

Battlebot - La Machina

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by

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## 1. Problem Statement

Our team is tasked with designing and building a 12-pound combat robot to compete in the 2025 NHRL Open World Championship – Qualifier Round 3, held on April 5th in Norwalk, CT. The robot must comply to NHRL regulations, including weight, safety, and material restrictions.

The main challenge is to optimize the robot's performance by balancing its frame, armor, weapon, drive, and electronics within the 12-pound limit. This requires good weight distribution, robust structural integrity to withstand aggressive attacks, and efficient power management to maintain agility and weapon use throughout 3-minute matches. The robot needs to deliver high-impact attacks capable of disabling opponents while navigating NHRL's arena and avoiding or absorbing damage.

Our goal is to deliver a durable and agile robot capable of withstanding combat in the arena. We plan to deliver knockouts and outmaneuver opponents during 3-minute matches. By applying our state-of-the-art research and the concepts we've learned throughout our time at UC—such as kinematics, material properties, and competitive strategies—we aim to overcome past design flaws and achieve success in the April 2025 event.

## 2. Research

### a. Background of the Problem

The impact of battle bot malfunctions and failures extends to multiple groups and parties. Competitors like us, other UC Combat Robotics teams, and senior design teams will experience financial and emotional costs when their battle bots fail or underperform. These costs include repair expenses, part replacements, and the time invested in design, building, and testing. Spectators and fans attending events such as NHRL may also be affected, as the quality and excitement of the matches are heavily influenced by the performance of the bots. Frequent malfunctions or poorly designed bots can detract from the entertainment value, leading to decreased engagement and satisfaction among viewers. Event organizers for NHRL face logistical challenges and even potential financial repercussions when bots do not meet performance expectations, potentially disrupting the event flow and damaging the competition's reputation.

The costs and consequences of battle bot failures are many and various. Competitors invest a decent amount of time in building and maintaining their bots. Failures due to inadequate protection or design flaws can result in substantial unplanned expenses, such as repairs and part replacements. Operationally, malfunctions or failures during competitions can lead to disqualification or a loss of competitive advantage, affecting the team's success and future reputation. Emotionally, the stress and frustration from failures can lower morale and motivation, potentially leading to reduced participation and interest in the sport. This could be especially challenging if our own bot underperforms.

To address these vulnerabilities, competitors often add protective layers or armor to safeguard critical components such as batteries, motors, electronic speed controllers, receivers, power switches and more. However, these solutions can increase the bot's weight or affect its performance. Teams frequently make design modifications based on past failures in an iterative process aimed at improving resilience. Extensive pre-combat testing is also conducted to identify potential weaknesses, though testing environments may not fully replicate actual match conditions, leading to unforeseen issues during competition. It is also important to note that teams conduct extensive research on the designs of previous battle bots, including nationally ranked ones.

Despite these current stop-gaps and solutions, these are sometimes inadequate because added protection often creates a trade-off between durability and performance, with increased weight reducing

speed and maneuverability. Additionally, even with extensive testing and design improvements, real-world combat conditions can introduce unexpected factors that weren't accounted for in testing environments. This makes it challenging to completely predict how a bot will perform under the intense and dynamic conditions of an actual match.

To tackle these problems, our group must thoroughly understand the weaknesses and shortcomings of previous UC Battle Bot teams as well as current nationally ranked battle bot designs. This involves research examining how well current temporary fixes are working and identifying areas for improvement to enhance the reliability and performance of battle bots in competitions. By implementing innovative ideas and new concepts in the design of the weapon, drivetrain, armor/frame, electronics and controls our team can increase its chances of success in highly competitive environments such as the NHRL event that we will be participating in.

However, it's important to acknowledge that while protective measures and design iterations are helpful, they often come with many trade-offs, such as increased weight that impacts speed and maneuverability. In addition, we must recognize that pre-combat testing may not fully replicate the real-fight conditions faced in live matches like the one we will compete in next semester, leaving bots vulnerable to unexpected failures. The consequences of these issues extend beyond competitors, affecting spectators, event organizers, and the overall quality of competitions. Addressing these challenges with more advanced and comprehensive strategies is important to ensure our bot's durability and performance under the intense, unpredictable conditions of competitive battlebot events.

## **b. State of the Art**

Over the years, several senior design teams and UC Combat Robotics teams have created and competed with combat robots, each using different approaches to tackle various design challenges. To improve our project, we conducted thorough research using credible outside sources, reviewing the design strategies of these teams to assess their effectiveness and identify possible improvements. Additionally, we studied robots from the National Havoc Robot League (NHRL) and the UC BattleBots club to gain further design insights and track the evolution of certain design principles through iterative testing.

This analysis will help our team apply practical and effective design concepts, focusing on key areas such as weapons, frame and armor, drivetrain, and electronics/controls. By leveraging these ideas, we aim to enhance our robot's performance and competitiveness during our design phase.

### **Weapon (s) – John Gamble**

A big factor in designing a combat robot is selecting its weapon(s), which serves as the main system for attacking and dealing out damage to opponents. As the main element of a robot's strategy, the weapon heavily influences the overall design of the robot. This approach results in multiple fundamental design categories, each defined by the weapon type it uses. The weapon's effectiveness directly impacts the robot's performance in battle, making it important to carefully choose a configuration that complements the robot's strengths. Whether it's a spinning vertical or horizontal blade, hammer, or wedge, the weapon dictates the overall structure, mobility, and defensive strategy of the robot (1). This design-first approach makes sure the robot can maximize its offensive capabilities while balancing durability and control during competition.

#### *Spinners*

Spinners seem to be the most popular weapon type in combat robots. They work by storing energy in a rotating flywheel and releasing it in a powerful, controlled strike (2). This makes them highly effective at both attacking and defending. Horizontal and vertical spinners will be explained in the

following paragraphs separately as they contain different benefits and drawbacks. But overall, the general benefits and drawbacks of spinners are to follow:

**Pros:** high damage potential, defensive capabilities, energy storage, and effective against armor (2).

**Cons:** complexity and reliability, energy management, at risk of self-damage, weight limitations, and difficult to control (2).

### Horizontal Spinners

Horizontal spinners are a class of robots which use a horizontally spinning blade designed to strike opponents from the side. These robots are categorized into three subtypes based on the weapon's vertical height: undercutters, center spinners, and overhead spinners. All which are very effective at damaging opponents (2).

Undercutters position their weapon low to the ground, targeting an opponent's wheels or undercarriage of the body/frame. This makes them highly effective at immobilizing their competition by damaging crucial components. However, undercutters are susceptible to floor damage due to their low weapon height, and if flipped over, they lose their combat advantage and sometimes control. Center spinners, also known as bar spinners, mount their weapons along the bot's centerline. This allows them to be equally effective whether flipped or upright, as the weapon continues to function in both orientations. Despite this versatility that comes with this configuration, center spinners are prone to self-inflicted damage since the spinning weapon is often positioned near the bot's frame. Overhead spinners are designed to attack opponents from above, offering flexibility in weapon size and the ability to strike from multiple angles. Although these are powerful, overhead spinners are less effective against shorter opponents and typically rely on the movement of their weapon or bouncing to self-right after a fall (2).

**Pros:** high damage output, effective mobility targeting, versatile orientation, multiple attack angles, and strategic control (2).

**Cons:** at risk for self-damage, vulnerability to flipping, floor damage, limited effectiveness against short opponents, and complex design considerations (2).

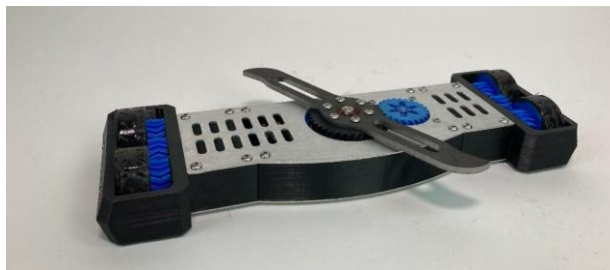


Figure 1: Horizontal Spinner – Blueberry (3)

### Vertical Spinners

Vertical spinners are categorized by having a weapon spin vertically, so that the cutting edge moves upwards or downwards towards the competing bot. Most vertical spinner weapons are disc shaped and circular, although it is not uncommon to see large bars, similar to a lawnmower blade. Vertical spinners generally will have their weapon centered over the body. The weapon also commonly serves as a self-righting mechanism, as the bot's weapon is generally too tall to allow it to drive when flipped over (2).

There are two main disadvantages to vertical spinners. First, the weapon contact point is generally further away from the center of mass of the bot. While this can be beneficial in some scenarios as a means

of keeping an opponent at bay, it also means that the moment of torque upon impact is much greater on your bot, leading to a high chance of it going flying and bouncing away as well. The second major limitation is that since the spinning weight has such a large radius, vertical spinners often struggle to move. They must overcome the gyroscopic forces of their weapon to effectively move. A vertical spinner is distinct from drum spinners in that the blade has a greater diameter than thickness (2).

**Pros:** high impact force, ability to self-correct bot orientation if flipped, decent weapon reach, and stable center of mass (2).

**Cons:** torque and momentum issues, mobility challenges, vulnerable to being flipped, weight distribution considerations, and potential for self-damage (2).



Figure 2: Vertical Spinner - Front Towards Enemy (4)

### Drum Spinners

Like vertical spinners, drum spinners have a single central weapon that spins to deliver upwards or downward strikes to the opponent. The main difference is that a drum spinner is much thicker and with a smaller radius than a vertical spinner. It is not uncommon for drum spinners to have the entirety of the front of the bot be the weapon. With a smaller and lower down weapon, it is possible to build your bot low enough to the ground that being inverted is no problem; just have the wheels stick out both above and below the chassis. Having the spinning weight of the weapon closer in reduces the moment as you spin, allowing you to spin up faster and reducing how much you are knocked back in a hit (5).

The downside to a drum spinner is that they tend to make for very heavy and hard to balance weapons. The most common profile for a drum weapon is a cylinder with a single tooth, so the center of mass is far away from the rotating axis. This leads to premature wearing of the bearings, pulleys, and motors. Another limitation of drum spinners is that they are extremely ineffective against other drum spinners, since it will mostly end up being the weapons always in contact with each other (5).

**Pros:** powerful strikes, low center of gravity, spin-up speed, ability to self-correct bot orientation if flipped, and full-front weaponry design (5).

**Cons:** weight and balance issues, bearing wear issues, limited defense against flips, and mechanical complexity (5).

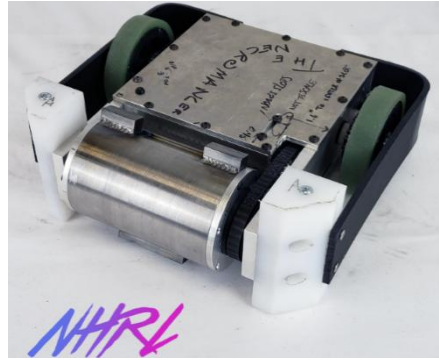


Figure 3: Drum - The Necromancer (6)

### Axes and Hammers

Axe bots and hammer bots are combat robots that use a tool on an arm to attack their competitor. Hammer bots usually do this with a large, blunt hammer to inflict damage to the top of the competitor, which is usually the weakest part of a bot. Axe bots, by comparison, use a sharpened point moving at high speeds to try and pierce the top of the competitor, and hopefully hit a battery or other important internal components (2).

**Pros:** effective against top armor, precise targeting, low-self damage risk, controlled attacks, and very little to no gyroscopic effect (2).

**Cons:** limited range of motion, slow attack speed, susceptible to being flipped, relies on only one single point of attack, and mechanical complexity (2).



Figure 4: Hammer/Axe - Spine Crawler (7)

### Flippers and Lifters

Flippers and lifters are two slightly different types of bots, that both use a spatula and lifting motion to attack. Flippers, usually powered by pneumatics, get under and throw their competitors, inflicting damage or hopefully having them land in an orientation they can't self-correct from (8). Lifters use somewhat more controlled motion to pick up and pin a competing bot. While this does little actual damage, it can score points in a fight that goes to the judges (9).

**Pros:** effective at flipping opponents, control over opponent, high strategic value, low risk of self-damage, and very versatile.

**Cons:** limited potential damage, vulnerable to faster bots, reliance on opponents' mistakes and potential mechanical failure.



Figure 5: Flipper – Lance (10)

### Wedges and Controls

Wedge bots and control bots are a well-known category of combat robots that focus on defensive and strategic maneuvers to disable their opponents, rather than inflicting direct damage through active weapons. These bots typically "win by breaking the other bot with their face," meaning they force their opponents into situations where they damage themselves through collisions or by being thrown off balance. This strategy operates on the principle that "my reliability > your reliability = win," where the goal is to outlast and outmaneuver the opponent, relying on the opposing bot's inability to sustain prolonged attacks or recover from being disabled. The advantages of this design include simplicity and durability, as these bots have fewer parts that can break. They are also effective at preventing the opponent from moving or attacking and are cost-effective and easier to build. However, the downside is that they lack active weapons, so they depend on the opponent making mistakes. Additionally, they can be less exciting to watch since they don't deal direct damage, and some competitions restrict their use due to their defensive style (11).

**Pros:** highly durable, simple design, cost-effective, good for control applications, and reliable (11).

**Cons:** lacks direct damage, relies on opponents' mistakes, not very exciting, and not very versatile against more agile or maneuverable bots (11).



Figure 6: Wedge – Wicked Wedge XL (12)

### **Drivetrain – John Gamble**

#### Wheel Drive Methods

In battle bots design, the drivetrain is very important for determining a bot's movement and maneuverability. There are a few different wheel drive methods to examine and consider, such as 2-wheel drive (2WD) and multi-wheel drive. A 2WD system is simpler and lighter, making it easier to control and energy-efficient, though it offers less traction and pushing power (13). On the other hand, multi-wheel drive, such as 4WD or 6WD, improves traction, weight distribution, and stability, allowing the bot to push harder and move better on the battle floor (13). However, this method is more complex and can be heavier, requiring more components and drawing more power.

### Drivetrain Assembly

When it comes to the drivetrain assembly, chain, belt, and gear drives are the main options. A chain drive system is durable and handles high torque loads well, but it's heavier and requires regular tension adjustments (13). Belt drives are lighter and provide smoother, quieter operation, though they are less durable under heavy loads and may slip. Gear drives, while compact and highly efficient, are more complex and heavier, making them suitable for bots that require significant torque without slippage (13).

Motors are another key component, with the choice between brushed and brushless types. Brushed motors are cost-effective, simple to control, and rugged, though they are less efficient and require maintenance. In comparison, brushless motors offer higher efficiency, a better power-to-weight ratio, and longer lifespan but are more expensive and complex to control (13). Overall, selecting the right drivetrain components requires careful consideration of weight, power efficiency, and durability, as each choice will affect how well the bot performs and withstands the rigors of combat.

### **Frame and Armor – Nguyen “Steven” Le**

Another important factor in designing a combat robot is the frame and armor system, which plays a big role in determining the robot's ability to withstand high-impact collisions, weapon strikes, and other destructive forces. Advances in materials science and design strategies have significantly enhanced the durability, flexibility, and overall performance of a bot's armor over the years. Today's state-of-the-art armor technologies use a variety of materials, each providing a unique balance of strength, weight, and cost-effectiveness.

Choosing the right materials is important for creating an effective combat robot. The harsh conditions of battle demand a careful balance of characteristics like strength, weight, durability, and ease of repair. The materials selected not only affect the robot's performance during combat but also influence its overall lifespan, including how easily it can be repaired and modified between matches.

#### Thermoplastic Polyurethane (TPU) Filament

TPU is a highly flexible and durable filament that's ideal for parts that need to bend or flex without breaking. This material is a prime choice for shock absorption components or components that need to withstand high stress (14). This material can be easily designed in CAD software and is typically 3D printed.

**Pros:** This material is highly durable, flexible, and resistant to wear and tear (increase longevity) (14).

**Cons:** Printing TPU is challenging because of flexible characteristics, which requires a slow print speed to achieve a quality print and limited compatibility with 3D printers (14).



Figure 7: TPU Filament (14)

#### Nylon/Carbon Fiber-Infused Nylon

Carbon fiber-infused nylon is a composite material that integrates micro-carbon fibers into nylon, resulting in a robust filament with improved stiffness, impact resistance, and tensile strength. This

composite is particularly well-suited for combat robot components, providing exceptional durability and resilience under high-stress conditions (15).

**Pros:** Enhanced stiffness, superior impact resistance, and high tensile strength (15).

**Cons:** The abrasive nature of carbon fiber necessitates the use of hardened steel or wear-resistant nozzles for 3D printing (15).

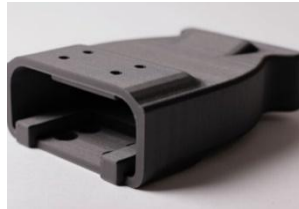


Figure 8: Carbon Fiber-Infused Filament (15)

### Polycarbonate (PC) Filament

Polycarbonate is known for its exceptional strength, durability, and impact resistance, making it a great option for combat robots. It can endure high temperatures and offers transparency, which can be useful for certain components (16). However, like nylon, polycarbonate is challenging to print, requiring high temperatures and a heated bed.

**Pros:** Polycarbonate offers excellent strength, impact resistance, heat tolerance, and transparency for combat robot components (16).

**Cons:** It is difficult to 3D print, prone to warping, more expensive, and can be brittle in thinner sections (16).



Figure 9: Polycarbonate (PC) Filament (16)

### PETG Filament

PETG filament offers a balance between ease of printing, similar to PLA, and enhanced durability and temperature resistance, making it well-suited for combat robots. Its strength and impact resistance, combined with user-friendly printing properties, make it a popular choice among 3D printing enthusiasts.

**Pros:** PETG filament offers excellent impact resistance and durability, which are crucial for withstanding the high stresses and impacts encountered in battle bots (17).

**Cons:** PETG can be more challenging to print with compared to PLA, requiring precise temperature control to minimize stringing and warping (17).



Figure 10: PETG Filament (17)

### ABS Filament

ABS filament is a popular choice for 3D printing due to its strength and durability, with greater flexibility than PLA, making it better suited for absorbing shocks. However, it can release unpleasant fumes during printing and is prone to warping without the use of a heated enclosure (18).

**Pros:** Strong, durable, and offers flexibility, making it well-suited for impact-resistant applications.

**Cons:** Emits unpleasant fumes during printing and tends to warp if not printed in a controlled, heated environment.



Figure 11: ABS Filament (18)

### UHMW (Ultra-high Molecular Weight Polyethylene)

Ultra-high molecular weight polyethylene (UHMW) is a durable, abrasion-resistant material increasingly favored in robot combat. Its properties make it effective as a buffer for armor, preventing opponent weapons from reaching the robot's core, while its low friction and impact resistance allow it to serve as a skid surface in various robotics applications (1).

**Pros:** UHMW is highly durable, abrasion-resistant, and offers excellent impact protection, making it ideal for shielding and structural applications in robotics (1).

**Cons:** It can be difficult to machine precisely due to its toughness and low friction, which may limit its versatility in more intricate designs (1).

