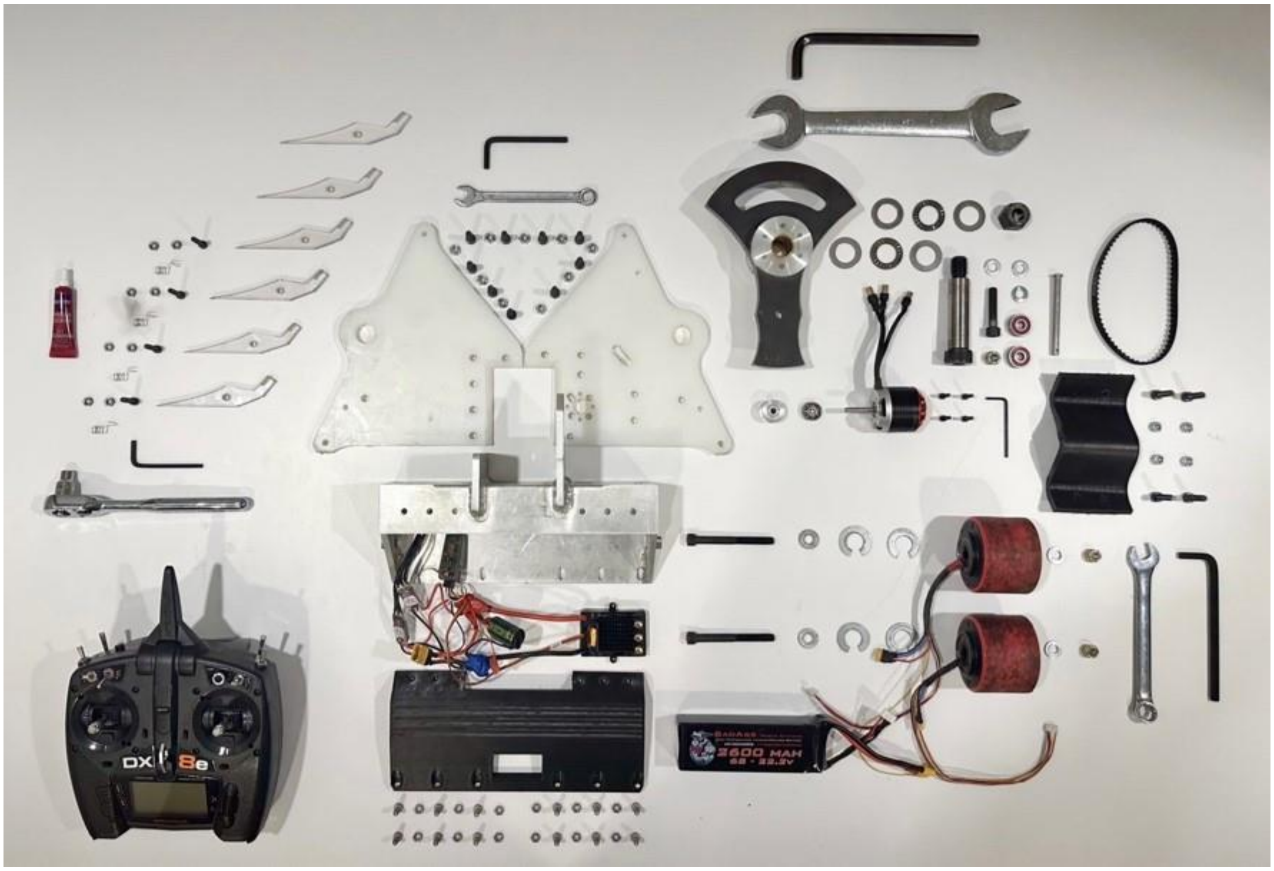


Figure 62 – Step 0: Layout of all the parts/tools needed for BAKA BOT.

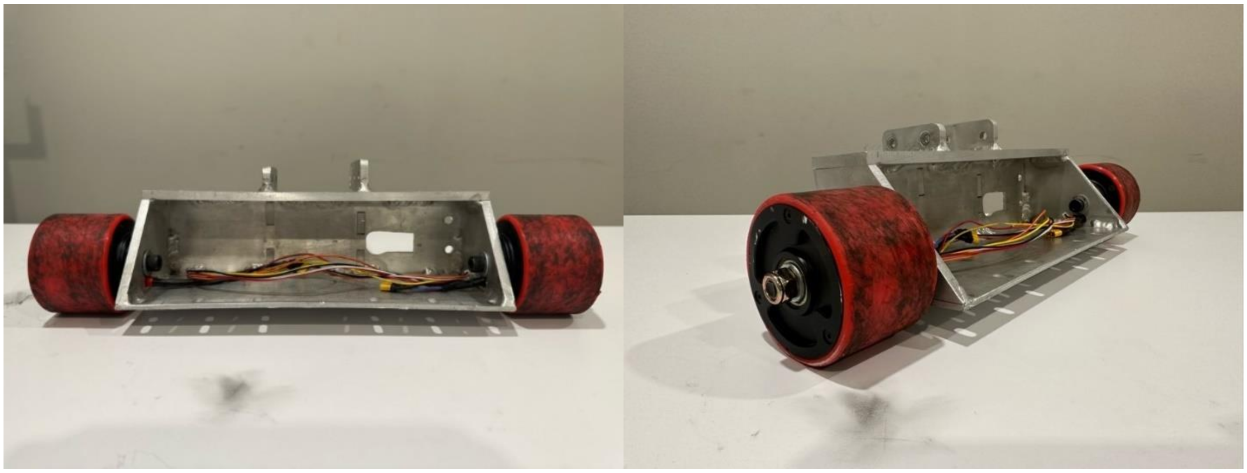


Figure 63 – Step 1: Attach drivetrain to chassis.

Figure 64 – Step 2: Attach weapon motor to chassis.

Figure 65 – Step 3: Attach first upright to chassis and slide on weapon motor shaft bearing.

Figure 66 – Step 4: Attach weapon motor armor.

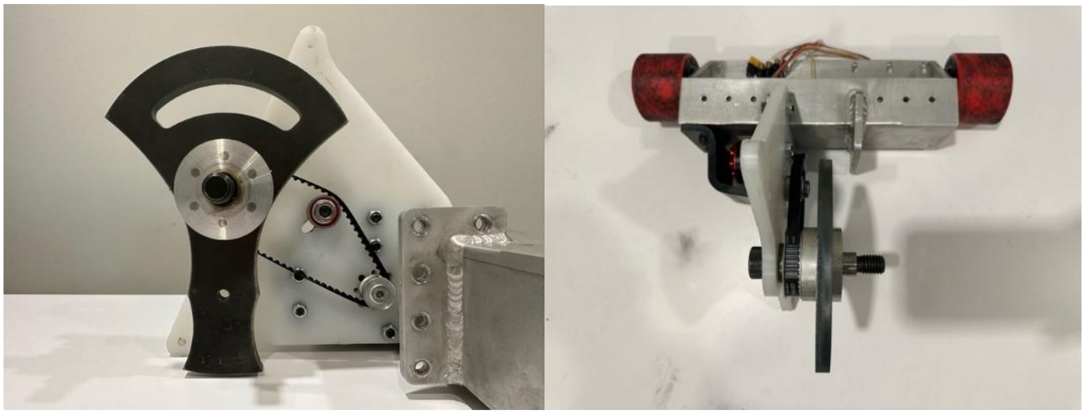


Figure 67 – Step 5: Attach weapon assembly.

Figure 68 – Step 6: Attach second upright and weapon safety lock pin.

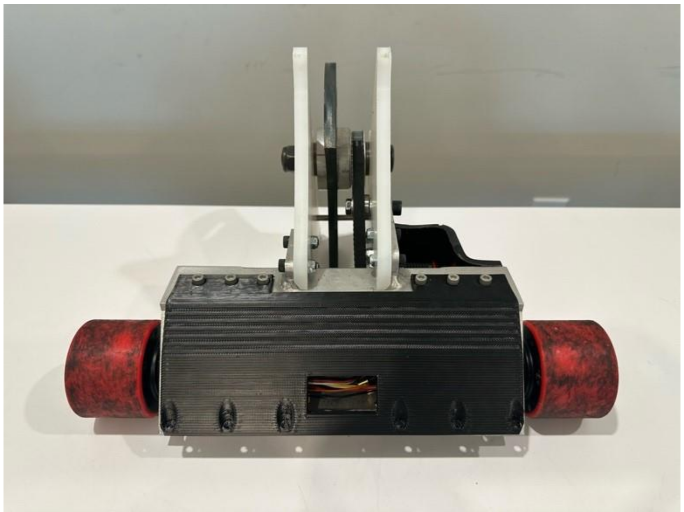


Figure 69 – Step 6: Attach electronic backing.

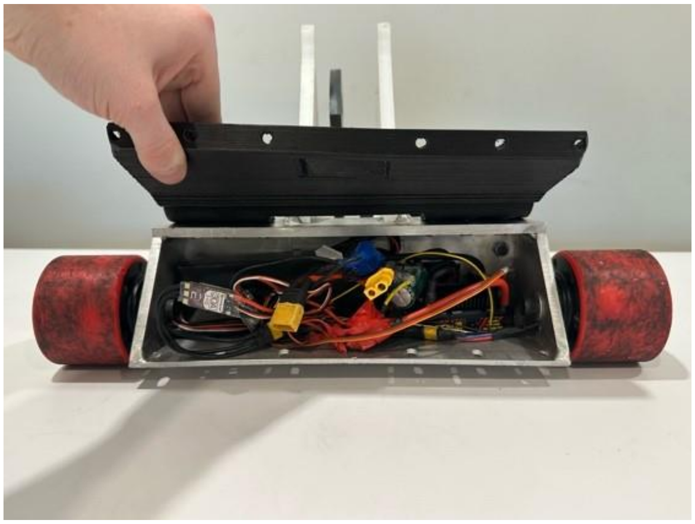


Figure 70 – Step 7: Insert and plug in electronics.

Figure 71 – Step 8: Tighten down backing and have battery plug sticking out for easy access.

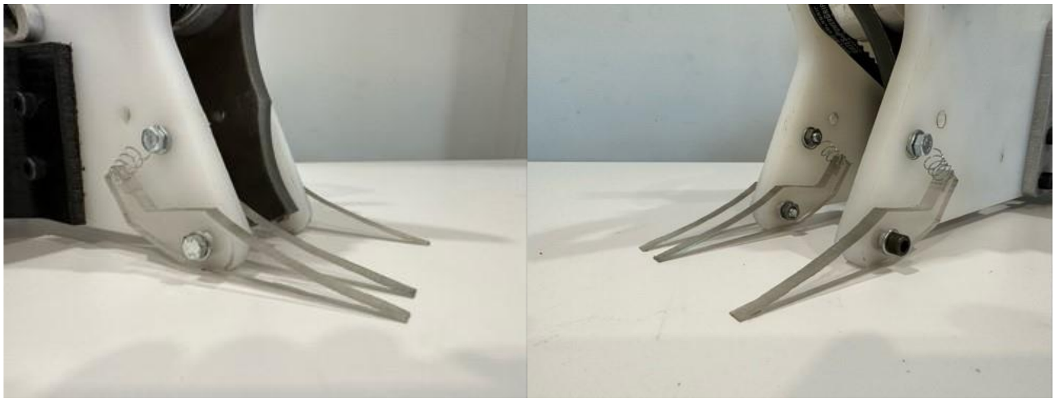


Figure 72 – Step 9: Attach 6 spring loaded forks on the top and bottom of the uprights.

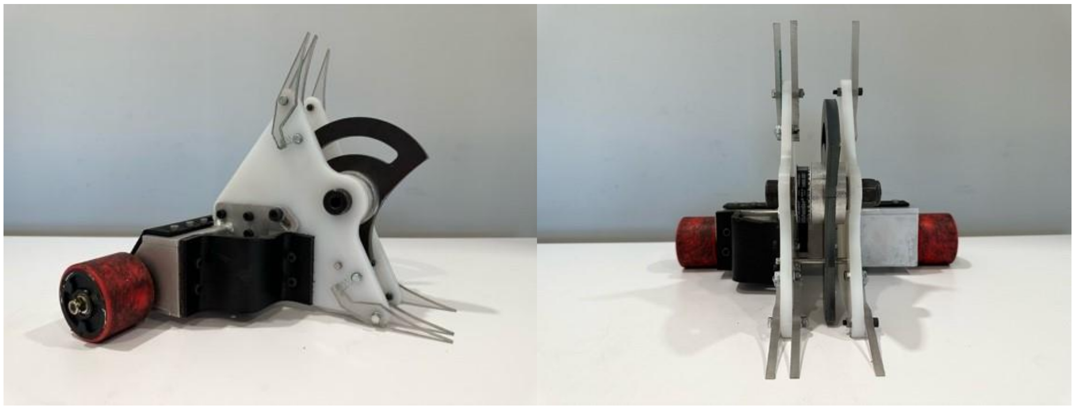


Figure 73 – BAKA BOT fully assembled.

Testing Plan

Since the Norwalk competition is after graduation, testing is extremely important during the 2023 Spring semester. Most of the testing will be completed in conjunction with the UC Combat Robotics Club. Upon completion of manufacturing and assembly, we will perform several tests to see how our robot holds up to our calculations and in future fights.

While watching videos of previous fights both professional and amateur, we noticed all robots fighting a vertical spinner get launched into the air. This height range is anywhere from a few inches to several feet in the air. This leaves a lot of robots extremely damaged or even knocked out of the fight. To test this, we will perform a 5 ft drop test with a variety of different angles to understand the damage that our BAKA BOT might endure during the fights. This will give us the opportunity to make final changes to reinforce any weak areas in the frame structure.

We will be testing the speed and start up time of the weapon by bolting the robot frame down and recording the full speed of the assembly. For safety reasons, this will be done from a safe distance to ensure nobody is hurt during the process. The test will prove our assembly can handle the forces of the weapon speed and prove our start up time calculations.

We will be driving the full robot assembly in UC Combat Robotics testing cage in Victory Parkway Campus (VPC). This gives us a safe way to practice maneuvering with the weapon engaged so we can hit objects such as wood.

To ensure our confidence in the performance of BAKA BOT at NHRL, all team members will practice driving the robot around prior to our competition to ensure we are all experienced operators. This will be done with the weapon assembly disengaged (weapon belt not attached) for safety reasons. The best driver will then be determined to ultimately fight the robot at NHRL.

Finally, during one of UC Combat Robotics Club meetings, we will have a professional combat robot competitor test our robot. Owen Cokley has tested previous UC Combat Robotics capstone projects. He has experience with a variety of robots, weapons, drivetrains, and fights. Owen has developed several highly competitive robots and will give his expert opinion on BAKA BOT. The testing consists of rules compliance, internal inspection, function test, weapon test, drive train test, match up analysis, and overall score. Refer to Appendix E (73) to see the testing form.

Testing Procedures

Drop Test – For this test, we dropped BAKA BOT multiple times at a height of 5 ft. We dropped it at different angles to see how the robot would behave and if any parts would disassemble or get loose.

Weapon Test – We performed a weapon test in an empty parking lot. For safety reasons, the robot was secured to the ground so it couldn't move, and we stood a safe distance away. Then we tested the weapon speed and time to get to the tip speed of 192 mph.

Driving Test – After completing the circuitry needed for the drive train, we drove BAKA BOT around VPC. The club has a wooden test arena to practice driving the robots around. This wooden floor is similar to the one at the NHRL competition on May 6th.

Owen Cokley Test – Owen has been supervising our testing procedures and filled out his UC Battlebot 12lb testing form. This form determines if a UC Combat Robotics Club robot is acceptable to compete, represent the club, and ultimately give insight to how it will hold up in competition.

Testing Results

Drop Test – BAKA BOT held itself together throughout all the falls and throws. No parts or components got loose or disassembled. We did not observe any structural damage to be concerned with, therefore no reinforcements were made. See *Figure 74* for an example of BAKA BOT being dropped.

Weapon Test – Before a full spin up was conducted, we tried to freehand spin the assembly and noticed a lot of resistance. This was due to the weapon hub and pulley rubbing against the UHMW uprights which caused a significant amount of friction. To counteract this, we added thrust bearings to either side of the assembly. This solved our friction problem and allowed free spinning motion. Once fully ran with the motor, the weapon was able to reach the designed tip speed of 192 mph with a 0.45 second start up time.

Driving Test – All 3 team members practiced driving BAKA BOT on the wooden test arena. After driving it a couple of times, we realized that the wheel was bottoming out of the frame and locking up. Therefore, we made custom washers so that the wheels can run smoothly. The rubber on the wheels doesn't give BAKA BOT a lot of friction force to push opponents. Our team is looking into adding spikes to the chassis side outer diameter of the wheels to help BAKA BOT dig into the wooden arena floor to stand our ground when pushing opponents.

Owen Cokley Test - The ranging score for the UC Combat Robotics 12lb testing form is from -320 to 150 points. Anything above zero is a robot approved to compete. BAKA BOT scored 104 points, so we are approved to compete at NHRL and will represent the UC Combat Robotics Club well.

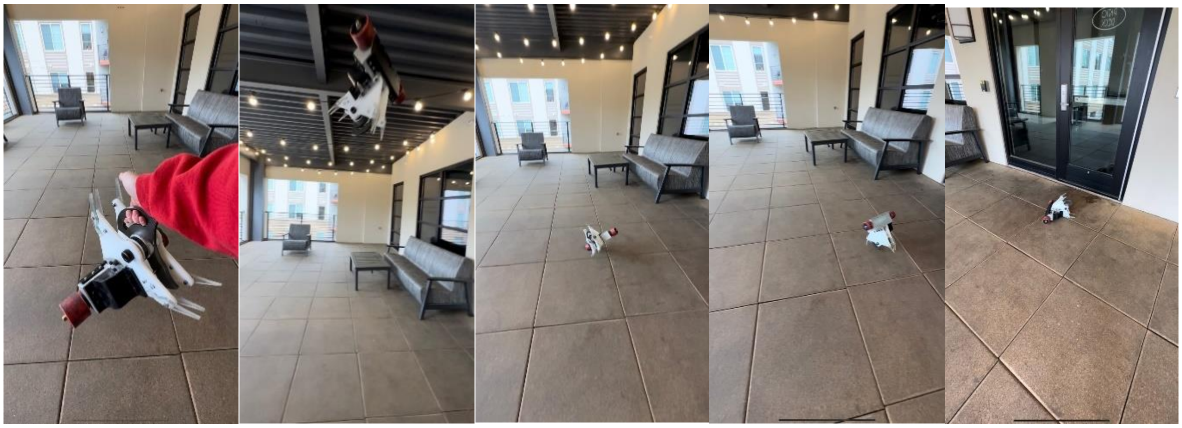


Figure 74 – Throwing BAKA BOT 6 feet high on a floor similar to plywood.

