Combat Robotics: Murder Burger

Senior Design Proposal submitted to the

Department of Mechanical & Materials Engineering

College of Engineering & Applied Science

University of Cincinnati

In partial fulfillment of the

requirements for the degree of

Bachelor of Science:

Mechanical Engineering Technology

by

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Background

Combat Robotics began as an underground phenomenon with hobbyists & engineers of the 1990s bringing mechanical creations to makeshift arenas & fighting (1). Quickly, television channels like comedy central were made aware of the excitement & ingenuity of these early competitions & worked to nationally televise them. In 2015, a combat robotics resurgence occurred when ABC picked up the BattleBots series & showcased the competitions to a whole new generation. Eventually, BattleBots moved from ABC to the Discovery Channel, while also gaining a significant following via YouTube. There are now official leagues of combat robotics such as NHRL & MRCA that have tournaments & championships broadcast live year around. NHRL, or National Havoc Robotic League, was founded in 2018 by Austin McChord & Ryan Sasloe. Since 2018, the league has gained a significant following with 525,000 subscribers & the BattleBots show boasts 2.12 million subscribers on YouTube.

In general, the cost to create a functional combat robot is $100 per pound (2). ”12lb bots are primarily made of aluminum or machined plastic, with steel & 3D printed plastic components making up the internals. The motors & electronics used are still general RC components most of the time, helping to keep costs relatively reasonable. A competitive 12lb robot can be built for less than $1000” (3).

Current popular design solutions for combat robotics are Horizontal, Vertical & Ring Spinners, Control Bots, & Hammer Bots. With all spinners, the goal is to charge up a spinner with stored energy & hit the opposing bot as hard as possible, ideally causing internal failure to the bot or damage to its spinner. Control bots benefit from maneuverability & control time in the arena. Hammer bots carefully work to line up significant strikes & execute on opposing bots. All designs are vulnerable to other designs, meaning there is not one single optimal design.

Applicable Standards

The following standards are design constraints required for fighting in the 12-pound Hobby Weight class of NHRL (4). through the UC Combat Robotics Team:

- Robot must fit within a 36in x 36in x 36in box
- Robot must have a safety lock on it to ensure the spinner cannot move when powered off
- Robot must have a way to turn off power without disassembling the robot
- All robots must pass a fail-safe test
- All robots must have an active weapon*. Defined as a mechanism that operates independently from the robot's drivetrain or means of locomotion & is clearly designed to influence the opposing robot.
- Robots receive a weight bonus for non-standard locomotion; meaning no wheels used
- Nominal battery voltage may not exceed 75 volts for a 12lb bot
- A fired projectile's maximum speed may not exceed 150 miles per hour
- No heat weapons*, flame throwers*, mini bots*

All rules marked by asterisk, *, are rules mandated by UCCR. In NHRL, there are 4 standard weight classes. All UCCR senior design teams build Hobby Weights.

Weight Class Name	Maximum Weight
Ant Weight	1 lb.
Beetle Weight	3 lb.
Hobby Weight	12 lb.
Feather Weight	30 lb.

Table 1: NHRL Weight Classes

Current State of the Art

Current State of the Art: Horizontal Spinner

Horizontal Spinners in combat robotics feature a large fast-moving disk that spins on the horizontal axis. This spinner style can be featured in the front or back of the robot & is especially successful against vertical spinner robots & robots with lift arms. Horizontal spinners can be mounted at different heights, depending on the desired results & damage output. These three different heights are known as under-cutters, mid-cutters, & over-cutters.

The horizontal spinner design allows for much of the robot weight to go directly into the Spinner, & the use of two wheels allows the robot to spin around quickly & attack on any side. However, while horizontal spinners thrive against vertical spinners & most other combat robot types, defense robots with ramps can minimize damage from horizontal spinners.

Figure 1: Tombstone (5)

Current State of the Art: Vertical Spinner

Vertical spinner robots have a fast-moving disk mounted to the front of the robot. These spinners rotate in the vertical plane & are designed for versatile high impacts against the opponents. Vertical spinners may also be defined as “beater bars” & “drum spinner.” Beater bars & drum spinners also have a high impact against the opposing robot but instead of having a small footprint on the robot they tend to take up the whole front side of the robot or are designed to be the body of both themselves.

While Vertical spinners have been becoming increasingly popular amongst contestants of combat robotics, the spinner itself has a low area of impact meaning it must get close to the opposing bot risking receiving damage itself. Because of the high inertia of the Spinner spinning in the opposite plane in which the robot is moving, a vertical spinner can be a challenge to control causing it to flip over more easily.

Figure 2: Bite Force (6)

Figure 3: Saiko!

Current State of the Art: Ring Spinners

A Ring Spinner robot is designed to be able to attack on all sides, with a spinner that spins a full 360 degrees around the body in the horizontal plane. Ring Spinners are purely offensive robots. The robot allows for easy hits on the opponents, while also dishing out damage to the opponent when being attacked. These generally low to the ground robots allow for easy control, & fast speed, allowing to get around their opponents & attack from behind with speed.

Since the Ring Spinner design is a horizontal robot, it can easily be unarmed with a robot that has a ramp as its defense. The ramp will lift the spinner just enough that it spins in the air unable to hit its opponent. Another downside to the Ring Spinner is that if flipped upside down, it cannot use any momentum from the spinner to aid in returning the robot back to its wheel.

Figure 4: Captain Shrederator (7)

Current State of the Art: Control Bots

A Control bot is designed to be fast & easy to maneuver. Its main attack strategy involves lifting its opponents to flip it over, minimizing the damage it may receive. A Control bot has forks or a ramp at the robot's front to help get the opposing robot off the ground. If the robot has a ramp in the front of the bot, it will fare well against an opponent with any type of horizontal spinners, but if the robot has forks at the front, then it will do well against a vertical spinner or Hammer/Crusher bot. Since there is no spinner, the Control robot does not have to worry about the forces of the spinner counteracting against it, allowing for a simpler design with high stability & control.

A Control bot is strictly a defensive robot. Since it does not have a spinner, if it receives an attack from behind or is not moving fast enough, the opponent can quickly sneak up behind & deal out damage. This robot, because of the location of its ramps/forks, must always charge the opposing robot from the front.

Figure 5: Banshee (8)

Current State of the Art: Hammer/Crusher Bots

Hammer or Crusher robots are designed to line up a high impact shot to an opponent with a large, weighted arm that can be lifted & swung. Hammer robots when attacking deal a high amount of damage. This damage usually results in damage to the top side of the opposing robot. Because of this, the opposing robot would need to have durable top plates to ensure that the motor & other electrical components inside of its body do not get damaged. These robots usually have larger bodies that provide stability, preventing it from flipping over as easily.

Hammer/Crusher robots, while they do wield higher damage, have a small attack range. If the opponent is too quick, then the hammer bot misses its open opportunity to get a solid hit on the opponent. The hammer itself is also not an active spinner. To get the full power of the swing it must retract all the way back to its starting position. This proves a disadvantage since other robots with spinners are active constantly, being able to inflict damage on the hammer bot more frequently.

Figure 6: Beta (9)

Current State of the Art: Locomotion

Locomotion for combat robotics is the form of transportation/traverse for each robot. Generally, two to four wheels with front, rear or all-wheel drive are used as each robot's primary form of movement. However, some designers take advantage of the NHRL's extra weight allowances due to abnormal locomotion styles. An example of abnormal locomotion would be "shuffler" style locomotion. The robot has no wheels & relies on vibrations or abrupt back & forth motion of "legs" to move around the field. Naturally, these are harder to maneuver than traditional wheeled designs. If the abnormal locomotion design is effective, this can allow the robot to have a leg up on the competition with some extra weight above the class limit.

Another example of abnormal locomotion would be using continuous-track treads in place of a wheeled assembly. Resembling a tank, these robots would have more surface contact than wheels, providing more traction in the field. An argument could be made that continuous-track treads are a more effective mode of locomotion, but there are associated drawbacks & risks. If the continuous-track breaks, the entire side of the robot can be considered non-functional as 50% of its effective locomotion is not operational. The design process for continuous-track treads can also be more tedious & complicated to implement than a standard wheel assembly. Overall, each form of locomotion, whether traditional or abnormal, has its own advantages & disadvantages.

Current State of the Art: Armor

Armor for a combat robot comes in many varieties. Some robots rely strictly on the material that their body is made of as armor & other robots rely on plates of a stronger material, such as titanium, to resist most of the impact of any damage. The most common material of armor on a combat robot is aluminum, plastic, or titanium. Picking the right material for armor can allow the driver of the robot to focus solely on fighting & being more aggressive in the competition instead of conservative to protect themselves.

While armor does help keep the interior components of the robot safe from impact, if the armor gets damaged it could cause repercussions for the assembly team. If the armor is badly damaged & needs to be replaced, the team only has a short amount of time to attempt to fix the damage & if they are unable to, they may have to compete with damaged armor. Damaged armor may also impede some outside components, such as getting bent & blocking the movement of the locomotion or the movement of the spinner.

End User:

Since our team will be competing against other combat robots at the NHRL competition in the spring, we are directly the end users of this product. Our ideal solution for this robot design prioritizes durability, ease of manufacturing, & damage output. Our future designs will prioritize using strong & accessible materials that are designed to easily be swappable for future design changes & specific combat situations. By creating removable parts & the ability to customize the robot, we can trial certain spinners & defense mechanisms without having to redesign our whole robot housing. By using materials like aluminum & AR500 steel for flat & straight components, & 3D printing TPU for absorption & more complex components, our bot will be a balance of rigidity & shock absorption.

Current combat robot design solutions could benefit from a greater ability to be repaired in a timely manner & better maintenance capability. Also, combat robots tend to have certain designs that a robot is strong against or weak against. Vertical spinners are strong against control bots but weak to horizontal spinners. Horizontal spinners are strong against hammers, & vertical spinners, but weak against control bots with ramps that deflect the spinner. There is no clear singular design that is superior to all other designs. For these reasons, our bot will be designed to take hits from a variety of robot types with durable design & materials.

Summary of Research:

From our research, we learned the importance of having a durable, modifiable design & that our ideal assembly would involve a vertical spinner. From the requirements provided by UCCR & NHRL, having a spinner & layout similar to Figure 2 and Figure 3 respectively would allow us to have a robot made of primarily flat components with a durable, high-damage spinner. Due to the broad variety of robot types, our design must be able to survive damage from any spinner & absorb the force our robot is applying to its competition. This means that our vertical spinner will have to have guards on the sides to protect against horizontal spinners. The gap we need to fill is a robot versatile against all opponents & capable of absorbing & landing high-damage hits.

Quality Function Deployment

Customer Features

Based on the research it was determined that the main customer features of our combat robot should be:

- Robot should be close to the maximum weight (12lbs)
- Robot must have rigid armor with intentional dampening & shock absorption
- Robot must be capable of high maneuverability & stability, especially to counteract the gyroscopic precession of a vertical spinner.
- Robot must operate at a modest safety factor, not overpower motors & power supplies.
- Robot must be capable of absorbing high-power hits from competitors as well as hits given to competitors.

Survey Results

The survey conducted was sent to four different platforms ranging from Reddit forums (r/battlebots) to student lead organizations (UC Combat Robotics). There were 13 questions asked in the survey. Each question asked the participant to rank key features of a combat robot based on how important it is, & how much they prefer each Spinner that could be possible. The survey received 17 different responses, & each question asked the participant to rake the characteristic of the robot on a scale of 1 to 10.

Customer Feature	Average	Standard Deviation
How important is a Defensive robot	7.38	2.7

How important is an aggressive robot	8.29	1.89
How important is speed of Spinner	6.41	2.57
How Important is speed of robot	6.76	2.25
How Favorable are Horizontal spinners	6.17	2.04
How Favorable are Vertical Spinners	7.76	1.64
How Favorable are wedges	6.71	2.28
How Favorable are MeltyBrains	4.59	3.04
How Favorable are Hammer bots	3.76	2.65
How important is Newton's 3rd law to be taken into consideration	7.71	2.28

Table 2: Survey Results

Engineering Characteristics

Using data found via our survey, we decided upon the engineering characteristics below:

- Spinner Rpm
- Yield Strength
- Acceleration of the robot
- Acceleration of the Spinner
- Gyroscopic forces
- Safety Factor
- Spinner power
- Shock absorption

House of Quality

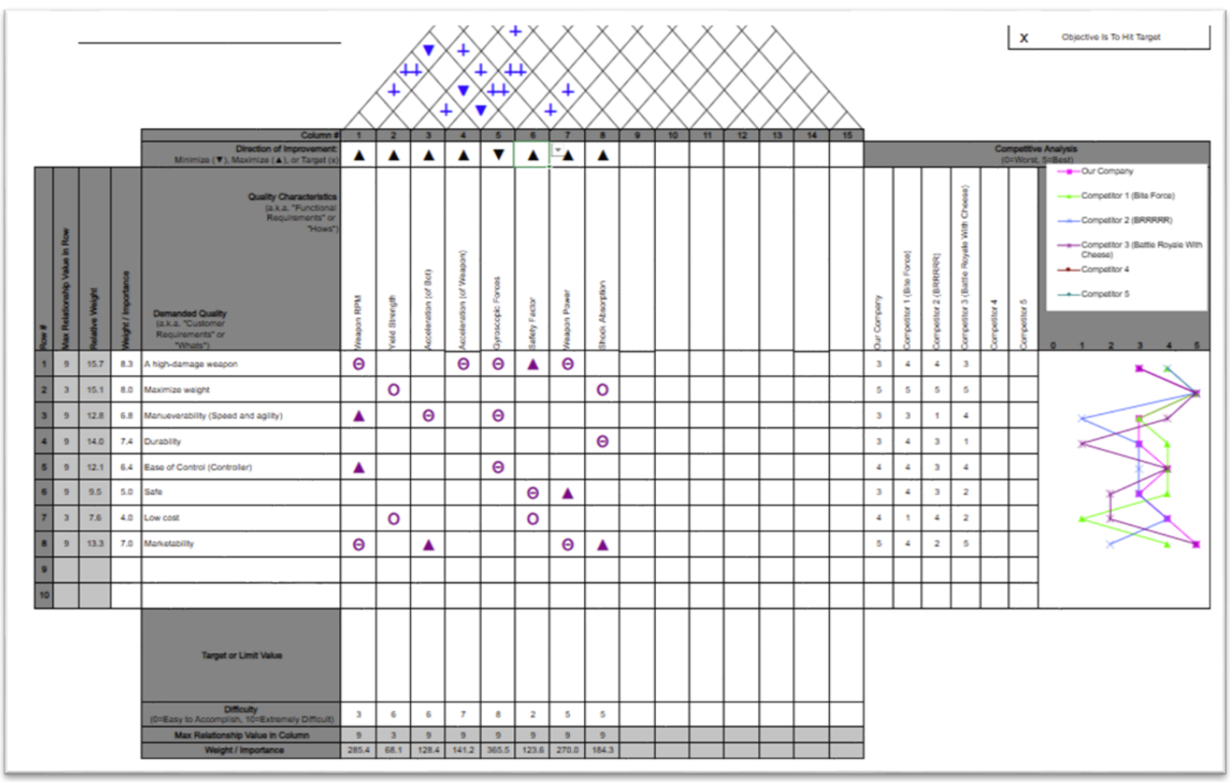


Figure 7: House of Quality

Product Objectives

Based on the survey results we can conclude that the survey participants found that an aggressive robot that carried a vertical spinner were key features to have for a combat robot. The survey also concluded that having a defensive robot (not a large spinner) & utilizing a Meltybrain robot would be the least desirable characteristics to have in a combat robot. The objectives that our team needs to fulfill in order to have a well-constructed robot are:

- Easy to control
- Aggressive
- Vertical Spinner that yields high damage (Thicker blade with higher RPM)
- High durability (high yield strength)
- Interchangeable plow & forks

Concept Drawings

Concept 1

Concept 1 consisted of a body made of 6061 Aluminum sheets with a TPU center to act as a shock absorber when hit. The Curved outside edges were designed to keep the wheels close to the body as well as deflect any crashes that may occur to the side of the robot. The vertical spinner is displayed as a disk in order to see the area in which the 6in Spinner would spin. Titanium plate is attached to the back of the body as an extra piece of armor in case of a hit from behind.