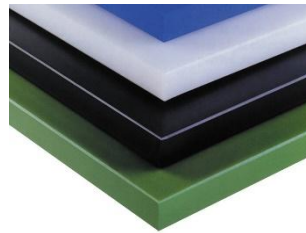


Figure 12: UHMW Filament (19)

## Aluminum

Aluminum is widely utilized across various industries, from consumer products to aerospace and automation, due to its lightweight and machinable properties. In combat robots, it is often chosen for internal structural components such as frame members and gearbox housings (1). However, because aluminum is a relatively soft metal, it is rarely used for armor unless applied in sufficient thickness to withstand damage from opposing weapons. Common aluminum alloys used in combat robots include 6061, 2024, and 7075 (1).

6061 is the most frequently used alloy due to its lower cost, weldability, and softer composition. In contrast, 2024 and 7075 are stronger and harder, offering a higher strength-to-weight ratio, but they are more expensive and cannot be welded (1). Overall, aluminum is highly machinable and can be easily worked on using tools such as mills, lathes, or waterjets. Majority of aluminum members end up being waterjet cut during the fabrication process.

**Pros:** lightweight, high strength-to-weight ratio, very machinable, corrosion resistant, and weldability.

**Cons:** lower hardness compared to steel, limited armor applications, some applications cannot be welded, and the cost varies.



Figure 13: 6061-T651 Aluminum Plate (20)

## Steel

Steel is another commonly used material in bots, known for its hardness compared to aluminum, though it is significantly heavier. Due to its weight, steel is selectively used for parts that require high durability, such as weapon blades, inserts, wedges, and shafts that endure high-impact forces. Key steel alloys used in bots include AR500, 1018, 4130, and AerMet 100, with tool steel (S7) often used for weapon inserts (21).

AR500 is a popular choice for armor and weapon components due to its exceptional hardness and resistance to abrasion, making it ideal for parts that face significant wear and tear. 1018 is a low-strength alloy that is easily machinable and weldable, though it is prone to bending, making it unsuitable for components that require high balance, such as spinning weapons. 4130 is slightly stronger than 1018, offering better weldability and machinability. AerMet 100 is a high-strength steel known for its excellent fracture toughness, but it is extremely costly due to its nickel and cobalt content. Tool steel (S7) is extremely hard but brittle, making it a common choice for weapon inserts (21).

Like aluminum, steel is machined using tools such as mills, lathes, or waterjets, though its machinability varies by alloy, making it essential to understand the specific material to avoid damaging tools.

**Pros:** high durability and hardness, fracture toughness, weldability, and strength (22).

**Cons:** heavy, machinability varies, brittle in some applications, and higher cost (22).

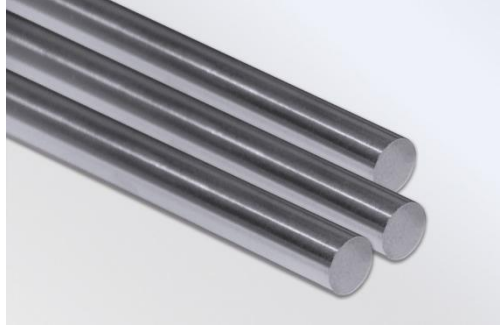


Figure 14: S-7 Tool Steel (23)

### Titanium

Titanium 6Al-4V Grade 5 is significantly lighter than aluminum yet offers three times the strength. Due to its light weight compared to steel, it is often used as armor when weight limits are a concern. However, titanium is more brittle than steel and is prone to fracturing rather than bending, making it less effective against high-impact kinetic weapons (22).

Modern armor designs focus on strategically distributing weight, integrating shock-absorbing structures, and utilizing angled surfaces to deflect rather than absorb energy from impacts. This approach minimizes damage while enhancing the bot's overall survivability during intense matches. By exploring the latest trends and technologies in armor systems, this section will outline the key advancements that inform the design of our proposed battle bot's protective framework.

**Pros:** high strength to weight ratio, corrosion resistant, durable, and heat resistance (22).

**Cons:** brittleness, high cost, difficult to machine, and often only used only in areas where impacts are less likely to occur (22).

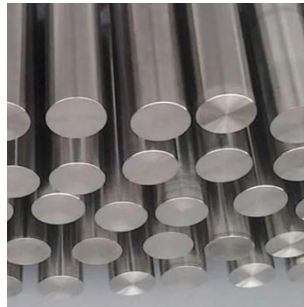


Figure 15: Titanium 6Al-4V Grade 5 (24)

### Chassis Frame – Type/Shape

The shape of a combat robot is an important factor in its overall success. For example, robots with spinning weapons generate a lot of angular momentum and gyroscopic forces due to the mass and speed of the weapon. If the center of mass is not properly positioned, the robot may become unstable, making it harder to control, drive effectively, or avoid flipping over during rapid movements. Ensuring the center of mass is correctly placed is critical for maintaining stability and performance.

Another important aspect of the robot's structure is how it handles impacts from various angles, including hits from the top, bottom, sides, front, and back. A simple way to manage these forces is by designing robots with angled or curved surfaces to deflect impacts, reducing the risk of direct damage. This design approach helps increase the robot's durability during combat.

**Pros:** improved stability, impact deflection, customizability, and weight distribution (25).

A well-designed chassis plays a crucial role in improving the robot's stability, particularly by positioning the center of mass to prevent tipping or losing control during rapid movements or while deploying spinning weapons. Additionally, incorporating angled or curved surfaces into the chassis design helps deflect incoming attacks, reducing the impact of direct hits and increasing the robot's durability in combat. The chassis can also be customized to accommodate specific weapon systems and defensive requirements, allowing for strategic choices that enhance both offensive and defensive capabilities. Finally, careful attention to weight distribution ensures better handling, traction, and overall maneuverability.

**Cons:** complexity of design, material limitations, vulnerability to certain angles, and potential for unwanted tipping (25).

Optimizing the chassis for stability and impact resistance can make the design more complex, requiring careful engineering and planning. Some chassis shapes might also dictate the use of certain materials, which can limit design options or increase costs depending on what's available and the performance requirements. Even with efforts to angle or curve surfaces for better protection, there will still be vulnerable spots on the robot, especially against attacks from vertical spinners or overhead weapons. Plus, if the center of mass isn't calculated correctly, the robot could easily tip over, particularly during sharp turns or when facing opponents with powerful weapons.

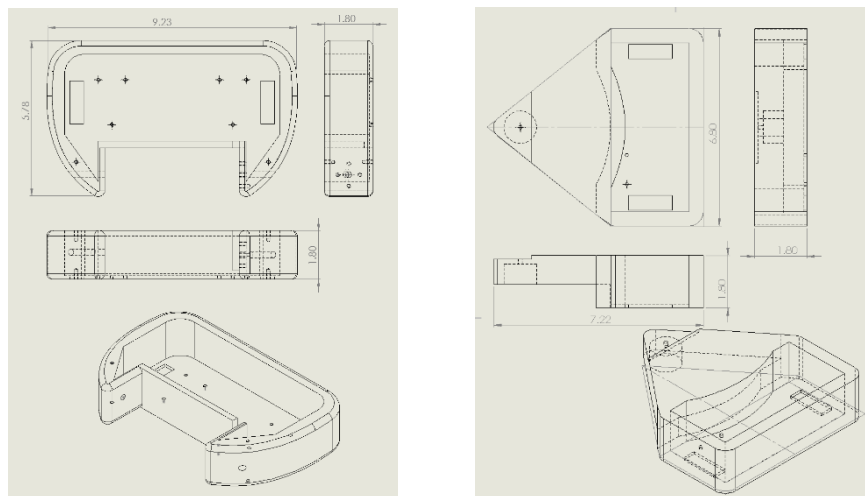


Figure 16: Chassis with rounded shapes to deflect direct impacts (26)

## Electronics and Controls – Paul Jarvis

### High-Performance Wireless Communication Systems

High-performance wireless communication systems are essential for ensuring real-time, reliable control of battle bots. These systems enable the swift transmission of commands and feedback between the operator and the bot, which is critical during combat.

Key aspects of these systems include low latency, which minimizes the delay between command inputs and bot actions, ensuring smooth control in the heat of battle. Interference mitigation, through advanced technologies like frequency hopping and spread spectrum techniques, reduces the risk of signal interference from other sources. Additionally, robust signal transmission ensures stable and reliable control even in challenging environments (27).

Examples of these technologies include Frequency Hopping Spread Spectrum (FHSS), which rapidly changes communication frequency to avoid interference and enhance security, and Direct Sequence Spread Spectrum (DSSS), which spreads the signal over a wider frequency range to improve resistance to interference.

**Pros:** low latency, reliable signal transmission, interference mitigation, enhanced security, flexibility, and improved range (27).

**Cons:** costly/expensive, degree of complexity, power consumption, regulatory compliances (NHRL), and overhead for low-power tasks (27).

### Mechanical Control Systems with Precision Actuators

Mechanical control systems utilize precision actuators to directly manage a bot's movements and functions, focusing on high precision and reliability through mechanical means.

Key aspects of these systems include direct mechanical control, which uses linkages, gears, and servos to ensure precise management of the bot's actions. High-torque servos and motors provide the necessary power and responsiveness, which are crucial for combat effectiveness. Custom gear systems, such as tailored gearboxes and linkages, are designed to optimize the bot's performance for specific tasks like speed or strength (28).

Examples include electro-mechanical actuators, which convert electrical energy into precise mechanical movements for functions like weaponry and mobility, and precision gear systems, which are designed for fine control and high-speed operations, enhancing the overall performance of the bot.

**Pros:** high precision, direct mechanical control, high-torque capability, customization, and durability (28).

**Cons:** very complex setup, weight, costly, high maintenance, limited flexibility, and high-power consumption (28).

### High-Frequency Control Systems

High-frequency control systems focus on achieving rapid and precise control of a bot's movements and actions, which is crucial for maintaining agility and responsiveness in combat scenarios.

Key aspects of these systems include fast processing speeds, utilizing advanced microcontrollers and processors to handle high-speed calculations and control commands. Precision actuators, such as high-resolution servos and motors, ensure accurate and quick responses, while low-latency communication reduces the delay between input commands and the actual actions of the bot, ensuring immediate and effective responses.

Examples of high-frequency control systems include Digital Signal Processors (DSPs), which handle complex control algorithms and processing with minimal latency to ensure swift bot reactions, and high-speed controllers, which manage rapid input-output operations to facilitate precise and agile control.

**Pros:** rapid response reaction time, precision control, low latency, complex algorithm handling, enhanced agility, and real-time feedback (29).

**Cons:** cost, power demand/consumption, complexity, fragility, and it is sometimes overkill for simple tasks such as a bot that doesn't require ultra-fast or highly complex movements (29).

## **c. End User**

The end users of our robot are the members of Team La Machina. We've designed the robot for intuitive operation, so any team member can step in and control it if needed, though one designated driver

will be trained to fully understand the controls for good performance during matches. Effective maneuvering and strategic weapon use are important for success in the arena, so ease of control and reliability were key design considerations. Rather than focusing on modularity, our team prioritized functionality, weight efficiency, and cost-effectiveness. The robot was built using reliable components that are standard among 12lb combat robots, chosen to stay within budget while still delivering strong performance in the weapon, drive, and control systems. Every aspect of the robot was developed with strict adherence to NHRL rules and safety regulations. This includes careful attention to weight distribution, fail-safes, weapon design & locks, and power systems to ensure eligibility and safety throughout the competition.

#### **d. Applicable Standard**

The standards for this project are outlined in the robot design rules of the NHRL Full Rulebook, covering 3lb, 12lb, and 30lb weight classes. Each class allows weight bonuses for multibots (no single bot exceeding 110% of class weight) and non-traditional locomotion (e.g., up to 15lb for non-wheeled 30lb bots). See Appendices for details.

##### Safety Standards

Robots must minimize risks with secure battery housing, insulated wiring, and a failsafe system stopping drive within 30 seconds and weapons within 60 seconds upon signal loss. All robots must pass a safety inspection, including weapon locks and sharp edge covers, and fit within a 23" x 23" x 44" fire safety cart (or be modifiable to fit) (30).

##### Weapon and Drive System Standards

Weapons must be active (independent of drivetrain, designed to influence opponents) and comply with safety rules (e.g., weapon locks, flame fuel limits). Banned weapons include EMPs, tasers, and visibility-obstructing devices. Non-traditional movement systems (e.g., walkers) qualify for weight bonuses but must demonstrate controlled motion during inspection (30).

##### Material Standards

Materials must meet weight limits and be durable. Hazardous materials (e.g., explosives, fireworks) are banned, and designs must avoid producing dangerous fragments or arena-fouling debris (e.g., glitter). Ablative armor like foam is allowed if it poses no entanglement risk (30).

##### Radio Control Standards

Robots require dedicated receivers and approved radio systems to prevent interference, passing a failsafe test (30s for drive, 60s for weapons). Autonomous bots need a radio module for remote activation/deactivation (30).

##### Electrical Standards

Batteries (e.g., LiPo) and electrical systems producing voltages above standard limits require NHRL approval via [safety@nhrl.io](mailto:safety@nhrl.io). Wiring must handle current loads, and connectors must be secure to pass inspection, ensuring no disconnections during matches (30).

##### Modular Design Considerations

Modular designs or spare parts are encouraged, with no more than 50% of a robot's weight changing between configurations. This supports quick repairs within the 20–30-minute match intervals (30).

### e. Summary of Research

In designing our combat robot, Team La Machina focused on four main subsystems: weapon system, drive system, frame and armor, and electronics/controls. After evaluating multiple approaches, we selected a two-wheel drive vertical spinner as our final design for its offensive reliability, weight efficiency, and effectiveness in the 12-pound weight class.

Vertical spinners are widely used due to their ability to deliver concentrated, high-energy impacts. If designed correctly, they're also capable of operating when the robot is flipped, adding resilience in unpredictable match conditions. While vertical spinners can introduce control challenges—such as torque reaction and uneven impacts, we chose this design because of its proven success in competitive settings.

Our two-wheel drive system was selected for its simplicity, lower weight, and ease of maintenance. Compared to four-wheel systems, it allows us to allocate more weight toward the weapon and armor while still maintaining maneuverability. Although two-wheel drive can be less stable after absorbing large hits, its straightforward design makes repairs and troubleshooting faster between rounds.

To increase survivability, we prioritized durability and component protection. The robot frame is reinforced using strong, lightweight materials to handle weapon and impact forces. Additionally, TPU (thermoplastic polyurethane) will be used in key areas to absorb shock and reduce the chance of frame damage from direct hits or hard landings.

For electronics and controls, we are using a reliable, standard configuration that includes brushless motors, ESCs, and a standard radio receiver system. This ensures responsive controls, consistent weapon spin-up, and reliable signal reception even in high-interference environments.

Cost was a critical factor throughout our research. We aligned our component selection with the guidance of previous robotics teams and their standard parts kit and budget constraints. We aimed to meet the unofficial \$100-per-pound guidelines often seen in combat robotics, capping our budget at around \$1200, while including a buffer for any modifications.

Finally, all design decisions were made in compliance with the official NHRL safety and weight regulations, including the use of weapon locking bars, failsafes, and safe battery systems. By focusing on functional efficiency, rule compliance, and damage resilience, our design is tailored for success in the environment of NHRL competition.

### f. Customer Features

The following customer features were gathered through research and will serve as the foundation for our QFD and survey. These features reflect the voice of the customer and highlight key performance criteria for the robot's design:

**Survey Link:** <https://forms.gle/UdagUGcibNWkceSP8>

#### List of Features:

- **Damage Delivery:** The robot's ability to inflict significant damage on opponents through its weapon system.
- **Weapon Durability:** The ability of the robot's weapon to endure repeated impacts and stresses without breaking or failing.
- **Weapon Effectiveness:** The overall performance of the weapon in combat, including its force, accuracy, and consistency.

- **Maneuverability:** The ease with which the robot can move and change direction in the arena, influencing its ability to effectively attack opponents.
- **Safety Features:** Components or systems designed to minimize risks of injury or damage, both during operation and outside of combat.
- **Maintenance & Repairability:** How easily the robot can be repaired and maintained, especially between rounds.
- **Traction:** The robot's ability to maintain a strong grip on the arena floor.
- **Wheel Protection:** Measures taken to protect the robot's wheels from damage, which could severely impact mobility and lead to defeat.
- **Total Cost:** The overall expenses related to building and maintaining the robot.
- **Ease of Use:** The simplicity of controlling the robot during combat.
- **Weapon Design:** The layout, configuration, and mechanism of the robot's weapon.
- **Weapon Size:** The physical dimensions of the weapon.
- **Weapon Motor Speed:** The operational speed of the weapon's motor.
- **Total Weight:** The combined weight of all robot components, ensuring compliance with the competition's weight limit (12 lb class).
- **Interesting Design:** The aesthetic and creative elements of the robot's appearance.

### 3. Quality Function Deployment

#### a. Survey Methodology and Results

This section discusses the method used to gather insights from potential end users regarding their preferences for battle bot features. The survey aimed to identify what users consider important in addressing the challenges of battle bot design.

*Sites used to gather information*

The primary source of data for this survey was an online questionnaire that Nguyen “Steven” Le created and distributed via the following link: [Battle Bot Features Survey](#). This survey was sent out to all the members of the UC Combat Robotics Team/Club, MCRA Discord, official NHRL Discord server, and a previous co-op employer. Survey questions can be found in the appendices.

Table 1: Customer Feature Data

Customer Feature	Total Surveyed	Importance of the feature		Satisfaction with the feature in the current technology	
		Average Rank	Standard Deviation	Average Rank	Standard Deviation
<i>Must meet OSHA safety requirements for noise</i>	<i>33</i>	<i>3.75</i>	<i>0.88</i>	<i>2.20</i>	<i>1.10</i>
Weapon Durability	38	8.8	1.08	6.5	1.82
Damage Delivery	38	8.3	1.82	7.0	1.63
Maneuverability	38	7.8	1.66	5.9	2.12
Weapon Effectiveness	38	7.6	2.20	6.8	1.74
Total Weight	38	8.1	3.55	7.2	2.15

Maintenance/Repairability	38	7.9	2.17	6.3	1.95
Traction	38	7.5	2.20	6.0	2.08
Weapon Motor Speed	38	7.1	2.39	6.7	2.00
Weapon Size	38	5.9	2.59	5.5	1.88
Safety Features	38	7.2	2.56	5.6	2.22
Ease of Use	38	6.5	2.29	4.9	2.10
Visual Appearance	38	5.9	1.75	5.4	1.80
Wheel Protection	38	4.7	2.45	3.8	2.05
Total Cost	38	5	3.55	4.5	2.37
Interesting Design	38	5.9	3.42	5.2	1.92

### *Data Comparison & Lack of Responses*

It is important to note that at the end of the Fall semester, we initially had only 12 responses for most customer features, which fell short of the threshold typically required for drawing statistically significant conclusions, particularly in areas like safety and user-centered design. This limited our ability to confidently validate specific design decisions.

However, by the conclusion of Senior Design III in the Spring, we increased our total number of survey respondents to 38 across all customer features. This now meets the recommended minimum for reliable data analysis and significantly improves the strength and validity of our findings. We distributed the survey through several channels, including three Discord communities—the UCCR Club, MCRA, and the official NHRL Discord. We also reached out to a previous co-op employer. These extra efforts helped us close the response gap that was present in the earlier phase of the project.

### *Feature Preferences (Head-to-Head Comparisons)*

In this section, we present head-to-head comparisons of key customer features based on their importance and relevance to the design of the battle bot. Each comparison identifies the feature that is preferred by customers, helping us prioritize our design elements.