Project Management

Preliminary Budget

An initial budget of $1,200.00 USD was thought to be provided by UC's Combat Robotics Club and is how we made our preliminary budget. An exact bill of materials and full project budget is itemized in Appendix D (72).

Item	QTY	Cost Per	Total Cost
Weapon ESC	1	$53.00	$53.00
BadAss 3515-1130Kv Brushless Motor	1	$65.99	$65.99
Receiver	1	$5	$5.00
AR500 Steel – Weapon	2	$50	$100.00
Aluminum 6061 Frame	1	$200	$200.00
Batteries	2	$70.00	$140.00
Wheel with Hub Motors	4	$60.00	$240.00
Wheel ESCs	2	$21	$42.00
Belt Tensioner	1	$20.00	$20.00
Belt	3	$30.00	$90.00
COTS Parts	1	$250.00	$250.00
Total			**$1,205.99**

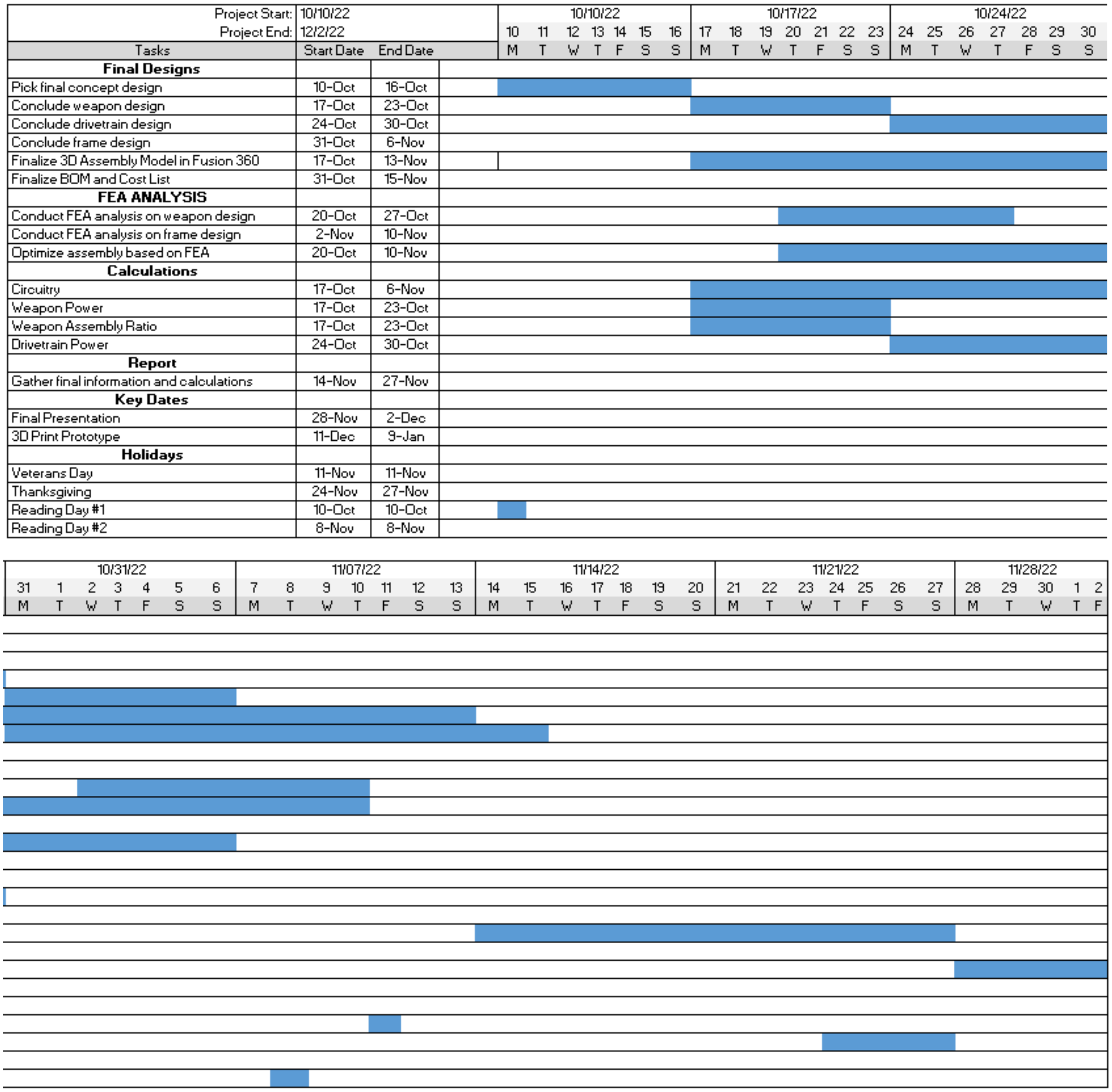
Figure 75 – Preliminary Budget

Actual Budget

After being fortunate enough to receive a sponsorship with Toyota TMMK for $1,500.00, the UC Combat Robotics Club also provided $500.00. Our final budget is $2,000.00 USD. Most of this budget was utilized. BAKA BOT itself ended up costing roughly $1400, and we used the remaining money for spare parts and to fix unforeseen problems. The budget at the time of this report is $30.54. The full bill of materials with expenses, vendors, and descriptions are laid out in Appendix D (72).

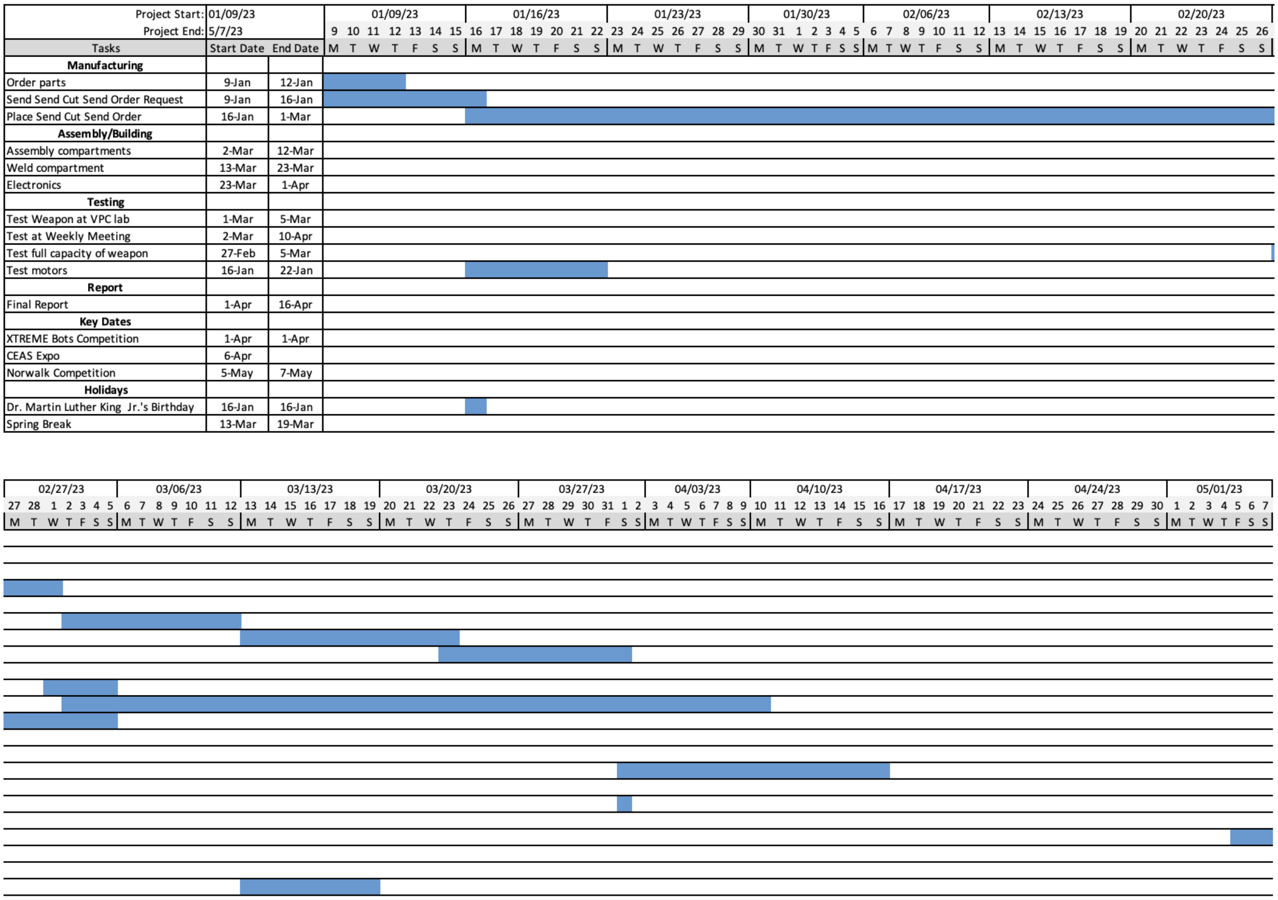
Key Milestones

Our team has also created a time schedule for different tasks to accomplish before the construction of our combat robot. The Gantt chart helped keep us on track and delegate work based on individual team member strengths. The chart also kept track of important dates and deadlines to ensure we were ready for the CEAS Tech Expo and our May 6th NHRL competition



Project Start:	10/10/22	
Project End:	12/2/22	
Tasks	Start Date	End Date
Final Designs		
Pick final concept design	10-Oct	16-Oct
Conclude weapon design	17-Oct	23-Oct
Conclude drivetrain design	24-Oct	30-Oct
Conclude frame design	31-Oct	6-Nov
Finalize 3D Assembly Model in Fusion 360	17-Oct	13-Nov
Finalize BOM and Cost List	31-Oct	15-Nov
FEA ANALYSIS		
Conduct FEA analysis on weapon design	20-Oct	27-Oct
Conduct FEA analysis on frame design	2-Nov	10-Nov
Optimize assembly based on FEA	20-Oct	10-Nov
Calculations		
Circuitry	17-Oct	6-Nov
Weapon Power	17-Oct	23-Oct
Weapon Assembly Ratio	17-Oct	23-Oct
Drivetrain Power	24-Oct	30-Oct
Report		
Gather final information and calculations	14-Nov	27-Nov
Key Dates		
Final Presentation	28-Nov	2-Dec
3D Print Prototype	11-Dec	9-Jan
Holidays		
Veterans Day	11-Nov	11-Nov
Thanksgiving	24-Nov	27-Nov
Reading Day #1	10-Oct	10-Oct
Reading Day #2	8-Nov	8-Nov

Figure 76 – Fall Semester Gannt Chart



Project Start: 01/09/23
Project End: 5/7/23

Tasks	Start Date	End Date
Manufacturing		
Order parts	9-Jan	12-Jan
Send Send Cut Send Order Request	9-Jan	16-Jan
Place Send Cut Send Order	16-Jan	1-Mar
Assembly/Building		
Assembly compartments	2-Mar	12-Mar
Weld compartment	13-Mar	23-Mar
Electronics	23-Mar	1-Apr
Testing		
Test Weapon at VPC lab	1-Mar	5-Mar
Test at Weekly Meeting	2-Mar	10-Apr
Test full capacity of weapon	27-Feb	5-Mar
Test motors	16-Jan	22-Jan
Report		
Final Report	1-Apr	16-Apr
Key Dates		
XTREME Bots Competition	1-Apr	1-Apr
CEAS Expo	6-Apr	
Norwalk Competition	5-May	7-May
Holidays		
Dr. Martin Luther King Jr.'s Birthday	16-Jan	16-Jan
Spring Break	13-Mar	19-Mar

Figure 77 – Spring Semester Gannt Chart

Future Considerations

The front fork design is still being tested to ensure they are perfect for competition. These forks have a spring-loaded design to allow constant pressure on the floor to help get underneath the opponents and direct them up into the weapon. The current fork design shown in this report works really well, but they still need to be tested in friendly scrimmages. They also need to be tested with the "Triangle of Death". This is when our robot gets stuck on three points: The wheel, the top of the upright, and the bottom of the upright. From current testing, BAKA BOT can easily fix itself by full throttling the wheel contacting the floor, and with majority of its weight in the chassis, it can spins itself to a combat ready position.

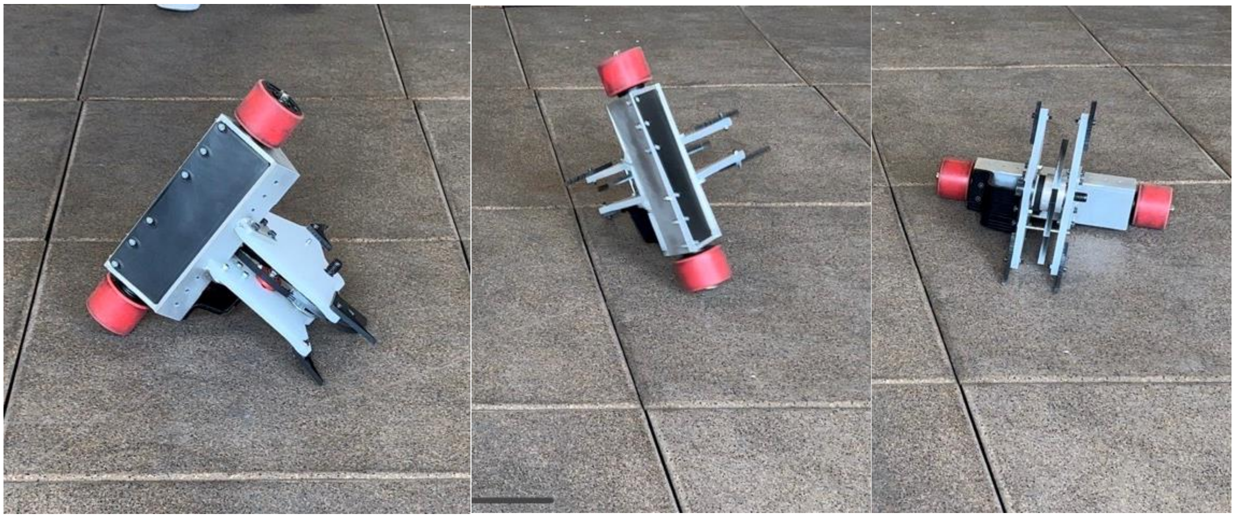


Figure 78 – Triangle of Death and BAKA BOT spinning out of it

The last future consideration that we will be trying to add before the competition is spikes on the chassis side of the hub motor wheels. These spikes will stick out past the outer diameter of the wheel. This will then help give BAKA BOT dig into the floor for better traction on the wooden arena to help us stand our ground when pushing opponents. The spikes will have a 5-degree rake angle with a 60-degree relief angle.

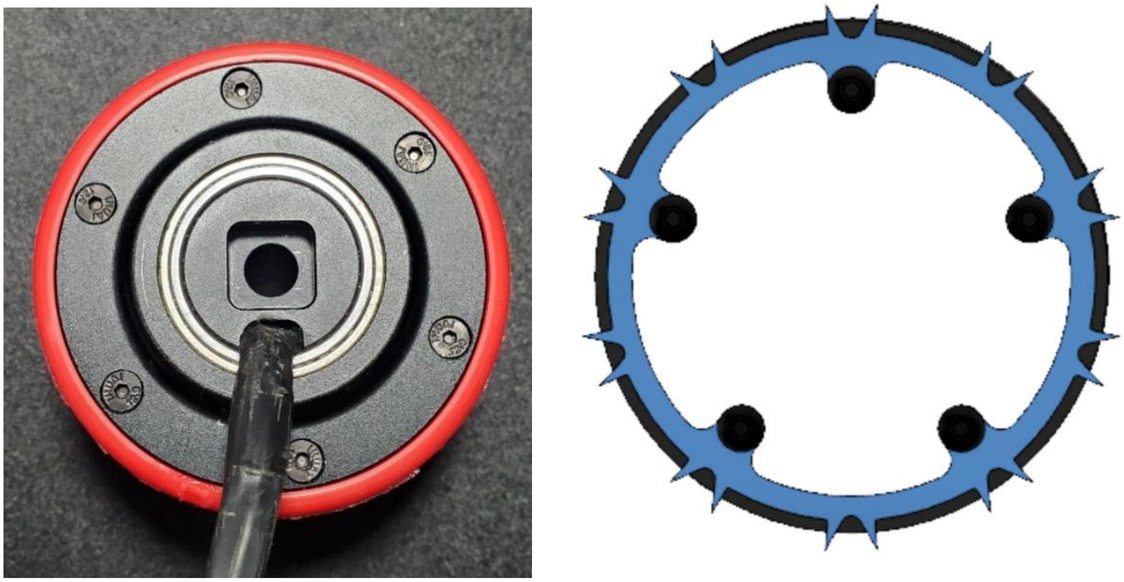


Figure 79 – Spike design example that we will be customizing to fit our hub motor wheels

Lessons Learned

Use Cloud-Based CAD Software

Fusion 360 was used within our team. This cloud-based software helped with the team members working remotely at home. We had access to the files at any location and each team member could update parts/assemblies seamlessly. It was such a game changer not having to worry about access to parts or if it parts were on their latest revisions. Our team would constantly log into Fusion to check dimensions on assemblies. It kept us on our feet and prepared at all times.