Some pros are the symmetrical nature of the robot, both vertically and horizontally. In the event the robot flips, ideally, we can still operate as desired. Another advantage is the armored wheels, preventing us from losing or damaging a wheel as long as our armor holds up. Some disadvantages are its lack of lifting/control capabilities. There are no forks, no ramps, and no ways to physically control our opponent on the floor. In the event we need to take a more conservative approach, should an opponent have too much firepower for us to compete with, we have no options. The wheels are also too close together, removing some of the purpose of a four-wheeled robot.

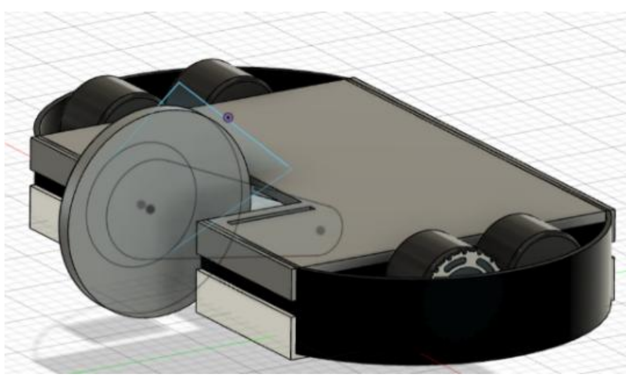


Figure 8: Concept 1 Body

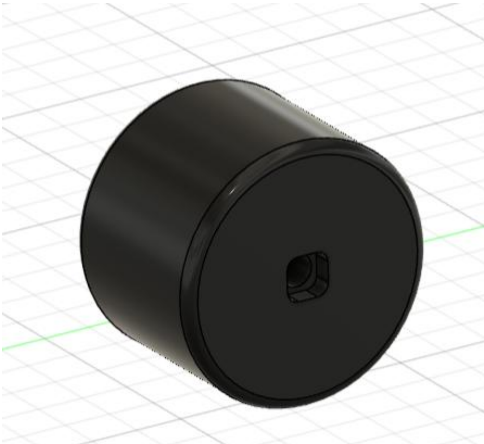


Figure 9: Concept 1 Wheels

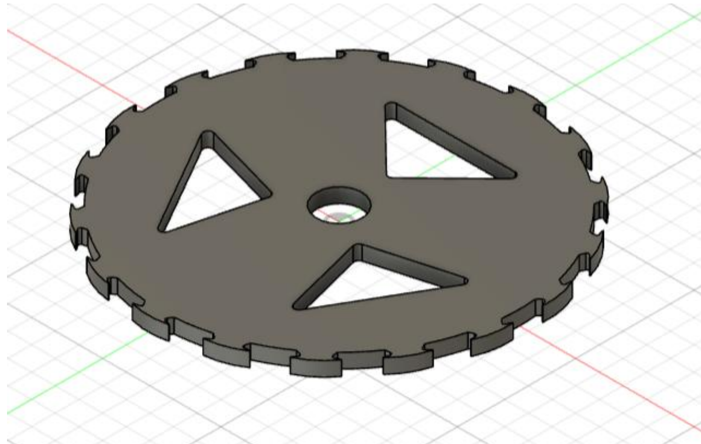


Figure 10: Concept 1 Spurs

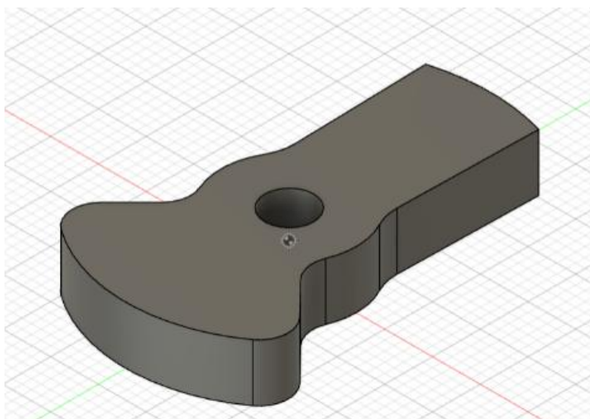


Figure 11: Concept 1 Spinner

Customer Features	Product Objectives	Engineering Characteristics
High Damage Spinner	Thick vertical Spinner results in heavier hits	Spinner RPM
Durability	TPU Rounded edges protect from high impact hits on the side	Yield Strength Shock absorption
Low Cost	Smaller Robot results in less material needed	

Table 3: Concept 1 Overview

Concept 2

Concept 2 had the same spinner dimensions of a 6in diameter. Larger wheels were added to lift the spinner itself more off the ground, which was an issue in concept 1. This design had wheels on the outside of the body to allow more space to spin, preventing any of the halting that would occur from hitting each other. The front wheels will be driven with no motor but instead a custom-made pully that will be controlled by the motor that is housed in the back of the robot's body. The body will still be using aluminum as its outer "shell" & TPU as its inside shock absorber protecting the electrical components inside. This design also has a theme of "Hamburger" to fulfill the optional entertainment aspect that many competitors utilize in NHRL.

Some pros of concept 2 are its wider and longer stance on its wheels, allowing for more stability and being kept off of the ground. The Spinner is raised as well, allowing for a little more height in our swing while not entirely losing the ability to hit shorter robots. Some cons are that this design has zero protection. If we were to face a horizontal spinner, we are in big trouble with no wheel armor and no ramp armor. We have very little defense on this design and would not be able to withstand many hits.

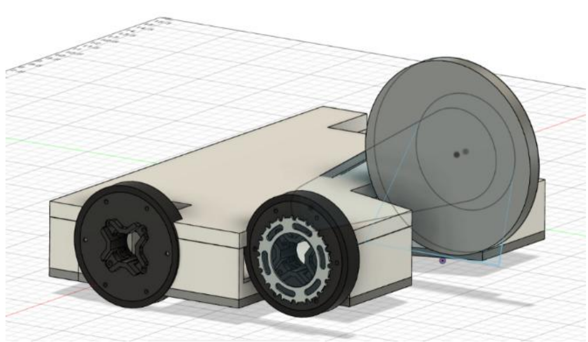


Figure 12: Concept 2 Body

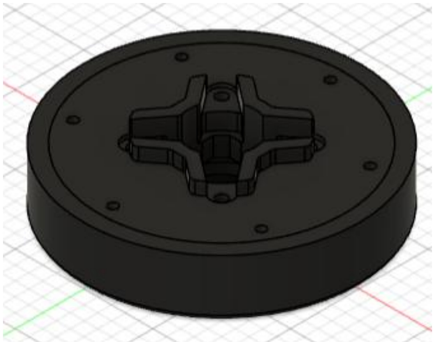


Figure 13: Concept 2 Wheels

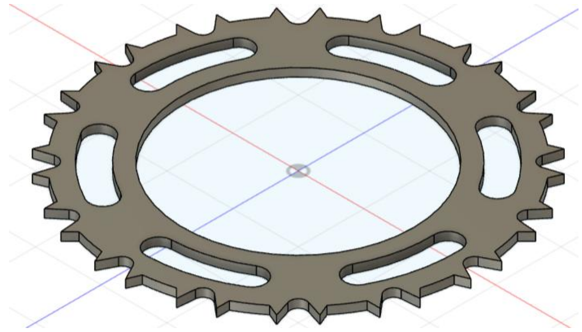


Figure 14: Concept 2 Spurs

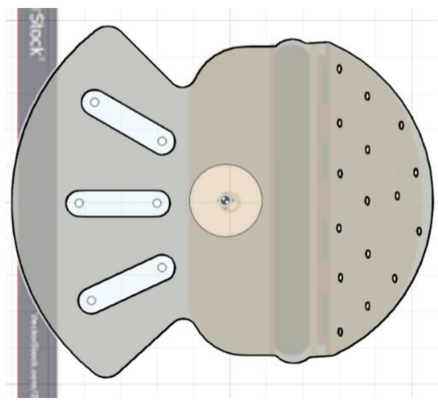


Figure 15: Concept 2 Spinner

Customer Features	**Product Objectives**	**Engineering Characteristics**
High Damage Spinner	Thick vertical Spinner results in heavier hits	Spinner RPM Acceleration of Spinner
Durability	TPU Rounded edges protect from high impact hits on the side	Yield Strength Shock absorption
Low Cost	Smaller Robot results in less material needed	
Marketability	The Robot has a “theme”	
Ease of Control	The robot has 4 wheels that are powered by the back wheels via a belt	Acceleration of bot, better control
Maximize weight	Larger robot body allows for more material to maximize weight	Yield Strength Shock absorption

Table 4: Concept 2 Overview

Concept 3

Concept 3 takes the front-end design of concept two & adds internal structure, increased space for wheel housing, & more room for damping materials & motor fixtures. Our spinner assembly has changed and improved tenfold, adding "ears" made from Aluminum 7075 to the side of the spinner assembly, allowing more stability of the bot should it flip and allowing the robot to drive upside down because of the rollers on the uprights.

The spinner shape has changed from our original "burger" concept design to a lighter, more simplistic, effective shape that will allow for easier machining and assembly. The armor around the front of the body is to protect both the front side, Spinner assembly, and the wheels.

Our wheels remain outside of the body and our body has shrunk considerably. Having custom 3D printed pulleys be attached to the back wheel and the front wheel being a pulley itself allows for a 400mm rubber timing belt to be utilized having the front wheel "pull" the robot forward. Titanium spurs are placed on both front wheels to increase traction & control, being able to pull instead of solely push with rear wheel drive, allowing for more smooth movements.

Some pros are a more efficient means of power transfer through the fly wheel Spinner assembly, as well as more optimized space utilization for a smaller but denser footprint. Our new armor allows us to keep the wheel assemblies outside of the body but still be protected. We want to keep our wheels outside for a wider base to counteract the gyroscopic forces of the high-speed spinner, spinning at around 266mph, or 14,000 RPM. Some disadvantages are that we still have some dead space within the robot's body, having a hard time shrinking the body without losing control due to the sheer size of our spinner. The back of the rear wheels are exposed, though we are banking on being able to maneuver well enough to never expose our rear.

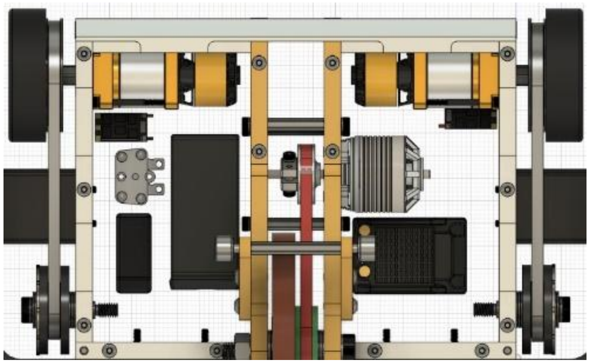


Figure 16: Concept 3 Housing

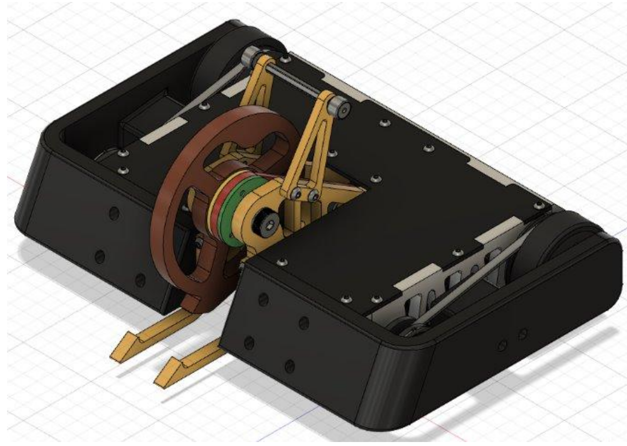


Figure 17: Concept 3 Body

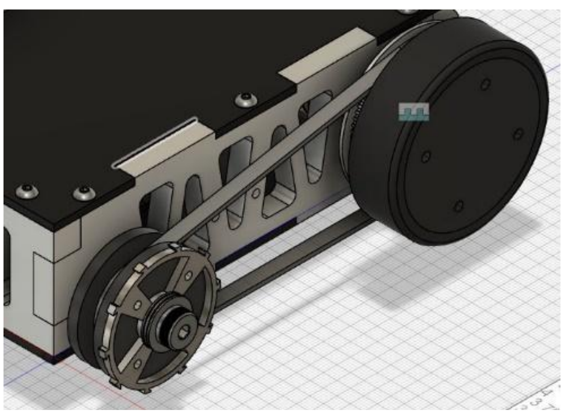


Figure 18: Concept 3 Drive Train

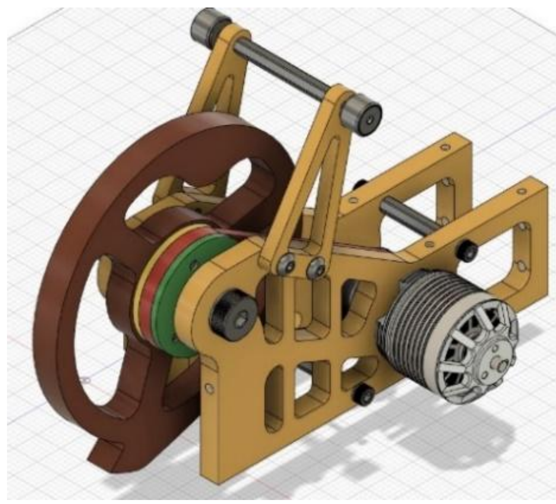


Figure 19: Concept 3 Spinner Assembly

Customer Features	Product Objectives	Engineering Characteristics
High Damage Spinner	High speed vertical Spinner results in heavier hits	Spinner RPM Acceleration of Spinner
Durability	TPU Rounded edges protect from high impact hits on the side	Yield Strength Shock absorption
Low Cost	Smaller Robot results in less material needed	

Marketability	The robot has a “burger” theme	
Ease of Control	The robot has 4 wheels that are powered by the back wheels via a belt	Acceleration of bot
Maneuverability	Custom wheels with custom spurs allow for more grip on the ground preventing jerking from being hit	Acceleration of bot
Maximize weight	Larger robot body allows for more material to maximize weight	Yield Strength Shock absorption
Safe	“Ears” allows for the robot if flipped upside down, to keep the Spinner off the ground & damaging the floor, & allows for a safety lock to be put in place when robot is not competing.	

Table 5: Concept 3 Overview

Decision Matrix

Based on the Decision Matrix it was determined that concept 3 would best satisfy the design defined by the house of quality.

Qualities	Weight	Concept 1	Concept 2	Concept 3
A High-Damage Weapon	8.3	7.4	7.6	7.6
Maximize weight	8	4	7	7.5
Manuverbility	6.8	3	5	6
Durability	7.4	6.8	4.5	6
Ease of Control	6.4	2	5	5.5
Safe	5	1	1	4
Low Cost	4	9	2	1
Marketability	7	1	6	6
	Total	224.94	273.38	309.48

Table 6: Decision Matrix

Project Management

Team & Expectations (Jobs)

Brooklyn: Drive system design, prototyping & 3D printing jobs.