Table 2: Customer Feature Data

<b>Comparison</b>	<b>Winner</b>
Damage Delivery vs. Maneuverability	Damage Delivery
Weapon Durability vs. Ease of Use	Weapon Durability
Weapon Effectiveness vs. Total Cost	Weapon Effectiveness
Safety Features vs. Cool Design	Safety Features
Maintenance & Repairability vs. Weapon Size	Maintenance & Repairability
Visual Appearance vs. Total Weight	Total Weight
Traction vs. Weapon Motor Speed	Traction
Wheel Protection vs. Maneuverability	Maneuverability

### Short Answer Feedback – Key Insights

Maneuverability and Damage Delivery were often cited as the most important features, as they play an important role in both avoiding damage and delivering effective strikes during combat. However, respondents highlighted those certain features, such as traction, acceleration, and battery protection, are often overlooked but are equally critical to a robot's performance. Suggested improvements included enhancing energy transfer and making designs more accessible for new builders entering the competition. While most respondents acknowledged that visual design could create an impression of strength, they agreed that actual performance is primarily dependent on function and engineering rather than aesthetics.

## b. Engineering Characteristics

### Weapon (22)

To ensure maximum durability, the weapon will be manufactured from AR500 steel, a material known for its exceptional resistance to deformation and damage under high-impact conditions. AR500 steel offers several key benefits, making it a popular choice for Battle Bot weapons. Its exceptional strength provides high resistance to deformation and damage, even under extreme conditions. The steel's hardness makes it difficult to penetrate, while its durability ensures long-lasting performance. Additionally, AR500 steel has good impact resistance, making it well-suited for environments involving frequent or forceful impacts. These qualities combine to make AR500 an ideal choice for applications that require strong, durable, and impact-resistant material (22).

#### AR500 Steel Properties

Table 3: AR500 Properties (31)

Property	Corresponding Value (ASTM E10)
Yield Strength	1480 MPa
Hardness	477-534 HB (Brinell Hardness)
Ultimate Tensile Strength	1655 MPa
Percent Elongation	8% (50.8mm gage)

We are designing the weapon to spin at about 14,000 RPM. This speed is key because it helps us achieve the best tip speed, which is important for penetrating armor and messing with the functionality of other bots. We expect the tip speed to reach between 180 and 220 mph, and the weapon will have an energy output of 1.5 to 2 kJ. These are all standard values within the 12lb bot weight class.

### Body Armor

To shield the robot from damage, the body will be encased in a TPU shell. This material is known for its ability to absorb shocks and protect the delicate internal components. The chassis will also be reinforced with a strong aluminum 6061 structure, providing additional protection against impacts and ensuring the robot's continued operation.

Table 4: TPU Properties (32)

Property	Corresponding Value
Tensile Strength	16.8 MPa (XY Axis) 17.4 MPa (XZ Axis)
Elongation at Break	552% (XY Axis) --- 482% (XZ Axis)
Tear Strength	84.6 N/mm (XY Axis)
Shore Hardness	92 Scale A

Table 5: Aluminum 6061 Properties (33)

Property	Corresponding Value
Hardness	40 (Rockwell A) & 60 (Rockwell B)
Tensile Strength, Yield	40,000 psi
Tensile Strength, Ultimate	45,000 psi
Percent Elongation	12% (typical, 1/16 in. thickness)
Impact Resistance	Moderate (Notched Tensile Strength: 47,000 psi)
Fatigue Resistance	14,000 psi (for 500 million cycles)
Flexural Modulus	$10.0 \times 10^6$ psi
Thermal Stability	Stable up to 350°F (177°C)
Chemical Resistance	Excellent (high corrosion resistance)

### Drivetrain & Maneuverability

The robot will feature a two-wheel drive (2WD) system with a high-torque drivetrain for smooth and precise movement. With the motor generating 15-30 Nm of torque, it will enable rapid acceleration and maneuverability in tight spaces. The wheels will be 2-4 in diameter, providing sufficient traction and stability while maintaining agility during combat.

Table 6: Motor Properties

Type	Corresponding Value (s)
Weapon Motor	2000w at 6s, 970Kv
Drive Motor	1400kv for use up to 6s

### Weight & Cost

The robot's design incorporates a range of selected materials to balance strength, durability, weight, and cost. The frame is mainly constructed from aluminum 6061, providing good structural support while keeping the overall weight within the 12 lb limit set by NHRL competition rules. Carbon fiber-reinforced polymer (CFRP) plates are used for the top and bottom panels, offering good rigidity and lightweight performance. TPU is strategically placed on the sides and back for shock absorption and added protection.

The front armor features a wedge made from AR500 steel, ensuring durability and effectiveness during head-on engagements. These materials were chosen to maximize performance while adhering to the weight constraints. The projected material cost is \$2,000, including a 20% contingency to cover potential errors or part replacements during construction, ensuring a cost-effective yet high-quality build.

### House of Quality

The House of Quality, part of Quality Function Deployment (QFD), converts customer needs into technical specifications for our battlebot. It ensures our design prioritizes customer satisfaction, improving quality and boosting competition success. See our complete House of Quality in the image below.

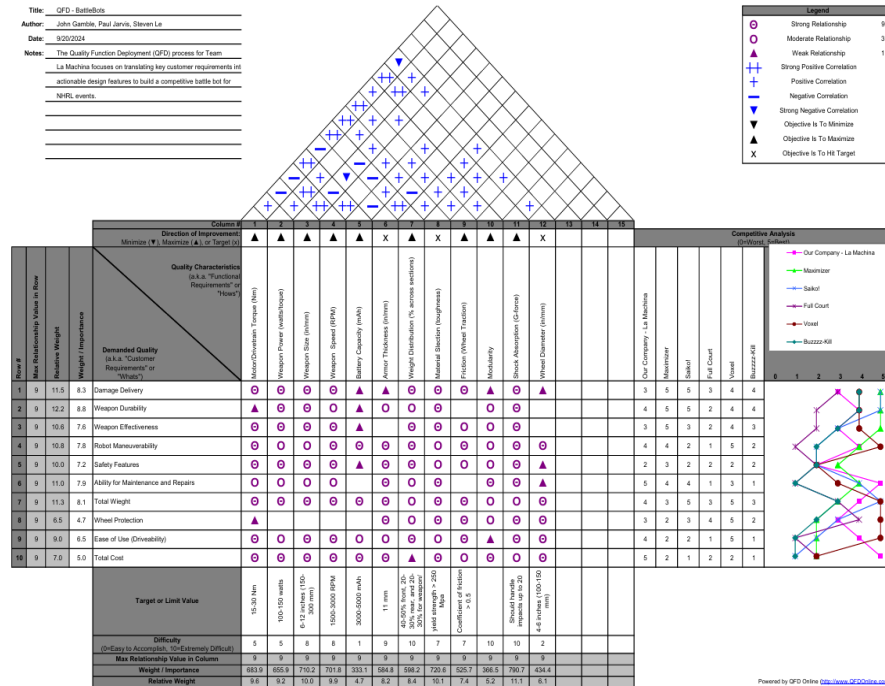


Figure 17: House of Quality

Based upon the survey results and the House of Quality, we ranked our top deliverables as follows: Weapon Durability, Damage Delivery, Maneuverability, Maintenance & Repairability, Total Weight, Traction, and Weapon Effectiveness. Blown up views of the HOQ can be seen in the appendices.

### c. Product Objectives

Taking customer feedback and our House of Quality analysis into account, we've set some key goals for the robot's design: maximizing damage, ensuring it's highly maneuverable, and building it to last. For damage, we're focusing on optimizing the vertical spinner. This means a high-speed blade and carefully designed impact points. We'll use tough materials like hardened steel to make sure the weapon can take a beating. Maneuverability is key for both attacking and dodging, but we're aware that the current two-wheel drive setup might lead to some instability. We'll be looking at different drivetrain options to address this. Keeping the weight under 12 pounds is crucial, so we'll be carefully selecting materials for the frame and internal parts. We'll also be fine-tuning the traction by choosing the right wheel materials to balance stability and agility. Finally, we'll be tweaking the weapon's effectiveness by adjusting the number of impact points, rake angles, and motor speed.

These objectives have been our guide as we move from Senior Design II & III, helping us build a robot that's both competitive and performs at a high level.

Quality Characteristics	Motor/Drivetrain Torque (Nm)	Weapon Power (watts/toque)	Weapon Size (in/mm)	Weapon Speed (RPM)	Battery Capacity (mAh)	Armor Thickness (in/mm)
Target / Limit Value	15-30Nm	100-150 Watts	6-12in (150-300mm)	1500-3000 RPM	3000-5000mAh	11mm
Difficulty (0=Easy to Accomplish, 10= Exteremely)	5	5	8	8	1	9
Max Relationship Value in Common	9	9	9	9	9	9
Weight / Importance	683.9	655.9	710.2	701.8	333.1	584.8
Relative Weight	9.6	9.2	10	9.9	4.7	8.2
Quality Characteristics	Weight Distribution (% across sections)	Material Slection (toughness)	Friction (Wheel Traction)	Modularity	Shock Absorption (G-force)	Wheel Diameter (in/mm)
Target / Limit Value	40-50% front, 20-30% rear, and 20-30% for weapon/ electronics	yield strength > 250 Mpa	Coefficient of friction > 0.5	----	Should handle impacts up to 20	4-6 inches (100-150 mm)
Difficulty (0=Easy to Accomplish, 10= Exteremely)	10	7	7	10	10	2
Max Relationship Value in Common	9	9	9	9	9	9
Weight / Importance	598.2	720.6	525.7	366.5	790.7	434.4
Relative Weight	8.4	10.1	7.4	5.2	11.1	6.1

Figure 18: House of Quality – Weight / Importance & Relative Weight

The data provided above shows various quality characteristics that are critical to the battle bot's overall performance. Key components such as shock absorption (with a weight/importance of 790.7 and a relative weight of 11.1) and material selection (weight/importance of 720.6, relative weight of 10.1) are given the highest priority. This suggests that the bot's ability to withstand high-impact forces and its toughness, likely related to the durability of its construction materials, are seen as crucial for its success in combat scenarios.

Other important factors include weapon size (710.2 weight/importance, 10 relative weight) and weapon speed (701.8 weight/importance, 9.9 relative weight), showing that the effectiveness of the weapon system is a major focus. The size and speed of the weapon are nearly as important as material toughness, indicating that delivering significant damage quickly will be an important strategy.

Overall, this data shows that the most critical aspects of the battle bot design revolve around robustness, weapon efficiency, and shock absorption capabilities.

## 4. Concepts Design

### *Key Aspects for a Successful Design*

Based on the QFD process, the most important features for our battle bot design are Weapon Durability, Damage Delivery, Maneuverability, and Maintenance & Repairability. These important features were identified as critical through our survey and technical analysis (HOQ), which aligns with the battle bot's functionality. Making sure our bot has a balance between performance, durability, and repairability will maximize its effectiveness in the NHRL competition.

In terms of state-of-the-art technology, most competitive battle bots prioritize modular designs, high-torque motors, and materials like AR500 steel for weapon, TPU and Aluminum 6061 for the chassis/frame. These materials and modular approaches are the standard in high-level competition, allowing for the success of bots by ensuring they can inflict significant damage while remaining operational during combat.

### *List of Key Functions for the Design*

- Weapon Durability – The weapon will be made of AR500 steel.
- Damage Delivery – The bot's vertical spinner weapon will operate around 14,000 RPM. It will also have a tip speed within the range of 180-220 mph & weapon energy around 1.5-2 kJ.
- Maneuverability – The drivetrain will consist of a high-torque two-wheel drive system.

- Modular Repairs – Components will be assembled with button and flat head screws to enable quick disassembly and replacement.
- Weight Management – All components will be optimized to stay under the 12-lb weight limit required by NHRL regulations.
- Traction and Stability – The wheels will be selected for optimal traction, ensuring stability.
- Weapon Effectiveness – The blade design will feature refined impact points and adjustments in motor speed for greater damage potential.
- Safety Compliance – Ensuring compliance with safety requirements and other applicable safety standards.

These key functions will ensure that the battlebot delivers competitive performance while remaining easy to maintain and repair during the NHRL competition.

### a. John Gamble - Function #1 – Weapon Design

*Concept #1 – Double-Edge Spinner:*

This concept features a heavy, double-edged design resembling a spinner, used for high-impact strikes. Some advantages include its high impact power and simple design. The design utilizes fillets in potential high-stress areas.

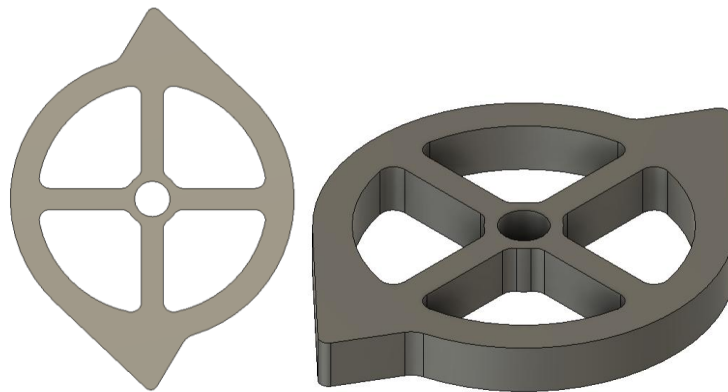


Figure 19: Vertical Spinner – Double-Edge

*Concept #2 – Symmetrical Pendulum Spinner:*

This concept features a symmetrical pendulum weapon. This weapon's unique shape incorporates sharp edges and protruding angles. This weapon is engineered for a recommended rake angle and weight efficiency.

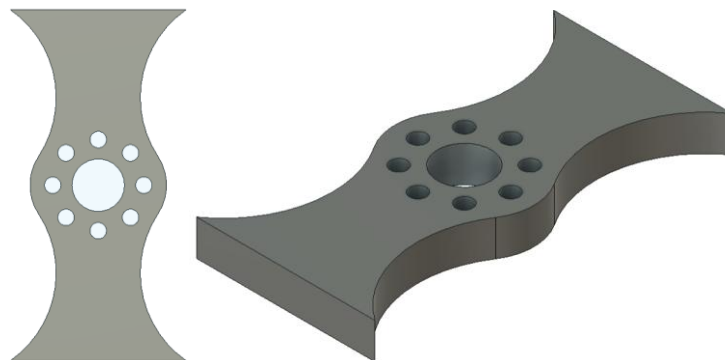


Figure 20: Vertical Spinner – Symmetrical Pendulum

### Concept #3 – Disc Spinner:

This concept features a vertical spinning disc weapon, inspired by a previous UC BattleBot team’s design—Team Voodoo. The disc’s unique shape is designed to maximize damage potential. It is engineered for high-impact hits and built to be extremely sturdy, making it well-suited for sustained combat and repeated weapon-to-weapon collisions.

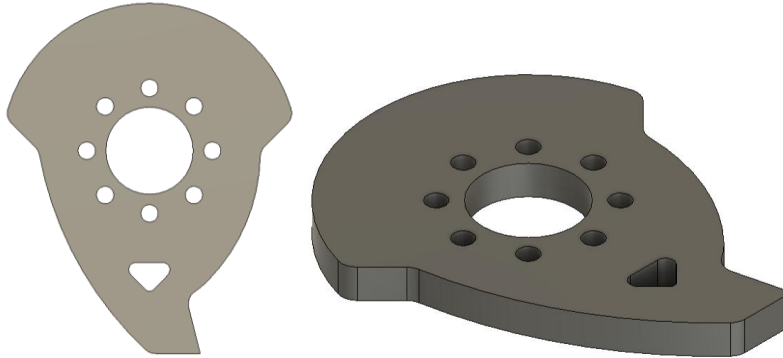


Figure 21: Vertical Spinner – Disc

## b. John Gamble - Function #2 - Drive Design

### Concept #1 – Two Wheel Drive (2WD)

A two-wheel drive setup has many advantages. It uses fewer motors and parts, which makes the robot lighter and frees up space inside for other important components such as the battery, ESCs, receiver, and the wiring. The extra space or weight savings can also be used to add more armor or make the bot smaller and faster. The main downside with this concept is reduced maneuverability. With only two wheels, the robot can’t move as precisely or quickly as other designs. It usually pivots in place and relies on facing opponents head-on with its weapon.

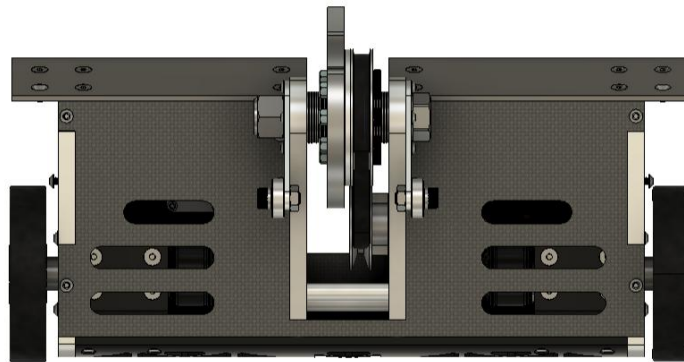


Figure 22: Two-Wheel Drive

### Concept #2 – Four Wheel Drive (FWD)

A four-wheel drive offers better stability and control than two-wheel drive. With power to all wheels, the bot gets improved traction, quicker movement, and easier direction changes. It also spreads out impact forces, helping prevent tipping during hits or sudden moves. One major perk is redundancy; if a wheel gets damaged, the bot can still drive. The downside is added weight and less space for other components. Still, the boost in control and reliability makes it a popular choice in battlebot designs.

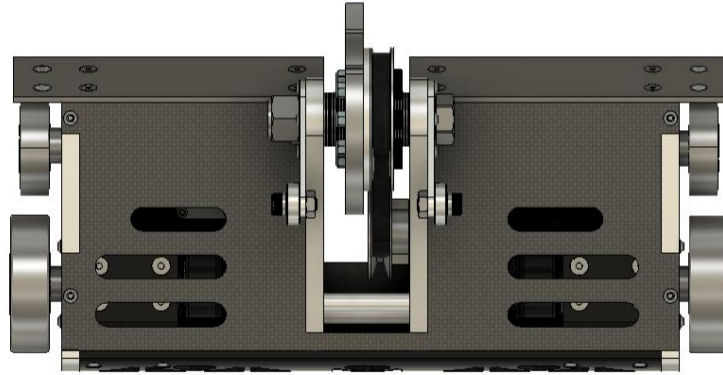


Figure 23: Four-Wheel Drive

### *Concept #3 – TPU Protected Two Wheel Drive*

This concept keeps the standard two-wheel drive layout but adds a protective layer made of TPU (thermoplastic polyurethane) around key drivetrain parts. TPU is light, flexible, and impact-resistant, making it great for shielding wheels and side plates from hits. This protection helps the bot stay mobile even after getting damage, especially in close fights where wheels are common targets.

While it still has the same turning limitations as a typical 2WD setup, the TPU helps solve one of its biggest weaknesses: exposed drive components. The goal is to improve durability and reliability without losing the simplicity and low weight of a two-wheel design.