Create a Meeting Schedule and Stick to It

Pick a method of virtual communication, such as Microsoft Teams, and use that to track all conversations and files made. Be sure to create and follow a schedule. Order parts as soon as possible because that waiting period caused us to be behind schedule at certain times. Even if you feel like there is nothing to do that week, still meet up and discuss it. You may just end up getting ahead of schedule or bonding with your team.

Use Uniform Hardware

We recommend trying to use the same type of nuts and bolts for every assembly to make the assembly process simpler and easier. Stick to the metric or the imperial system. It causes too much confusion if you are constantly switching units. Pick a screw head type and stick to that. That way you can simplify your tooling. Try to use the same thread type across your robot so nuts are universal. In other words, simplify your whole system. There is no need to complicated things.

Prepare For the Unknown

Overall, the manufacturing process reveals the imperfections from the CAD model and the design phase. When actual parts and prebuilt assemblies are finally in hand, you start to realize how the design could be improved. Ideally, you have worked with all parts before and have experience in the project you are working on, but you do not. Coming up with a robot completely from scratch is a difficult process that hopefully has many iterations before the final product is satisfactory. Not everything goes as planned, and your timeline should have wiggle room for it. You need time to adjust your design and fix any imperfections. Not only that but multiple people should review CAD assemblies at several instances throughout the design of the project. Therefore, mishaps can be caught before being produced. It ends up costing you more time and money than you planned for, be ready.

Make Combat Robotics a Passion Not Just a To-Do List

If you make your senior design capstone one of your passions, you will enjoy your time significantly more. It won't just become something you are forced to do but rather something you care about and look forward to doing. You will also start to involve yourself in a deep and rich community full of interesting ideas. Advice and resources from others are a very crucial aspect of your capstone, it should be utilized every step of the way.

Conclusion

Creating a combat robot within 2 semesters for our senior design project was fun but not an easy task. BAKA BOT was designed, built, and now combat ready for the NHRL competition on May 6th in Norwalk, Connecticut. The robot weighs 11.8 lbs, so we are under the 12lb weight limit for our specific competition. In addition, BAKA BOT meets all safety requirements under the UC Combat Robotics Club and the NHRL rules. Despite not having competed yet, we believe our robot will be a dark horse at the event. This project has been a huge success with solving our problem statement by planning, designing, building, and testing BAKA BOT. Each team member played a big part in all aspects including time management, great leadership, and practical engineering.

Time management was the hardest aspect that we had to manage. It was a success due to all the members working when needed. We met at least two times a week and even more during our last semester. We all had our general roles with what was needed to be done, but when times became stressful, everyone was always open to give their time and help each other. Having managed our time efficiently, it was crucial to our success at the CEAS Tech Expo. We ended up winning 3 awards: MET Best of Expo 2nd Place, MET Best Poster Award, and MET Best Team Dynamic.

Great leadership was demonstrated by every team member. We didn't designate one specific person to be the leader. This allowed us to be closer as a team and have a mentality that everyone is accountable for all aspects and deadlines. Our team did a great job splitting up the robot into its different departments and working together to pick a final design. Then when it came to fabrication, we always worked together. This not only resulted in a great team dynamic and product, but it also resulted in everyone having fun throughout the whole senior year duration. If our team had not connected as easily so soon, our project would not have been as successful.

Practical engineering methods that we all learned from The University of Cincinnati and our co-ops helped guide us on the right track with designing and building BAKA BOT. Starting in Senior Design I, research and initial concepts jumpstarted our project. Then Fusion 360 was selected as our main CAD software to use. This allowed us to have a cloud giving easy access to all members to work on the CAD designs. Then Senior Design II started, and we began finalizing our concepts by using laser printers at the 1819 Ground Floor Makerspace to test our concepts before manufacturing the final design. Once our wooden model met our satisfaction, manufacturing BAKA BOT began. Senior Design III consisted of us all working at the VPC workshop for a countless number of hours. All this time was spent fabricating BAKA BOT in an efficient and precise manner. Initially, working so hard with our design concepts allowed our team to easily assemble BAKA BOT in the end. The only aspect that held us back from building our robot was waiting for parts to be shipped and delivered. So, apply everything that we have learned through our 5-year CEAS program, the engineering portion of the project was the smoothest and the most fun.

Through the course of this whole project, our team showed pristine time management, great leadership/team dynamic/accountability, and quality engineering. These principles allowed us to always be confident in every step of our project resulting in a well-built robot that should do very well in competition. We are excited to represent The University of Cincinnati and the UC Combat Robotics Club in Norwalk, Connecticut. We are very proud of the outcome of the project, and we are ecstatic to see BAKA BOT destroy the competition at the NHRL 12lb weight class competition on May 6th, 2023.

Figure 80 – BAKA BOT

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Appendices

Appendix A (Industry Standards):

Bot Design Rules

From NHRL

Here are our updated bot design rules. These will take effect starting at our May 2022 competition.

Differences from previous ruleset

- All bots, including sportsmen, must have an active weapon (exceptions: meltybrains and thwackers are allowed).
- The non-wheeled bonus for the 30lb class is now +15 lbs.

Weight

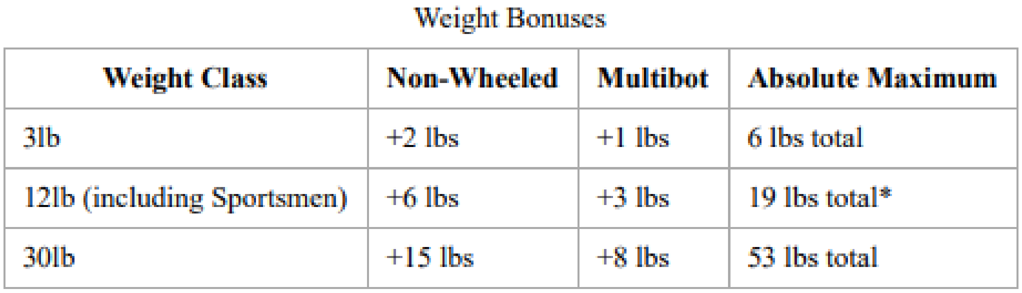
All bots must be at or below their maximum weight listed below at the start of the fight. Any cameras or recording equipment on the bot does not count towards the weight. All bots can qualify for two additional weight bonuses, as defined below.

Non-Traditional Movement Bonus

A weight bonus for non-traditional motion systems. Traditional (usually wheeled) motion systems are generally defined as a locomotion system that operates primarily through angular momentum of the component touching the ground, but also includes any system that uses unpowered rotating objects (wheels, drums, rollers, ball bearings, etc.) as a means of friction reduction. Any motion system that does not meet this definition qualifies for the weight bonus. In the event of a multibot, only the heaviest bot needs to be non-wheeled to get the bonus.

Multibot Bonus

An entrant consisting of multiple independent bots qualifies for a weight bonus. Every bot in a multi bot must have active control and be able to influence the fight. In 12lb and 30lb entrants, the maximum weight of any single bot cannot exceed 110% of the normal bot weight. Only the heaviest bot needs an active weapon; see “Weapon” section below for further details. If your configuration does not rely on a multibot for a weight bonus, you may choose to run with or without that multibot for each fight.



Weight Bonuses

Weight Class	Non-Wheeled	Multibot	Absolute Maximum
3lb	+2 lbs	+1 lbs	6 lbs total
12lb (including Sportsmen)	+6 lbs	+3 lbs	19 lbs total*
30lb	+15 lbs	+8 lbs	53 lbs total

* 12lb and Sportsman bots cannot fully take advantage of both weight bonuses at the same time.

Size

3lb and 12lb Sportsman bots must fit into a 30 x 30 x 24 inch cube at the start of the fight.

12lb and 30lb bots must fit into a 36 x 36 x 36 inch cube at the start of the fight.

Bots can expand or contract to any size during the fight, so long as they can start at this size. Multibots must all fit and start the fight within this cube together.

Weapons

All entrants must have a weapon system operated independently of locomotion that can contact or impact the opponent (known as an active weapon). Meltybrains (bots that can show controlled movement while spinning rapidly) and thwackbots (bots that attack with a hammer on an unpowered arm, using inertia from driving) are exempt from this rule. Only the heaviest bot in a multibot needs an active weapon.

Sportsmen are not permitted to have a conventional horizontal or vertical spinning weapon (with the exception of saws). Rotary lifters are allowed, so long as they do not do damage like a conventional spinning weapon.

All weapon systems must have a lock that stops their actuation. Weapons that move must have a lock that stops movement in all directions. Weapons that fire or shoot must have a physical means of blocking firing and blocking the expulsion of a projectile.

Flame and heat based weapons are allowed and encouraged at NHRL, including low- and medium-power rocket motors. Flame weapons should self-extinguish within 30 seconds of losing contact with the transmitter. 3lb bots are allowed up to 6 ounces of fuel. 12lb, 12lb sportsman, and 30lb bots are allowed 12 ounces of fuel. Fuel storage canisters must default to the closed position if damaged or removed from the bot.

Projectile weapons cannot exceed speeds of 150 miles per hour.

Weapons that primarily act by **obstructing visibility** (e.g. smoke grenade or fog machine) are not permitted. Weapons that produce smoke or fog as a by-product of their attack (e.g. rocket motors) are allowed.

Electrical and shock weapons such as tasers and cattle prods are not permitted, nor are electrical weapons that purposefully block radio signals.

Any weapons that result in **harm to those outside the cage** (lasers, strobe lights, excessively loud noises) are not permitted.

Modular Bots

Modular bots are permitted at NHRL. Modular bots are robots that can change offensive or defensive features depending on who they up against in the tournament. Repairs and replacing broken components of your robot don't count as a modular robot.

No more than 50% of the weight of a modular bot can change between configurations. A configuration cannot cause a bot to gain or lose the non-traditional motion weight bonus. If you bring spare robots, your modules must be interchangeable between spares.

Like all other bots you still need to bring it to the green room in its final ready state. You can only bring entries you intend to fight into the green room. Swapping of modules or bots at the cage is not allowed.

If your configuration does not rely on a multibot for a weight bonus, you may choose to run with or without that multibot for each fight. Adding, removing, or swapping multibots counts towards the maximum configurable weight of a modular bot.

Spare Bots

Bringing exact copies of your bot is allowed. In order to count as the same bot spares must be as close to exact copies as possible. All copies must pass safety before competing. If you are bringing spare modular bots, all spare bots must be able to use any module.

Design Restrictions

Entanglement devices, defined as “a component of the bot that is designed to be entangled in the rotational or moving parts of the opponent,” are not permitted.

Liquids expelled from the bot are not permitted. Liquids used as a fuel source are allowed. Liquids expelled from the bot that become gaseous shortly after leaving the bot and/or before hitting the opponent are allowed.

Combustion-powered bots are allowed and encouraged. Combustion engines may be manually started during load in, assuming they do not cause the weapon to move. Electrically started engines are also allowed.

Fabric, foam, and other ablative armor are allowed.

Electrical systems cannot exceed 60 volts for 3lb bots, and 72 volts for 12lb and 30lb bots. Your bot should be designed to be powered on in the cage for up to 3 minutes before the start of your match.

Batteries that are charged inside the bot are permitted if the bot measures less than 11 x 8 x 6 inches.

If you are unsure if your bot design is in violation of the rules or not, please email us (mailto:hello@nhrl.io)! We’d rather see new and interesting bots fight than disqualify them.

Appendix B (Survey):

Q1 – With a weight limit of 12lbs at our Battle Bot competition, distribute the concepts below that are needed for a combat robot in percentages on how you think we should prioritize them. (Please have the percentages add up to 100%)

Frame/Armor Design

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

Weapon Design

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

Drivetrain Design

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

Q2 – What weapon do you think would be the most effective in a 15lb Battle Bot competition?

Vertical Spinning Blade Horizontal Spinning Blade Drum Spinner Flipper

Why?

____

____

____

Q3 – If you chose a spinning blade in Q2, how long do you think it should be?

3 – 5 inches 6 – 8 inches 9 – 10 inches N/A

Q4 – For the weapon speed, how fast do you think the weapon should spin?

200 – 239 rpms 240 – 279 rpms 280 – 319 rpms 320+ rpms

Q5 – How many wheels would be best on a 12lb combat robot?

2 3 4 5+

Q6 – Which drivetrain assembly do you think would be the most successful for a 12lb combat robot?

Gear Drive Chain Drive Belt Drive Hub Motor Wheels

Q7 – How would you prioritize the concepts below when building a successful combat robot?

(1 = Lowest Priority, 5 = Highest Priority)

Total Cost	1	2	3	4	5	N/A
Ease of Use (Repair)	1	2	3	4	5	N/A
Weapon Design	1	2	3	4	5	N/A
Weapon Size	1	2	3	4	5	N/A
Motor Speeds	1	2	3	4	5	N/A
Total Weight	1	2	3	4	5	N/A
Maneuverability	1	2	3	4	5	N/A
Cool Design	1	2	3	4	5	N/A
Safety	1	2	3	4	5	N/A

Q8 – How much time is a <u>reasonable</u> amount (in minutes) for the BAKA Bot team to take apart/access the internal components of the robot to do maintenance? (Ease of use/repair)

2 – 3 minutes 4 – 5 Minutes 6 – 7 Minutes 7 - 8 Minutes

Q9 – How important is the color/theme of the robot to you?

1) Unapplicable
2) Somewhat Important
3) Neutral
4) Important
5) Crucial

Q10 – What is the <u>least</u> amount of money you think you would need to build a 1st Place 12lb combat robot?

$500-$999 $1000 - $1499 $1500 - $1999 $2000+

Survey Results (41 responses)

(Only showing the majority answers)

Q1 – Frame/Armor Design [30%], Weapon Design [40%], Drivetrain Design [30%]

Q2 – Vertical Spinning Blade	(33 responses)
Q3 – 6-8 inches	(30 responses)
Q4 – 240-279 rpms	(24 responses)
Q5 – 2 Wheels	(25 responses)
Q6 – Belt Drive	(29 responses)

Q7 –

Total Cost [5]	(35 responses)
Ease of Use(Repair) [3]	(26 responses)
Weapon Design [5]	(25 responses)
Weapon Size [4]	(29 responses)
Motor Speeds [4]	(31 responses)
Total Weight [4]	(36 responses)
Maneuverability [3]	(25 responses)
Cool Design [2]	(29 responses)
Safety [4]	(25 responses)

Q8 – 4-5 Minutes (33 responses)

Q9 – Unapplicable (16 responses), Somewhat Important (16 responses)

Q10 – $1000-$1499 (29 responses)

Appendix C (Calculations):

Weapon Motor Parameters:

- Motor KV Value = 970 RPM/Volt
- Max Continuous Power = 2000 Watts
- Max Continuous Current = 90 Amps
- Driving Gear Pulley = 10 teeth
- Driven Gear Pulley = 30 teeth
- Weapon Diameter = 9”

Weapon Speed Calculations:

$$Motor\ RPM = \ 970 \frac{RPM}{Volt} * 22.2V = 21{,}534\ RPM$$

$$Weapon\ RPM = \frac{10\ teeth}{30\ teeth} * 21{,}534\ RPM = 7{,}178\ RPM$$

$$Weapon\ Tip\ Speed = \frac{9\ in}{12\ in} * \pi * 7{,}178\ RPM * \frac{1\ mile}{5280\ ft} * \frac{60\ min}{1\ hr} = 192.09\ mph$$

Battery Parameters:

- Capacity = 2600 mAh
- Voltage = 22.2 V
- 6S LiPo Battery

Battery Calculations:

$$Estimated\ Battery\ Life = \frac{2600\ mAh\ Battery\ Capacity}{32000\ mA\ Load\ Current} = 0.081\ hrs = 4\ minutes$$

Drivetrain Parameters:

- Motor RPM = 1,600 RPM
- Wheel Diameter = 2.76”
- $\mu_{static} = 0.9\ (rubber\ and\ wood)$