Andrew: Spinner design, spinner pulley design & body design.

Cade: Armor design, mounting, controller programming, document management.

Josh: Electronics housing & layout, budgeting & FEA stress testing/analysis.

All members: Robot manufacturing, robot assembly, research.

Project Budget Limit

For our Combat Robot "Murder Burger", we have acquired a sponsorship check of $2,500 from Collins Aerospace. The budget for our combat robotics is estimated to cost approximately $1,200. The UCCR (University of Cincinnati Combat robotics) provides the internal electrical components such as:

- Ar410 Receiver
- BA-3520, Tempest-2814 Motors
- Battery
- Club ESC, Castle Sidewinder ESC
- The material needed to create the body, wheel, Spinner, & any other components are listed below with pricing.

Components	Price
TPU 95 A Filament	$25.99 per kg
Titanium (1/8" thick sheet)	$ 195.00 per square foot
AR 500 (3/8" thick sheet)	$250.00 per square foot
Aluminum 6065 (1/10" thick sheet)	$41.96 per square foot
Aluminum 7075 (1/10" thick sheet)	$12.74 per square foot

Table 7: Component Prices

Any Machining needing to be done will take place at Victory Park Campus, or the 1819 makerspace available for students to use if training courses are taken beforehand. Our teammate Brooklyn Piper owns a Bambu X1 Carbon 3D printer that will be utilized for printing TPU filament prototypes & finalized pieces of the robot.

The final project budget for our robot is shown below in Figure 20 and Figure 21.

	Component	Quantity	Packaging	Cost per unit	Cost total
Weapon	Needle bearings inside pulley	2	Each	5.93	11.86
	3 in V belt Pulley	1	Each	28.01	28.01
	2 in V belt Pulley (same stock)				
	Screws- Driving pulley	2	100 Pack	14.48	14.48
	Locking Screw- Driving Pulley	1	100 Pack	15.34	15.34
	Weapon belt	1	Each	12.9	12.9
	Ears	1	Each	5.72	5.72
	Motor Ball Bearing	3	Each	14.85	44.55
ht (2)	Uprights	1	Each	30.56	30.56
	Ear screws to uprights (front fork mount	8	100 pack	12.02	12.47
	Upright screws to standoffs	8	50 Pack	12.62	12.62
	Weapon	1	Each	59.36	54.01
	Weapon Shaft Shoulder Bolt	1	5 Pack	15.8	15.8
	Standoff for ear rollers	1	Each	1.16	1.16
	Needle bearing weapon shaft	2	Each	3.91	7.82
	M5 screws spinner to pulley	4	100 Pack	12.47	12.47
	Hex nut for shoulder bolt	1	50 Pack	11.9	11.9
	Washer on weapon shaft	4	Each	1.23	4.92
	Upright screws to motor	4	100 Pack	8.27	8.27
	top same as motor ball bearing				
	Hex standoffs	3	Each	0.82	0.82
	Total	49		267.35	305.68
Drive	HTD-5m Belt	2	Each	29.2	58.4
	UCCR_Goldibox_Gearbox	2	Each	150	300
	Wheel Hub	4	Each	11.99	47.96
	Wheel hub bolts	8	100 Pack	10.27	10.27
	Needle bearings	4	Each	3.27	13.08
	Washers next to bearings	8	Each	1.23	9.84
	Bronze sleeve bearing	2	Each	1.32	2.64
	Shoulder screw	2	Each	10.97	21.94
Ordered by club	Cleats				
	Shoulder Screw nuts	2	100 Pack	11.03	11.03
	Belt tensioner	4	Each	6.04	24.16
	Polycarbonate screws into front wheel	10	25 Pack	14.68	14.68
	Belt tensioner rod	2	10 pack	5.36	5.36
	Belt tensioner nuts	4	100 Pack	2.81	2.81
	Back pulley wheel screws	8	100 Pack	14.89	14.89
	Total	62		273.06	537.06

Figure 20: Project Budget Limit Top Half

Frame Assembly	Sidewalls + front walls	1	Each	24.76	24.76
	Backwall	1	Each	23.5	23.5
	Armor screws	8	50 pack	9.8	9.8
ight (2)	Top/Bottom Plate	2	Each	35.98	71.96
ıt (2)	1kg TPU	1	Each	24.98	24.98
	Dowel rod wall corners	2	25 pack	17.7	17.7
	Side armor screws	4	10 Pack	10.79	10.79
	Screws in walls from top/bottom	28	50 Pack	13.33	13.33
	Front wall (left/right) (0.5 in thick)	1	Each	13.87	13.87
	Screws In wall sides	8	100 Pack	14	14
	Screws in wall sides	12	100 Pack	15	15
	Wall to gearbox screws	8	100 Pack	13.74	13.74
	Alloy steel shoulder screw for forks	2	Each	3.5	7
	Steel locknut for forks	2	10 Pack	5.12	5.12
	Forks	2	Each	65.63	65.63
	Total	82		291.7	331.18
Electronics	Receiver	1	Each	34.99	34.99
	Battery	1	Each	48.27	48.27
	Weapon ESC	1	Each	129.95	129.95
	Drive ESCs	2	Each	22.99	45.98
	Kake Switch	1	Each	40	40
	Total	6		276.2	299.19
	Grand Total	199	0	1108.31	**1473.11**

Figure 21: Project Budget Limit Bottom Half

Gantt Chart

The combat robot must be completed by April 5, 2025, to compete at NHRL (National Havoc Robot League). All designs are on schedule to be completed by the end of the Fall academic semester (December 7, 2024). The building of the combat robot "Murder Burger" will start during the spring academic semester (January 13, 2025). Figure 23***Figure 23*** shows key dates that must be met to ensure all testing & building phases are completed by the competition date.

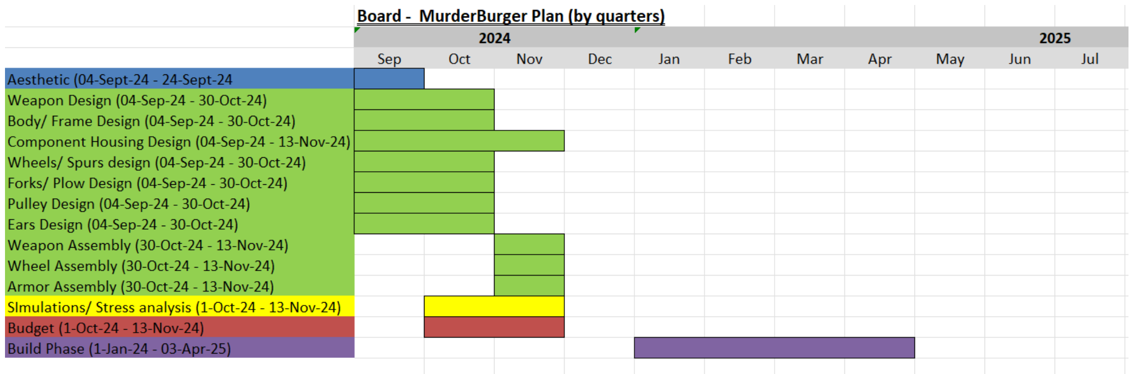


Figure 22: Gantt Chart

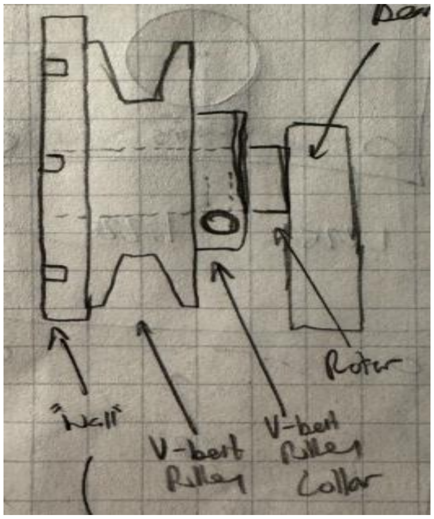
To-Do

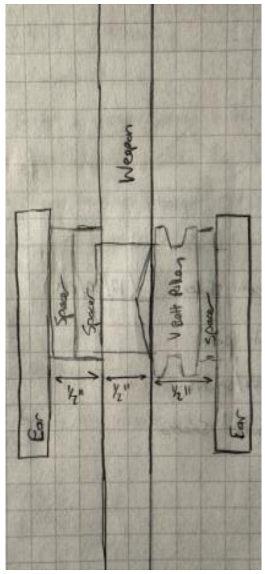
Task	Status	Key Dates	Timeline	Notes
Aesthetic	Done	Sep 24, 2024	-	
Weapon Design	Done	Oct 30, 2024	Sep 4, '24 - O...	
Body/ Frame Design	>75%	Oct 30, 2024	Sep 4, '24 - O...	
Component Housing Design	>75%	Nov 13, 2024	Sep 4, '24 - N...	
Wheels/ Spurs design	>75%	Oct 30, 2024	Sep 4, '24 - O...	
Forks/ Plow Design	>75%	Nov 13, 2024	Sep 4, '24 - O...	
Pulley Design	Done	Nov 13, 2024	Sep 4, '24 - O...	
Ears Design	Done	Nov 13, 2024	Sep 4, '24 - O...	
SImulations/ Stress analysis	Not Started	Nov 13, 2024	Oct 1, '24 - N...	
Budget	50%	Nov 13, 2024	Oct 1, '24 - N...	
Weapon Assembly	Done	Nov 13, 2024	Oct 30, '24 - ...	
Wheel Assembly	Done	Nov 13, 2024	Oct 30, '24 - ...	
Armor Assembly	>75%	Nov 13, 2024	Oct 30, '24 - ...	
Build Phase	<25%	Apr 3	Jan 1 - Apr 3	
Certifications	Done	Feb 28	-	
Frame Construction	>75%	Apr 5	Jan 13 - Apr 5	
Drive Construction	<25%	Apr 5	Jan 13 - Apr 5	
Weapon Construction	<25%	Apr 5	Jan 13 - Apr 5	
Armor Construction	Done	Apr 5	-	
Wiring and Electronics Integration	Not Started	Apr 5	Mar 10 - Apr 5	
Drive Testing	Not Started	Apr 5	Mar 18 - Apr 5	

Figure 23: Key Dates

Design Drawings & Considerations

Design Drawings: Spinner Assembly





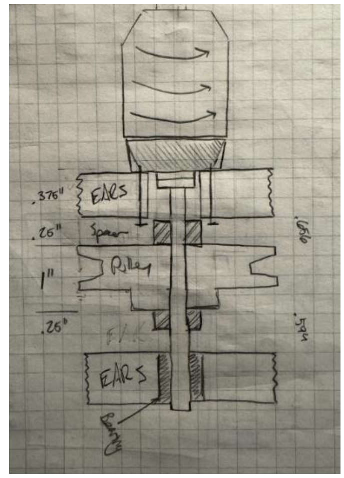


Figure 24: Pulley & Motor

Figure 25: Spinner Stack

Figure 26: Pulley & Motor

Above are three sketches dated 10/9/24 to 10/16/24, showing early designs for our spinner stack and drive motor shaft assemblies. Figure 24 and Figure 26 show our motor mounted to one of two uprights, with a bearing in the opposite upright and a locking v-belt pulley spinning fixed to the motor output shaft. In the spinner stack illustration in Figure 25, the final spinner and pulley sizes as well as the keying interaction between the spinner and driven pulley are shown. The additions of needle bearings and thrust bearings are used in our final design, rather than TPU spacers, susceptible to melting from high spinner speeds and temperatures.

Design Drawings: Body

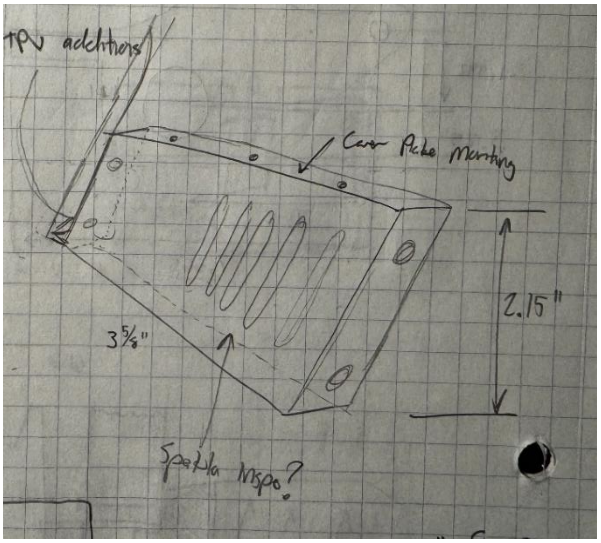


Figure 27: Front Wall

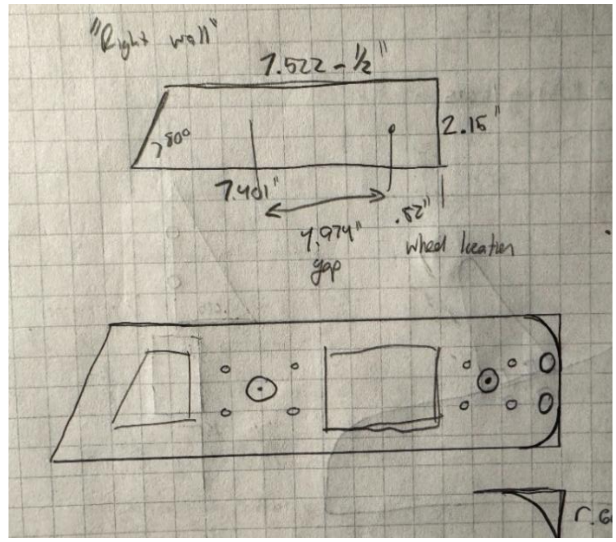


Figure 28: Side Wall

The two sketches shown above are from 10/16/24 to 10/23/24 and show early designs for the front and side walls of Murder Burger. The designs show an angled front wall, precise mounting for multiple drive motors and gearboxes, and weight cutting areas between important components. This design changed when we decided to only have driven motors in the back, and to make the front wall vertical for easier assembly and machining. The walls have also reduced in size from 7.4" to less than 7". The front wall design shown was inspired by the angle and slits of a grill spatula, befitting the Murder Burger name.