Figure 24: TPU Protected Two-Wheel Drive

## **c. Nguyen “Steven” Le - Function #3 – Frame and Armor Design**

### *Concept #1 – Turtle Shell Frame and Armor:*

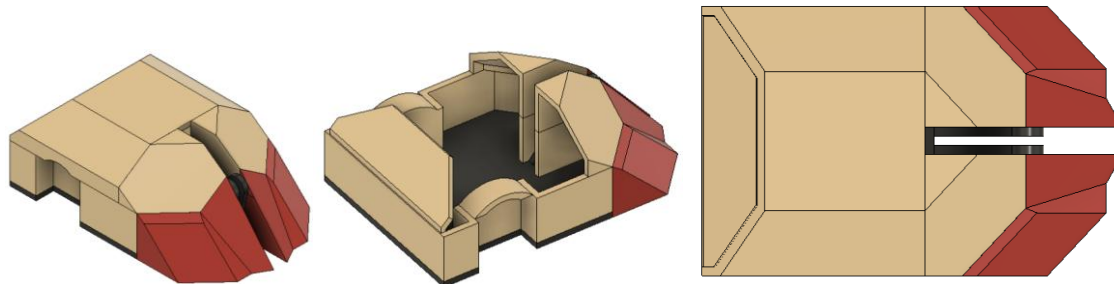


Figure 25: Turtle Shell Frame and Armor

This concept features a compact, hexagonal-shaped battlebot designed for maximum defense. The frame and armor are primarily constructed from ¼” 6061 aluminum, chosen for its balance of strength and flexibility, providing good protection against opponent weapons. The front wedge, intended to lift opponents off the ground and feed them into the vertical spinner weapon, is made from either ¼” AR500 steel or titanium, depending on available weight within the 12lb NHRL limit. The aluminum armor, while strong, may deform under heavy competition impacts. The hexagonal shape and sloped red components enhance durability by deflecting attacks, acting as a “brick” that’s hard to destroy. However, the irregular shapes make manufacturing challenging, requiring complex waterjet cutting and assembly, which is impractical.

The design’s weight is a significant concern, potentially exceeding the 12lb limit, and the bot’s inability to drive if flipped reduces its competitiveness. Additionally, the compact frame limits space for an active weapon, and the weapon’s integration relies on the wedge guiding opponents into the spinner. This concept prioritizes aesthetics and defense but sacrifices practicality and offensive capability.

#### *Concept #2 – Standard Vertical Spinner*

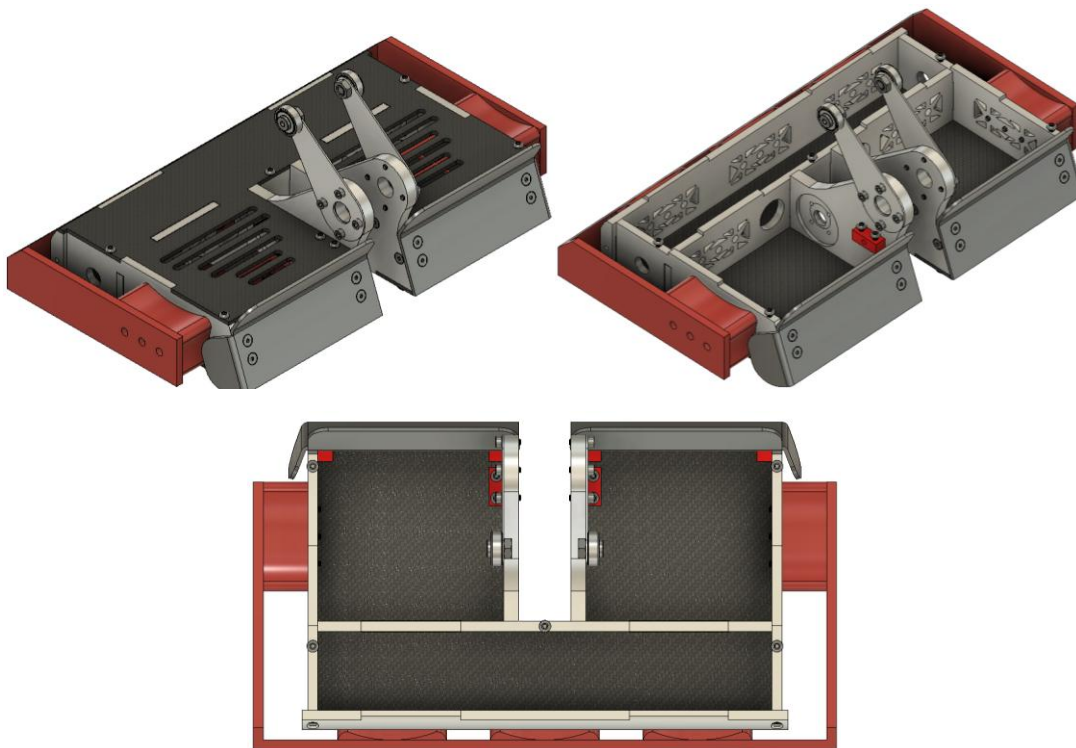


Figure 26: Standard Vertical Spinner Frame

This concept uses a box frame divided into three sections to house internal components, optimized for a vertical spinner battlebot. The frame is constructed from ¼” 6061 aluminum, balancing weight and durability, while the front wedge uses 1/8” AR500 steel for impact resistance. TPU protection on the sides and back shields vulnerable areas, and 3mm carbon fiber top and bottom plates provide lightweight, durable protection against horizontal attacks. The vertical spinner weapon is designed to deliver aggressive attacks, with the frame supporting its operation by protecting internal electronics and drive components. All components are waterjet cut, with holes manually drilled and tapped at a machine shop, and a lathe used for precision work. This standard design is familiar in vertical spinner builds, offering reliable durability and straightforward construction. However, the design is on the heavier side, posing challenges for the 12lb weight limit, and the TPU mounts may interfere with the drive system,

potentially affecting mobility. The frame's protective elements, while robust, leave some concern about internal component exposure under intense attacks.

*Concept #3 – Weight & Armor Adjusted Vertical Spinner:*

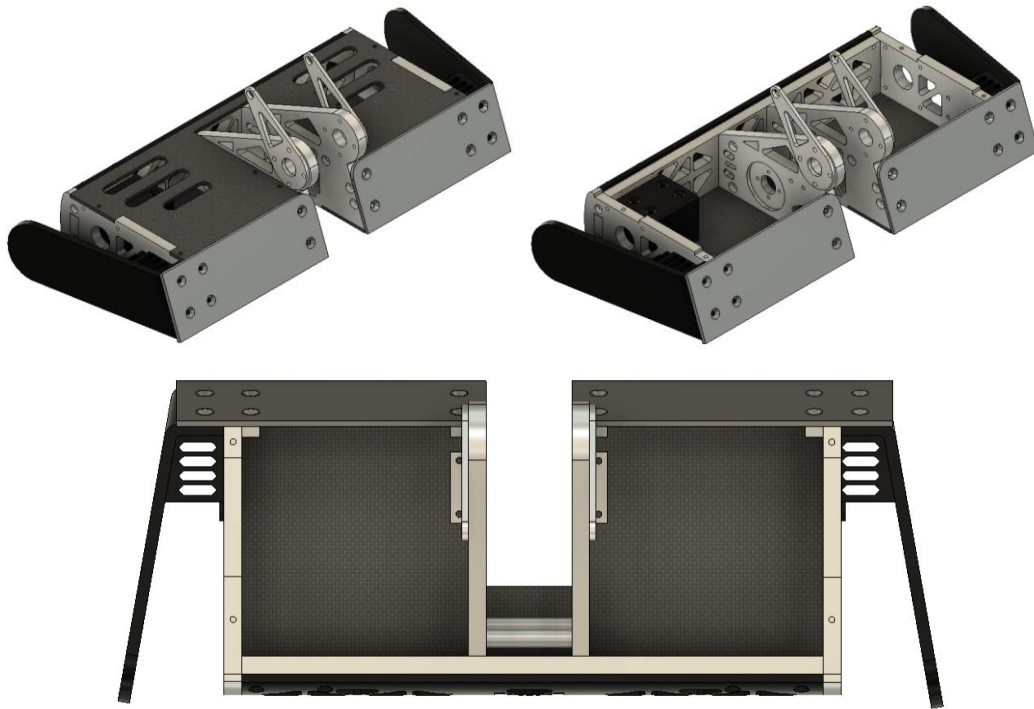


Figure 27: Adjusted Vertical Spinner Frame

This concept refines the Standard Vertical Spinner by reducing weight to meet the 12lb NHRL weight class requirements. The box frame, still made from 1/4" 6061 aluminum, is lighter through reduced material use, maintaining durability while trimming mass. The front wedge remains 1/8" AR500 steel for impact resistance, and TPU armor varies in thickness to optimize weight savings while protecting vulnerable areas. The 3mm carbon fiber top and bottom plates are retained for lightweight protection.

Like the standard design, the frame supports the vertical spinner weapon, focusing on offensive capability while safeguarding internals. Manufacturing mirrors the standard spinner, using waterjet cutting, manual drilling, tapping, and lathe work for precision. The adjusted design is sleeker and less bulky, improving compliance with weight limits and offering a competitive edge with increased headroom for weapon power. It is also simpler to manufacture than the Turtle Shell concept, enhancing practicality. However, the reduced armor thickness may compromise protection in high-impact areas, trading some durability for weight efficiency.

#### **d. Paul Jarvis - Function #4 – Electronics Design**

*Concept #1 – Basic Component Layout:*

This image illustrates the basic component layout for the battle bot, it shows the connection of various components essential for operation. The battery is located on the left, supplying power to the drive motors and weapon motor via their respective Electronic Speed Controllers (ESCs). The design also includes a power switch for easy activation and fuses for safety. The layout allows for an efficient power distribution system.

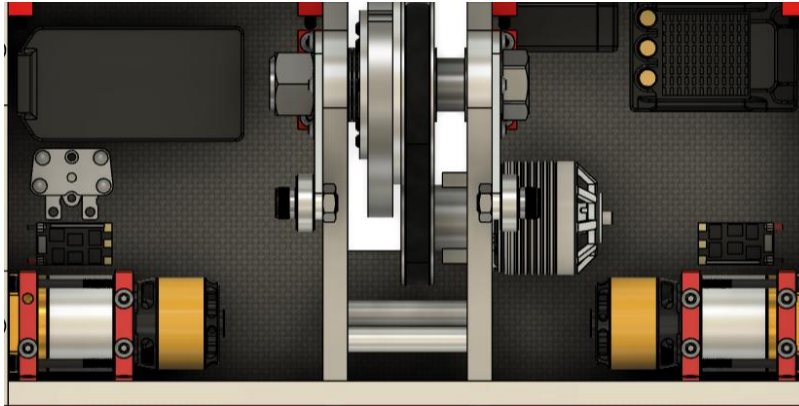


Figure 28: Basic Component Layout

*Concept #2 – Wiring Layout with Components:*

This sketch presents a detailed layout of the battle bot's electrical wiring system. It highlights the connections between weapon motor, drive motors, ESCs, and the LiPo battery, ensuring power flows correctly throughout the system. Positive and negative terminals are color-coded for clarity, while ESC signal wires are noted separately. The bot is powered by a 22.2V LiPo battery, and the design lists specific components, such as the BA 3520 weapon motor, Tempest 2814 drive motors, and the Castle Sidewinder 8th weapon ESC.

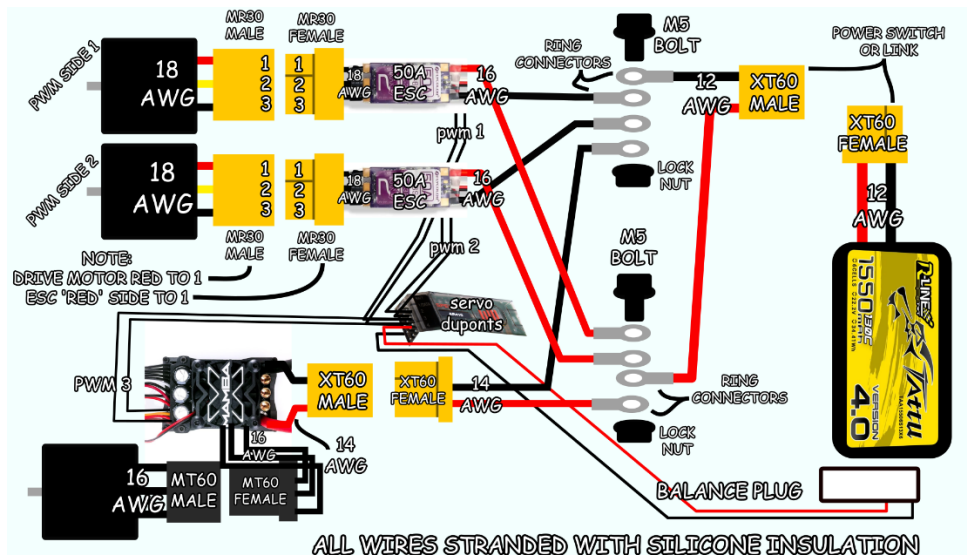


Figure 29: Wiring Layout with Components

## e. Final Design Concepts

### Concept #1: Two-Wheel Drive, Single Blade Spinner

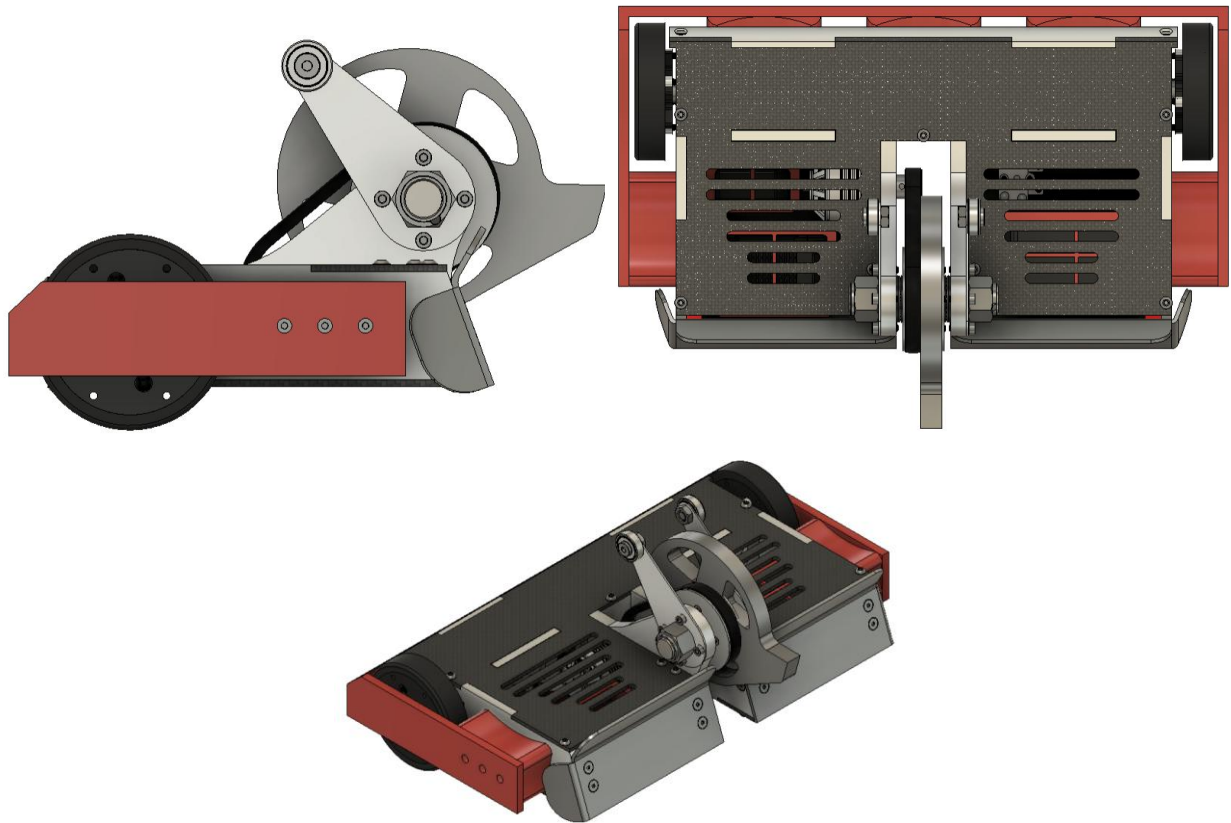


Figure 30: Two-Wheel Drive, Single Blade Spinner Concept

This design is a single-blade vertical spinner featuring a three-section 6061 aluminum box frame, an AR500 steel front wedge, and two TPU-protected wheels. The large, lightweight, and simple-to-manufacture single-blade spinner is designed for easy production of spares, reducing machining time and costs. Its low weight allows for greater allocation to the frame and armor, enhancing overall durability. The AR500 front wedge ties the aluminum frame together, increasing stiffness, and sits close to the ground to prevent opponents from getting underneath. Armor extends beyond the wedge to shield the wheels from side impacts that could immobilize the robot and rises above the top plate to offer protection from vertical attacks. The two-wheel design ensures good mobility while staying within weight limits. Although the rear wheels are vulnerable to impacts, their large diameter, combined with "bunny ear" extensions, enables the robot to drive when flipped, facilitating self-righting.