Drivetrain Calculations:

$$Wheel\ Circumference = 2.76 * \pi = 8.66"$$

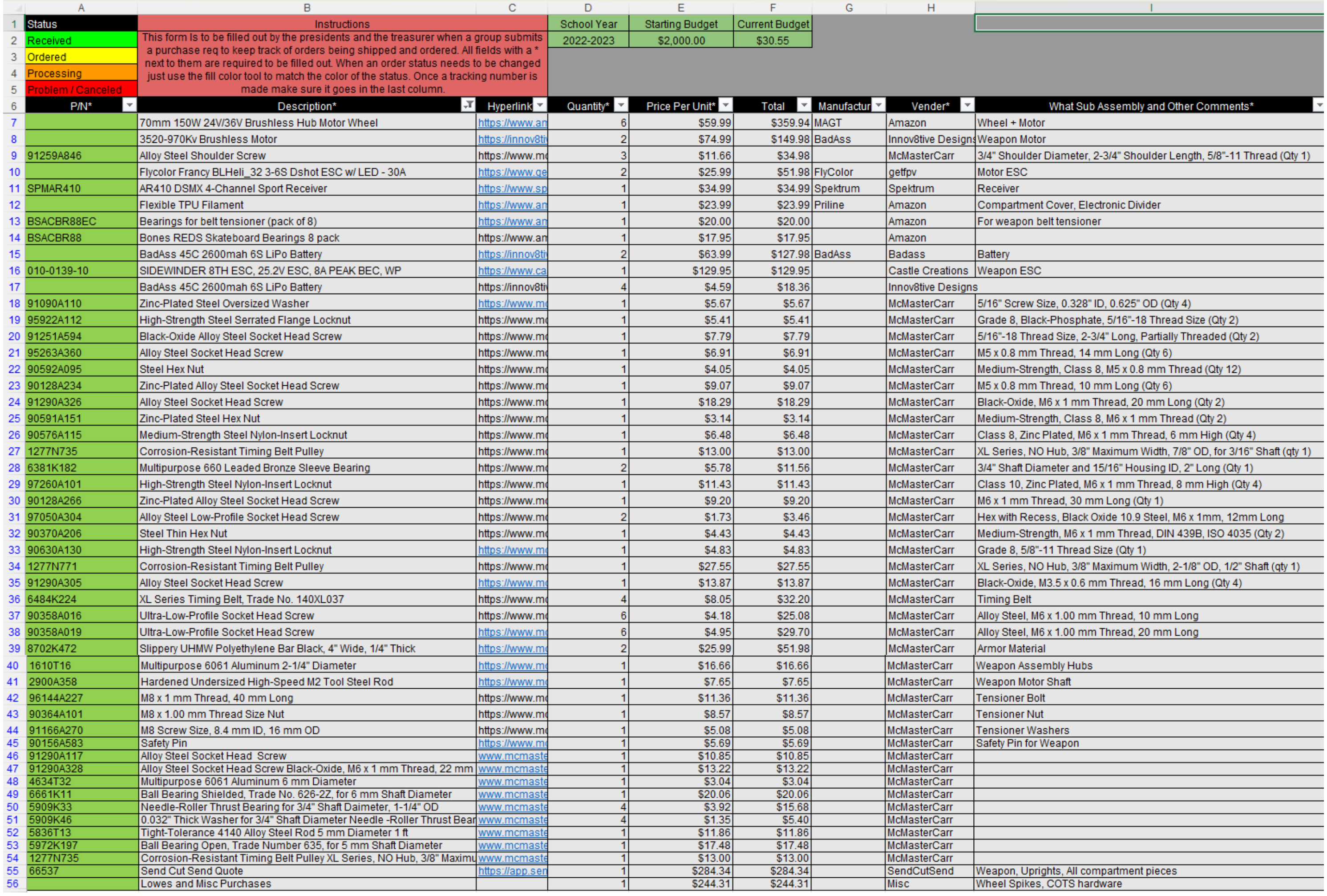
$$Linear\ Velocity = 8.66" * [(1600/60)/12] = 19.24 \frac{ft}{s} = 13.12\ mph$$

$$Wheel\ Load = \frac{12\ lbs}{2\ wheels} = \frac{6\ lbs}{wheel}$$

$$Friction\ Force = 0.9 * \frac{6lbs}{wheel} = \frac{5.4lbs}{wheel}$$

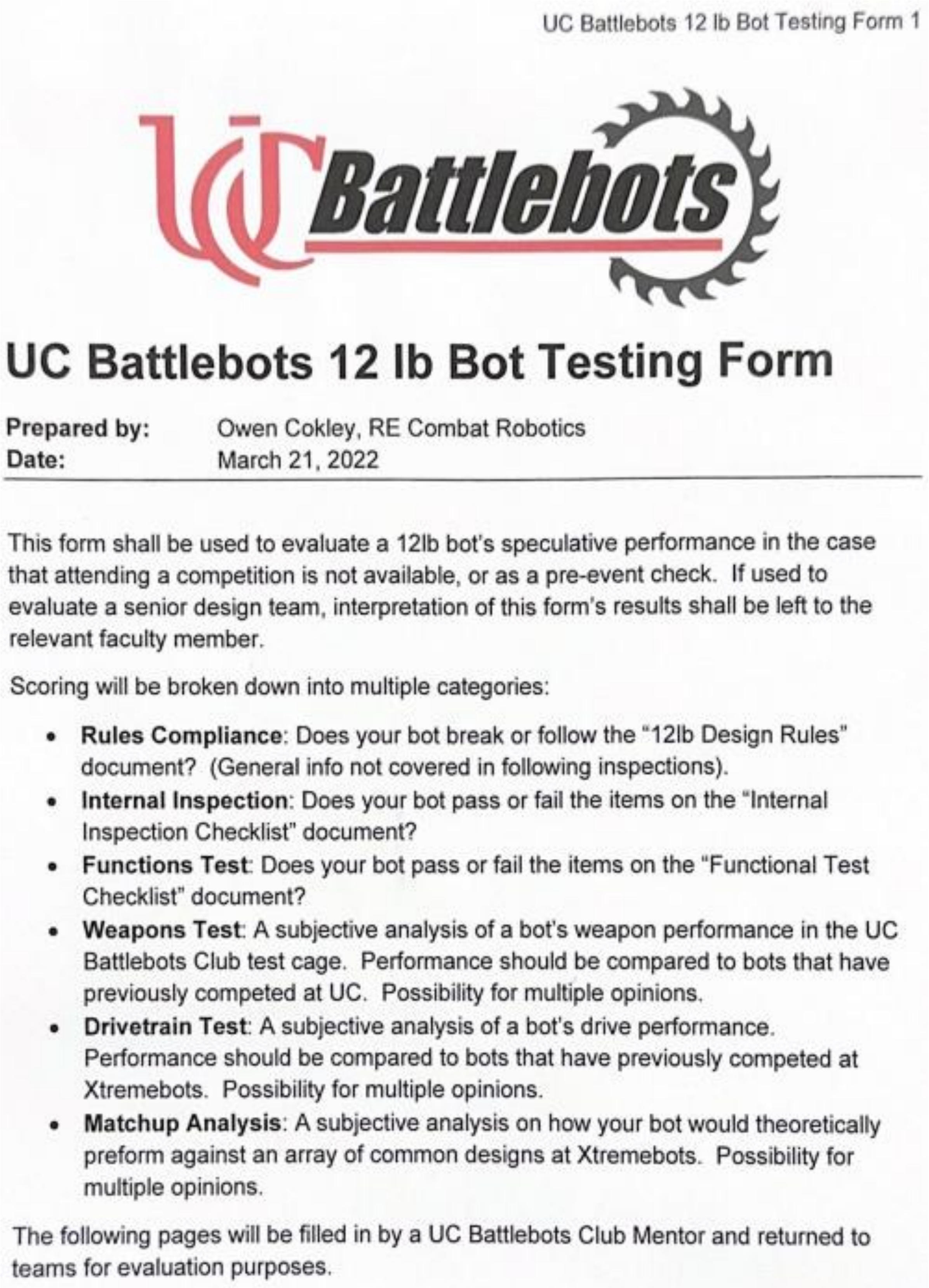
$$Wheel\ Friction\ Torque = \frac{5.4lbs}{wheel} * 2.76" = 14.9 \frac{in{-}lb}{wheel}$$

Appendix D (Bill of Materials):



	A	B	C	D	E	F	G	H	I
1	Status	Instructions		School Year	Starting Budget	Current Budget			
2	Received	This form Is to be filled out by the presidents and the treasurer when a group submits a purchase req to keep track of orders being shipped and ordered. All fields with a * next to them are required to be filled out. When an order status needs to be changed just use the fill color tool to match the color of the status. Once a tracking number is made make sure it goes in the last column.		2022-2023	$2,000.00	$30.55			
3	Ordered								
4	Processing								
5	Problem / Canceled								
6	P/N*	Description*	Hyperlink	Quantity*	Price Per Unit*	Total	Manufactur	Vender*	What Sub Assembly and Other Comments*
7		70mm 150W 24V/36V Brushless Hub Motor Wheel	https://www.an	6	$59.99	$359.94	MAGT	Amazon	Wheel + Motor
8		3520-970Kv Brushless Motor	https://innov8ti	2	$74.99	$149.98	BadAss	Innov8tive Designs	Weapon Motor
9	91259A846	Alloy Steel Shoulder Screw	https://www.mc	3	$11.66	$34.98		McMasterCarr	3/4" Shoulder Diameter, 2-3/4" Shoulder Length, 5/8"-11 Thread (Qty 1)
10		Flycolor Francy BLHeli_32 3-6S Dshot ESC w/ LED - 30A	https://www.ge	2	$25.99	$51.98	FlyColor	getfpv	Motor ESC
11	SPMAR410	AR410 DSMX 4-Channel Sport Receiver	https://www.sp	1	$34.99	$34.99	Spektrum	Spektrum	Receiver
12		Flexible TPU Filament	https://www.an	1	$23.99	$23.99	Priline	Amazon	Compartment Cover, Electronic Divider
13	BSACBR88EC	Bearings for belt tensioner (pack of 8)	https://www.an	1	$20.00	$20.00		Amazon	For weapon belt tensioner
14	BSACBR88	Bones REDS Skateboard Bearings 8 pack	https://www.an	1	$17.95	$17.95		Amazon	
15		BadAss 45C 2600mah 6S LiPo Battery	https://innov8ti	2	$63.99	$127.98	BadAss	Badass	Battery
16	010-0139-10	SIDEWINDER 8TH ESC, 25.2V ESC, 8A PEAK BEC, WP	https://www.ca	1	$129.95	$129.95		Castle Creations	Weapon ESC
17		BadAss 45C 2600mah 6S LiPo Battery	https://innov8ti	4	$4.59	$18.36		Innov8tive Designs	
18	91090A110	Zinc-Plated Steel Oversized Washer	https://www.mc	1	$5.67	$5.67		McMasterCarr	5/16" Screw Size, 0.328" ID, 0.625" OD (Qty 4)
19	95922A112	High-Strength Steel Serrated Flange Locknut	https://www.mc	1	$5.41	$5.41		McMasterCarr	Grade 8, Black-Phosphate, 5/16"-18 Thread Size (Qty 2)
20	91251A594	Black-Oxide Alloy Steel Socket Head Screw	https://www.mc	1	$7.79	$7.79		McMasterCarr	5/16"-18 Thread Size, 2-3/4" Long, Partially Threaded (Qty 2)
21	95263A360	Alloy Steel Socket Head Screw	https://www.mc	1	$6.91	$6.91		McMasterCarr	M5 x 0.8 mm Thread, 14 mm Long (Qty 6)
22	90592A095	Steel Hex Nut	https://www.mc	1	$4.05	$4.05		McMasterCarr	Medium-Strength, Class 8, M5 x 0.8 mm Thread (Qty 12)
23	90128A234	Zinc-Plated Alloy Steel Socket Head Screw	https://www.mc	1	$9.07	$9.07		McMasterCarr	M5 x 0.8 mm Thread, 10 mm Long (Qty 6)
24	91290A326	Alloy Steel Socket Head Screw	https://www.mc	1	$18.29	$18.29		McMasterCarr	Black-Oxide, M6 x 1 mm Thread, 20 mm Long (Qty 2)
25	90591A151	Zinc-Plated Steel Hex Nut	https://www.mc	1	$3.14	$3.14		McMasterCarr	Medium-Strength, Class 8, M6 x 1 mm Thread (Qty 2)
26	90576A115	Medium-Strength Steel Nylon-Insert Locknut	https://www.mc	1	$6.48	$6.48		McMasterCarr	Class 8, Zinc Plated, M6 x 1 mm Thread, 6 mm High (Qty 4)
27	1277N735	Corrosion-Resistant Timing Belt Pulley	https://www.mc	1	$13.00	$13.00		McMasterCarr	XL Series, NO Hub, 3/8" Maximum Width, 7/8" OD, for 3/16" Shaft (qty 1)
28	6381K182	Multipurpose 660 Leaded Bronze Sleeve Bearing	https://www.mc	2	$5.78	$11.56		McMasterCarr	3/4" Shaft Diameter and 15/16" Housing ID, 2" Long (Qty 1)
29	97260A101	High-Strength Steel Nylon-Insert Locknut	https://www.mc	1	$11.43	$11.43		McMasterCarr	Class 10, Zinc Plated, M6 x 1 mm Thread, 8 mm High (Qty 4)
30	90128A266	Zinc-Plated Alloy Steel Socket Head Screw	https://www.mc	1	$9.20	$9.20		McMasterCarr	M6 x 1 mm Thread, 30 mm Long (Qty 1)
31	97050A304	Alloy Steel Low-Profile Socket Head Screw	https://www.mc	2	$1.73	$3.46		McMasterCarr	Hex with Recess, Black Oxide 10.9 Steel, M6 x 1mm, 12mm Long
32	90370A206	Steel Thin Hex Nut	https://www.mc	1	$4.43	$4.43		McMasterCarr	Medium-Strength, M6 x 1 mm Thread, DIN 439B, ISO 4035 (Qty 2)
33	90630A130	High-Strength Steel Nylon-Insert Locknut	https://www.mc	1	$4.83	$4.83		McMasterCarr	Grade 8, 5/8"-11 Thread Size (Qty 1)
34	1277N771	Corrosion-Resistant Timing Belt Pulley	https://www.mc	1	$27.55	$27.55		McMasterCarr	XL Series, NO Hub, 3/8" Maximum Width, 2-1/8" OD, 1/2" Shaft (qty 1)
35	91290A305	Alloy Steel Socket Head Screw	https://www.mc	1	$13.87	$13.87		McMasterCarr	Black-Oxide, M3.5 x 0.6 mm Thread, 16 mm Long (Qty 4)
36	6484K224	XL Series Timing Belt, Trade No. 140XL037	https://www.mc	4	$8.05	$32.20		McMasterCarr	Timing Belt
37	90358A016	Ultra-Low-Profile Socket Head Screw	https://www.mc	6	$4.18	$25.08		McMasterCarr	Alloy Steel, M6 x 1.00 mm Thread, 10 mm Long
38	90358A019	Ultra-Low-Profile Socket Head Screw	https://www.mc	6	$4.95	$29.70		McMasterCarr	Alloy Steel, M6 x 1.00 mm Thread, 20 mm Long
39	8702K472	Slippery UHMW Polyethylene Bar Black, 4" Wide, 1/4" Thick	https://www.mc	2	$25.99	$51.98		McMasterCarr	Armor Material
40	1610T16	Multipurpose 6061 Aluminum 2-1/4" Diameter	https://www.mc	1	$16.66	$16.66		McMasterCarr	Weapon Assembly Hubs
41	2900A358	Hardened Undersized High-Speed M2 Tool Steel Rod	https://www.mc	1	$7.65	$7.65		McMasterCarr	Weapon Motor Shaft
42	96144A227	M8 x 1 mm Thread, 40 mm Long	https://www.mc	1	$11.36	$11.36		McMasterCarr	Tensioner Bolt
43	90364A101	M8 x 1.00 mm Thread Size Nut	https://www.mc	1	$8.57	$8.57		McMasterCarr	Tensioner Nut
44	91166A270	M8 Screw Size, 8.4 mm ID, 16 mm OD	https://www.mc	1	$5.08	$5.08		McMasterCarr	Tensioner Washers
45	90156A583	Safety Pin	https://www.mc	1	$5.69	$5.69		McMasterCarr	Safety Pin for Weapon
46	91290A117	Alloy Steel Socket Head Screw	www.mcmaste	1	$10.85	$10.85		McMasterCarr	
47	91290A328	Alloy Steel Socket Head Screw Black-Oxide, M6 x 1 mm Thread, 22 mm	www.mcmaste	1	$13.22	$13.22		McMasterCarr	
48	4634T32	Multipurpose 6061 Aluminum 6 mm Diameter	www.mcmaste	1	$3.04	$3.04		McMasterCarr	
49	6661K11	Ball Bearing Shielded, Trade No. 626-2Z, for 6 mm Shaft Diameter	www.mcmaste	1	$20.06	$20.06		McMasterCarr	
50	5909K33	Needle-Roller Thrust Bearing for 3/4" Shaft Daimeter, 1-1/4" OD	www.mcmaste	4	$3.92	$15.68		McMasterCarr	
51	5909K46	0.032" Thick Washer for 3/4" Shaft Diameter Needle -Roller Thrust Bear	www.mcmaste	4	$1.35	$5.40		McMasterCarr	
52	5836T13	Tight-Tolerance 4140 Alloy Steel Rod 5 mm Diameter 1 ft	www.mcmaste	1	$11.86	$11.86		McMasterCarr	
53	5972K197	Ball Bearing Open, Trade Number 635, for 5 mm Shaft Diameter	www.mcmaste	1	$17.48	$17.48		McMasterCarr	
54	1277N735	Corrosion-Resistant Timing Belt Pulley XL Series, NO Hub, 3/8" Maximu	www.mcmaste	1	$13.00	$13.00		McMasterCarr	
55	66537	Send Cut Send Quote	https://app.sen	1	$284.34	$284.34		SendCutSend	Weapon, Uprights, All compartment pieces
56		Lowes and Misc Purchases		1	$244.31	$244.31		Misc	Wheel Spikes, COTS hardware

Appendix E (Testing Form):



UC Battlebots 12 lb Bot Testing Form 1

UC Battlebots 12 lb Bot Testing Form

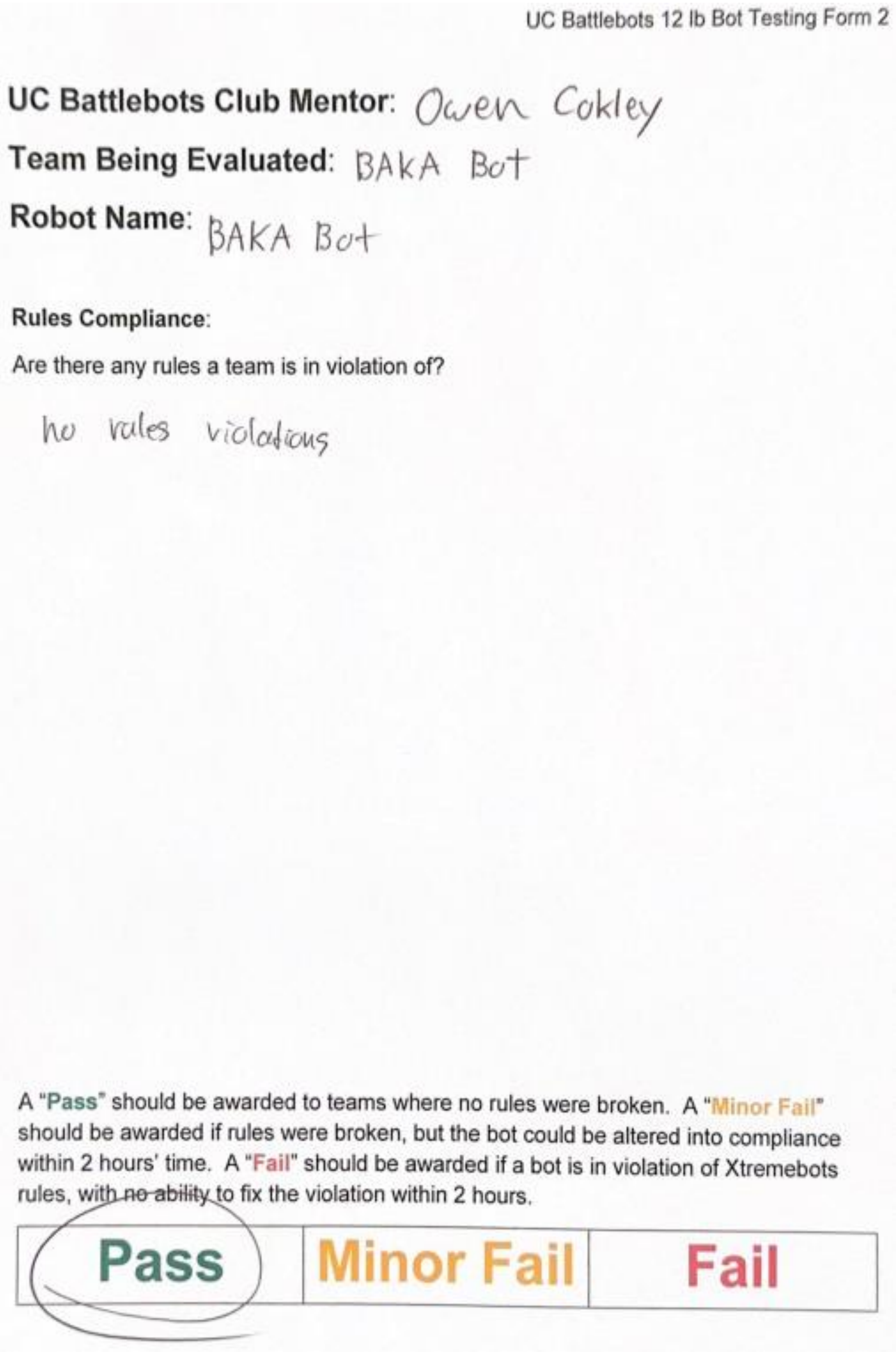
Prepared by: Owen Cokley, RE Combat Robotics
Date: March 21, 2022

This form shall be used to evaluate a 12lb bot's speculative performance in the case that attending a competition is not available, or as a pre-event check. If used to evaluate a senior design team, interpretation of this form's results shall be left to the relevant faculty member.