Design Drawings: Body Keying

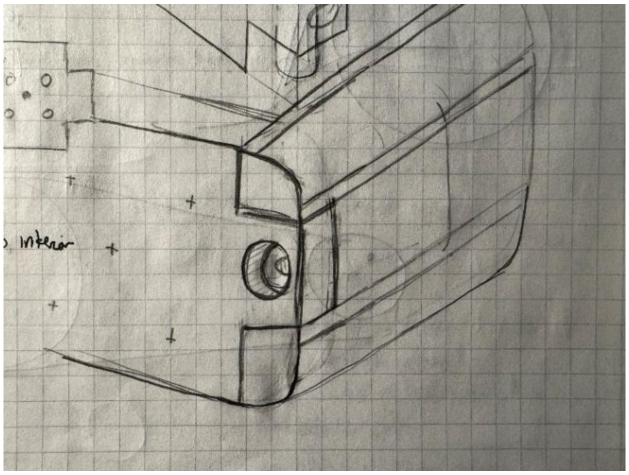


Figure 29: Side & Rear Keying

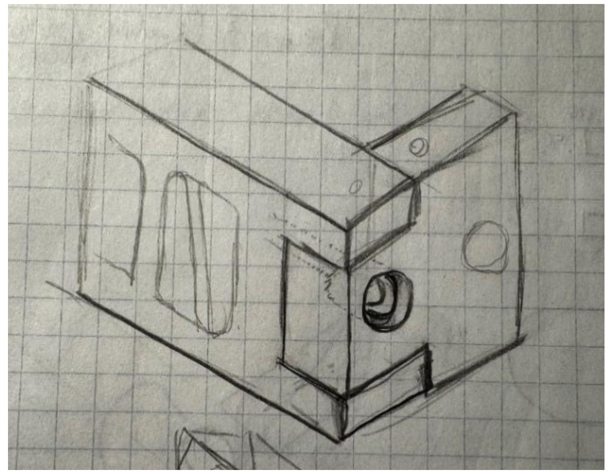


Figure 30: Side & Front Keying

The two sketches above were created 10/23/24 and showed early concepts for keying designs in our front, side, and back walls. By keying, we can limit the amount of hardware used in the robot assembly and allow shock to be distributed throughout the robot rather than isolating the hardware and corners. Rather than a single screw as shown in the second sketch, our design uses steel dowels to fix the front walls to the side walls and strengthen the front corners. Changes were also made to the back wall following these sketches, changing the filleted top and bottom corners to chamfers to allow for easier machining while maintaining wheel clearance around the back wall.

Design Drawings: TPU Armor

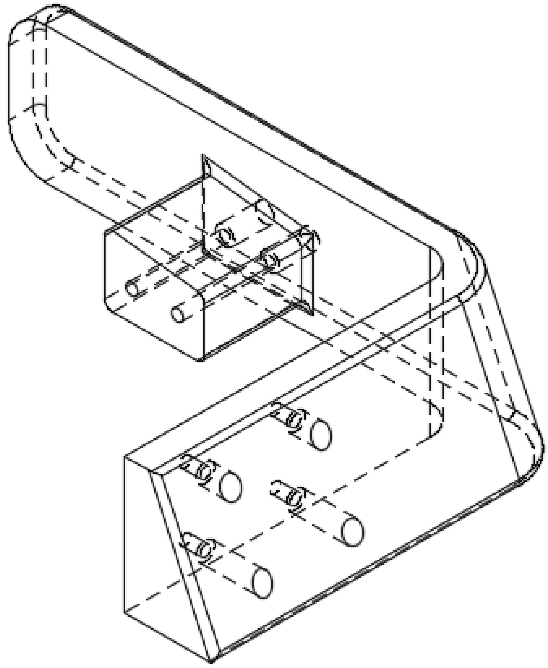


Figure 31: Wrap-around TPU Armor

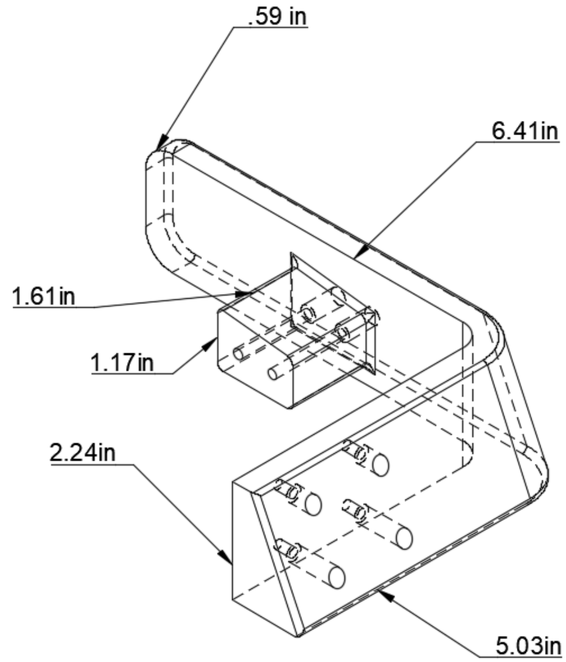


Figure 32: With Dimensions

The two sketches above were ideated early on in our design process, but not “put onto paper” (CAD) until we had a general direction for our robot, as well as a first concept design that could incorporate the wrap-around armor style. We took inspiration from Saiko! for this armor design, as mentioned earlier in the Summary of Research section. By using wrap-around armor, we can combine a front plow and side armor into one, 3D-printable piece. By using TPU, we can absorb more shock than if we were to use PLA or Aluminum 6061/7075 and create a much simpler way of manufacturing for multiple sets of armor.

Design Drawings: Forks

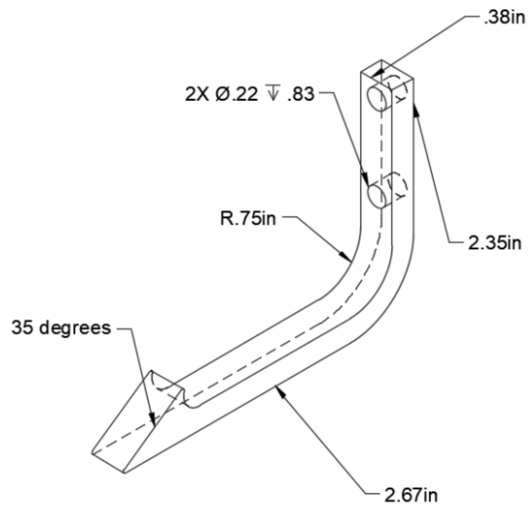


Figure 33: Hard-mounted Forks

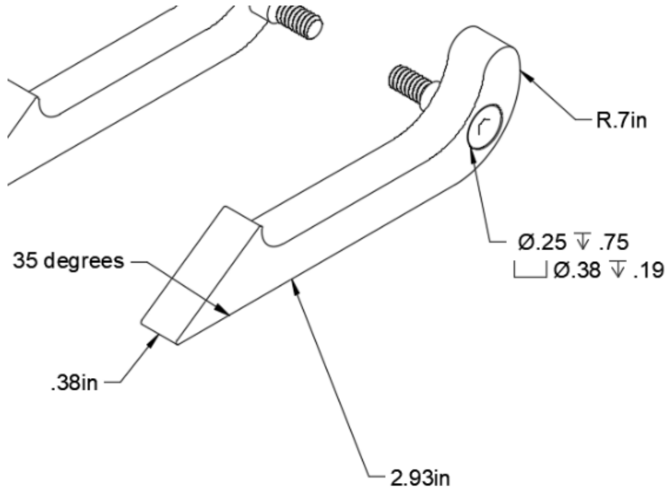


Figure 34: Hinged Forks

The above sketches show two iterations of the Aluminum 7075 forks, one iteration to be hard mounted to the front of the uprights and through front wall keying, and the other iteration to be mounted on a hinge, allowing for more flexibility in fights and reducing the direct stress being placed on our uprights should the forks be struck and/or damaged. The current design only includes hard-mounted forks, but an idea for slight modifications in our final analysis would include hinged forks. The purpose of our forks is to provide balance and engagement support for our moderately front-heavy robot, ensuring we do not tip forwards and crash our spinner into the ground.

The secondary purpose, and more common on most other robots, is to provide a “guide” of sorts when initiating contact during an attack. The forks will slip under the opposing robot, and the angled barbs will lift the side of the robot we initiate the attack on, as well as potentially grab onto the robot somewhere underneath. This can almost guarantee a hit, and potentially in a more vulnerable spot as compared to a direct hit into opposing armor.

Design Drawings: Wheel Assemblies

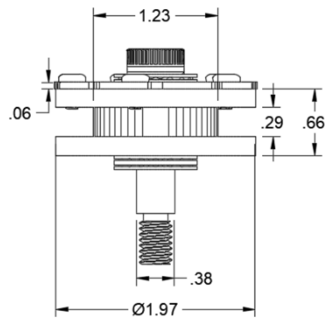


Figure 35: Front Wheel with Dimensions

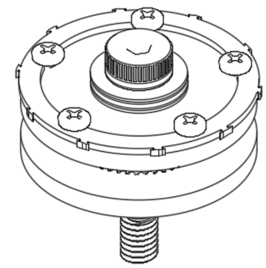


Figure 36: Front Wheel Spurs/Cleats

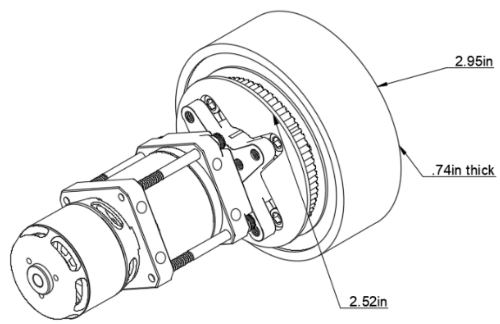


Figure 37: Back Wheel Assembly

The figures above were created by 11/12/24. These finalized drawings of the front and back wheels show the utilization of a pulley as the wheel for the front component and an attached pulley to the wheel hub for the rear component. The front pulley needed to have a thick enough outer diameter of the pulley to be stable enough to hold the load of the robot. Because of designing the front pulley from scratch, the ideal speed wanted for the robot was approximately 10 ft/sec. Because of this the back wheel was designed second to make sure the gear ratio would be exact to gain the projected 10 ft/sec. Without a custom pulley the risk of being too heavy and not being able to find components that fit onto the given BA-3520-Motor shaft would prove to be an issue.

Development of Prototype

The prototyping of the combat robot was broken into multiple different parts:

- Spinner Assembly Prototype
- Drive System Prototype
- Armor and Forks Prototype

Spinner Assembly Prototype

The spinner assembly prototype was 3D printed out of PLA plastic on a Bambu X1 Carbon 3D printer. Each section was printed in a different color filament to see each component easily. The main purpose of this 3D print was to see a scaled model to determine if the general size of the Spinner was accurate to the CAD drawings, to confirm that electrical components (motors) would fit, and to calculate the tolerance of the 3D print for the components that will be 3D printed in the final assembly.

Figure 38: 3D-Printed Spinner Assembly

Based on the prototype it was determined that the pulleys, spinner, ears, and uprights were designed with satisfactory measurements because of the near seamless fit-up & assembly, and how no component needed to be “forced” together to fit. The uprights were lower or shorter than expected but were still deemed satisfactory as they were not short enough to impede the functionality of the spinner motor.

Wheel Assembly Prototype

The wheel assembly prototype was the main point of concern for 3D printing. Since both wheels and pulleys would be printed out of 95a TPU it was important to determine that these components could print without any issue. TPU is tricky to print and can clog and damage a 3D printer easily. It was also imperative that tolerance be determined in case any adjustments on mounting holes needed to be made to fit the wheel hub, gearbox, or shoulder bolt in the drive system.

The 400mm belt for the wheel assembly was also an important component to prototype. To make sure that the 400mm timing belt would fit on the pulleys the belt was 3D printed with 95a TPU and fit onto the front and back wheel prototypes. This was to make sure that the belt would fit, and no size adjustment was needed when ordering the official timing belt.

Figure 39: Front Custom Pulley

Figure 40: Back Custom Pulley

Armor Assembly Prototype

The armor and forks were prototyped using PLA filament (for the forks) and 95a TPU for the armor. Two different designs were printed for the forks, one that utilized hinges and one that did not. The purpose of two iterations was to see which one would be more compatible with the spinner assembly when approaching an obstacle or opponent. The goal is to allow just enough flexibility to run under the opponent and force them upwards into the spinner and not take on enough force for the forks to snap or bend, impeding the movement of the robot.

Multiple iterations of the armor were printed to test the stability and sturdiness based on the number of walls/layers (number of times the 3D printer prints/lays filament around the outer edge) of the armor. Based on the prototypes and multiple rounds of forcefully bending the armor it was determined that a six-wall minimum was the best configuration to use and would still comply with weight limitations.

Figure 41: TPU Armor Prototype

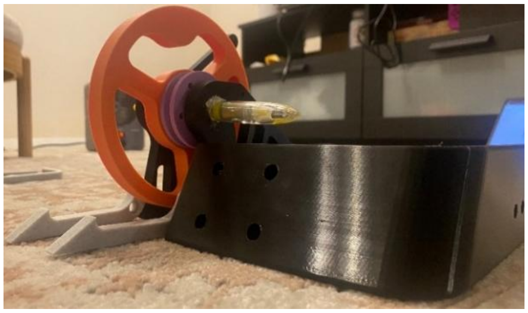


Figure 42: Hinged Forks

Figure 43: Hard Mounted Forks

Testing Plan

Testing will be broken up into the main groups of the combat robot's assembly:

- Spinner testing
- Drive system Testing
- Driver practice

To prevent the possibility of damage to the whole robot system each group of combat robots will be tested separately. Each system will utilize the same remote controller to individually test the electronic components of each group to make sure that they are properly programmed.

Due to the Regulations of safety at the University of Cincinnati, there is no testing of the vertical spinner on any campus-owned facilities. All vertical spinner testing will be conducted at the competition in the secure cages provided. When testing in these cages an official from the competition will be overseeing safe practices and to make sure the vertical spinner is not on longer than three minutes at a time.

Drive system testing will be done when the combat robot body is complete and the spinner assembly is attached. The spinner assembly will have a safety lock on it to make sure that it will not move when testing only the drive system. Testing the drive system will begin with a check of the electrical components and the controller to make sure that the controller is properly programmed to the motors. The drive system will be run on a column structure to make sure the wheels do not touch the ground. This allows for an up-close look at the drive system to make sure that the belt moves properly when the rear wheels are directed to move forward and backward.

Driving practice will take place once the testing of the drive system is completed and deemed acceptable. The driving practice will take place in multiple phases:

- Forward Driving
- Backwards Driving
- Circular Driving
- Driving with an active spinner

Each of these sections will allow Cade Budinski (designated competition driver) to take the robot through multiple driving situations. While the focus of driving practice would be to drive with an active spinner, the safety regulations at the University of Cincinnati would only allow the testing of the vertical spinner at the competition. Because of this Cade Budinski will have to utilize the one day period before the competition to get a feel for the drive of the robot and how it will move.

Mathematical Analysis

To find our robot speed, spinner energy and stress concentrations, we took an analytical approach to gather this data, including calculations and computerized finite element analysis.

The maximum speed of the robot drive system would be determined using the motors' rotations per minute, tire circumference, drive ratio, and the gear ratio of the pulleys on the wheel hub as well. Utilizing the maximum speed equation as well as a Tempest 2814-2100Kv Brushless motor that has a maximum RPM of 2100 RPM per volt, it was found that the maximum speed the robot can move is 10.2 ft/sec.

*Maximum Speed = (Maximum RPM * Tire Circumference) / (Gear Ratio)*

The robot utilizes a driving motor only for the back wheel of the drive system. Although the back wheel has a motor the front wheel utilizes spurs to pull the robot forward. This would make the front wheel the driving wheel, therefore the tire circumference utilized in the maximum speed calculation would be that of the front tire. Since a timing belt connects the front and back pulleys together, the gear ratio will be with respect to the back pulley. The calculated values are as shown:

*Tire Circumference = 1.97 in * pi = 6.18 inches*

Gear ratio = (size of the back wheel pulley / size of the front wheel pulley) =

2.22in /1.25 in. = 1.76 gear ratio

Maximum speed (in/min) = (2100 6.18in) / (1.76) =* ***7342.807 inches per minute***

*Maximum speed (ft/sec) = 7342.807 in/min * 1/12 ft/in * 1/60 min/sec =* ***10.198 ft/sec***

As shown above, the maximum speed equation gives an approximation in inches per minute, when converted this will result in **10.2 ft/sec**.