*Concept #2: Modified Two-Wheel Drive, Single Blade Spinner*

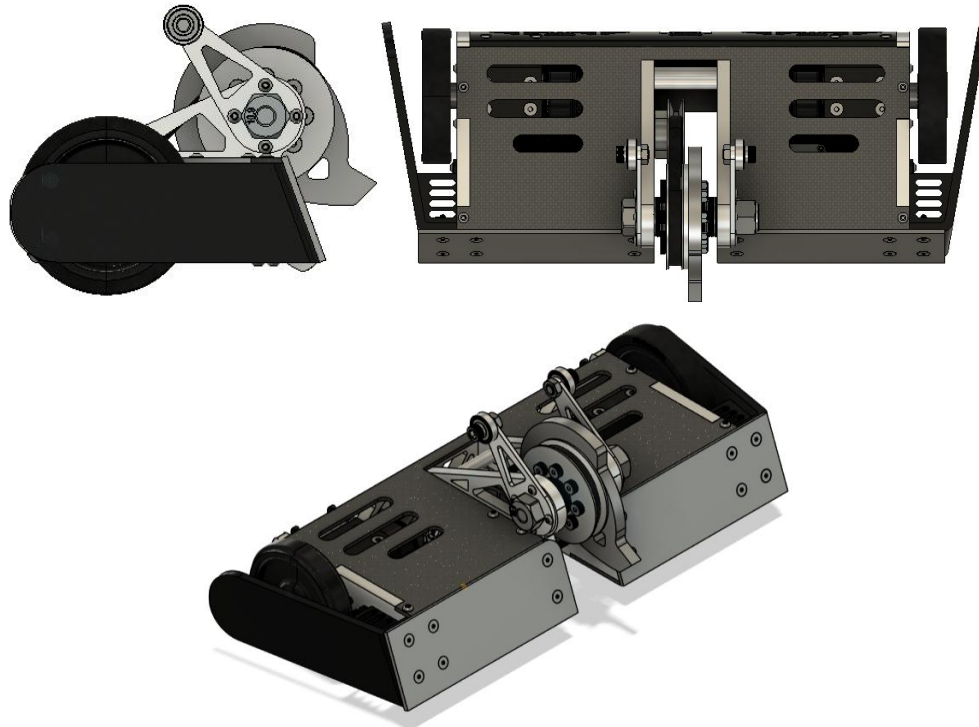


Figure 31: Modified Two-Wheel Drive, Single Blade Spinner Concept

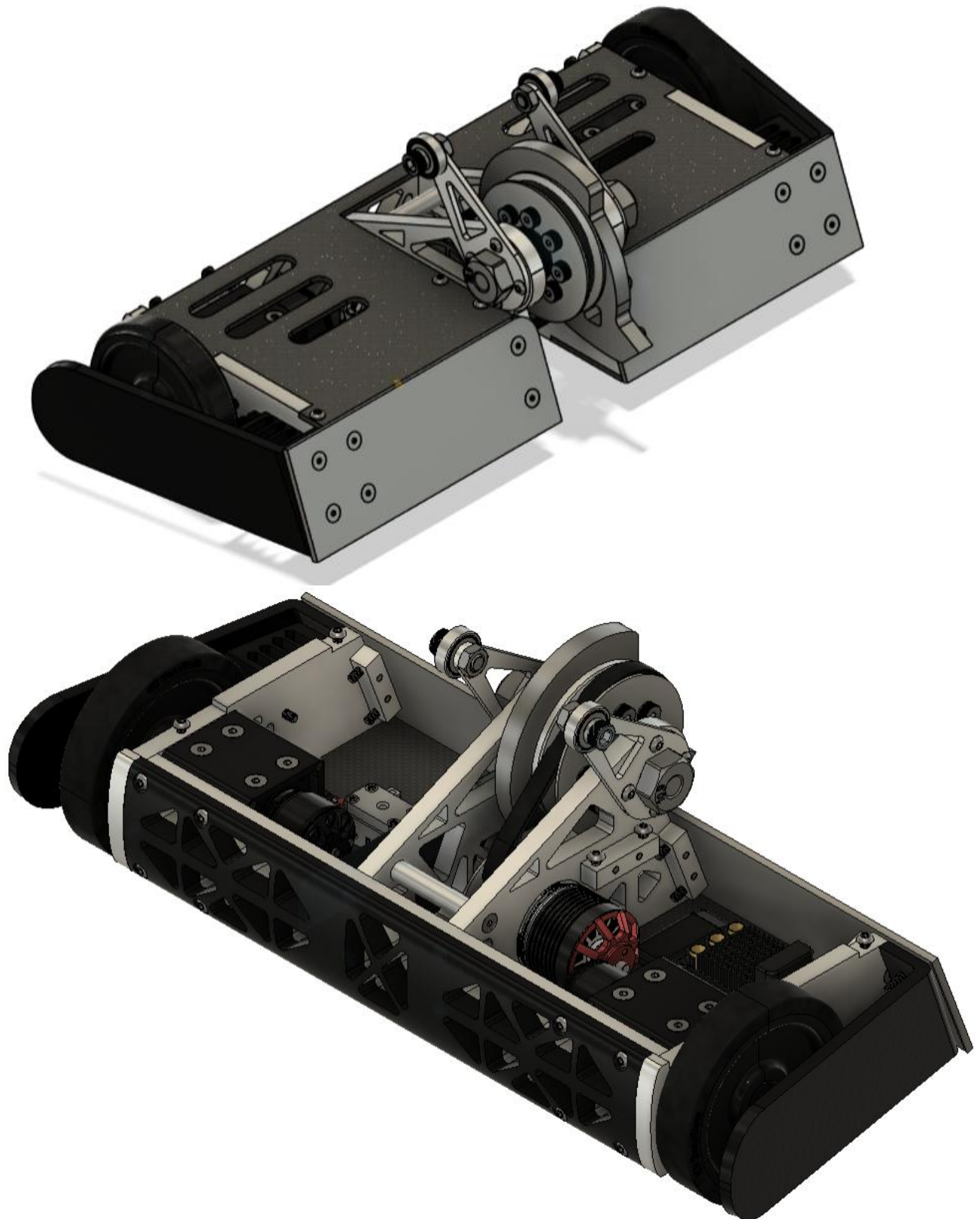
This design is a refined version of Concept 1, keeping its single-blade vertical spinner configuration but incorporating a two-section 6061 aluminum box frame instead of three to reduce weight and overall size. It features an AR500 steel front wedge and two wheels protected by TPU guards. The spinner, similar in size to Concept 1, is optimized for increased impact damage and improved performance under load, as validated by finite element analysis (FEA). Its large, lightweight, and simple-to-manufacture design facilitates the production of spares, minimizing machining time and costs. The spinner's low weight allows for greater allocation to the frame and armor, enhancing durability.

The AR500 steel front wedge connects the aluminum frame sections, increasing structural stiffness, and sits close to the ground to prevent opponents from getting underneath. Unlike Concept 1, the armor avoids curved designs, as bending AR500 steel is infeasible with available resources. The armor extends to protect the wheels from side impacts and rises above the top plate to shield against vertical attacks. The two-wheel design ensures good mobility while adhering to weight limits. Although the rear wheels remain vulnerable to impacts, their large diameter, combined with "bunny ear" extensions, enables the robot to drive when flipped, facilitating self-righting. The TPU wheel guards are redesigned for improved aesthetics, functionality, and weight savings.

### *Conclusion*

Concept 2 was selected over Concept 1 due to its optimized design, which balances weight, durability, and manufacturability while enhancing performance. By reducing the 6061-aluminum box frame from three sections to two, Concept 2 achieves significant weight savings and a more compact profile without compromising structural integrity. The redesigned single-blade spinner, validated through finite element analysis, delivers greater impact damage and improved load performance, while its simple construction ensures cost-effective spare production. Additionally, the elimination of curved AR500 steel armor addresses manufacturing constraints, and the upgraded TPU wheel guards improve aesthetics, functionality, and weight efficiency. These refinements make Concept 2 a more practical and effective choice for competitive performance, leading to our decision to move forward with this design.

## 5. Final Design



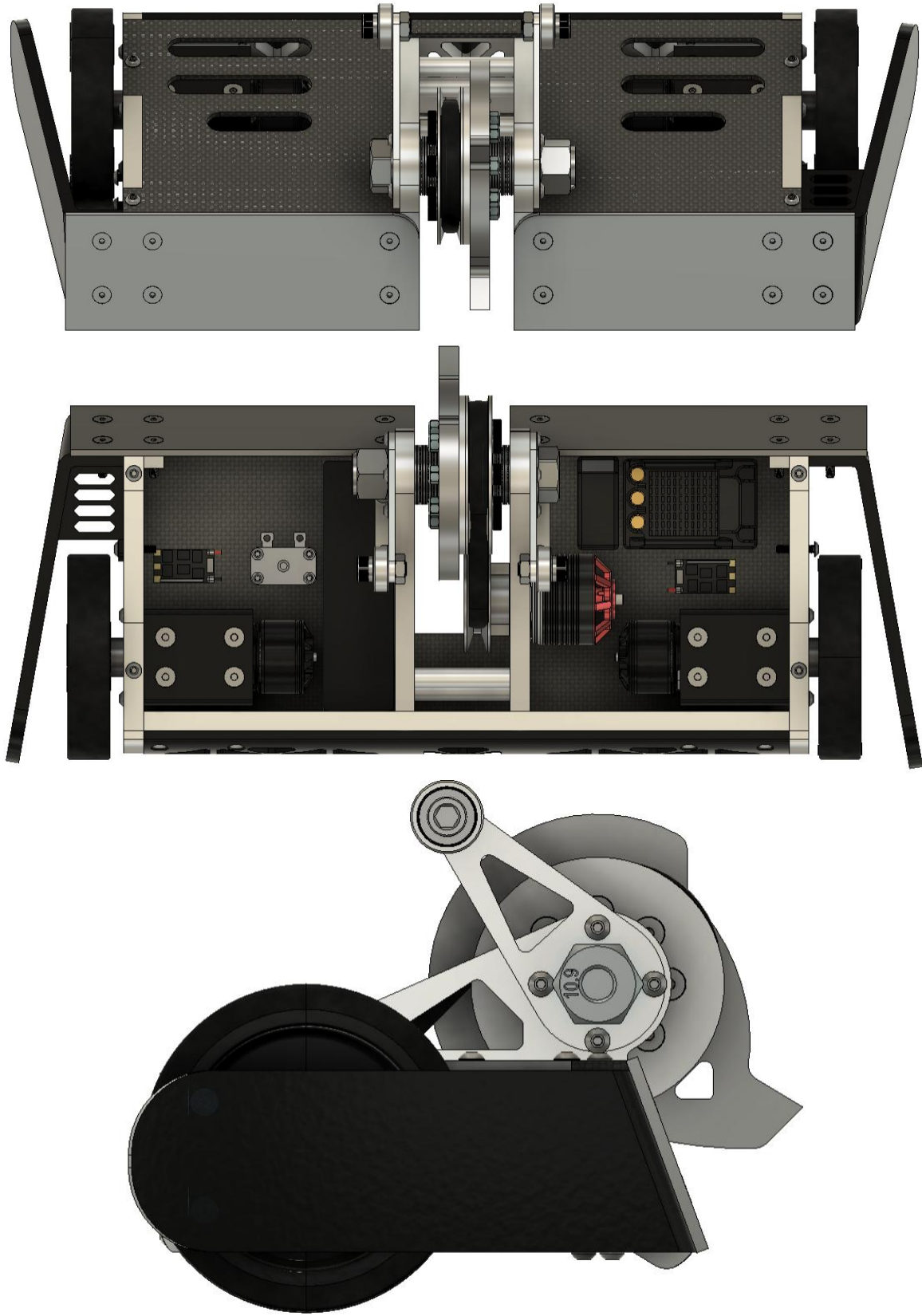


Figure 32: Final Design Isometrics

## a. Component Selection

### *Weapon*

Our team built a single-tooth vertical spinner weapon with a 4.834" attack diameter, crafted from 0.375" thick AR500 steel for strength in combat. It's mounted on a shoulder bolt pivot axle, secured with a vibration-resistant lock nut to stay tight at high speeds. Two 6903-2RS ball bearings, pressed into the AR500 disc and pulley mount, ensure smooth rotation. Eight M5 bolts with vibration-resistant locknuts distribute impact stress to prevent shearing.

The weapon is driven by a BadAss 3520-970Kv brushless motor, powered by a standard LiPo battery. To optimize performance, a 3"-OD zinc pulley and a 2"-OD zinc pulley from McMaster-Carr gear down the motor, lowering the weapon's RPM to 14,356. This yields a tip speed of 206.45 mph and 2.09 kJ of energy, fitting the 12lb battle bot ideal range (180-220 mph, 1.5-2 kJ). The setup includes needle-thrust bearings, washers, and a custom 6061 aluminum mounting plate to minimize wear on the pulley and shaft at high speeds.

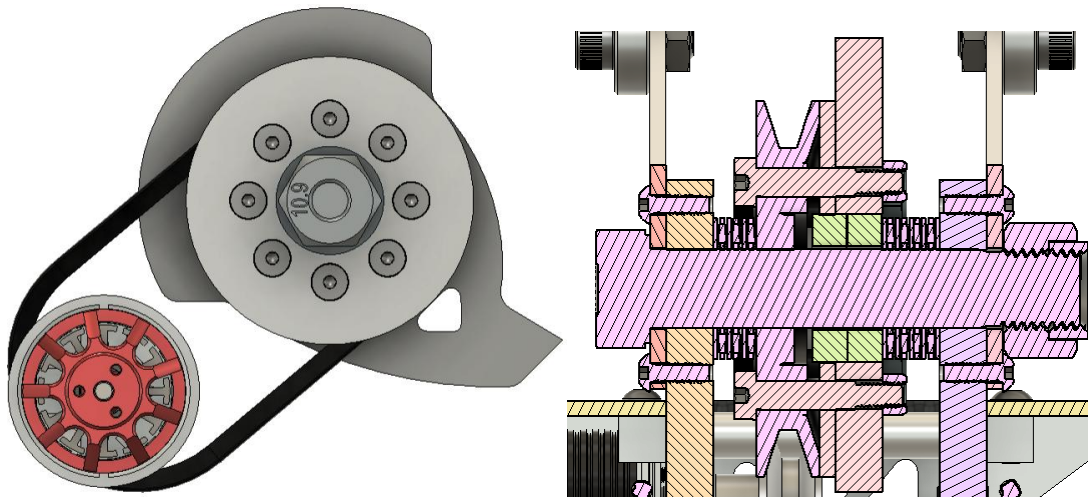


Figure 33: Weapon Stack Isometric & Section View

### *Drive Train*

The drivetrain features a comprehensive two-wheel drive (2WD) system designed for maneuverability, durability, and reliability in combat environments. Each side is powered by a Repeat Drive Magnum assembly, utilizing robust 3536 brushless motors paired with 19:1 gearboxes. This setup offers a balanced trade-off between torque and speed, ideal for rapid acceleration and precise control in the arena.

The wheels in this system are 3-7/8" x 0.8" BaneBots Compliant Wheels, constructed from 60A black rubber for good traction and shock absorption. Each wheel is mounted to a T81 hub designed for a 1/2" hex shaft, ensuring a secure and torque-resistant connection. To reinforce drivetrain durability, the system incorporates extra-large hardened steel output shafts supported by oversized bearings, reducing the risk of mechanical failure under high loads.

Custom 3D-printed TPU mounts are used to mount the gearbox and motor assemblies directly to the robot's side plates. This approach improves stability and reduces vibration but also simplifies alignment during assembly.

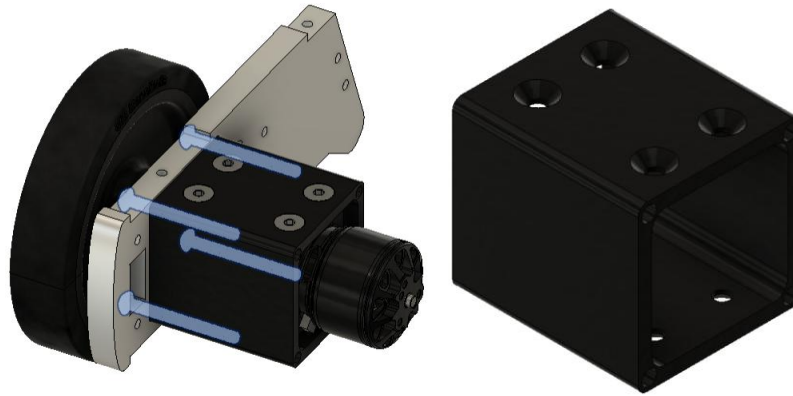


Figure 34: Drive Assembly & Custom TPU Mount

### *Frame*

The frame is constructed using  $\frac{3}{8}$ " aluminum 6061 plates for all frame rails, the back plate, and vertical uprights. A 3mm thick carbon fiber reinforced polymer (CFRP) bottom plate and top plate tie the entire structure together. Aluminum 6061 was selected due to its excellent balance of strength, weight, and machinability—qualities identified through state-of-the-art research.

To improve ease of assembly, the frame members are designed to key together using interlocking tabs and slots. This method ensures precise alignment during assembly and enhances the structural rigidity of the frame by distributing loads across multiple surfaces.

The frame also includes six custom-machined aluminum 6061 nut strips (2" x 3"), mounted along the frame rails. These strips are used to fasten the AR500 wedge and the carbon fiber top plates. By using nut strips instead of tapping threads directly into the frame, we reduce manufacturing time and increase structural support. These were machined in-house from existing stock to minimize both weight and cost. Two aluminum support shafts will be utilized as well to improve the bot's overall structure. These shafts will tie into the back of the uprights.

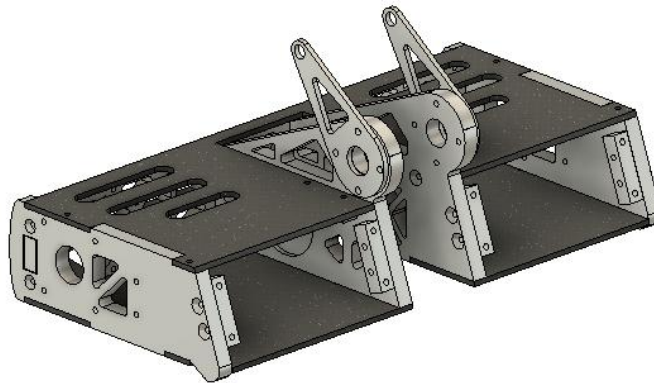


Figure 35: Frame Isometric

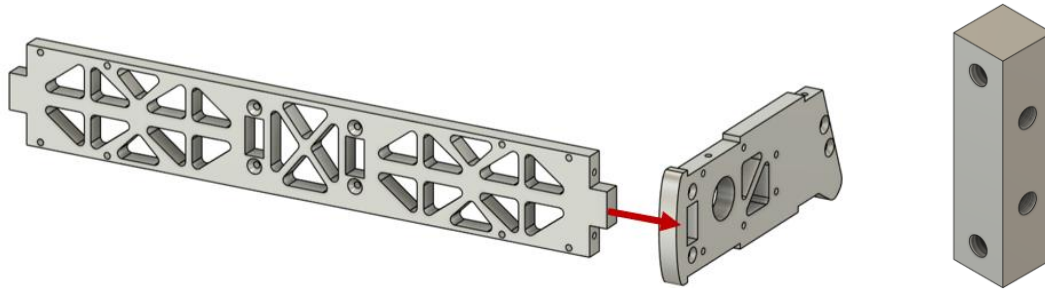


Figure 36: Keying Example &amp; Custom Nut Strip

### *Armor*

The armor system consists of AR500 steel and TPU (thermoplastic polyurethane). The main weapon-facing armor is an AR500 wedge, chosen for its exceptional durability and impact resistance. It is particularly effective against horizontal spinning weapons. This wedge is securely mounted to the aluminum frame using the custom nut strips.

To improve side and rear protection, TPU shock mounts and deflector guards are used. TPU's flexibility allows it to absorb impacts and dissipate energy, protecting the wheels and internal components from direct hits. Additionally, a TPU rear backplate will be secured to the back aluminum plate using button head screws, adding another layer of protection to the frame.

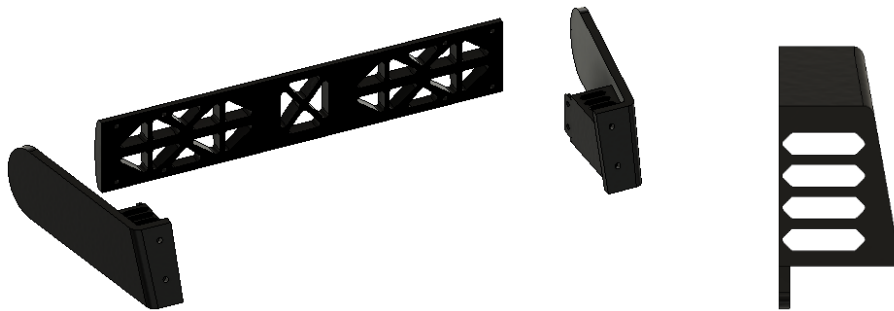


Figure 37: TPU Armor

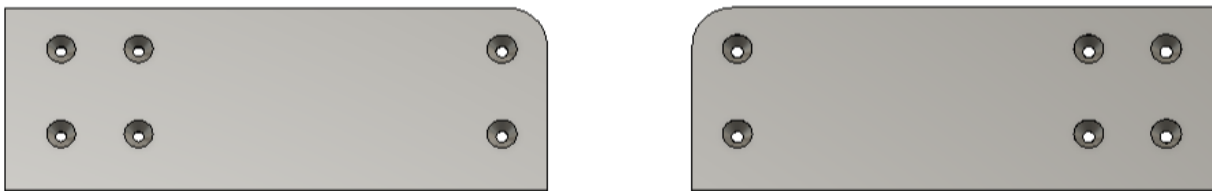


Figure 38: Wedge

### *Electronics*

The electronics system was selected to deliver a reliable balance of performance, durability, and cost-efficiency, ensuring dependable operation during high-impact combat while remaining within competition constraints. Below is a breakdown of the components selected:

The BadAss 3520-970Kv Brushless Motor (Innov8tive Designs) powers the vertical spinner weapon, selected for its good power-to-weight ratio. It can deliver up to 2000W on a 6S setup, this motor's 970Kv rating offers an ideal balance of torque and rotational speed, tailored to the needs of a

high-energy vertical weapon. Weighing only 0.494 lbs, it supports efficient energy transfer with minimal weight penalty.