Scoring will be broken down into multiple categories:

- **Rules Compliance**: Does your bot break or follow the "12lb Design Rules" document? (General info not covered in following inspections).
- **Internal Inspection**: Does your bot pass or fail the items on the "Internal Inspection Checklist" document?
- **Functions Test**: Does your bot pass or fail the items on the "Functional Test Checklist" document?
- **Weapons Test**: A subjective analysis of a bot's weapon performance in the UC Battlebots Club test cage. Performance should be compared to bots that have previously competed at UC. Possibility for multiple opinions.
- **Drivetrain Test**: A subjective analysis of a bot's drive performance. Performance should be compared to bots that have previously competed at Xtremebots. Possibility for multiple opinions.
- **Matchup Analysis**: A subjective analysis on how your bot would theoretically preform against an array of common designs at Xtremebots. Possibility for multiple opinions.

The following pages will be filled in by a UC Battlebots Club Mentor and returned to teams for evaluation purposes.



UC Battlebots 12 lb Bot Testing Form 2

UC Battlebots Club Mentor: Owen Cokley

Team Being Evaluated: BAKA Bot

Robot Name: BAKA Bot

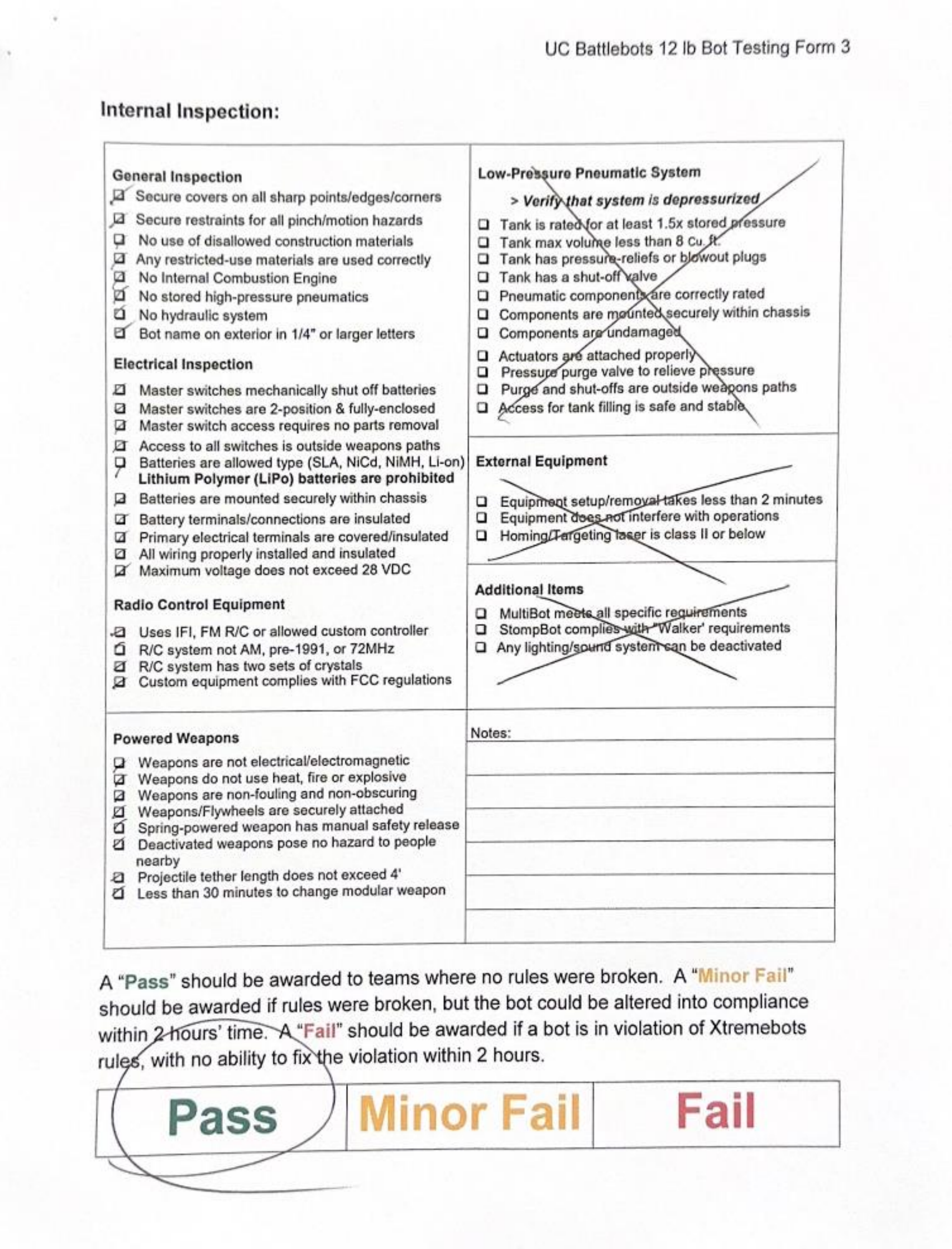
Rules Compliance:

Are there any rules a team is in violation of?

no rules violations

A "**Pass**" should be awarded to teams where no rules were broken. A "**Minor Fail**" should be awarded if rules were broken, but the bot could be altered into compliance within 2 hours' time. A "**Fail**" should be awarded if a bot is in violation of Xtremebots rules, with ~~no ability~~ to fix the violation within 2 hours.

[✓ **Pass**]	**Minor Fail**	**Fail**



UC Battlebots 12 lb Bot Testing Form 3

Internal Inspection:

General Inspection
- ☑ Secure covers on all sharp points/edges/corners
- ☑ Secure restraints for all pinch/motion hazards
- ☑ No use of disallowed construction materials
- ☑ Any restricted-use materials are used correctly
- ☑ No Internal Combustion Engine
- ☑ No stored high-pressure pneumatics
- ☑ No hydraulic system
- ☑ Bot name on exterior in 1/4" or larger letters

Electrical Inspection
- ☑ Master switches mechanically shut off batteries
- ☑ Master switches are 2-position & fully-enclosed
- ☑ Master switch access requires no parts removal
- ☑ Access to all switches is outside weapons paths
- ☑ Batteries are allowed type (SLA, NiCd, NiMH, Li-on) **Lithium Polymer (LiPo) batteries are prohibited**
- ☑ Batteries are mounted securely within chassis
- ☑ Battery terminals/connections are insulated
- ☑ Primary electrical terminals are covered/insulated
- ☑ All wiring properly installed and insulated
- ☑ Maximum voltage does not exceed 28 VDC

Radio Control Equipment
- ☑ Uses IFI, FM R/C or allowed custom controller
- ☑ R/C system not AM, pre-1991, or 72MHz
- ☑ R/C system has two sets of crystals
- ☑ Custom equipment complies with FCC regulations

Powered Weapons
- ☑ Weapons are not electrical/electromagnetic
- ☑ Weapons do not use heat, fire or explosive
- ☑ Weapons are non-fouling and non-obscuring
- ☑ Weapons/Flywheels are securely attached
- ☑ Spring-powered weapon has manual safety release
- ☑ Deactivated weapons pose no hazard to people nearby
- ☑ Projectile tether length does not exceed 4'
- ☑ Less than 30 minutes to change modular weapon

Low-Pressure Pneumatic System

> Verify that system is depressurized
- ☐ Tank is rated for at least 1.5x stored pressure
- ☐ Tank max volume less than 8 Cu. ft.
- ☐ Tank has pressure-reliefs or blowout plugs
- ☐ Tank has a shut-off valve
- ☐ Pneumatic components are correctly rated
- ☐ Components are mounted securely within chassis
- ☐ Components are undamaged
- ☐ Actuators are attached properly
- ☐ Pressure purge valve to relieve pressure
- ☐ Purge and shut-offs are outside weapons paths
- ☐ Access for tank filling is safe and stable

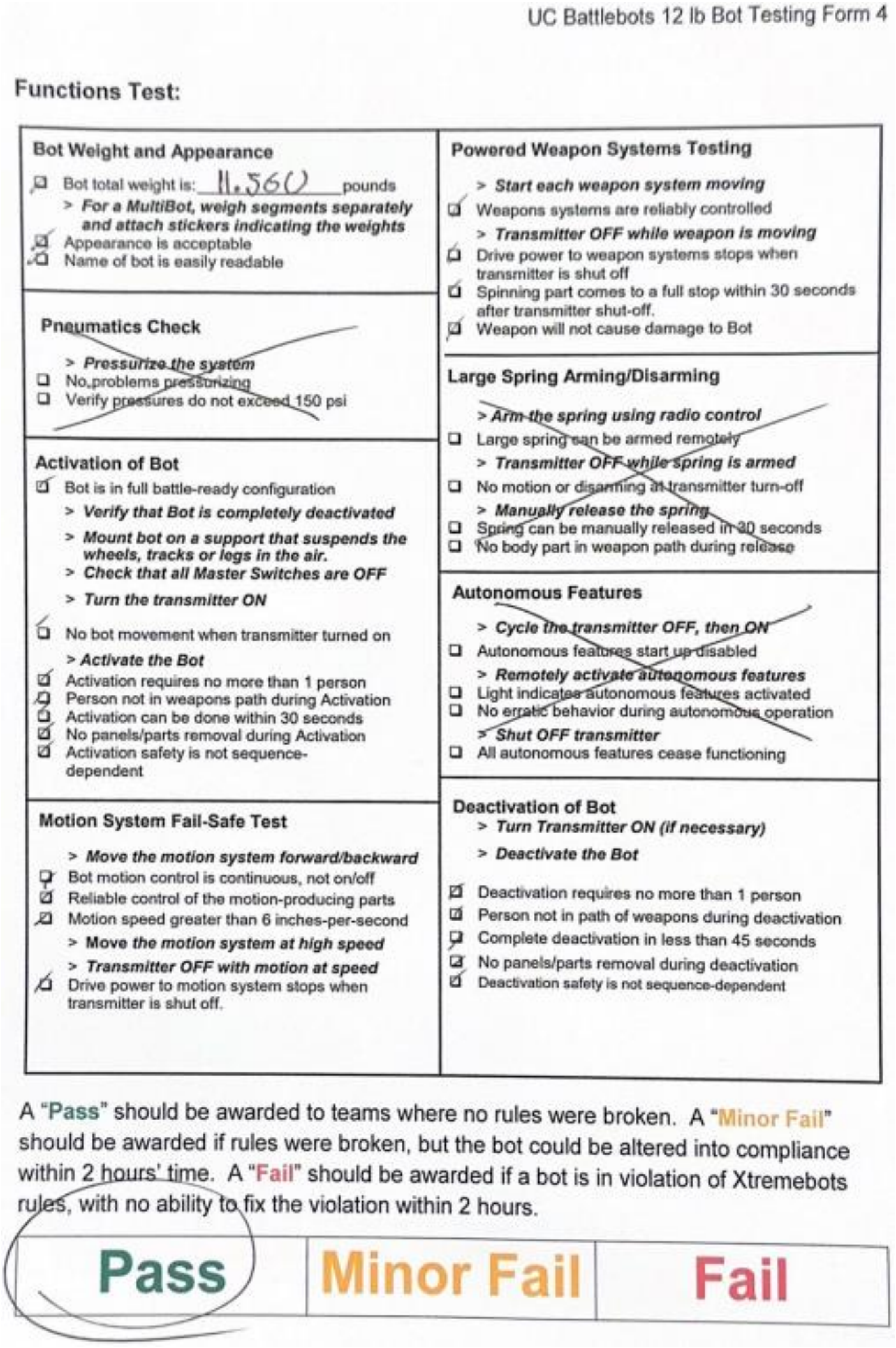
External Equipment
- ☐ Equipment setup/removal takes less than 2 minutes
- ☐ Equipment does not interfere with operations
- ☐ Homing/Targeting laser is class II or below

Additional Items
- ☐ MultiBot meets all specific requirements
- ☐ StompBot complies with 'Walker' requirements
- ☐ Any lighting/sound system can be deactivated

Notes:

A "Pass" should be awarded to teams where no rules were broken. A "Minor Fail" should be awarded if rules were broken, but the bot could be altered into compliance within 2 hours' time. A "Fail" should be awarded if a bot is in violation of Xtremebots rules, with no ability to fix the violation within 2 hours.

[✓ **Pass**] **Minor Fail** **Fail**



UC Battlebots 12 lb Bot Testing Form 4

Functions Test:

Bot Weight and Appearance

☑ Bot total weight is: 11.560 pounds
> *For a MultiBot, weigh segments separately and attach stickers indicating the weights*

☑ Appearance is acceptable
☑ Name of bot is easily readable

~~Pneumatics Check~~

> ~~*Pressurize the system*~~

☐ ~~No problems pressurizing~~
☐ ~~Verify pressures do not exceed 150 psi~~

Activation of Bot

☑ Bot is in full battle-ready configuration
> *Verify that Bot is completely deactivated*
> *Mount bot on a support that suspends the wheels, tracks or legs in the air.*
> *Check that all Master Switches are OFF*
> *Turn the transmitter ON*

☑ No bot movement when transmitter turned on
> *Activate the Bot*

☑ Activation requires no more than 1 person
☑ Person not in weapons path during Activation
☑ Activation can be done within 30 seconds
☑ No panels/parts removal during Activation
☑ Activation safety is not sequence-dependent

Motion System Fail-Safe Test

> *Move the motion system forward/backward*

☑ Bot motion control is continuous, not on/off
☑ Reliable control of the motion-producing parts
☑ Motion speed greater than 6 inches-per-second
> *Move the motion system at high speed*
> *Transmitter OFF with motion at speed*

☑ Drive power to motion system stops when transmitter is shut off.