To find the energy generated and stored by the spinner, we need to find our motor voltage, battery voltage, spinner diameter, both the driven and driving gear diameters (and/or their ratio), and our spinner's moment of inertia. Our motor KV and battery voltage are 970 KV, and 22.2 V, respectively. Our spinner diameter is 6.25", and our driven and driving gear diameters are 2" and 1 1/3", respectively. Finally, our spinner moment of inertia is 1.85×10^{6} g/mm^2, or 1.85×10^{-3} kg/m^2. Our first step is to find our spinner's rotations per minute:

*Spinner RPM = (Motor KV * Battery Voltage) * (Driving Gear Dia. / Driven Gear Dia.)*

*Spinner RPM = (970 KV * 22.2 V) * (1 1/3" / 2") =* ***14,356 RPM***

Next, we convert our units from rotations per minute to degrees per second, and again to radians per second.

$$Spinner\ °/sec = Spinner\ RPM * 6$$

$$Spinner\ °/sec = 14{,}356\ RPM * 6 = 86{,}136\ °/sec$$

$$Spinner\ rad/sec = Spinner\ °/sec * (\pi/180)$$

$$Spinner\ rad/sec = 86{,}136\ °/sec * (\pi/180) = \mathbf{1{,}503.4\ rad/sec}$$

To calculate spinner tip speed, we must take our spinner diameter (in feet), our spinner's rotations per minute, to calculate below:

$$Tip\ Speed = (Spinner\ Diameter / 12) * \pi * Spinner\ RPM * (1mile/5280ft) * 60min/ 1hr$$

$$Tip\ Speed = (6.25'' / 12ft) * \pi * 14{,}356\ RPM * (1mi / 5280ft) * (60min / 1hr) = \mathbf{267\ mph}$$

Finally, using our spinner's moment of inertia and radians per second, applying it to the kinetic energy of a cylinder gives a grand total of **2.09 KJ** of energy.

$$KE = 0.5 * I * \omega^2$$

$$KE = [0.5 * 1.85x10^{-3}\ kg/m^2 * (1{,}503.4\ rad/sec)^2] / 1000 = \mathbf{2.09\ KJ}$$

Motor KV	970	KV
Battery Voltage	22.2	Volts
Driven Gear Dia	2	any unit
Driving Gear Dia	1.3333333	any unit
Diameter	6.25	in
Weapon RPM	14355.99964	rpm
Weapon Deg/s	86135.99785	Deg/s
rad/sec	1503.356767	Rad/s
tip speed	266.9312441	mph
MOI Weapon	1.85E+06	g/mm^2
MOI Weapon	1.85E-03	kg/m^2
Weapon Energy	2090.6	J
Weapon Energy	2.09	KJ

Figure 44: Spinner Energy Chart

During the final design process, it was also determined that running an FEA analysis and a dynamic stress analysis on the spinner and the uprights to the spinner would be beneficial to see if loads of impacts will be distributed evenly among the components or if here was too high of a stress concentration that would result in bending, or snapping of the components.

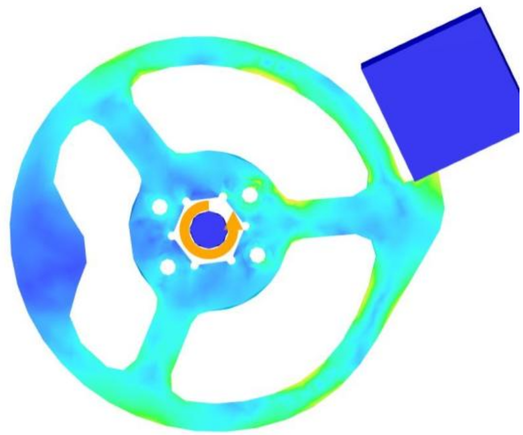


Figure 45: Dynamic Stress Test Results

Conducting the dynamic stress test of the spinner, had the spinner connect with a stationary titanium block. The speed at which the spinner was rotating was the max speed of 14355.99rpm that was calculated when determining the spinner energy. When hitting the block, it is shown that the main points of stress are at the tip of the spinner. This was not a concern, since the tip of the spinner will make the initial hit, it makes sense that it would take on most of the stress. The rest of the stress in the spinner seemed to have spread throughout the spinner evenly. This allows for the conclusion that a snap or bend of the spinner would be unlikely to occur.

The FEA analysis that occurred on the uprights of the spinner assembly had two purposes. To determine the maximum displacement the uprights would endure, and to determine if there was a concerning amount of stress that would overload one specific area of the uprights.

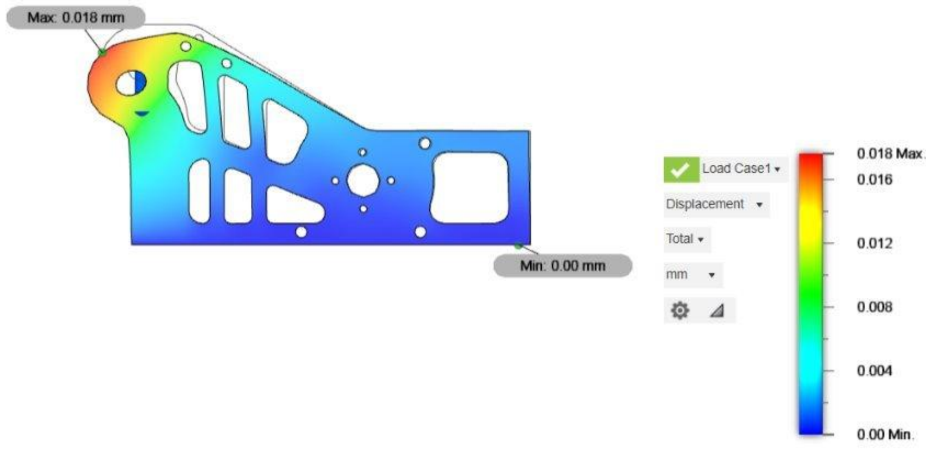


Figure 46: FEA Analysis on Uprights

The FEA analysis was conducted with a load that is the same as what the spinner would give off if it were to hit the uprights. The reason for this is that since there are many different robot opponents that carry many different loads it was decided that running the analysis with a load that is known and calculated would be best. As seen in the figure above, the max displacement that the uprights would endure if getting hit at the top of the upright that is closest to the spinner, would be 0.018mm. The stress also forms right where the impact occurs but spreads evenly down through the upright. This did not pose a concern and confirmed the ideal design of the uprights.

Electronic/ Internal Component Selection

The following components were club-provided, below are descriptions that provide the reasoning behind selecting each individual component.

- Ar410 Receiver
  - Reliable and compact unit, integrated with the standard club-provided transmitters. Lightweight design minimizes overall weight, which is crucial when it comes to staying below weight limitations.
- BA-3520-Motor (Spinner)
  - Motor offers the necessary torque and speed for functionality, optimized for high-performance scenarios and applications. Compatible with the castle sidewinder ESC, ensuring no issues and sufficient power.
- 22V Lithium Polymer Battery
  - Compatible with club-provided components. Offers high power and low weight.
- Drive ESCs
  - Club-provided standard components known for their reliability, light weight, and compatibility with the tempest-2814 motors.
- Tempest-2814 Motors (drive)
  - Offers a high power-to-weight ratio and serves as an efficient motor. Standard club-provided motor, ensuring compatibility.
- Castle Sidewinder (Spinner ESC)
  - High-speed controller with specifications to handle the power output of the BA-2520.
- Kake Switch
  - Reliable and light weight mechanism to provide and cut off power to the bot.

Most screws are steel M5s or #8-32s due to their strength and large supply on McMaster Carr as well as their compatibility with standard components.

Proposed Fabrication

Most of the building/fabrication plans are using waterjet cutting, CNC machining, routing, and 3D printing. Below in Table 8 is a more visual description of each component and its correlated test equipment.

Task	Component and Fabrication Method	Details
Spinner Assembly	Ears: Water Jet Uprights: Water Jet Spinner (Spinner): Water Jet	Spinner assembly will consist of Al6061 ears & uprights, & a waterjet will be used to cut to specified dimensions. The Spinner will be AR500, & a waterjet will be used here as well. The water jet is the chosen instrument due to its low cost, precision & ability to handle a wide variety of materials.
Drive Assembly	Back Wheels: 95a TPU Front Wheels: 95a TPU Spurs: Titanium	TPU serves as a material that is flexible, durable, lightweight, and is simply an easier alternative to the majority of other fabrication methods. The back wheels and front wheels will be using this method. The spurs, however, will use titanium. Titanium is very strong and will increase our ability to control the bot and dig into

		the ground increasing traction. We will use the CNC machine to cut the forks due to its precision; a water jet could also be used but may serve as less precise.
Frame Assembly	Armor: 95a TPU Back Wall: CNC Front/Sidewalls: Water Jet Top/Bottom Plates: Routing Forks: Water Jet	The armor uses TPU due to its strong shock absorption and flexibility. The back wall will be CNC machined due to its precise cut-outs. The top and Bottom plate will be cut with the use of a router because it is made of carbon fiber material because the use of a water jet could cause splinters or other damages due to its light weight and small thickness.

Table 8: Proposed Fabrication

Manufacturing and Assembly

All manufacturing and assembly will take place at 1819 makerspace. Preceding any construction of the robot, a series of certifications needed to be completed, including Metal Shop A, Manual Mill, Manual Lathe, Powder Coating, and 3D Laser Cutting. These certifications were necessary to understand all safety guidelines and concerns as well as a deeper understanding of how to use each individual piece of equipment before using for robot construction purposes.

Frame Assembly

The frame of the robot serves as its structural backbone, providing support for all components while maintaining durability and rigidity. It consists of interlocking exterior walls, or keying, all made from 3/8-inch-thick Aluminum 6061, chosen for its high strength to weight ratio and ease of machining. These walls were waterjet cut to ensure precision and keyed together to ensure a secure fit, as shown in Figure 47. To ensure proper fastening, additional holes were manually drilled and tapped to accommodate #8-32 size screws.

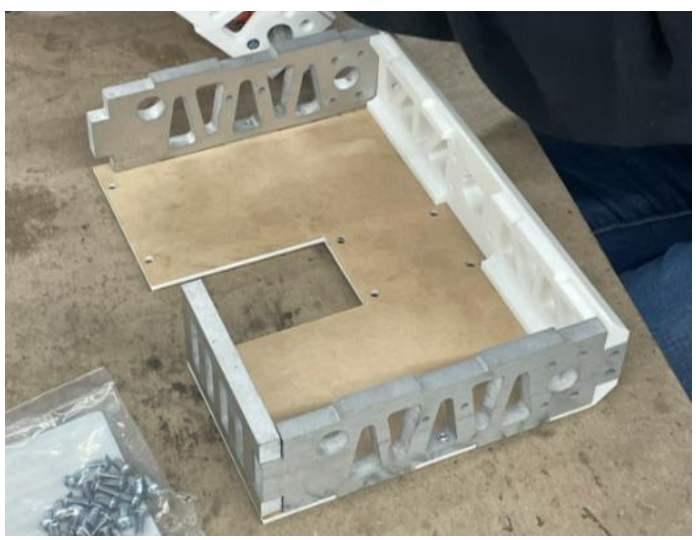


Figure 47: Frame Assembly

The rear frame wall required additional machining beyond the waterjet process. The mill was first used to create fillets, chamfers, and precise 45-degree edges. However, an issue was encountered. The required 45-degree angle on such a large workpiece was too steep of a challenge for the chamfer tools, and the team ended up breaking multiple tools in the process. To compensate, the workpiece was switched over to a grinder to complete the deep angle cuts, ensuring the correct geometry. Figure 48 and Figure 49 below illustrates this process.

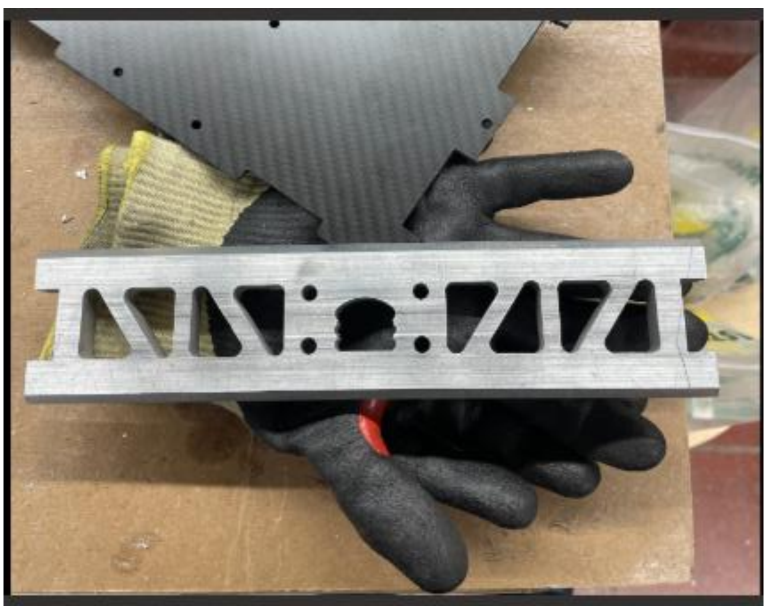


Figure 48: Back Plate

Figure 49: Back Plate in Mill

The top and bottom plates were CNC routed from carbon fiber, chosen for its high strength and low weight. Per safety requirements (and the toxicity of carbon fiber if ingested), gloves, masks, and a vacuum to provide ventilation were all used while the top and bottom plates were being cut. Some holes were not perfectly aligned due to the lack of tolerance capability on the CNC router. Because of this, multiple holes were ground and filed to enlarge or "move" them, and edits to the hole locations were made to accommodate these findings when the spare top and bottom plates were produced. Figure 50 below shows the bottom plate, while Figure 51 displays the top plate's interior. To mitigate the risk of electrical shorts, the interior of the top and bottom plates were lined with electrical tape, preventing exposed wiring from contacting the conductive carbon fiber surface.

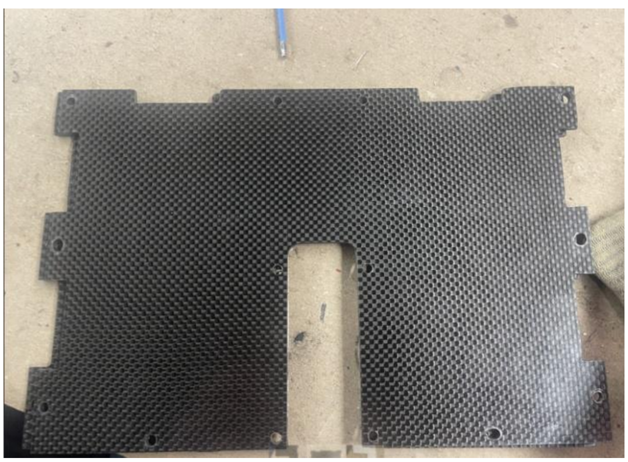


Figure 50: Bottom Plate

Figure 51: Top Plate Interior

Spinner Assembly

For the spinner assembly, the ears and uprights were manufactured from 3/8-inch-thick and ¼-inch-thick Aluminum 6061, respectively. Both ears and uprights were produced via waterjet. The uprights had top and bottom holes, drilled and tapped to align with the carbon fiber plates, as well as having multiple countersunk holes to attach to the front walls.

The vertical spinner was made from ½-inch-thick AR500 due to its exceptional durability, hardness, and impact resistance. This ensures that it can withstand repeated high-energy impacts with minimal wear or deformation. The vertical spinner is connected to a driven pulley system, also manufactured from Aluminum 6061 stock. The pulley system was made using the lathe, and later on milling the specific hexagonal pattern design to ensure multiple points of contact and stability within the spinner assembly while active.