Figure 39: BadAss 3520-970Kv Brushless Motor (34)

Paired with the weapon motor is the Castle Creations Sidewinder 8th ESC, chosen for its high current handling and combat-proven durability. This ESC provides consistent performance even under extreme thermal and mechanical stress, making it a reliable solution for high-drain weapon systems.



Figure 40: SIDEWINDER 8TH ESC, 25.2V ESC, 8A PEAK BEC, WP (35)

Drive performance is delivered by Repeat Drive Magnum 3536 Brushless Motors, selected for their robust construction and compatibility with heavier battlebot applications. These motors are mated to 19:1 gearboxes with extra-large hardened steel output shafts and oversized bearings, which ensure long-term reliability and high torque output during maneuvers.



Figure 41: Repeat Drive Magnum With 3536 Motor (36)

Each drive motor is paired with a SoloGood Flycolor Francy 2 50A ESC, which supports both PWM and DShot input protocols. These ESCs are compact and lightweight, running BLHeli-32 Test firmware to enable precise throttle control and improved responsiveness, critical for competitive driving performance.



Figure 42: SoloGood 2PCS FLYCOLOR Francy 2 50A Brushless ESC (37)

Power is supplied by a 6S 1550mAh LiPo Battery, chosen for its compact form factor and sufficient capacity to run both the weapon and drive systems efficiently. Its availability and affordability also support easy replacement and charging between matches.



Figure 43: Turnigy nano-tech 1550mah 6S 65~130C Lipo Pack (38)

Control is handled via the Spektrum AR410 4-Channel Receiver, offering reliable signal performance and compatibility with the Spektrum DX6i Transmitter. Its small footprint and low weight (0.060 lbs) make it well-suited for our application.



Figure 44: AR410 DSMX 4-Channel Sport Receiver (39)

The system is operated using a Spektrum DX6i 6-Channel Full Range Transmitter, which offers dependable 2.4GHz communication, customizable mixing, and intuitive dual-rate controls. This handheld controller provides the driver with responsive, low-latency inputs and full-channel flexibility for managing weapon activation and drive commands in real time.



Figure 45: DX6i 6-Channel Full Range w/o Servos MD2 (40)

A Kake Switch (by Maximizer) is used as the main power switch. This high-current-rated switch ensures safe and rapid power delivery during competition, and its rugged construction allows repeated use without failure. It is also a requirement to compete in NHRL to have a reliable master power switch.



Figure 46: Kake Switch (41)

Overall, the electronics package was designed with a focus on reliability and consistent performance in combat environments. All components used are standard for battlebot applications, with most selections based on recommendations from the UC Combat Robotics Club (UCCR). Each part was chosen to integrate efficiently with the others, resulting in a maintainable and well-organized system that delivers stable power to both the drivetrain and weapon systems.

### **b. Weight Optimization**

To optimize the battle bot's weight within the 12-pound limit, we chose materials and components based on their functionality, weight, and structural strength. The approach prioritized lightweight, durable materials and eliminated unnecessary weight while maintaining performance and reliability. By tracking each component's weight, the total system weight was kept at 11.64 pounds, providing a 0.36-pound buffer for unexpected adjustments. This process ensured adherence to weight constraints without compromising the bot's effectiveness.

#### *Structural Components*

The robot's frame was designed to be as light as possible while still strong enough to handle impacts during competition. The total weight of the structure, including fasteners and support parts, comes to about 5.05 pounds (82.155 ounces). To keep weight low, we used carbon fiber for the top and bottom plates, which are both strong and lightweight. These parts weigh just 0.27 lbs and 0.40 lbs. For the main frame—such as the side plates, back plate, and uprights—we used 3/8" aluminum 6061, which is a strong yet lightweight metal. These parts range from 0.405 lbs to 0.566 lbs each.

We added AR500 steel wedges to areas that take the most hits, since this material is very impact-resistant. Each wedge weighs about 0.567 lbs. We also used TPU for some flexible parts, like the back plate and shock dampers, to help absorb impacts without adding much weight. The heaviest TPU part is just 0.144 lbs.

To cut down weight even more, we added trussing to the back plate, uprights, and side plates. Trussing is a design method that removes material where it's not needed while keeping the part strong. This optimization led to significant savings across the frame: the back plate dropped from 13.347 oz to 9.064 oz (a savings of 4.283 oz), while each side plate was reduced from 6.979 oz to 6.481 oz. The uprights saw further improvements after stress simulations guided strategic material removal—reducing the left upright from 9.432 oz to 7.248 oz and the right from 8.811 oz to 7.962 oz. Altogether, these adjustments saved over 9.3 oz, allowing us to reallocate weight toward critical systems like the weapon and drive modules.

We also chose lightweight screws and fasteners, like button head and socket head screws, to hold everything together without adding much weight. Even with many small parts, like 30 screws in some spots, these only add a small amount to the total weight.

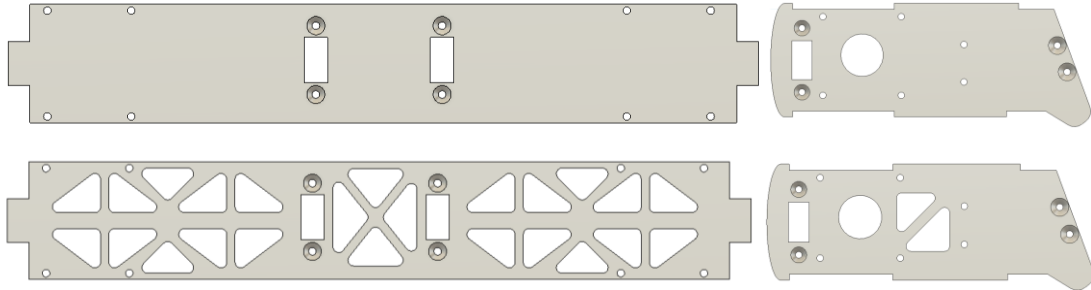


Figure 47: Back & Side Plate Weight Saving

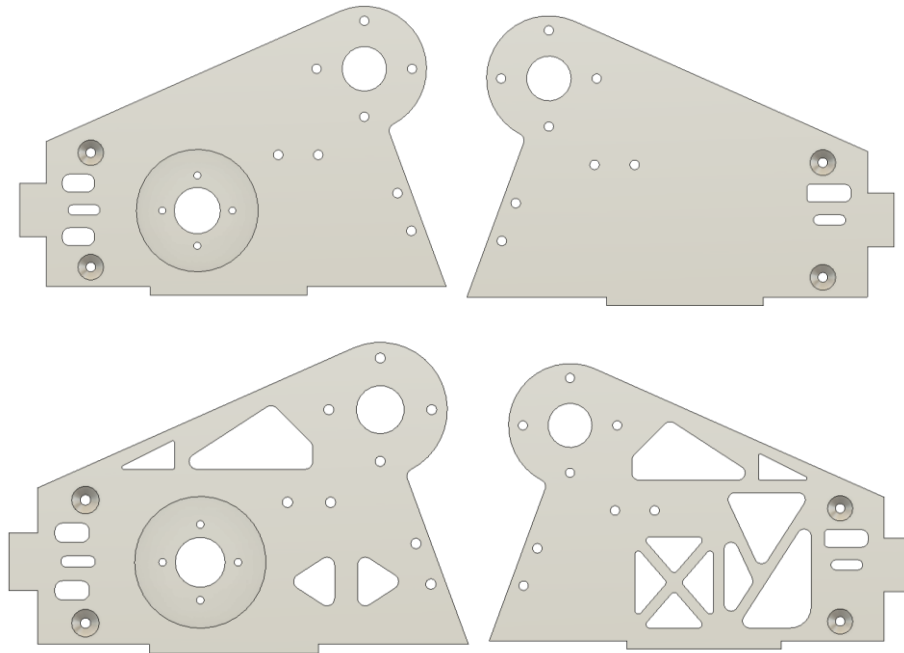


Figure 48: Upright(s) Weight Saving

Table 7: Total Structure Weight

Part	oz	lb	# of Item	Total lb	Total oz
Structure	oz	lbs	Quantity	lbs	oz
Top Plate	4.432	0.277	1	0.277	4.432
Bottom Plate	6.404	0.40025	1	0.40025	6.404
Back Plate	9.064	0.5665	1	0.5665	9.064
Side Plate - R	6.484	0.40525	1	0.40525	6.484
Left Plate - L	6.484	0.40525	1	0.40525	6.484
Upright - R	7.984	0.499	1	0.499	7.984
Upright - L	7.236	0.45225	1	0.45225	7.236
Wedge - R	9.073	0.5670625	1	0.5670625	9.073
Wedge - L	8.706	0.544125	1	0.544125	8.706
TPU Back Plate	2.298	0.143625	1	0.143625	2.298
Deflector - R	1.291	0.0806875	1	0.0806875	1.291
Deflector - L	1.273	0.0795625	1	0.0795625	1.273
Shock Damper - R	0.616	0.0385	1	0.0385	0.616
Shock Damper - L	0.71	0.001565256	1	0.001565256	0.71
Bunny Ears	0.562	0.035125	2	0.07025	1.124
Bunny Ear Button Head Screws (91239A148)	0.05	0.000110229	8	0.000881834	0.4
Bunny Ear Bearings (6153K51)	0.432	0.027	2	0.054	0.864
Bunney Ear Socket Head Screws (91251A580)	0.377	0.0235625	2	0.047125	0.754
Bunny Ear Hex Nuts (94846A203)	0.131	0.0081875	2	0.016375	0.262
Support Shafts	0.295	0.0184375	2	0.036875	0.59
Custom Nut Strips	0.295	0.0184375	6	0.110625	1.77
#8-32 Flat Head Screws for Nut Strips & 6061 Supports (91253A197)	0.076	0.00475	30	0.1425	2.28
M4 Flat Head Screws for Keying (91294A195)	0.061	0.0038125	8	0.0305	0.488
M4 Button Head Screws for Top/Bottom Plate (91239A144)	0.045	0.0028125	12	0.03375	0.54
#8-32 Button Head Screws for Top Plate (92949A194)	0.056	0.000123457	4	0.000493827	0.224
Button Head Screws for TPU Back Plate & Shock Damper Side(91239A151)	0.067	0.0041875	12	0.05025	0.804
<b>Totals:</b>				<b>5.054253417</b>	<b>82.155</b>

### Weapon System

The weapon system balances power and weight efficiency. The AR500 steel weapon disc weighs 1.07375 lbs, delivering significant impact force. Lightweight components like pulleys (0.04375 lbs), thrust washers (0.00625 lbs each), and needle roller thrust bearings (0.0094375 lbs each) ensure smooth operation, keeping the total weapon system weight at roughly 2.8 lbs.

Table 8: Total Weapon System Weight

Weapon System	oz	lbs	Quantity	lbs	oz
Weapon Blade - AR500 Steel	17.18	1.07375	1	1.07375	17.18
Weapon Shaft (91310A864)	6.147	0.3841875	1	0.3841875	6.147
Shaft Steel Insert Locknut (93520A209)	1.356	0.08475	1	0.08475	1.356
Driver Pulley (6245K214)	5.467	0.3416875	1	0.3416875	5.467
Custom Driven Pulley (6245K616)	7.555	0.4721875	1	0.4721875	7.555
Custom Weapon Mount (6061)	0.682	0.042625	1	0.042625	0.682
Weapon Blade Mounting Screws (grainger-6EU17 v1)	0.285	0.0178125	8	0.1425	2.28
Weapon Blade Mounting Locknuts (grainger-26LJ84 v1)	0.051	0.000112434	8	0.000899471	0.408
Pulley V Belt	0.7	0.04375	1	0.04375	0.7
Thrust Washers	0.1	0.00625	8	0.05	0.8
Needle-Roller Thrust Bearings	0.151	0.0094375	6	0.056625	0.906
Weapon Motor Mounting Flathead Screws (91294A132)	0.023	0.0014375	4	0.00575	0.092
6903-2RS Ball Bearing 17x30x7 Sealed 61903-2RS	0.93	0.058125	2	0.11625	1.86
<b>Totals:</b>				<b>2.814961971</b>	<b>45.433</b>

### Drive System

The drive system uses BaneBots wheels (0.21875 lbs each) and a T81 hub (0.031875 lbs), paired with the Repeat Robotics 3536 motor (0.76069375 lbs), totaling 2.21506821 lbs for efficient power and

maneuverability. TPU gearbox mounts (0.0406875 lbs each) and frame screws (0.004375 lbs each) add stability with minimal weight. The total drive system weight added to roughly 2.2 lbs.

Table 9: Total Drive System Weight

Drive System	oz	lbs	Quantity	lbs	oz
BaneBots Wheel, 3-7/8" x 0.8", Hub Mount, 60A, Black	3.5	0.21875	2	0.4375	7
T81 Hub, 1/2in Hex Shaft	0.3	0.01875	2	0.0375	0.6
Repeat Drive Magnum Gearbox w Repeat Robotics 3536 (motor)	12.1695	0.76059375	2	1.5211875	24.339
TPU Gearbox Mount	0.651	0.0406875	2	0.081375	1.302
Gearbox Mount Screws (TPU) (91294A210)	0.074	0.004625	16	0.074	1.184
Gearbox Mount Screws (Side Frame) (91239A160)	0.127	0.0079375	8	0.0635	1.016
<b>Totals:</b>				<b>2.2150625</b>	<b>35.441</b>

### Electronics

Our electronics were optimized for performance and weight. The BadAss 3520 970 kV weapon motor weighs 0.494 lbs, and the Castle Sidewinder 8th ESC adds another 0.22 lbs. Power is supplied by a Turnigy nano-tech 1550mAh 6S 65~130C LiPo battery, weighing 0.6327 lbs. Each FLYCOLOR Francy Drive ESC weighs 0.04 lbs, contributing 0.08 lbs total for two. The AR410 receiver weighs 0.06 lbs, and the Kake Power Switch adds another 0.055 lbs. This brings the total electronics weight to approximately 1.54 lbs (or 24.55 oz). It's important to note that this total does not include wiring, solder joints, connectors, electrical tape, or glue, all of which will slightly increase the final installed weight.

Table 10: Estimated Electronics Weight

Electronics	oz	lbs	Quantity	lbs	oz
Battery: Turnigy nano-tech 1550mah 6S 65~130C Lipo Pack	10.1236	0.632725	1	0.632725	10.1236
D ESC: FLYCOLOR Francy	0.582	0.04	2	0.08	1.164
W ESC: castle sidewinder 8th	3.52	0.22	1	0.22	3.52
W Motor: BA 3520 970 KV	7.904	0.494	1	0.494	7.904
P Switch: Kake Switch	0.88	0.055	1	0.055	0.88
Receiver: ar410	0.96	0.06	1	0.06	0.96
<b>Totals:</b>				<b>1.541725</b>	<b>24.5516</b>

### c. Stress Analysis and Safety Factor

#### Weapon System – FEA Analysis Dynamic Event Simulation

To test the weapon's strength during high-speed hits, a dynamic FEA simulation was run. It modeled the weapon hitting an aluminum block while spinning at 86,136 degrees per second—similar to real combat. The highest stress, 12,520.674 MPa, appeared at the tip, as expected from the shape. Stress was lower elsewhere, suggesting that if the weapon fails, it'll start at the tip. These results support the weapon's ability to handle dynamic impacts.

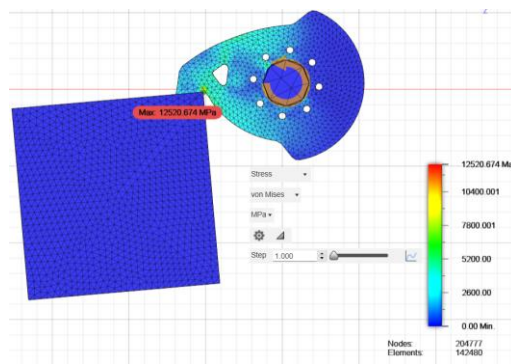


Figure 49: Weapon Dynamic Event Simulation

### Weapon Side Impact Test

To evaluate the risk of weapon flexing and potential damage to the robot's frame or drive belt, a side impact test was conducted.

- Test Parameters: A 1000 N force was applied to the side of the weapon's impact face.
- Results:
  - Max Displacement: 0.107 mm
  - Max Stress: 166.154 MPa

This analysis indicates that the weapon remains within acceptable limits without excessive deformation.

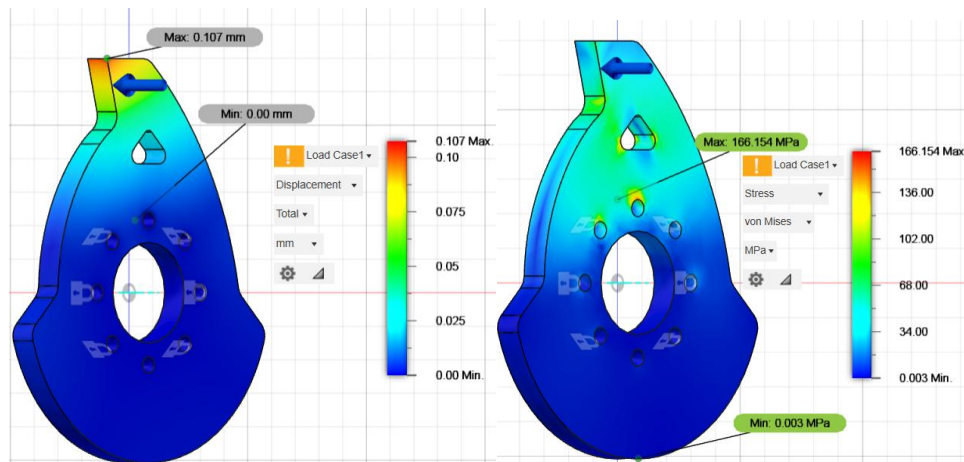


Figure 50: Weapon Static Event Simulation

### Weapon Uprights – Static Stress Simulation

#### Right Upright

This simulation analyzed the forces resulting from the weapon impacting an opponent.