Powered Weapon Systems Testing

> *Start each weapon system moving*

☑ Weapons systems are reliably controlled
> *Transmitter OFF while weapon is moving*

☑ Drive power to weapon systems stops when transmitter is shut off
☑ Spinning part comes to a full stop within 30 seconds after transmitter shut-off.
☑ Weapon will not cause damage to Bot

~~Large Spring Arming/Disarming~~

> ~~*Arm the spring using radio control*~~

☐ ~~Large spring can be armed remotely~~
> ~~*Transmitter OFF while spring is armed*~~

☐ ~~No motion or disarming at transmitter turn-off~~
> ~~*Manually release the spring*~~

☐ ~~Spring can be manually released in 30 seconds~~
☐ ~~No body part in weapon path during release~~

~~Autonomous Features~~

> ~~*Cycle the transmitter OFF, then ON*~~

☐ ~~Autonomous features start up disabled~~
> ~~*Remotely activate autonomous features*~~

☐ ~~Light indicates autonomous features activated~~
☐ ~~No erratic behavior during autonomous operation~~
> ~~*Shut OFF transmitter*~~

☐ ~~All autonomous features cease functioning~~

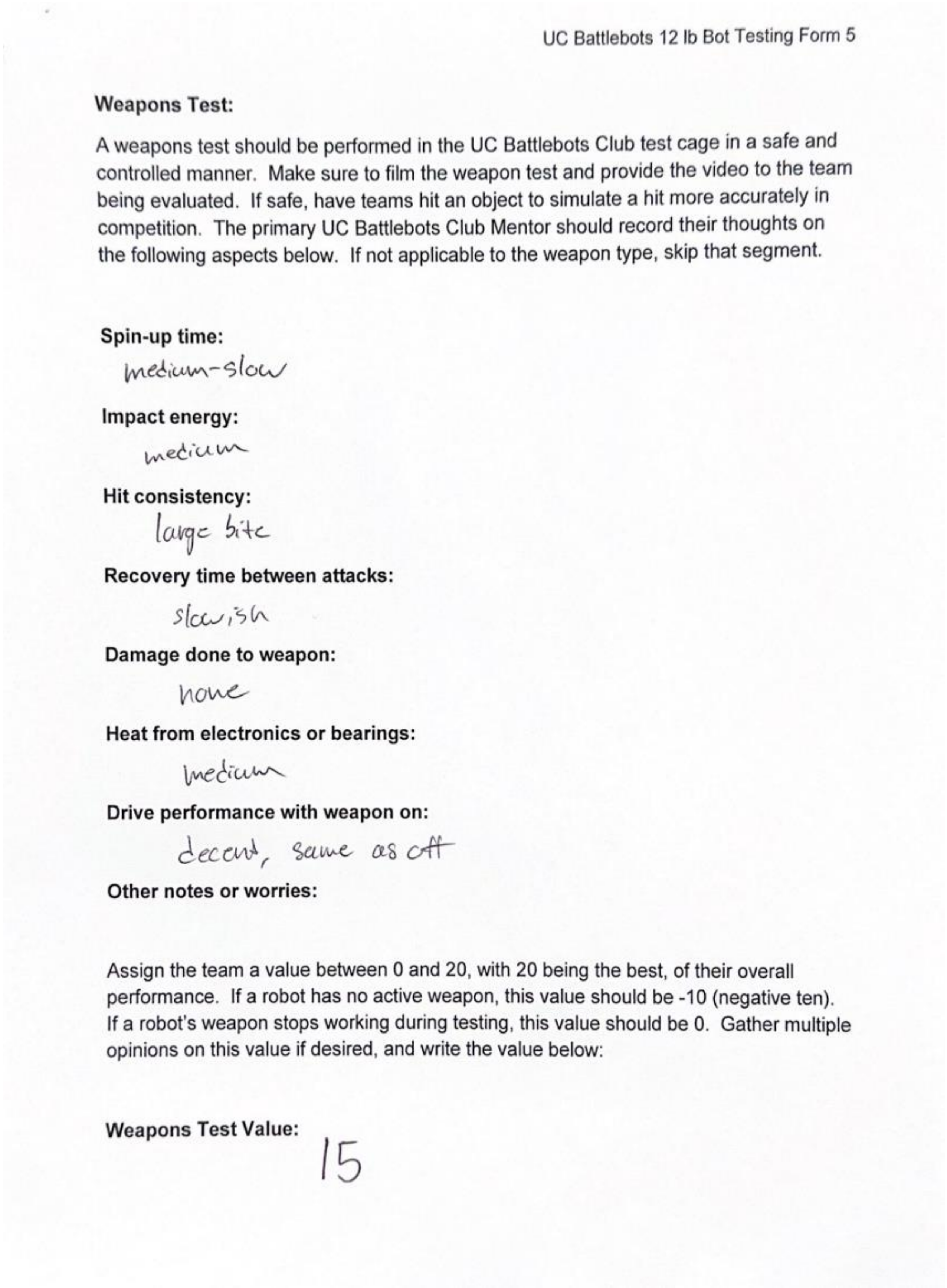
Deactivation of Bot

> *Turn Transmitter ON (if necessary)*
> *Deactivate the Bot*

☑ Deactivation requires no more than 1 person
☑ Person not in path of weapons during deactivation
☑ Complete deactivation in less than 45 seconds
☑ No panels/parts removal during deactivation
☑ Deactivation safety is not sequence-dependent

A "Pass" should be awarded to teams where no rules were broken. A "Minor Fail" should be awarded if rules were broken, but the bot could be altered into compliance within 2 hours' time. A "Fail" should be awarded if a bot is in violation of Xtremebots rules, with no ability to fix the violation within 2 hours.

[✓ **Pass**]	**Minor Fail**	**Fail**



UC Battlebots 12 lb Bot Testing Form 5

Weapons Test:

A weapons test should be performed in the UC Battlebots Club test cage in a safe and controlled manner. Make sure to film the weapon test and provide the video to the team being evaluated. If safe, have teams hit an object to simulate a hit more accurately in competition. The primary UC Battlebots Club Mentor should record their thoughts on the following aspects below. If not applicable to the weapon type, skip that segment.

Spin-up time:

medium-slow

Impact energy:

medium

Hit consistency:

large bite

Recovery time between attacks:

slowish

Damage done to weapon:

none

Heat from electronics or bearings:

medium

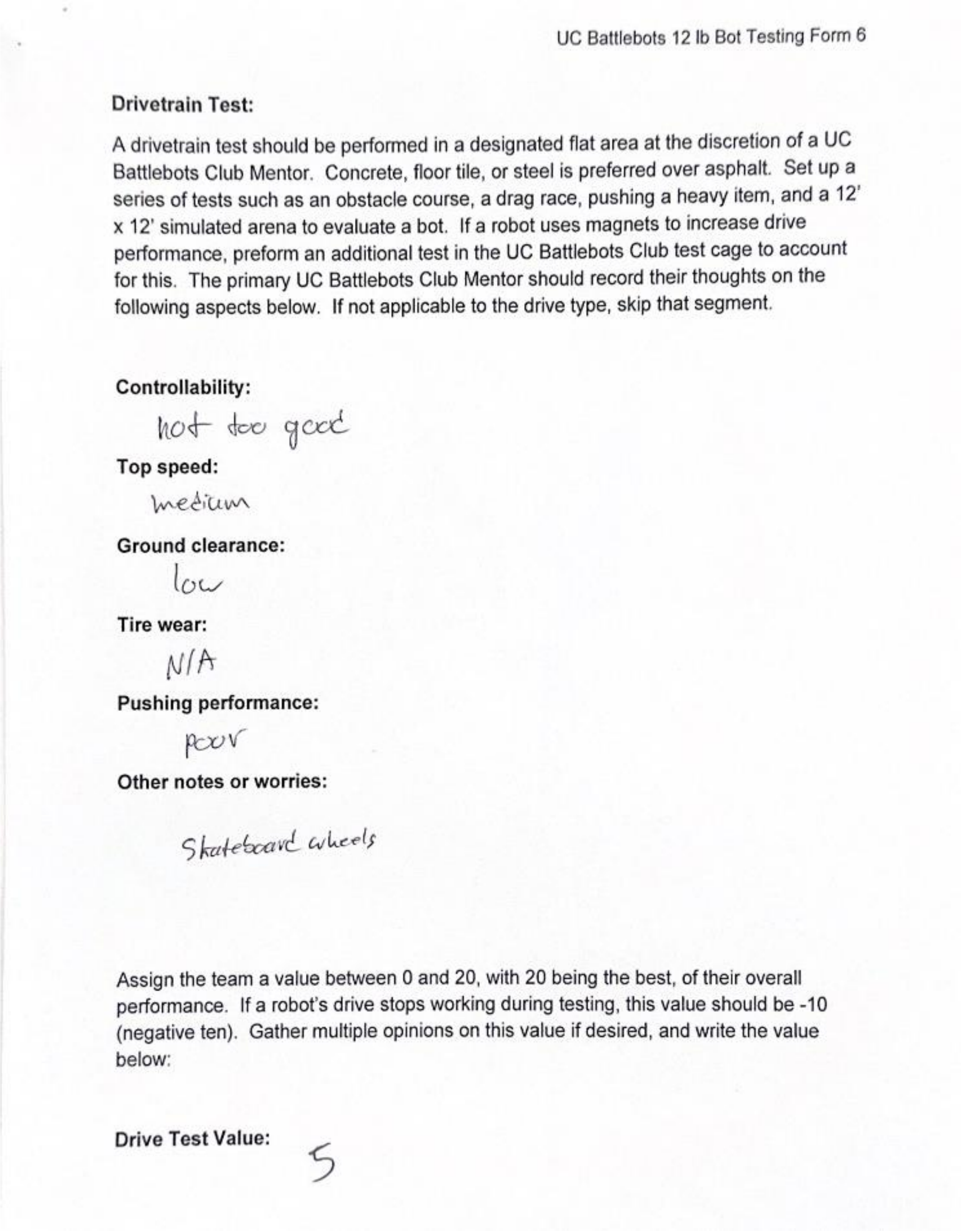
Drive performance with weapon on:

decent, same as off

Other notes or worries:

Assign the team a value between 0 and 20, with 20 being the best, of their overall performance. If a robot has no active weapon, this value should be -10 (negative ten). If a robot's weapon stops working during testing, this value should be 0. Gather multiple opinions on this value if desired, and write the value below:

Weapons Test Value: 15



UC Battlebots 12 lb Bot Testing Form 6

Drivetrain Test:

A drivetrain test should be performed in a designated flat area at the discretion of a UC Battlebots Club Mentor. Concrete, floor tile, or steel is preferred over asphalt. Set up a series of tests such as an obstacle course, a drag race, pushing a heavy item, and a 12' x 12' simulated arena to evaluate a bot. If a robot uses magnets to increase drive performance, preform an additional test in the UC Battlebots Club test cage to account for this. The primary UC Battlebots Club Mentor should record their thoughts on the following aspects below. If not applicable to the drive type, skip that segment.

Controllability:

not too good

Top speed:

medium

Ground clearance:

low

Tire wear:

N/A

Pushing performance:

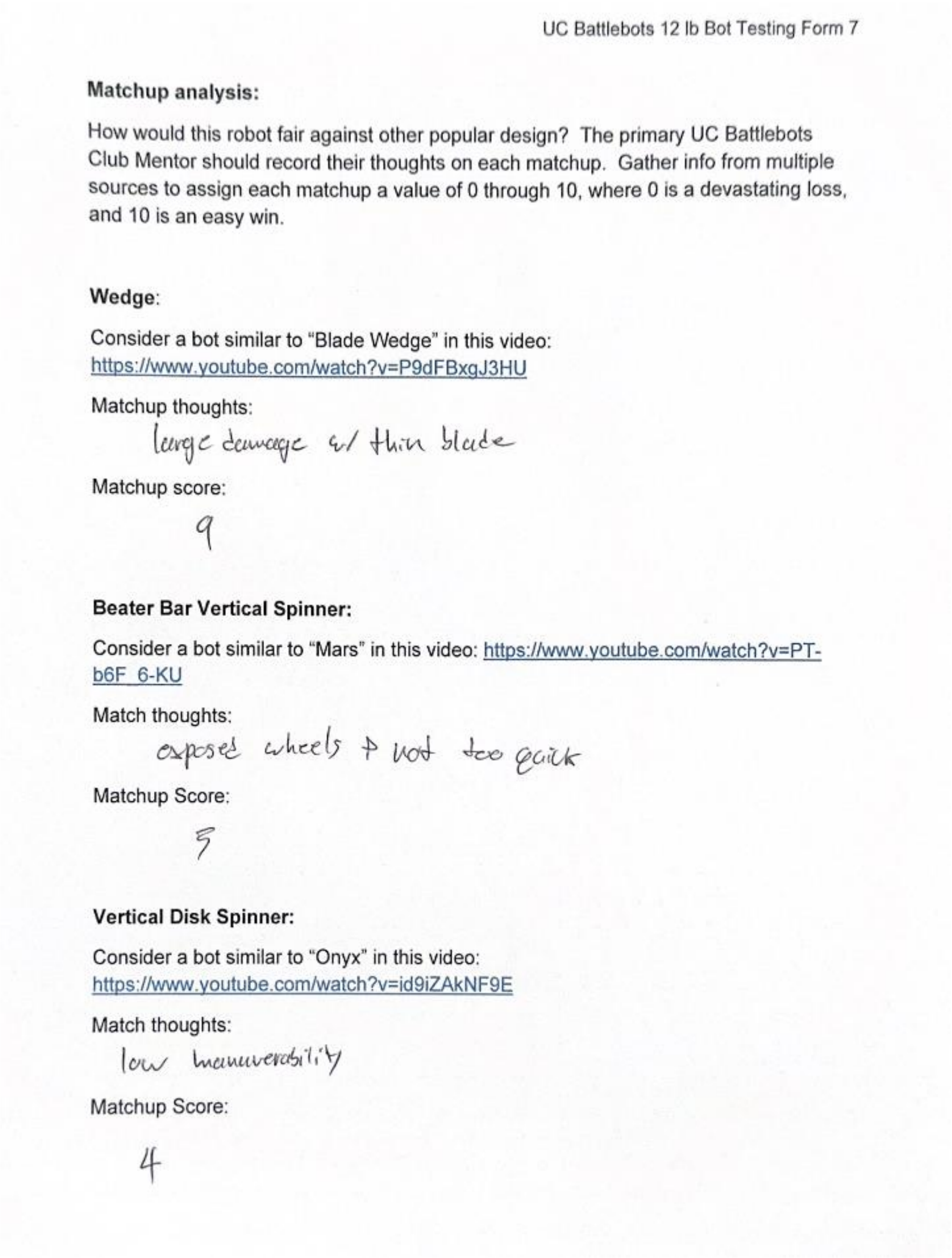
poor

Other notes or worries:

Skateboard wheels

Assign the team a value between 0 and 20, with 20 being the best, of their overall performance. If a robot's drive stops working during testing, this value should be -10 (negative ten). Gather multiple opinions on this value if desired, and write the value below:

Drive Test Value: 5



Matchup analysis:

How would this robot fair against other popular design? The primary UC Battlebots Club Mentor should record their thoughts on each matchup. Gather info from multiple sources to assign each matchup a value of 0 through 10, where 0 is a devastating loss, and 10 is an easy win.

Wedge:

Consider a bot similar to "Blade Wedge" in this video: https://www.youtube.com/watch?v=P9dFBxgJ3HU

Matchup thoughts:

large damage w/ thin blade

Matchup score:

9

Beater Bar Vertical Spinner:

Consider a bot similar to "Mars" in this video: https://www.youtube.com/watch?v=PT-b6F_6-KU

Match thoughts:

exposed wheels & not too quick

Matchup Score:

5

Vertical Disk Spinner:

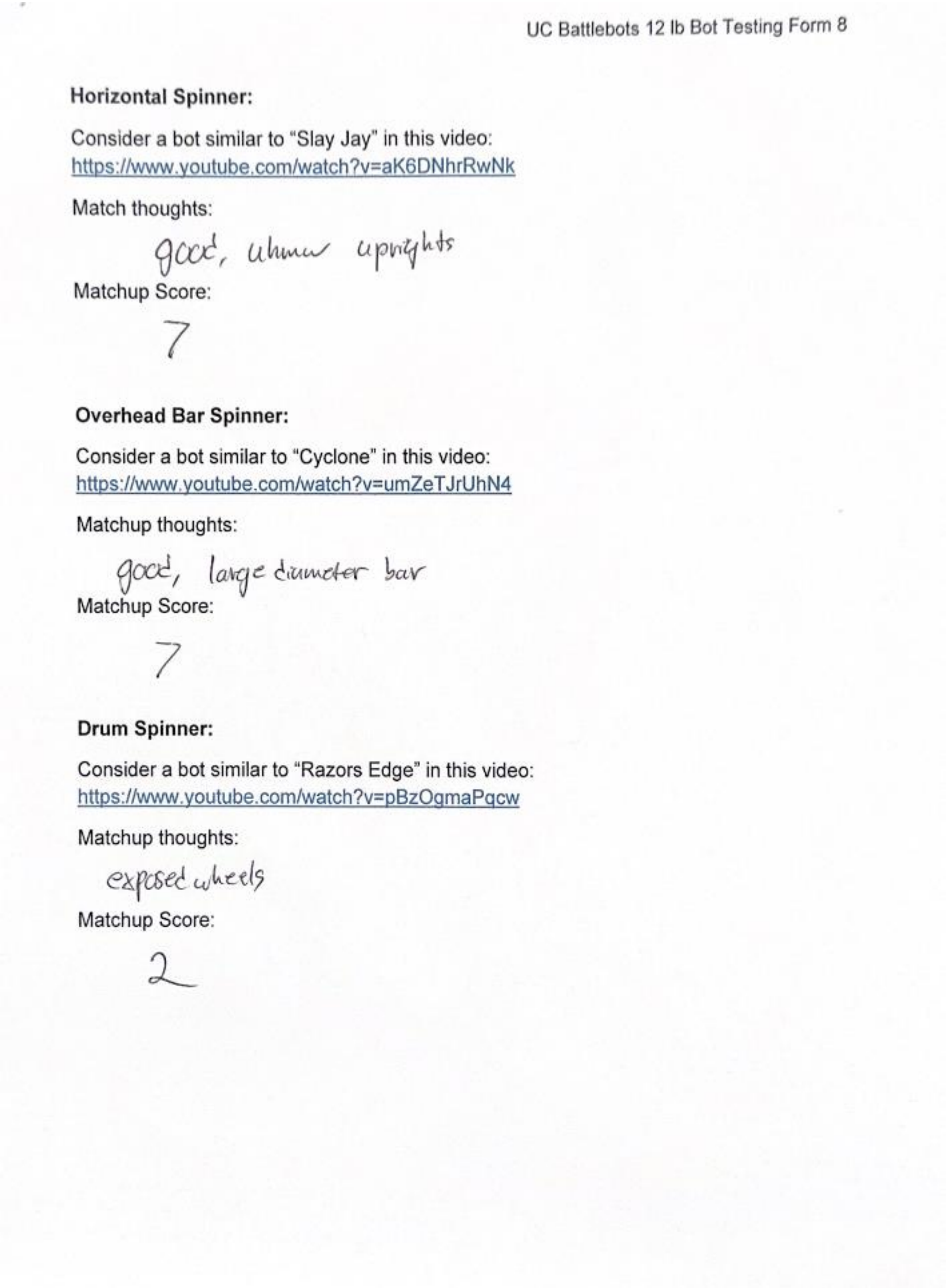
Consider a bot similar to "Onyx" in this video: https://www.youtube.com/watch?v=id9iZAkNF9E

Match thoughts:

low maneuverability

Matchup Score:

4



UC Battlebots 12 lb Bot Testing Form 8

Horizontal Spinner:

Consider a bot similar to “Slay Jay” in this video:
https://www.youtube.com/watch?v=aK6DNhrRwNk

Match thoughts:

good, thinner uprights

Matchup Score:

7

Overhead Bar Spinner:

Consider a bot similar to “Cyclone” in this video:
https://www.youtube.com/watch?v=umZeTJrUhN4

Matchup thoughts:

good, large diameter bar

Matchup Score:

7

Drum Spinner:

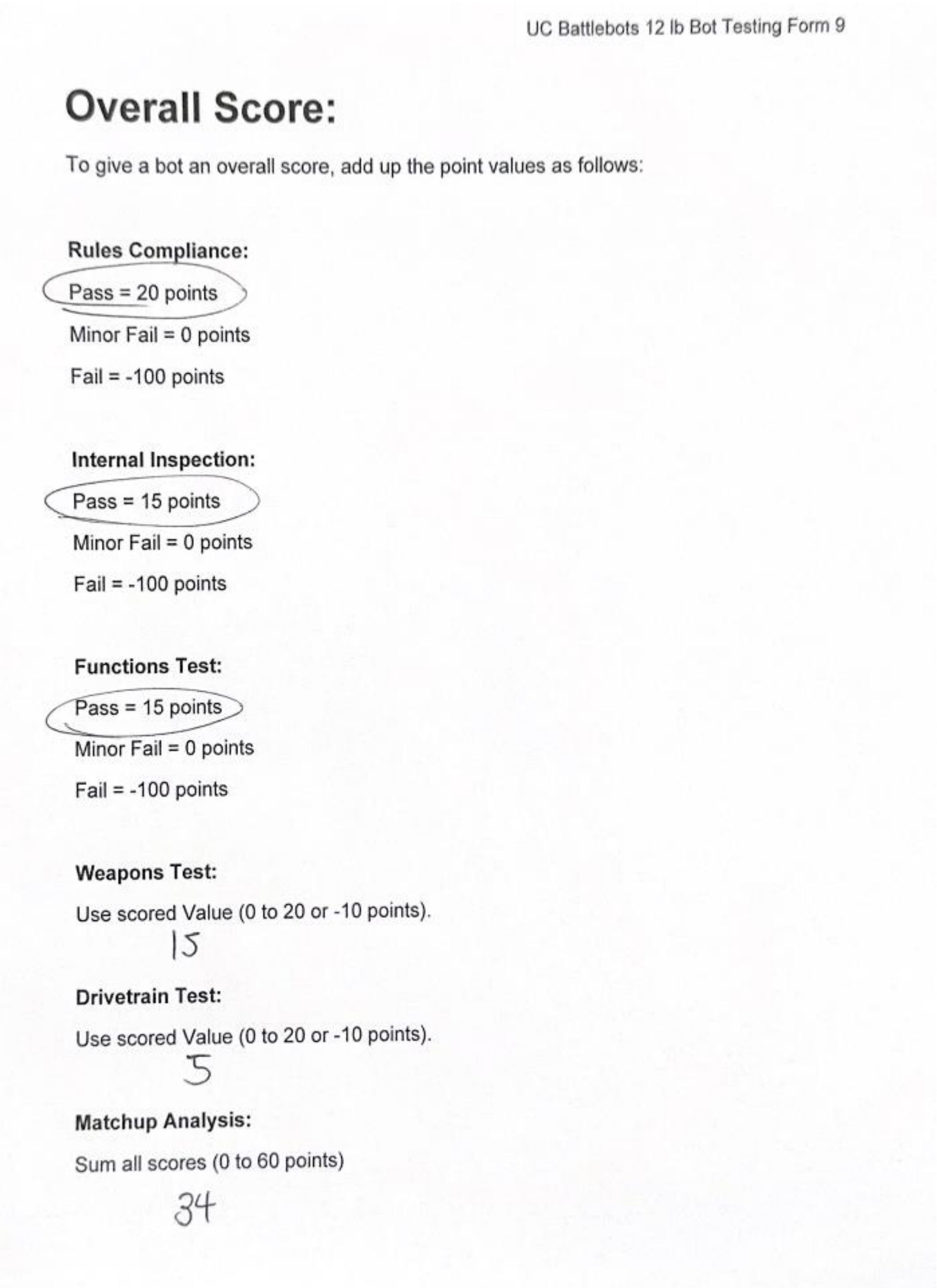
Consider a bot similar to “Razors Edge” in this video:
https://www.youtube.com/watch?v=pBzOgmaPqcw

Matchup thoughts:

exposed wheels

Matchup Score:

2



UC Battlebots 12 lb Bot Testing Form 9

Overall Score:

To give a bot an overall score, add up the point values as follows:

Rules Compliance:

[✓ Pass = 20 points]

Minor Fail = 0 points

Fail = -100 points

Internal Inspection:

[✓ Pass = 15 points]

Minor Fail = 0 points

Fail = -100 points

Functions Test:

[✓ Pass = 15 points]

Minor Fail = 0 points

Fail = -100 points

Weapons Test:

Use scored Value (0 to 20 or -10 points).

15

Drivetrain Test:

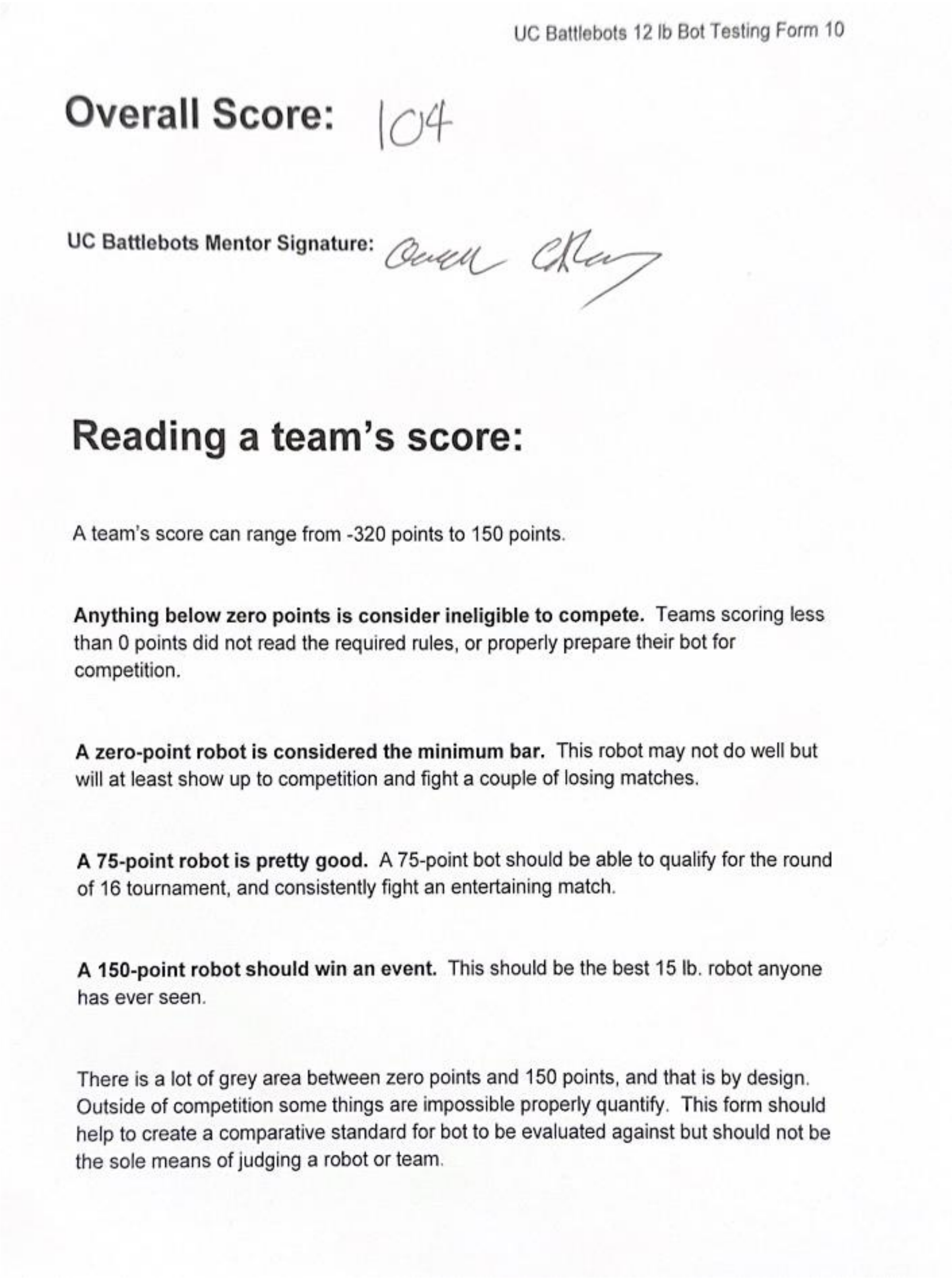
Use scored Value (0 to 20 or -10 points).

5

Matchup Analysis:

Sum all scores (0 to 60 points)

34



UC Battlebots 12 lb Bot Testing Form 10

Overall Score: 104

UC Battlebots Mentor Signature:

Reading a team's score:

A team's score can range from -320 points to 150 points.

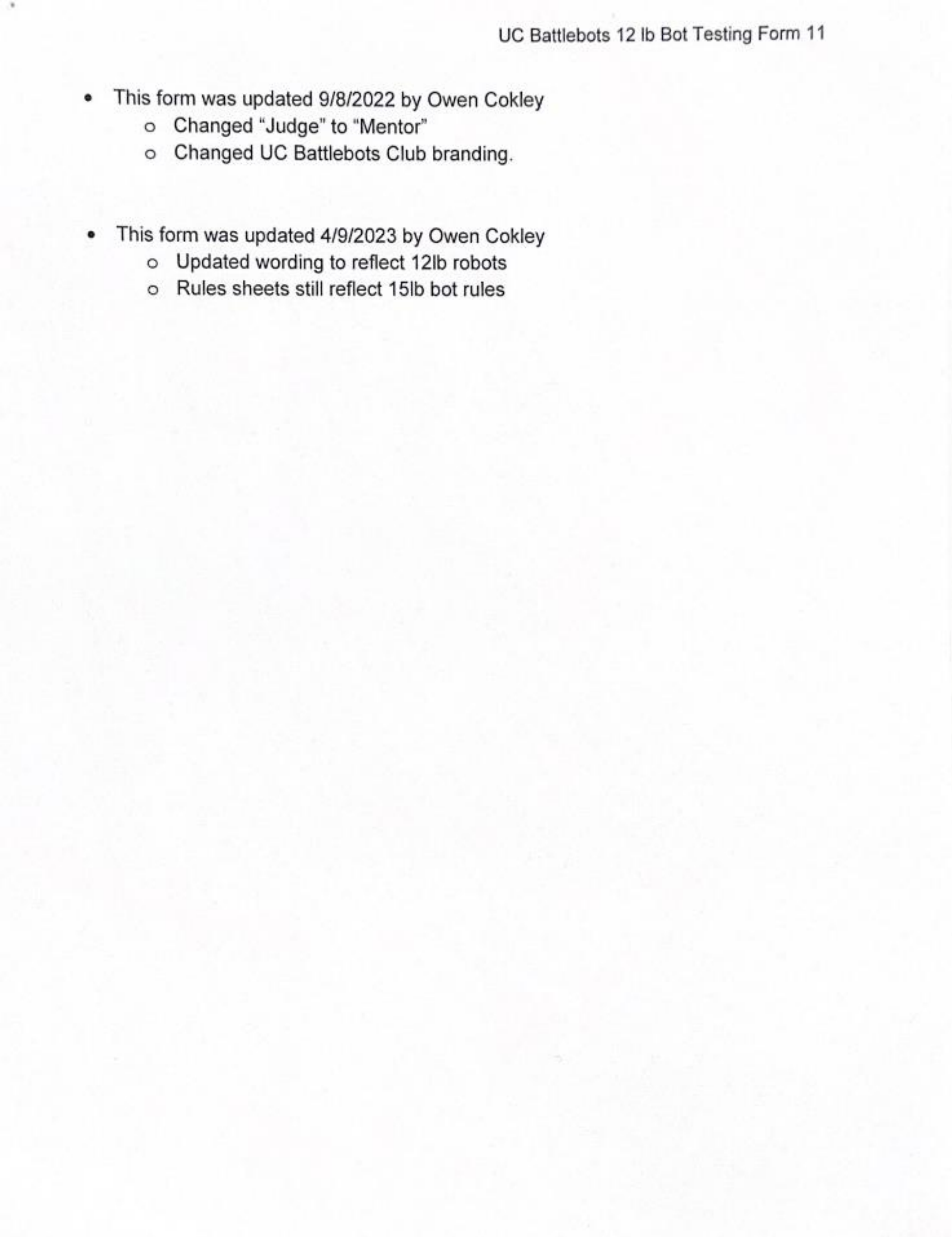
Anything below zero points is consider ineligible to compete. Teams scoring less than 0 points did not read the required rules, or properly prepare their bot for competition.

A zero-point robot is considered the minimum bar. This robot may not do well but will at least show up to competition and fight a couple of losing matches.

A 75-point robot is pretty good. A 75-point bot should be able to qualify for the round of 16 tournament, and consistently fight an entertaining match.

A 150-point robot should win an event. This should be the best 15 lb. robot anyone has ever seen.

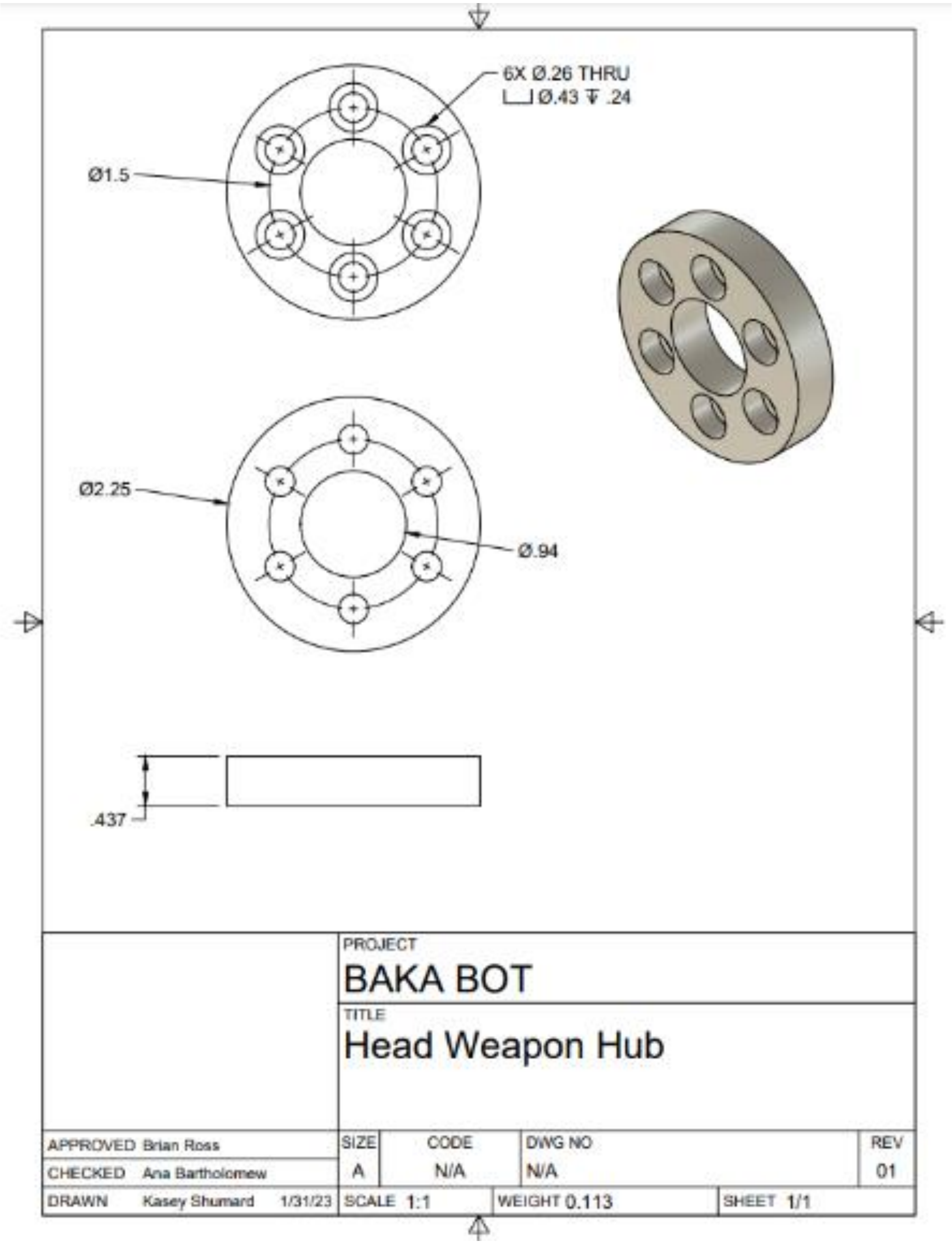
There is a lot of grey area between zero points and 150 points, and that is by design. Outside of competition some things are impossible properly quantify. This form should help to create a comparative standard for bot to be evaluated against but should not be the sole means of judging a robot or team.



- This form was updated 9/8/2022 by Owen Cokley
    - Changed “Judge” to “Mentor”
    - Changed UC Battlebots Club branding.