The ears were then attached to the side of the uprights with a standoff in the middle and bearing screwed into both sides. The bearings acted as an extra set of wheels if the robot was ever flipped upside down and needed to keep moving.

The last component in the spinner assembly is a V-belt connecting the pulley system. Shown in Figure 52 , the entire spinner assembly is observed.

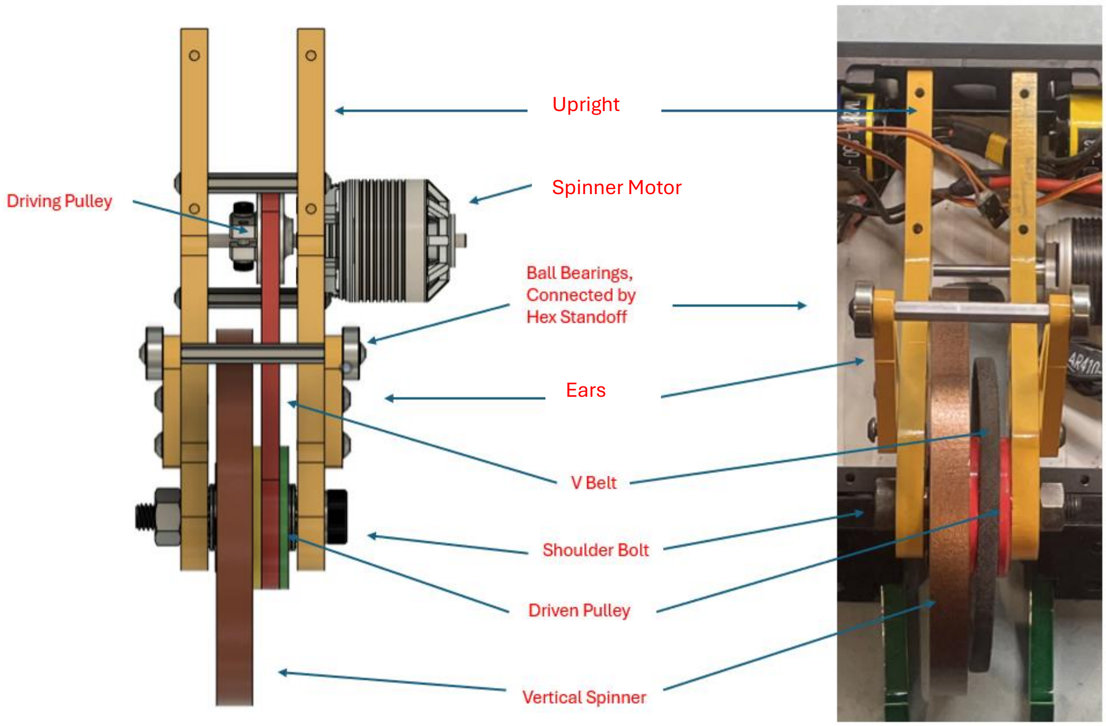


Figure 52: Full Spinner Assembly

As shown above, a 3/8-inch shoulder bolt is used as the spinner shaft. The shoulder bolt was lithium greased and utilized needle bearings between the end of the pulley and the inside of the upright to ensure minimal friction.

The pulley system was chosen due to its precise control over the spinner's speed and torque output, the smaller driving pulley on the motor and larger driven pulley increased torque at the spinner, producing a greater storage of kinetic energy for powerful strikes.

Drive Assembly

The drive system was made utilizing a 31-tooth to 40-tooth pulley ratio. The back wheels made entirely out of 95a TPU were printed with the 40-tooth pulley attached to it. This was to ensure no belt slip and minimal belt slack when moving at high speeds. The back wheels also had a urethane mold around the outer edge to increase the amount of friction and traction between the cage floor and the wheel itself. This allowed for more control when driving the robot. The back wheels also had the motor hub press-fitted and screwed in to ensure that the back wheels would not be knocked off the motor shaft.

The front wheels, also printed from 95a TPU, were printed as a pulley with a larger outer wall. This was to make sure that the belt, if hit hard enough, would not slip from the pulley but stay stationary. The front wheels also had titanium spurs screwed into the outside face to ensure more traction on the cage floor. The titanium spurs were designed to slightly dig into the floor and allow for a "gripping" effect to assist in ease of traverse.

The shoulder bolt "shaft" on the front wheels utilized two "bearing stacks" that consisted of a needle bearing in between two washers on both sides of the pulley. This was used to minimize the amount of friction the wheel would have against the side wall. A bearing was also press-fit into the wheel with white lithium grease to make sure the wheel itself would not friction weld to the shoulder bolt. The belt that was used was a 16-inch XL series timing belt that had 80 teeth. This belt allowed our front wheel to pull our robot forward and fit nicely between both pullies.

Armor & Forks Assembly

The armor was 3D printed with 95a TPU to help protect the wheels because of its resiliency and shock absorption properties. Two sets of armor were printed using two different print configurations. One was a set that had 6 inner walls or print layers, and one that had 8 inner walls or layers. Depending on the size and speed of the opponent's spinner, these walls would be swapped out for a better matchup. The armor also covers the front walls protecting the electronics that were secured inside on the front end of the robot.

Figure 53: Armor Profile

Figure 54: Armor Live

The forks were made from 3/8-thick-aluminum 6061 and were waterjet cut to fit the specified design. The forks were then counter sunk and screwed into the bottom of each upright - (shown below in Figure 55 and Figure ***56***) by a shoulder bolt and nut directly into the uprights of the spinner assembly. Since these forks utilized a shoulder bolt, they acted as if they were on a hinge which would keep the forks from snapping off completely if hit with enough force in the wrong direction. They were also covered slightly by the TPU armor to act as a “buffer” so that the forks’ range of motion was limited to avoid snapping or bending. The forks were designed to barely graze the floor and lock onto or under the opponent while the vertical spinner would strike.

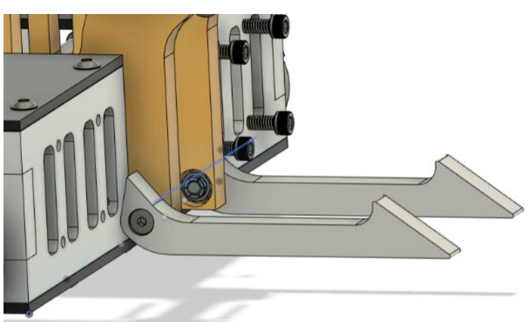


Figure 55: Hinged Forks Side Profile

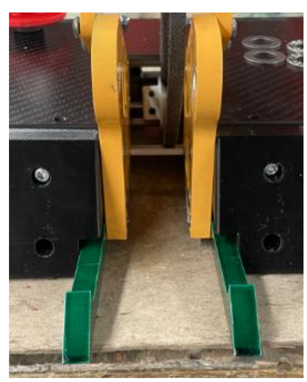


Figure 56: Forks Live Front Profile

Full Assembly

The final assembly was completed on April 2nd. At the competition, there was an open testing day that occurred on April 4th. In this Open testing day Murder Burger was taken completely apart and then reassembled with lock tight on every screw. Lock tight would allow for the screws to hold more tension and be less likely to come loose through vibrations during the competition.

The Spare components did not utilize lock tight. The reason being that if a spare part was needed it would be easier to remove from the spare bot without lock tight holding all the screws securely.

Figure 57: Full Assembly

Electronic Harness and Wiring

To direct power from the LiPo battery safely to the 2 drive motors and spinner motor, the following wiring harness was designed and soldered, shown below in Figure 58.

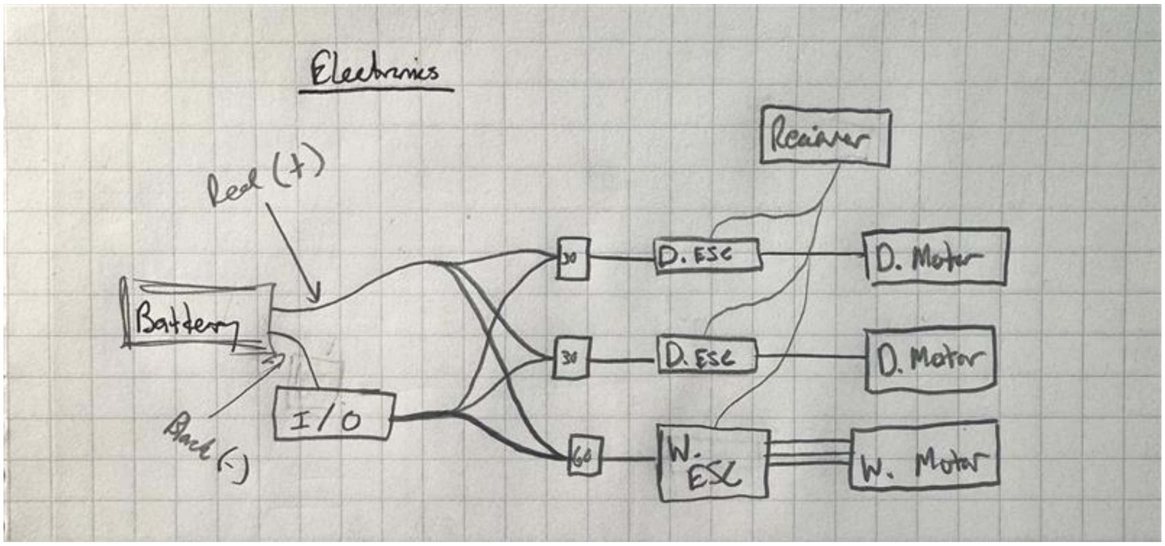


Figure 58: Wiring Harness

Starting from the left, the battery is connected to a positive (red) and negative (black) wire through XT60 PCB connector (Figure 60) with 14-gauge stranded wire (Figure 62). The black ground wire is then soldered to the Kake switch (Figure 61), or the power switch. From this point, each 14-gauge wire is split and soldered into three wires, where one positive and one negative wire will each attach to the 2 drive ESCs and singular Spinner ESC through 2 XT30 connectors (Figure 59) and one XT60. Using XT30 connectors and 16-gauge wire, the 2 drive ESCs are soldered to the harness described above. For the connection of the spinner motor ESC, 14-gauge wire and an XT60 are used as well.

Figure 59: XT60

Figure 60: XT30

Figure 61: KAKE Switch

Figure 62: 14-g Wire

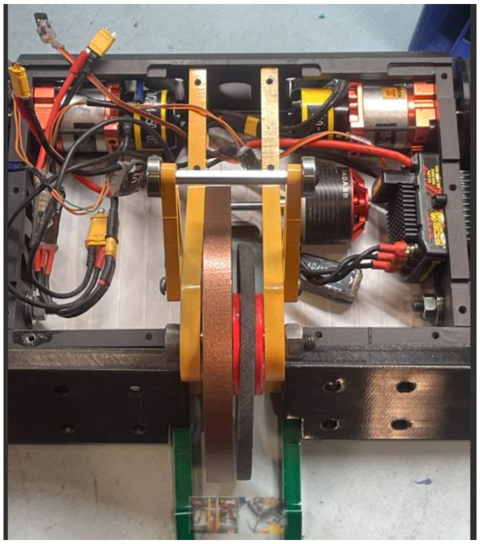


Figure 63: Wiring Harness Integration

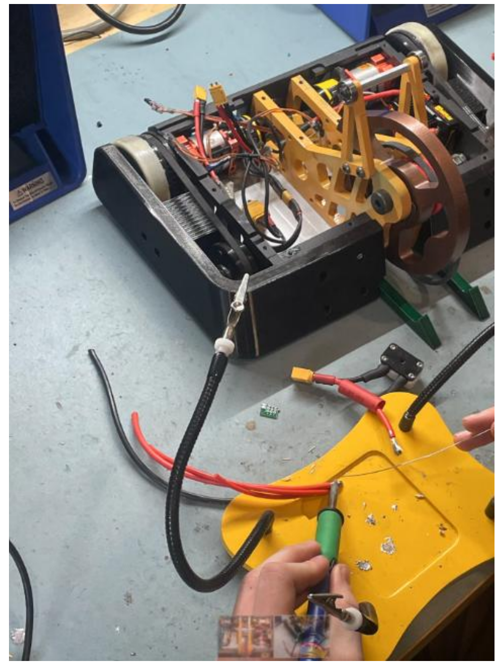


Figure 64: Wiring Harness Soldering Process

System Testing

There were two stages of testing for the robot. Drive and spinner. Drive testing was conducted at the University of Cincinnati Victory Parkway Campus. The robot was placed in a wooden blocked off area where the robot would be turned on and driven around. The drive testing was used to calibrate the settings on the controller in order to make sure all the settings and control curves would be well adjusted for competition.

Once the robot was turned on it would be driven around the blocked off area for a maximum of three minutes. Three minutes is the maximum time the fights at the competition would be and this would allow for testing to make sure that the battery would be able to withstand the whole three minutes. When the three minutes were completed, the robot was turned off and the motors were checked to see if they were just warm or too hot.

After the first drive test, the motors were overheating due to some of the electronics' wires rubbing up against the motors. This was fixed by rearranging the electronics with electrical tape and spacers to ensure that they would no longer rub against the motors (Figure 65).

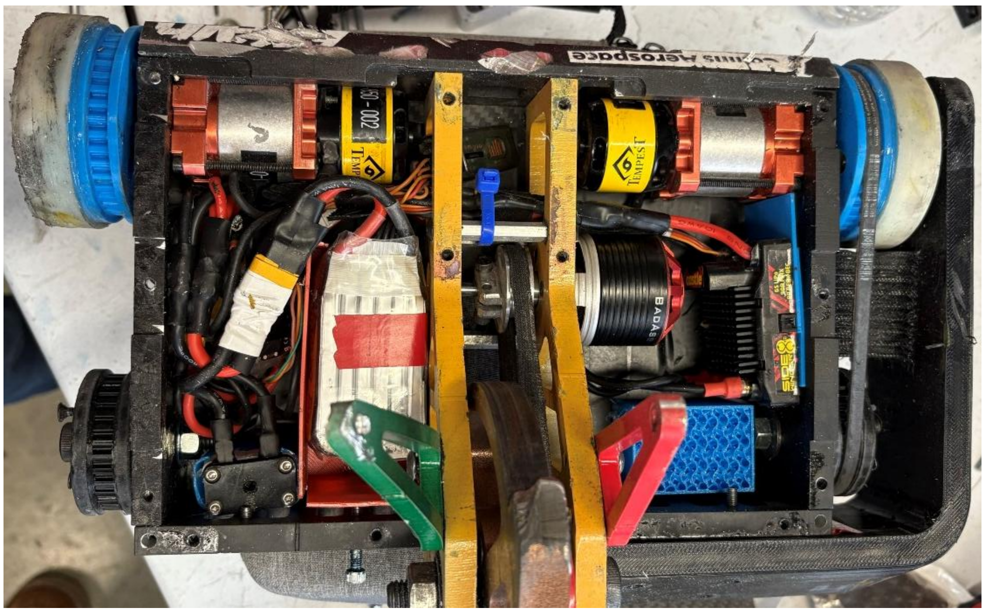


Figure 65: Wiring Harness and Electrical Tape and Spacers

The next stage of testing was for the spinner assembly. Due to regulations from The University of Cincinnati, since the vertical spinner is labeled as a weapon in the NHRL rules and regulations, no (vertical) spinner testing was permitted at the University. Because of these restrictions, testing for the spinner assembly was conducted entirely at the NHRL competition. The spinner assembly had to go through fail-safe testing. This means that if the vertical spinner is spinning at top speed and the controller is turned off, all movement and power from spinner would cease and come to a stop. NHRL also permitted testing of both spinner and drive systems in one of the test cages under supervision of an NHRL official. This testing followed the same three-minute testing rules that were followed for driving prior to the event.