- Load: 1000 N applied on the shaft.
- Results:
  - Max Displacement: 0.007 mm
  - Max Stress: 15.119 MPa

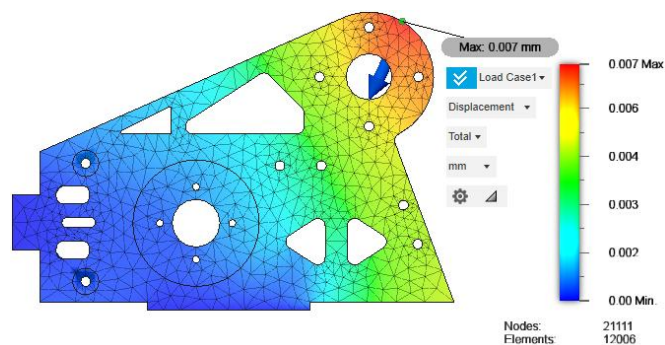


Figure 51: Right Upright Displacement

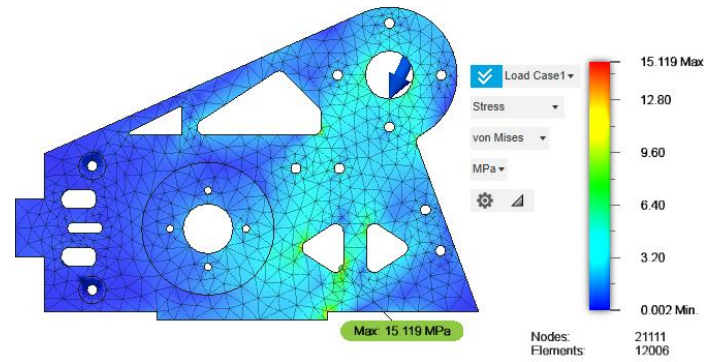


Figure 52: Right Upright Stress

### Left Upright

- Load: 1000 N applied on the shaft.
- Results:
  - Max Displacement: 0.006 mm
  - Max Stress: 18.481 MPa

Both uprights demonstrated high structural integrity under the applied load.

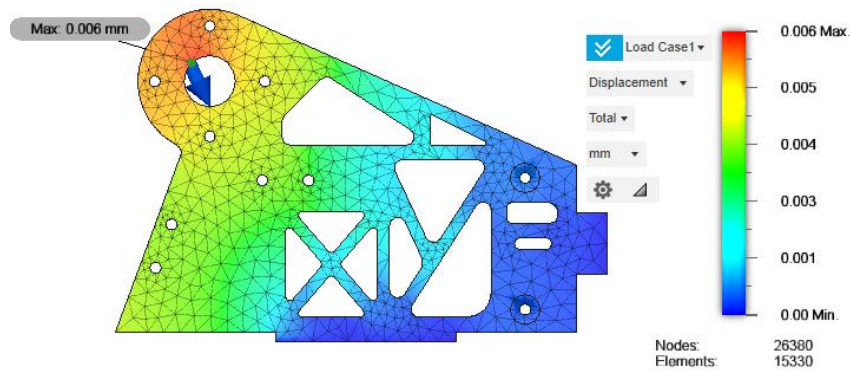


Figure 53: Left Upright Displacement

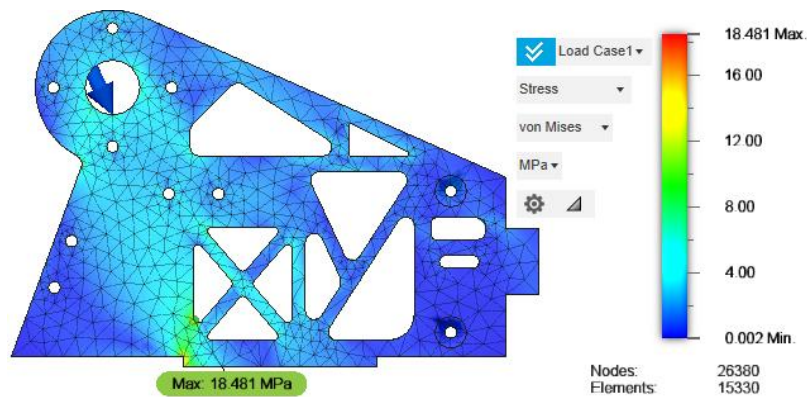


Figure 54: Left Upright Stress

### Frame – Back Plate Static Event Simulation

#### Horizontal Impact

A simulation was conducted to assess the forces resulting from the impact of a horizontal spinning weapon on the side face of the back plate.

- Load: 1000 N
- Results:
  - Max Displacement: 0.559 mm
  - Max Stress: 129.437 MP

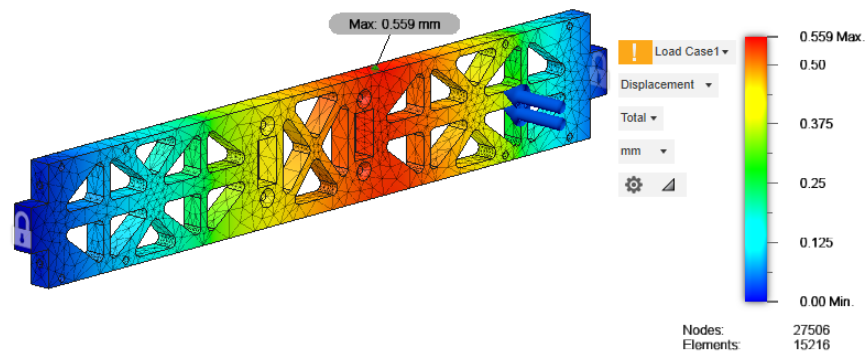


Figure 55: Back Plate Horizontal Displacement

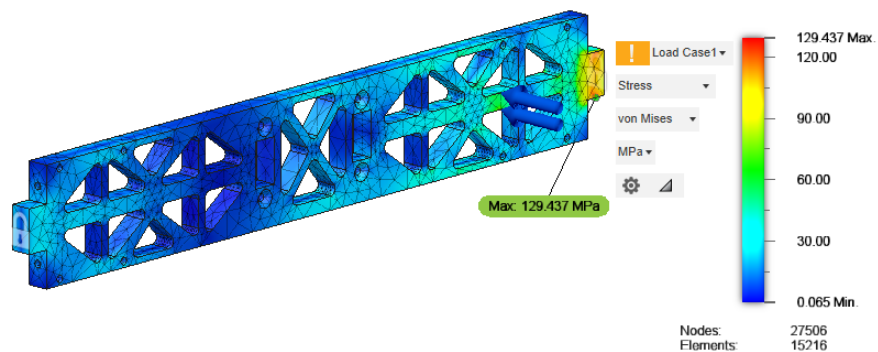


Figure 56: Back Plate Horizontal Stress

#### Vertical Impact

This simulation evaluated forces from the impact of a vertical spinning weapon on the bottom of the frame member.

- Load: 1000 N
- Results:
  - Max Displacement: 0.099 mm
  - Max Stress: 29.161 MPa

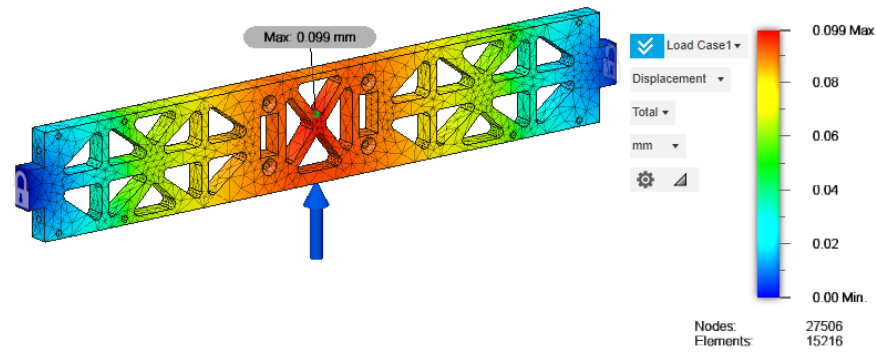


Figure 57: Back Plate Vertical Displacement

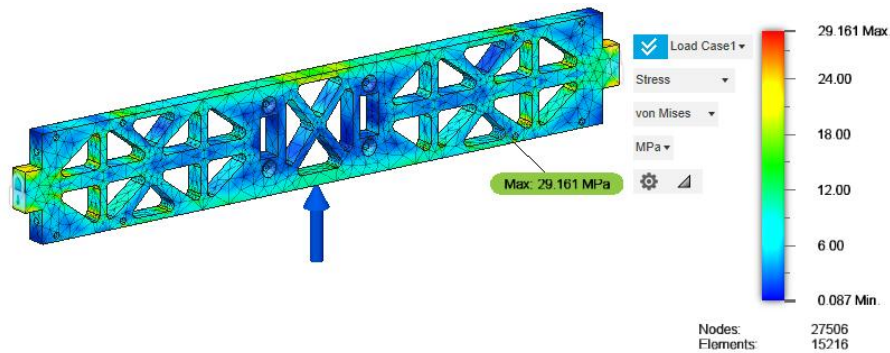


Figure 58: Back Plate Vertical Stress

### Frame – Side Plate Static Stress Simulation

#### Horizontal Impact

To simulate the forces from the impact of a horizontal spinning weapon, a 1000 N load was applied to the side face of the plate.

- Results:
  - Max Displacement: 0.02 mm
  - Max Stress: 50.381 MPa

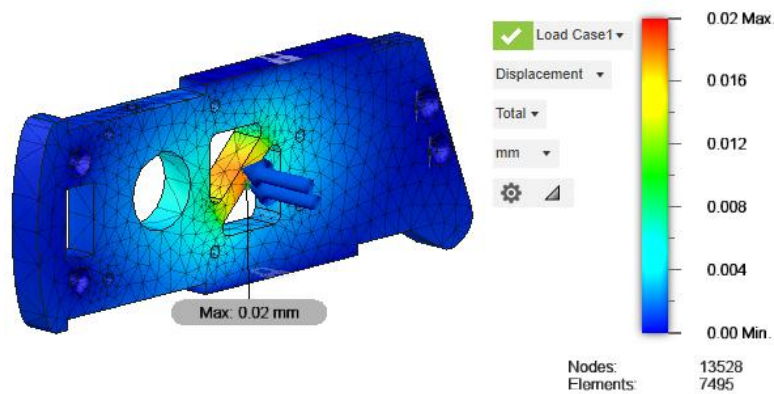


Figure 59: Side Plate Horizontal Displacement

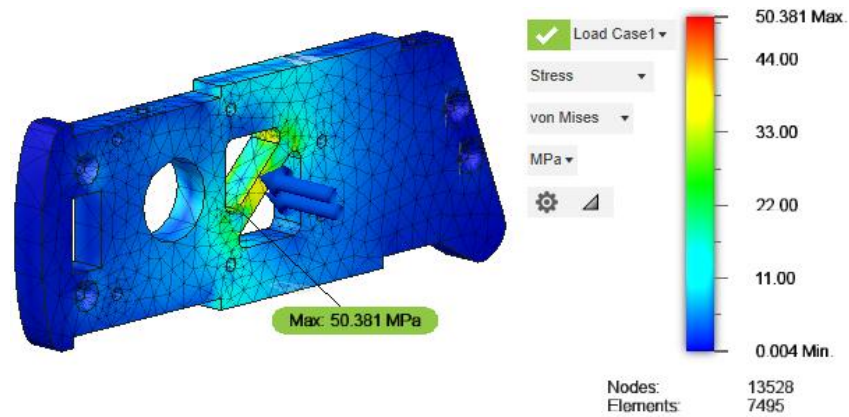


Figure 60: Side Plate Horizontal Stress

### Vertical Impact

Forces from a vertical spinning weapon impacting the bottom of the side plate were analyzed under a 1000 N load.

- Results:
  - Max Displacement: 0.07 mm
  - Max Stress: 59.202 MPa

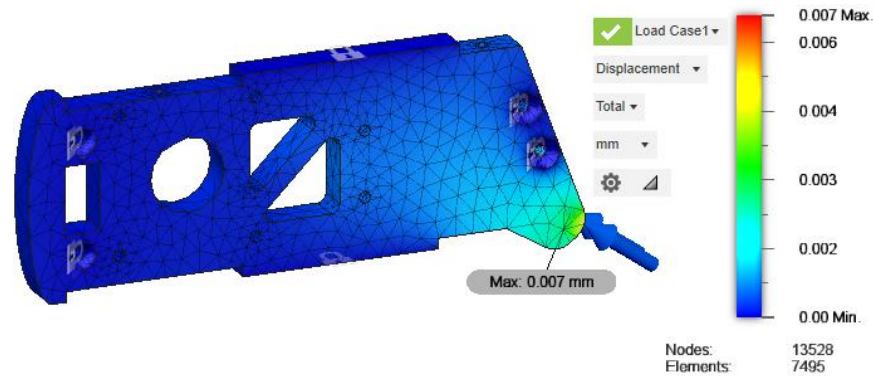


Figure 61: Side Plate Vertical Displacement

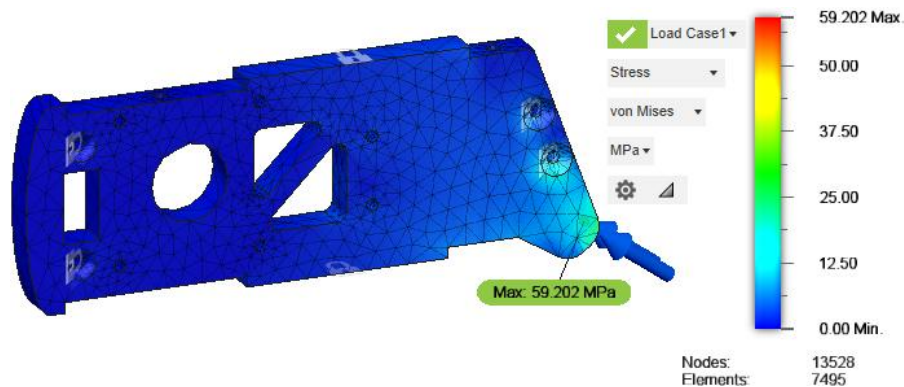


Figure 62: Side Plate Vertical Stress

## Armor – Wedge Static Stress Simulation

### Horizontal Impact

To simulate the forces from the impact of a horizontal spinning weapon, a 1000 N load was applied to the side face of the wedge.

- Results:
  - Max Displacement: 0.076 mm
  - Max Stress: 76.271 MPa

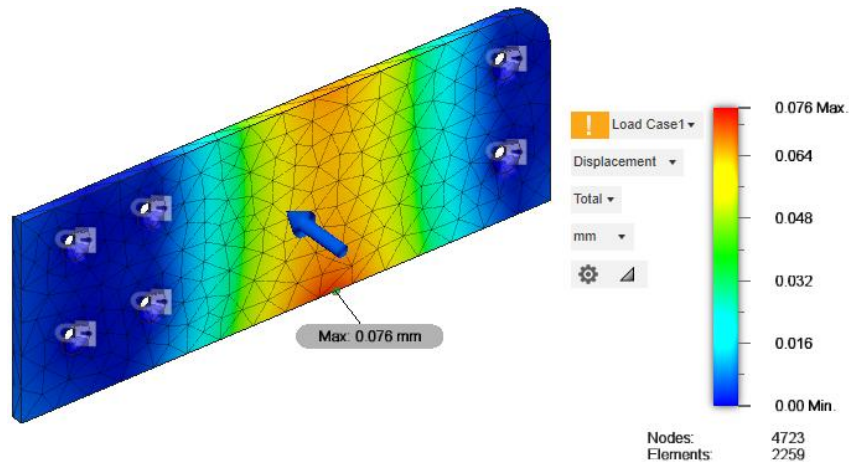


Figure 63: Wedge Horizontal Displacement

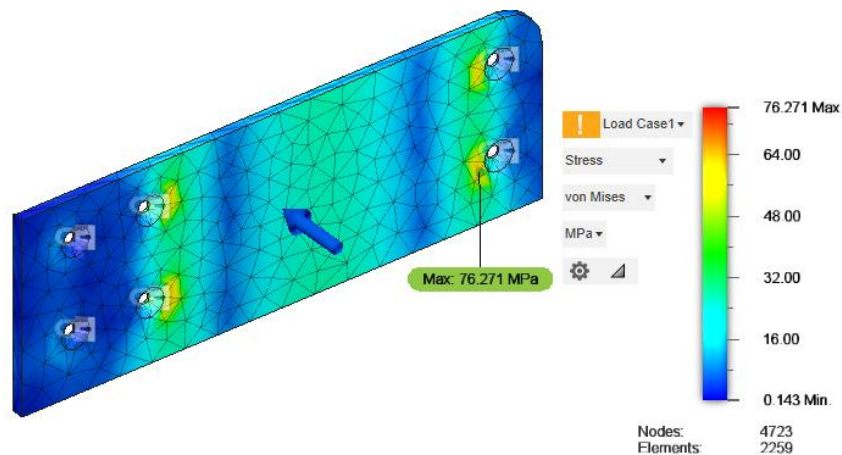


Figure 64: Wedge Horizontal Stress

### Vertical Impact

Forces from a vertical spinning weapon impacting the bottom of the wedge were analyzed under a 1000 N load.

- Results:
  - Max Displacement: 0.001 mm
  - Max Stress: 10.049 MPa

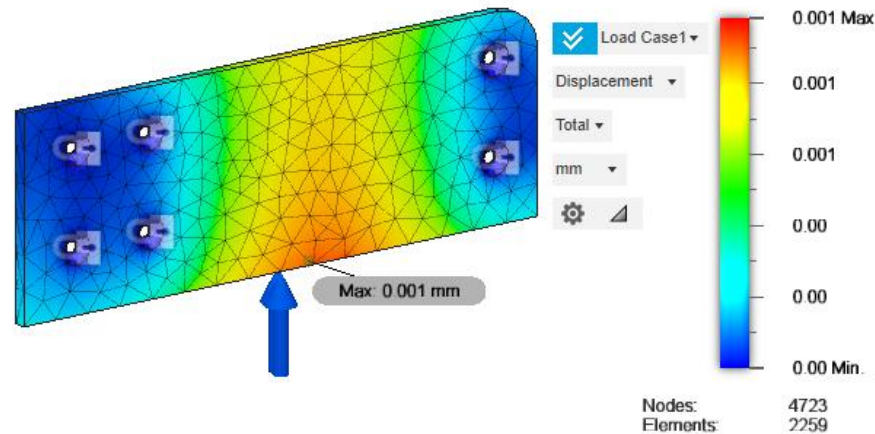


Figure 65: Wedge Vertical Displacement

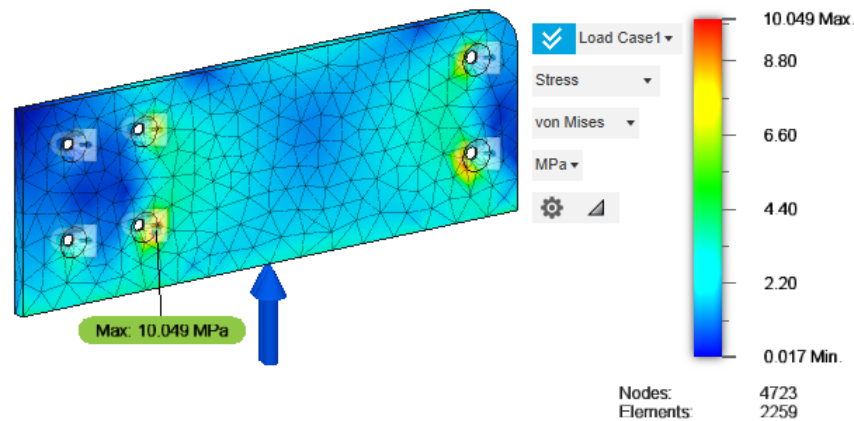


Figure 66: Wedge Vertical Stress

### Factor of Safety Concerns

FEA shows that the weapon uprights exhibit exceptional strength, with a minimum safety factor of 14, with no structural concerns under expected combat conditions. The back plate, under horizontal impact, has a safety factor of 2.125, which is slightly lower but still sufficient to handle typical loads; the vertical impact safety factor is much higher at 9.43, confirming its overall resilience under loads. For the side plates, the horizontal impact safety factor of 5.454 provides good protection, while the vertical impact factor of 4.645 remains within safe limits, ensuring that these components can withstand various attack angles. The side and back plates are of highest concern, hence the reason we incorporated TPU armor around these frame members for extra protection and shock absorption.