- This form was updated 4/9/2023 by Owen Cokley
    - Updated wording to reflect 12lb robots
    - Rules sheets still reflect 15lb bot rules

Appendix F (Engineering Drawings):

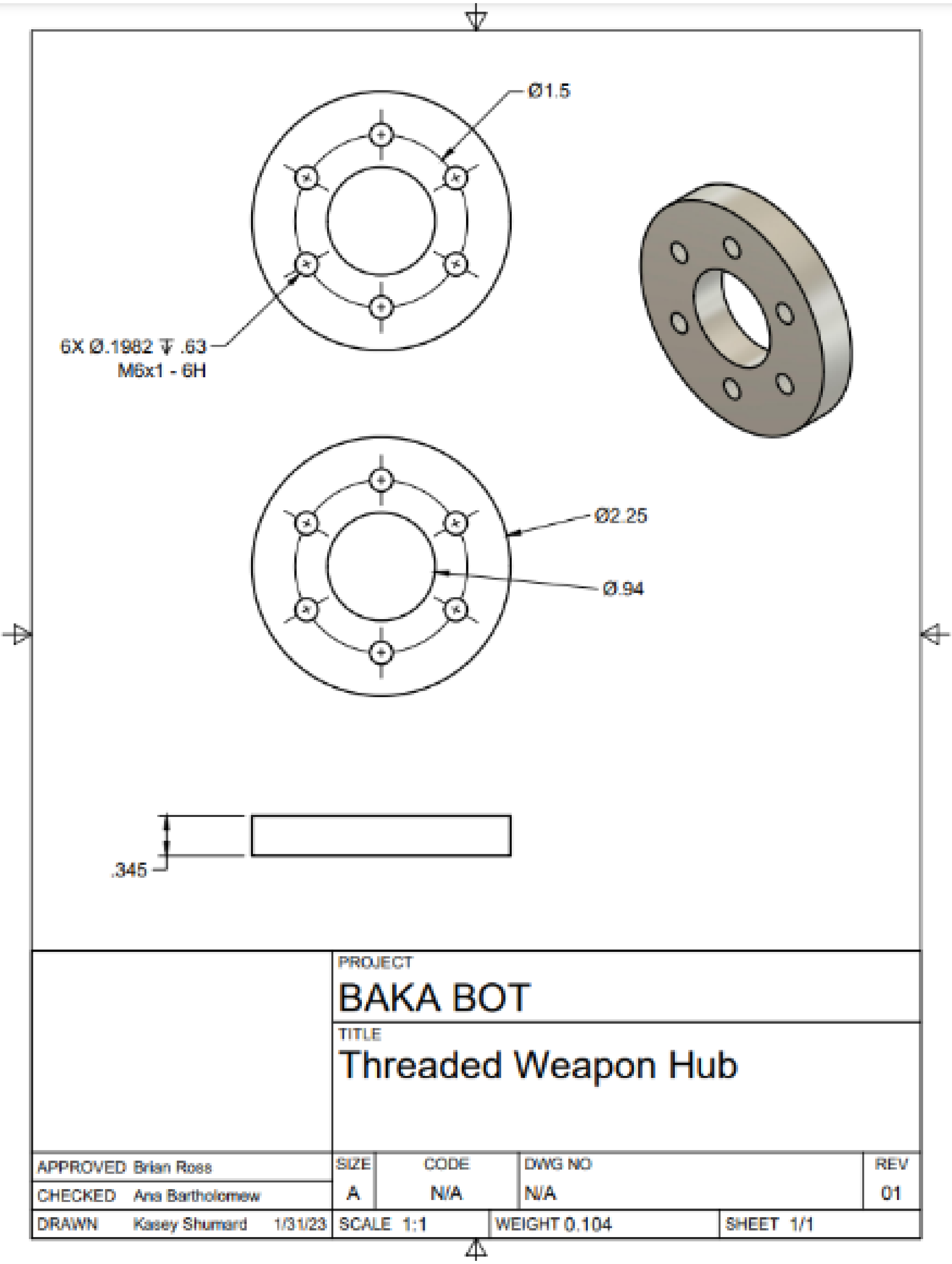


PROJECT
BAKA BOT

TITLE
Head Weapon Hub

APPROVED Brian Ross
CHECKED Ana Bartholomew
DRAWN Kasey Shumard 1/31/23

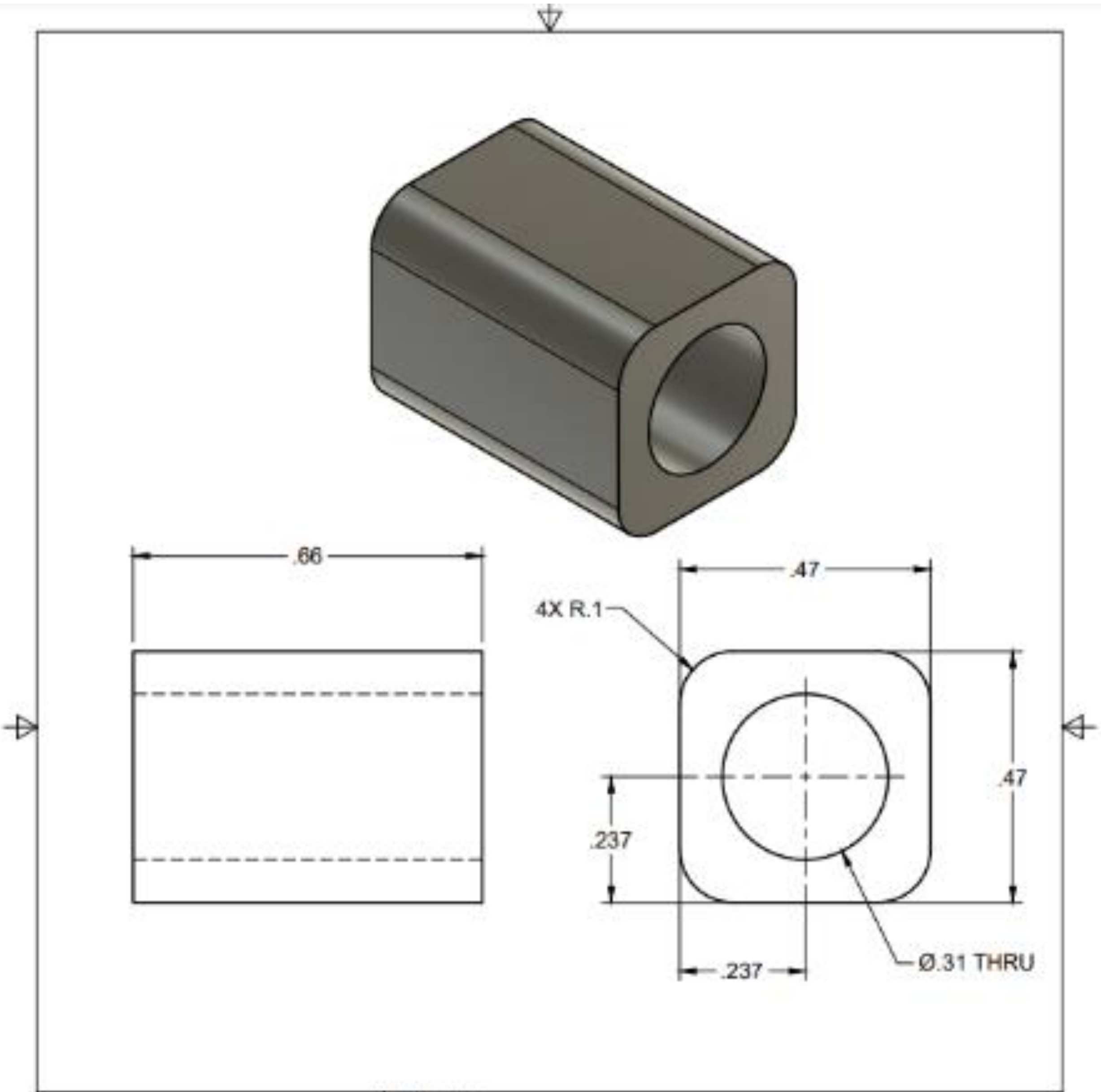
SIZE A
CODE N/A
DWG NO N/A
REV 01
SCALE 1:1
WEIGHT 0.113
SHEET 1/1



PROJECT
BAKA BOT

TITLE
Threaded Weapon Hub

APPROVED Brian Ross
CHECKED Ana Bartholomew
DRAWN Kasey Shumard 1/31/23
SIZE A
CODE N/A
DWG NO N/A
REV 01
SCALE 1:1
WEIGHT 0.104
SHEET 1/1



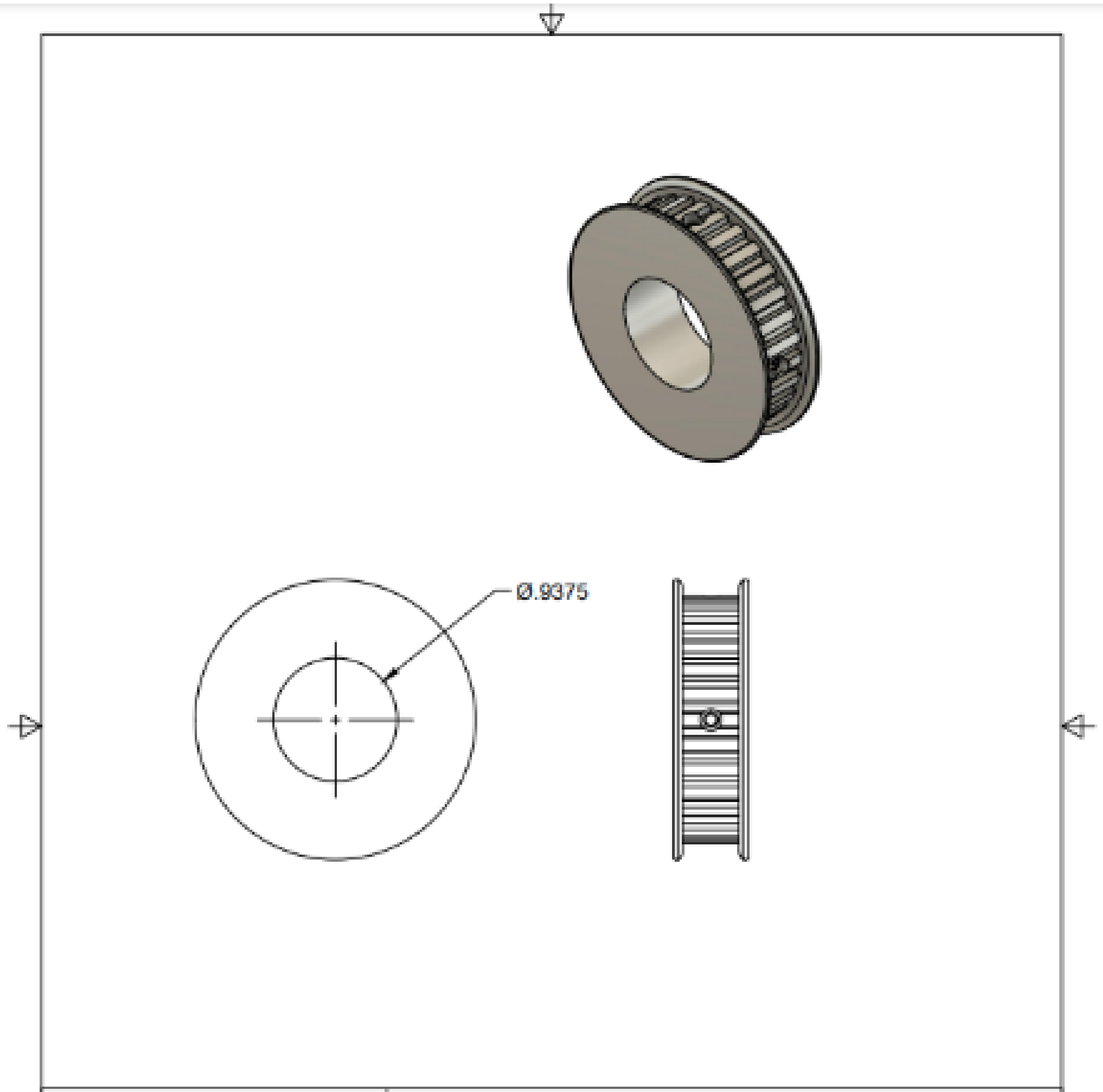
PROJECT
BAKA BOT

TITLE
Drivetrain Square Spacer

APPROVED Brian Ross
CHECKED Ana Bartholomew
DRAWN Kasey Shumard 2/28/2023

SIZE	CODE	DWG NO	REV
A	N/A	N/A	02

SCALE 4:1
WEIGHT 0.026
SHEET 1/1



PROJECT

BAKA BOT

TITLE

Large Weapon Pulley

APPROVED Brian Ross

CHECKED Ana Bartholomew

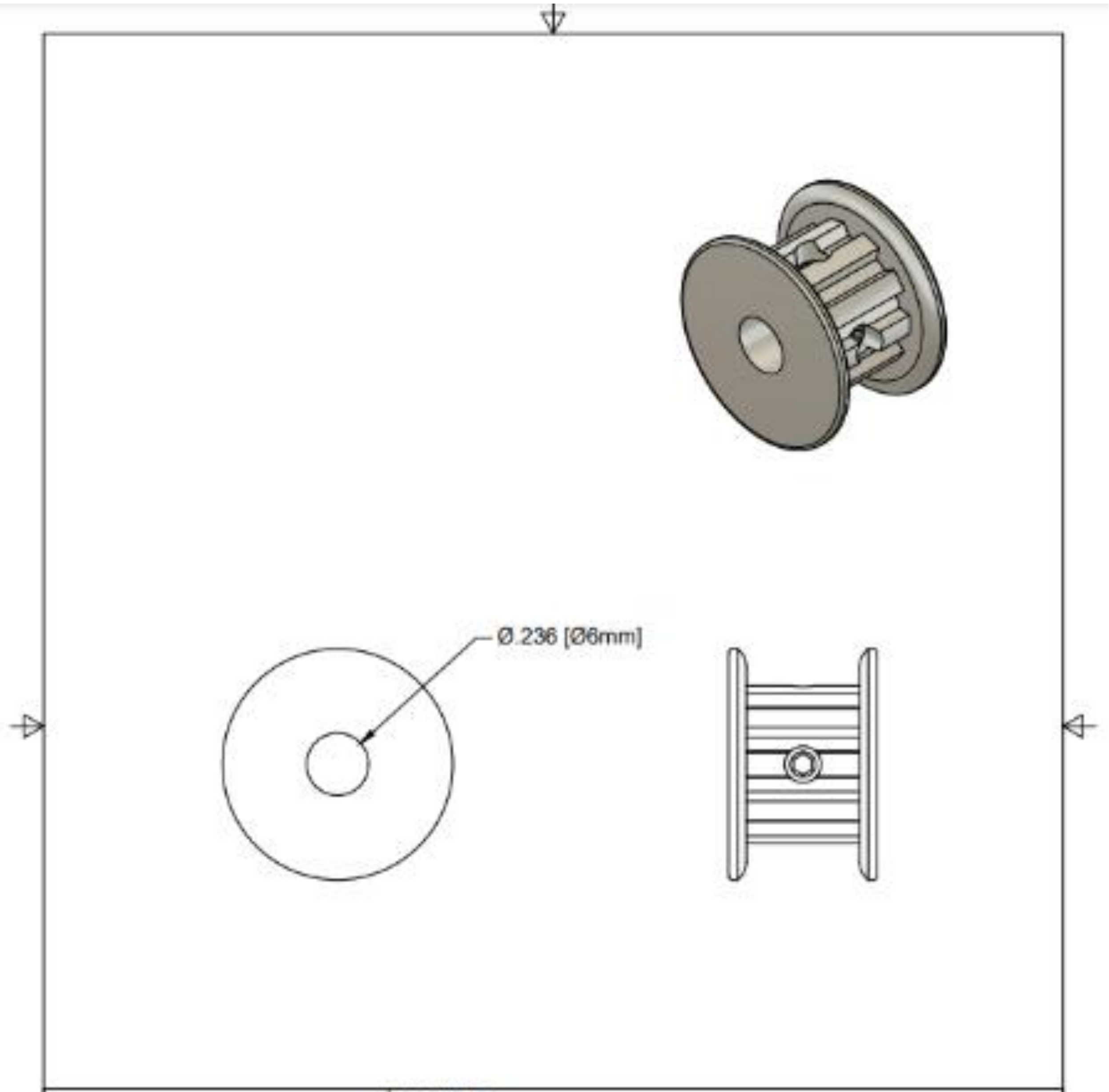
DRAWN Kasey Shumard 1/31/2023

SIZE	CODE	DWG NO	REV
A	N/A	1277N771	01

SCALE 1:1

WEIGHT 0.118

SHEET 1/1



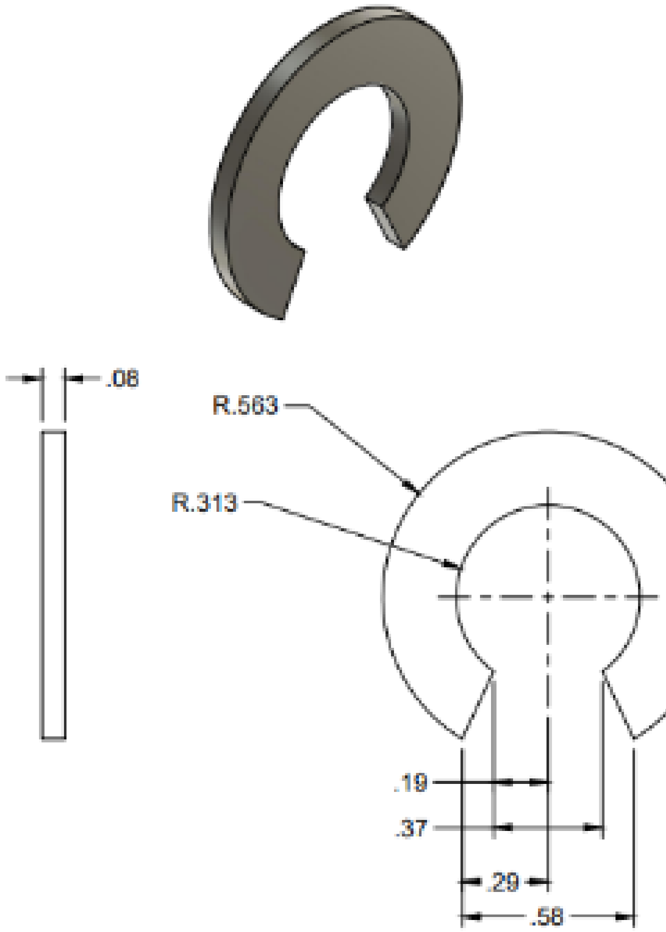
PROJECT
BAKA BOT

TITLE
Small Weapon Pulley

APPROVED Brian Ross
CHECKED Ana Bartholomew
DRAWN Kasey Shumard 1/31/2023

SIZE	CODE	DWG NO	REV
A	N/A	1277N735	01

SCALE 2:1
WEIGHT 0.013
SHEET 1/1



PROJECT
BAKA BOT

TITLE
Drivetrain Custom Washer

APPROVED Brian Ross
CHECKED Ana Bartholomew
DRAWN Kasey Shumard 4/22/2023

SIZE A
CODE N/A
DWG NO N/A
REV 01
SCALE 2:1
WEIGHT 0.013
SHEET 1/1