Competition Results

The NHRL preliminary competition fights are formatted as a double-elimination bracket. Every competitor participates in a minimum of two fights. If the competitor wins two fights, they move on to Prime Time, the top 8 bracket that becomes single elimination. The winner of each monthly competition returns to NHRL in December for the championship event.

The first match was against Massachusetts Institute of Technology's new robot Traiano (Figure 66), a hammer-saw style robot. Like a hammer bot, this robot swings a circular saw down onto its opponent, hoping to slice into and through the top side of its opponent.

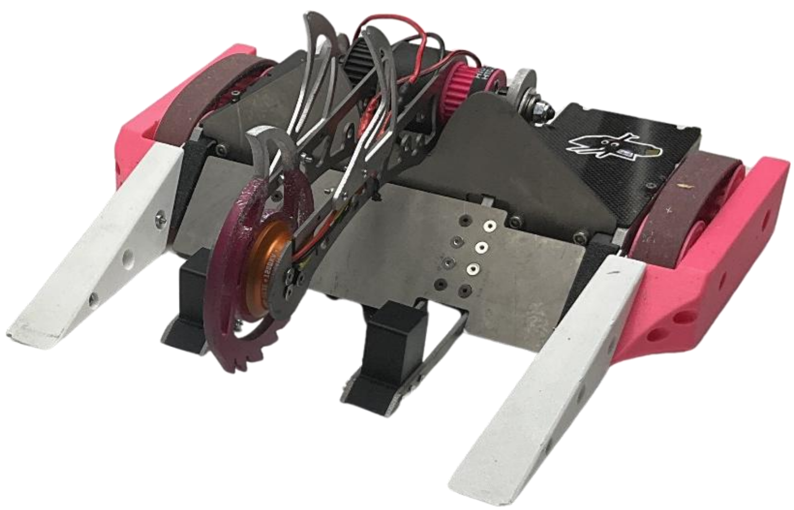


Figure 66: Traiano

This match resulted in a victory for Murder Burger by knockout in forty-two seconds. This match was the first win of the day for the University of Cincinnati Combat Robotics team.

The second match was against Donald Sung, a hobbyist who has been competing in NHRL since 2023, with his #25 ranked Torrent (Figure 67). Torrent is a vertical drum spinner robot that instead of being wide, is long and narrow to mitigate gyroscopic precession (to the team's surprise, much more efficiently than a wider base).

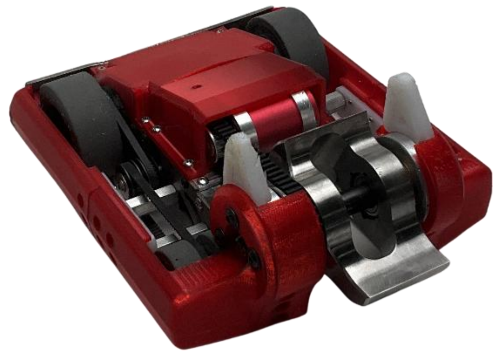


Figure 67: Torrent

This fight went the full match duration and resulted in a judge's decision. While Murder Burger was able to expose the LiPo battery in Torrent, unfortunately, the damage that was done to Murder Burger gave Torrent the win.

The Torrent match damaged both back wheels of Murder Burger, as well as tearing off the left-side armor and the bearings from the top of the robot. The team used their one 15-minute extension allowed for repairs to switch out the left side wall, wheels, and armor for the next fight.

The final match was against Kent State's Flash-BANG (Figure 68). Similar to a vertical spinner, Flash-BANG is a toothed drum spinner that consists of three components welded together.

Figure 68: Flash-BANG

During the match, Murder Burger was able to knock out the right-side drive motor of Flash-BANG and damage the spinner motor enough to reduce the speed of their spinner significantly. Unfortunately, during the match the spinner fully seized, and no movement was coming from Murder Burger's spinner. This resulted in little to no aggression points from the judges as the match became dominated by a grasp for control with no capability to inflict any damage post-spinner-seize. As a result, Murder Burger was driven to pin Flash-BANG against the wall to gain control points. Because of these pins, Flash-BANG had to completely replace their spinner motor due to the damage it incurred from digging into the cage wall. This match also went the full three minutes and although Murder Burger controlled the match overall, another judge's decision occurred, with Flash-BANG being named the winner and officially eliminating Murder Burger from the April 2025 event.

Lessons Learned

After manufacturing and competing, it became clear that standardization plays a crucial role in the design of a combat robot. The robot had many different screws of multiple sizes that resulted in switching between multiple sizes of allen wrenches that took up a large portion of repair time in between fights. During the repair process it was also found that the design of the spinner assembly required taking apart the entire frame in order to repair any damage that might have occurred to the spinner stack. Luckily, the spinner stack did not receive any significant damage or was deemed enough to disassemble.

It was also determined that some design choices such as the keying in the frame, made it difficult to fully remove some pieces of the frame. Because of the keying, every component had to be put together in a certain order or else it would have to be taken completely apart and reassembled in the right order.

After the competition, it felt very necessary to have more testing with the spinner turned on before the event. While the University of Cincinnati has rules against the testing of the spinner, the team was unable to drive test with the spinner. With the spinner running at just 45% while driving, gyroscopic procession posed a challenge against consistent control for driver Cade Budinski. Because of this, Cade was still learning to adapt and drive the robot during all three official matches.

Conclusion and Recommendations

If another opportunity to compete were to arise, there would be multiple design choices made to improve the robot. The first change would be adjusting the size of the vertical spinner. The vertical spinner has a very large diameter that needs some optimization. While designing the spinner, it was believed that a larger diameter would allow for a larger reach and bite. This isn't entirely untrue, but a smaller diameter with the vertical spinner's axis of rotation being shifted closer to the front edge of the robot would work just as well. With a smaller diameter, the spinner would be able to gain thickness/material, allowing for a greater collection of stored energy to unleash on opponents, as well as being more durable. This would also further centralize the center of mass and gravity, reducing the amount of gyroscopic precession that the robot experienced during most turns.

The next design change would be to make the robot narrower instead of the original wide footprint. There was a moderate amount of space inside the robot, and a concern that the electronics would have the potential to move around and come loose during the fight. Luckily, this was not the case. Future designs would have a narrower body to secure the electronics without the need for filler material to fill space. The narrow body would also reduce the amount of gyroscopic precession and allow for easier handling and control of the robot.

Lastly, the spinner assembly's uprights and ears would be completely redesigned for the robot. The ears were mangled regularly and took constant damage to the point that the attached bearings (designed to let the robot drive upside down) were knocked off in two of three fights. The ears would be redesigned to be more rounded and angled with a wider base to provide more support and resiliency when struck. The spinner assembly uprights would also be shortened. If the vertical spinner's diameter is decreased, the upright height can shrink as well. Clearance between the spinner and the ground was the driving factor in how high/tall the uprights needed to be. This would lower the robot's center of mass and gravity, further increasing control.

Increasing Murder Burger's ease of handling and control of the gyroscopic precession would help reduce the amount of time spent upside down. This will allow for more aggressive driving as well as more opportunities to strike opponents. The more time spent upside down, the longer the driver must play "defense" and remain conservative, focusing on flipping over again. This negatively affects performance as NHRL judges grade on control, aggression, and damage. If Murder Burger is upside down, it cannot display control, it cannot exert much aggression, and its damage capability is extremely hindered. If Murder Burger can stay upright, the possibilities and potential will skyrocket.

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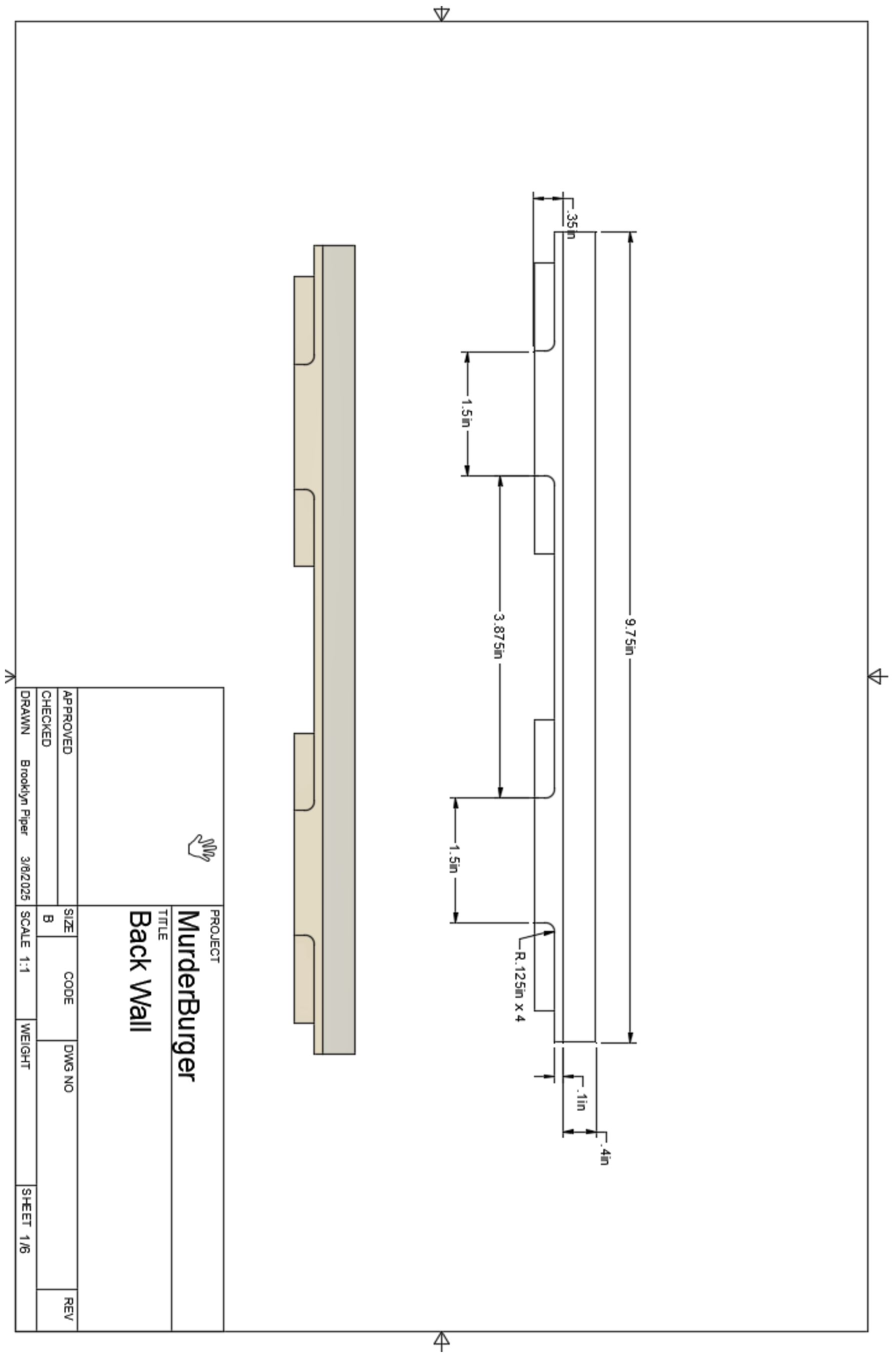
Appendices

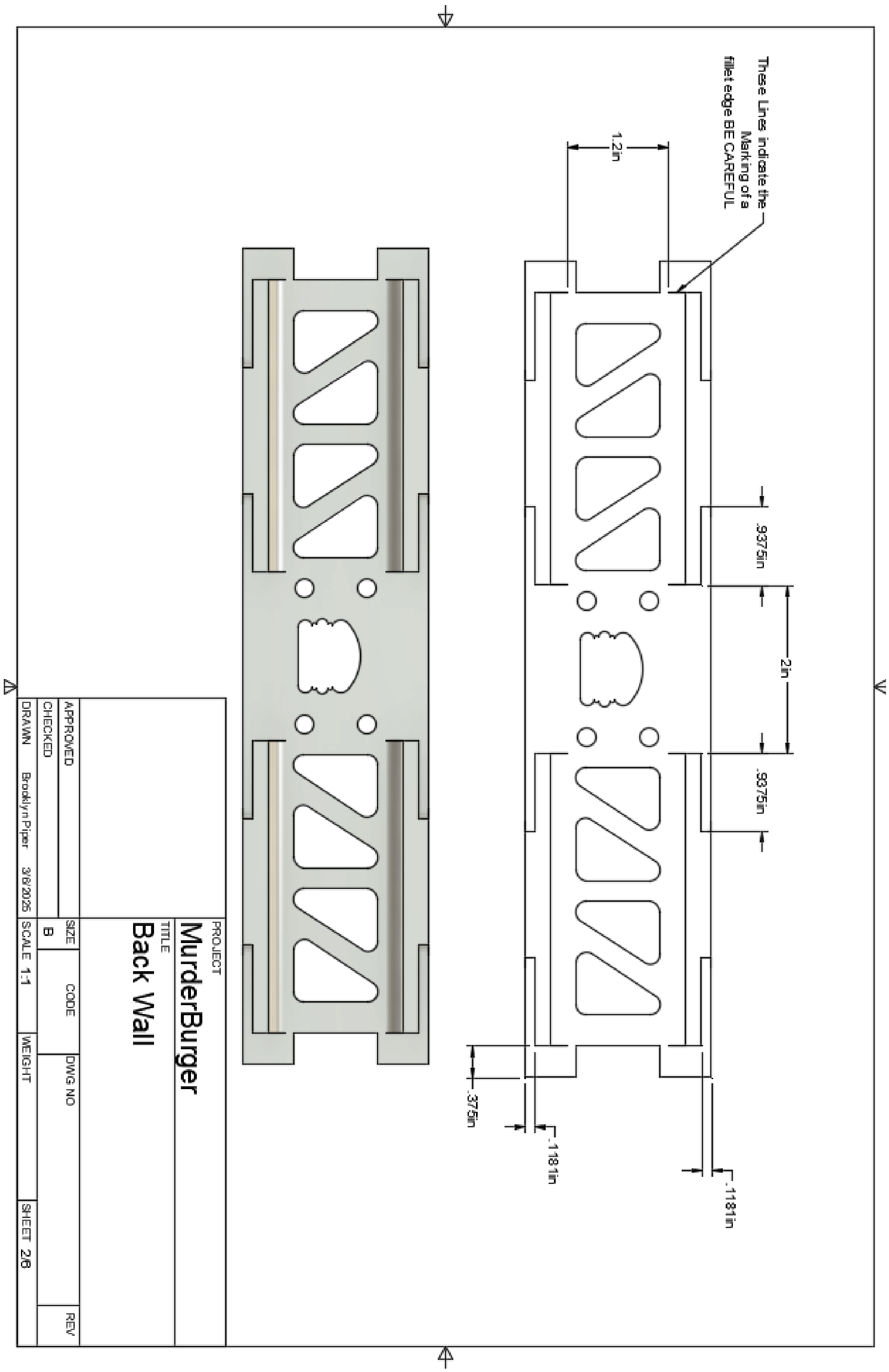
Fusion Drawings Appendix A

Each of the components seen below used the manual mill, the Lathe, or required more complex machining than the water jet.

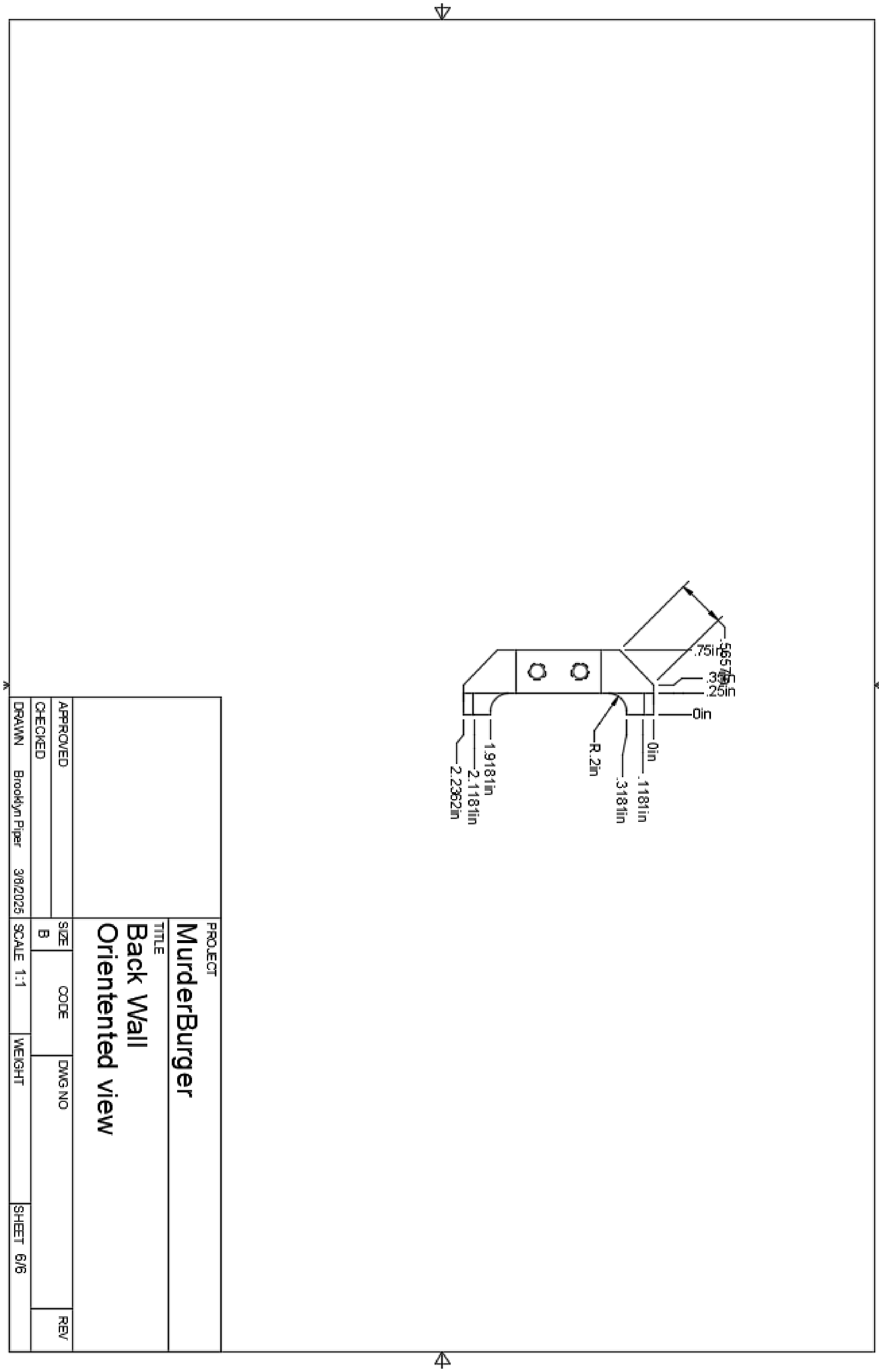
Back Wall drawing (Top View)



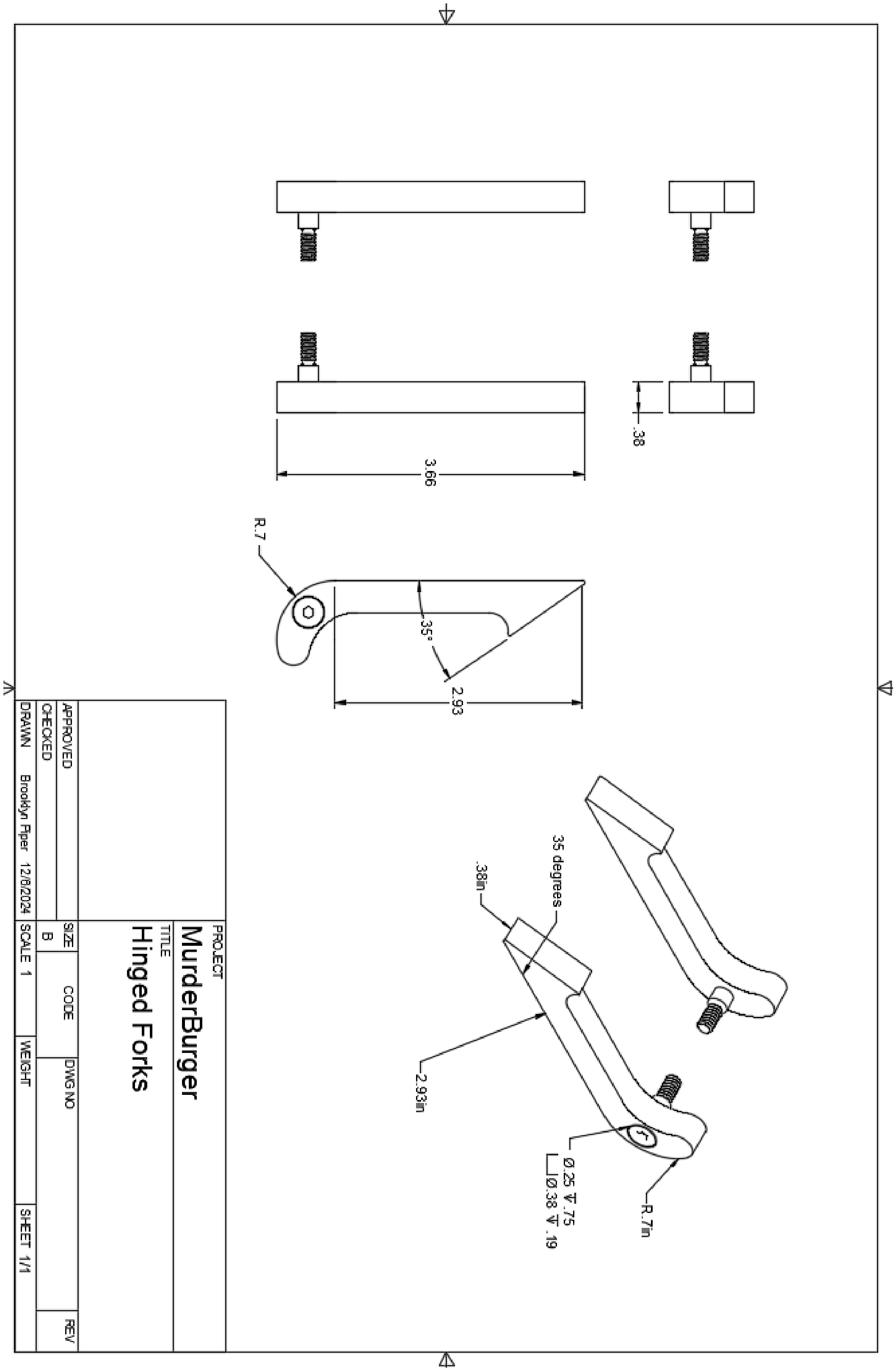
Back Wall Drawing (Front view)



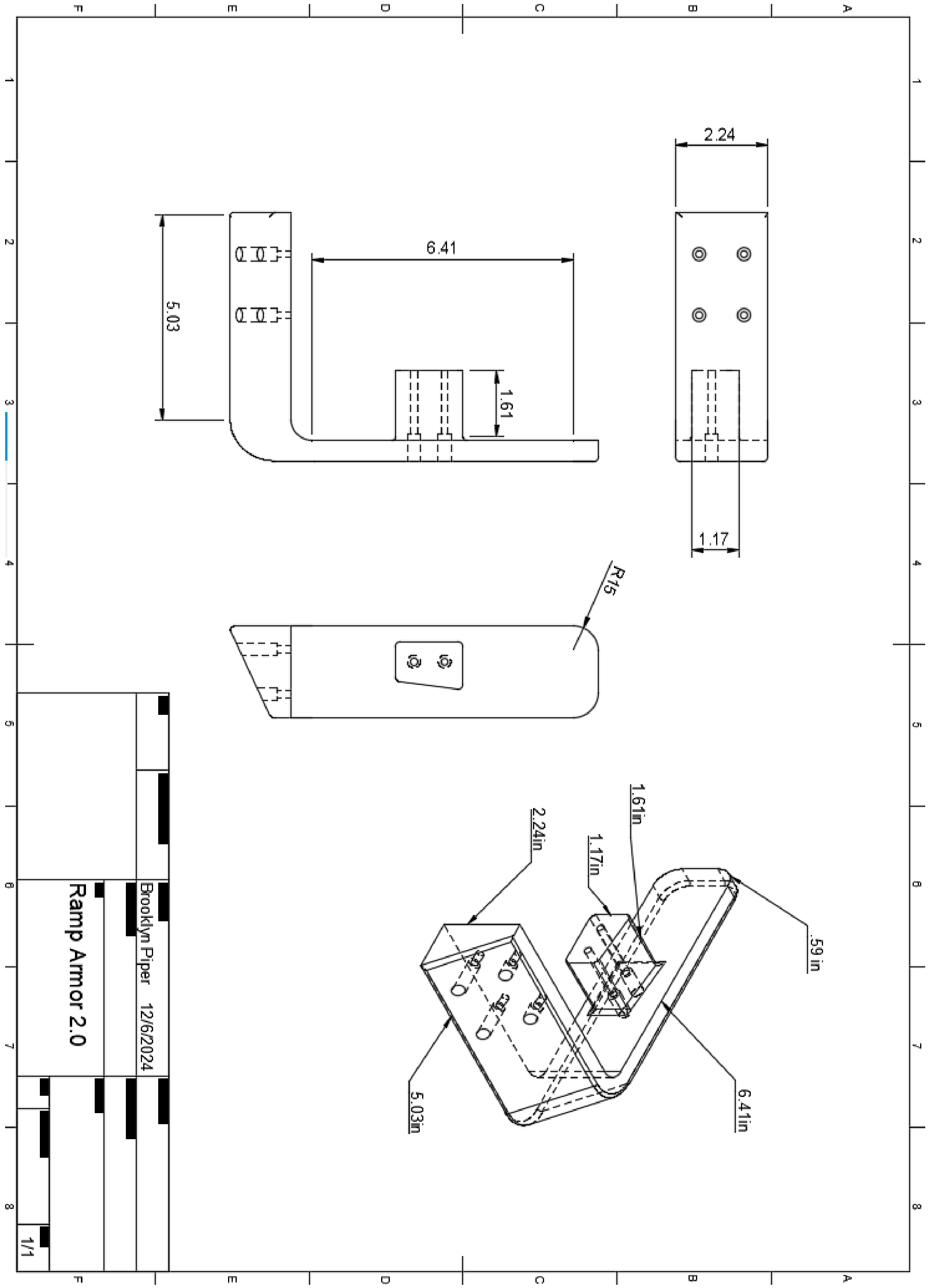
Back Wall Drawing (Side View)



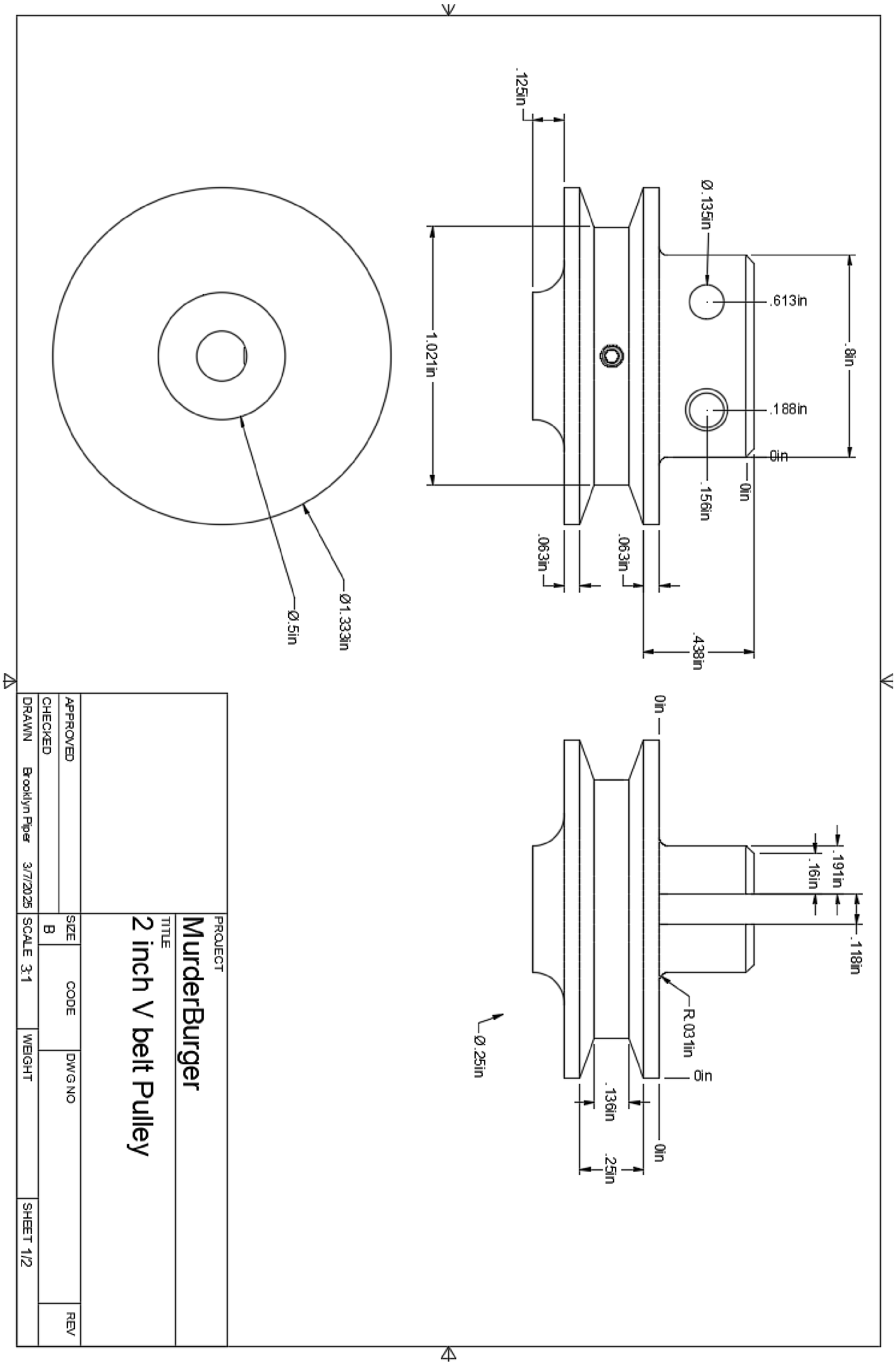
Fork Drawing



Armor Drawing



Driving Pulley Drawing



Driven Pulley Drawing