The wedge armor has varying safety factors depending on impact direction. Under horizontal loading, the safety factor is 2.83, while the vertical impact factor is much stronger at 14, which ensures durability and a lower risk of failure in most scenarios. The wedge design is intended to deform in controlled ways, acting as a crumple zone to absorb energy during impacts and protect the frame. While the horizontal safety factor might seem borderline, this intentional design feature ensures that the wedge will sacrifice itself in high-stress moments to prevent damage to critical internal components.

These results show that the robot's key structural components are designed to hold up under the stresses of combat, with safety factors that ensure they can handle impacts from different angles and forces.

#### d. Proof of Design

When our team started refining the design and organizing internal components, we identified the need for a physical model to support key tasks: testing frame assembly, verifying electronic component fit, and identifying design flaws. We printed the entire frame using PLA at the 1819 Innovation Hub and superglued the parts together to visualize the final frame before submitting waterjet orders for the actual frame and armor components at 1819.

By placing all electronics in the 3D-printed frame, we discovered a critical design issue: the weapon motor and right drive motor were positioned too closely, leaving no space for wiring and raising concerns about potential collisions during combat. This prototype proved successful, as it provided valuable insights and prompted us to extend the back plate's length to mitigate these issues and reduce the likelihood of problems in combat.

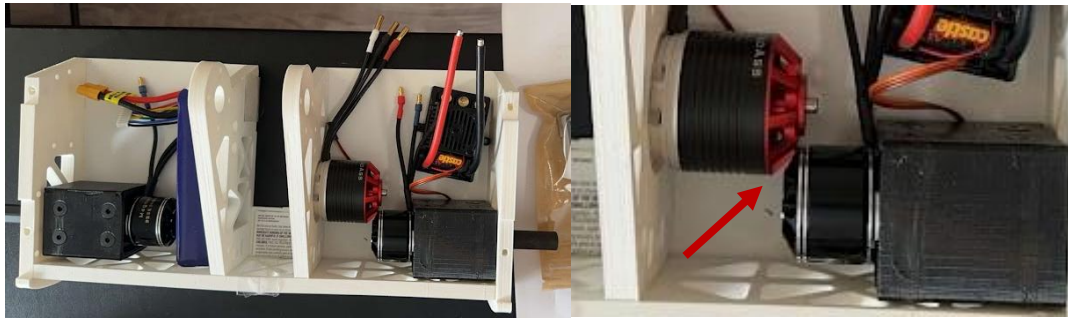


Figure 67: 3D Printed Prototype

#### e. Modifications

During prototyping, the main issues we encountered were related to spacing for the weapon and drive motors. To resolve this, we extended the back plate and updated our fabrication drawings accordingly. We expect further adjustments during fabrication and testing, primarily due to either unforeseen design flaws or opportunities for improvements.

Since this is our first time handling the complete design and building of a battlebot, we understand that iteration is essential. We will make sure to test each system rigorously to uncover any weaknesses and refine the design as needed. Potential changes may include resizing or reconfiguring the weapon for better damage output and durability, improving the drive system for traction and control, and reinforcing high-stress areas without exceeding weight limits.

We'll also focus on making the bot safer to operate. Every change will be evaluated, including the reason, the testing process, and results. This continuous improvement approach will help us deliver a reliable and competitive final product.

#### f. Plan for Testing

##### *Safety Inspection*

The safety inspection ensures NHRL compliance by verifying the robot's 12lb weight limit, weapon locking system, and safe power-on/off procedures. The robot will be "safe bound" to the transmitter to cut power on signal loss. We plan to conduct simulated inspections in a controlled environment to ensure safety and adherence to standards.

### *Weapon Testing*

Weapon testing evaluates performance and durability. An electrical inspection will check for shorts and secure wiring, followed by low- and high-speed spin-up tests to assess balance and motor response.

### *Drivetrain Testing*

Drivetrain testing assesses power, control, and reliability. Component tests will confirm motor and electronic functionality, while performance tests evaluate pushing power and control in competitive scenarios. Inverted driving and self-righting will be tested, along with simulated pushing contests and non-destructive sparring to ensure maneuverability.

### *Sparring and Competitive Testing*

The March NHRL event will provide official testing and feedback, ensuring the robot is competition-ready.

## 6. Fabrication

The final design of the robot was developed to streamline fabrication by prioritizing the use of purchased components and a centralized waterjet cutting process. All major parts including the top and bottom carbon fiber plates, aluminum 6061 frame, nut strips, AR500 steel wedge, and AR500 weapon disc—were sourced online and sent to the 1819 Innovation Hub for waterjet cutting. DXF files and detailed fabrication drawings were created for each component to ensure precise profile cuts. Our team also met with the manufacturing lead at 1819 to review our DXF files and to discuss our project needs. We also met with the head of the VPC Machine Shop to discuss our needs as well.

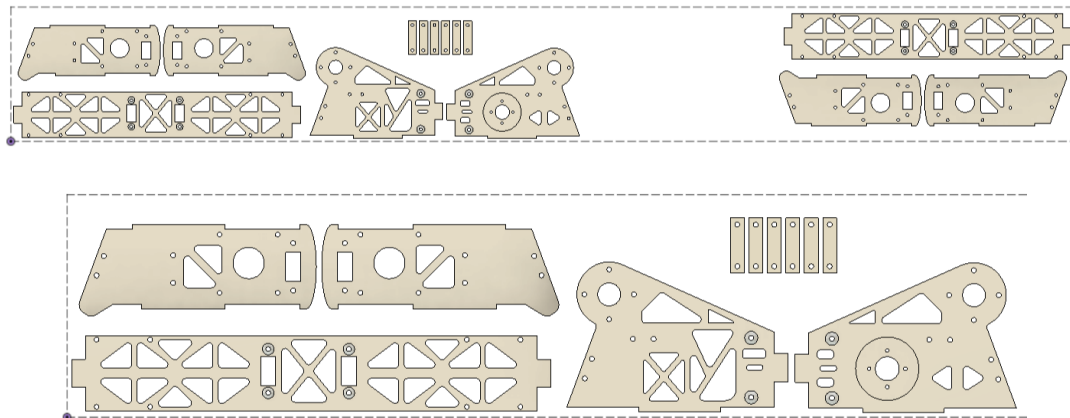


Figure 68: 6" x 48" Aluminum Frame Layout for Waterjet

To manage costs, our team opted to handle post-processing in-house. Additional machining and finishing operations were conducted at the Victory Parkway Campus (VPC). We applied knowledge from our prior machining class and received support from the VPC machine shop supervisor and student workers.

During the manufacturing planning phase, our team created a shared machining spreadsheet to track build progress. Adapted from a previous senior design team's manufacturing schedule, this document was instrumental in keeping the project organized and on schedule. Each machining task was logged with its corresponding component, process, tools, quantity, and estimated completion time. A color-coded system indicated task status: red for tasks on hold or canceled, yellow for tasks in progress, and green for completed tasks. The spreadsheet included separate sections for each process category,

including 3D printing, water jet cutting, frame fabrication, armor fabrication, and weapon fabrication. Below are the processes outlined for water jet cutting and frame fabrication.

WATER JET @ 1819 Hub					FRAME FABRICATION @ VPC				
Process	Component	Tools	Qty.	Est. Time (day)	Process	Component	Tools	Qty.	Est. Time (hrs)
r Jet	Back Plate	1819 Water Jet	1	5 days	Drill / Tap	Back Plate	#30 Bit (.1285) M4x.7 Tap	16	3
r Jet	Side Plate - L	1819 Water Jet	1	5 days	Countersink	Back Plate	90 Degree Countersink Bit	4	0.5
r Jet	Side Plate - R	1819 Water Jet	1	5 days	Drill / Tap	Side Plate - L	#30 Bit (.1285) M4x.7 Tap	12	2.5
r Jet	Upright - L	1819 Water Jet	1	5 days	Countersink	Side Plate - L	90 Degree Countersink Bit	2	0.25
r Jet	Upright - R	1819 Water Jet	1	5 days	Drill / Tap	Side Plate - L	#29 Bit (8/32) Tap #8-32	2	1
r Jet	Wedge	1819 Water Jet	2	5 days	Countersink	Side Plate - L	82 Degree Countersink Bit	2	0.25
r Jet	Weapon Disc	1819 Water Jet	1	5 days	Drill / Tap	Side Plate - R	#30 Bit (.1285) M4x.7 Tap	12	2.5
r Jet	Weapon Mount(s)	1819 Water Jet	2	5 days	Countersink	Side Plate - R	90 Degree Countersink Bit	2	0.25
r Jet	Top Plate	1819 Water Jet	1	5 days	Drill / Tap	Side Plate - R	#29 Bit (8/32) Tap #8-32	2	1
r Jet	Bottom Plate	1819 Water Jet	1	5 days	Countersink	Side Plate - R	82 Degree Countersink Bit	2	0.25
r Jet	Nut Strips	1819 Water Jet	6	5 days	Drill / Tap	Upright - L	#30 Bit (.1285) M4x.7 Tap	8	2
r Jet	Bunny Ears	1819 Water Jet	4	5 days	Drill / Tap	Upright - L	#29 Bit (8/32) Tap #8-32	7	2

Figure 69: Manufacturing Spreadsheet

### Frame and Armor Fabrication

Aluminum 6061 plates were used to construct the bulk of our robot's frame. Both plates were purchased from McMaster-Carr: one Multipurpose 6061 Aluminum sheet, 3/8" thick, 6" x 48", and another Multipurpose 6061 Aluminum sheet, 1/8" thick, 8" x 8". The 3/8"-thick plate was used to fabricate the side plates, back plate, and uprights for the frame, while the 1/8"-thick plate was used to create the robot's "bunny ears." These plates were sent to the 1819 Innovation Hub for waterjet cutting, following the same fabrication process as the other components, with DXF files and fabrication drawings provided to ensure precise cutting of their profiles. Fabrication drawings can be seen in the appendices.

After receiving the waterjet-cut parts, we brought the frame components to the Victory Parkway Campus (VPC) Machine Shop for post-processing. To accurately create clearance holes, we secured the aluminum plates in a vise during end milling, which prevented shifting and ensured clean cuts. For tapping, we used a precision hand tapper to maintain perpendicularity and consistent thread quality across all mounting and keying holes. To avoid issues like tap breakage or thread damage, we followed best practices from our machining course and VPC staff guidance, including applying tapping fluid to reduce friction and wear. Once tapped, we verified thread quality using M4 or #8-32 screws, depending on the specific part. Additional clearance holes were milled or dilled using a drill press as needed to guarantee proper fastener fit during final assembly.

Additional frame components, including nut strips and support shafts, were fabricated to support the structure. The nut strips were waterjet-cut at the 1819 Innovation Hub from 3/8-inch 6061 aluminum stock, then filed to remove burrs and hand-tapped with #8-32 threads at VPC. The support shafts were cut to length from a 3/8-inch diameter, half-foot-long 6061 aluminum rod, purchased from McMaster-Carr, using a band saw, and then hand-tapped with #8-32 threads to ensure secure fastening.

The armor fabrication focused on a 1/8"-thick AR500 steel front wedge and 3D-printed TPU components. The wedge, also waterjet-cut at the 1819 Innovation Hub, required clearance holes and chamfers, which were drilled on a drill press using carbide-tip bits due to the material's hardness. This tedious process involved frequent speed adjustments, ample tap fluid, and multiple bits to ensure precision. Additionally, TPU side deflectors, shock-absorbing mounts, and a protective backplate were printed at the 1819 Innovation Hub on an industrial FDM printer to enhance frame protection.



Figure 70: Tapping Frame Member



Figure 71: Drilling Holes with End Mill

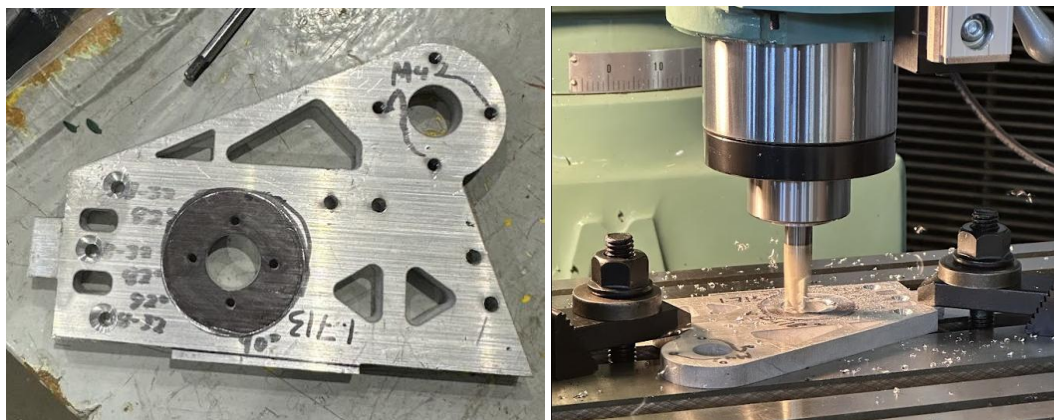


Figure 72: Weapon Motor Slot on Upright



Figure 73: Carbide Tip Masonry Drill Bit Set (42)



Figure 74: Clearance Holes for Wedge on Drill Press

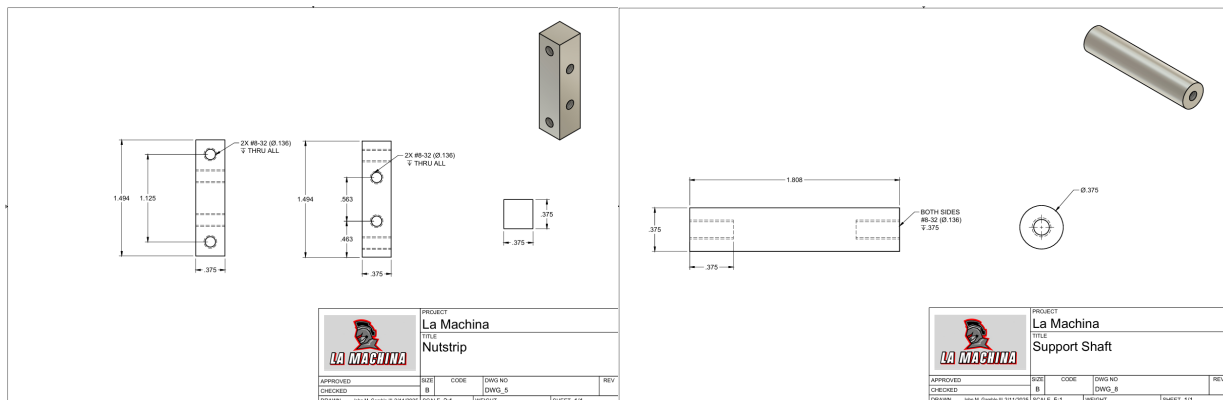


Figure 75: Nut Strip and Support Shaft Drawings

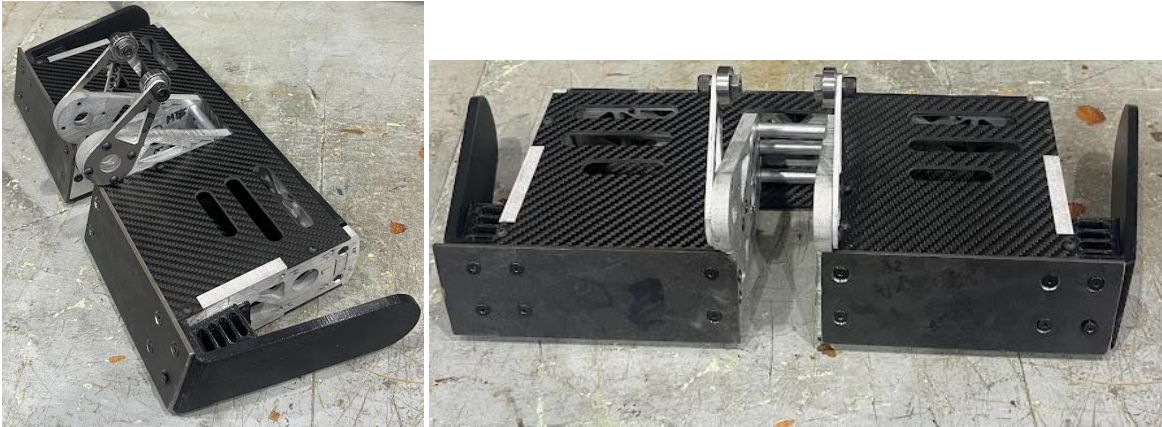


Figure 76: Completed Frame and Armor Assembly

### *Weapon Stack*

After completing the frame and armor, the team focused on fabricating the robot's weapon assembly. The assembly includes an AR500 steel single-tooth vertical spinner (0.375 inches thick), a 3-inch OD zinc driven pulley, a 2-inch OD zinc driver pulley, two 6903-2RS ball bearings, a custom 1/8-inch aluminum 6061 mounting plate, needle-thrust bearings, washers, and eight M5 socket head cap screws with vibration-resistant locknuts. A BadAss 3520-970Kv brushless motor powers the weapon, geared down to achieve a tip speed of 206.45 mph and 2.09 kJ of energy.

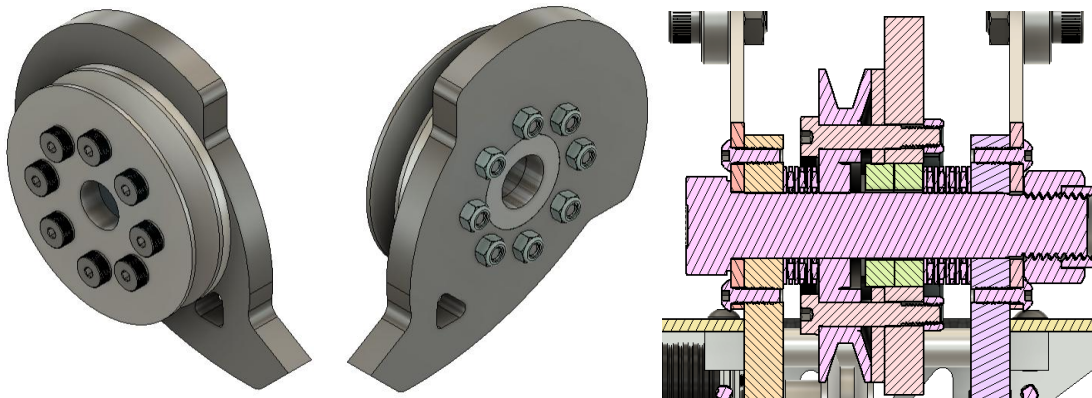


Figure 77: Weapon Stack-up Model & Section View

The AR500 steel disc was purchased as a 3/8-inch plate and waterjet-cut at the 1819 Innovation Hub, requiring no further machining. The driven pulley was turned on a lathe to reduce weight and flatten its outer surface, then drilled on a drill press for eight M5 through holes. The weapon shaft was cut to length using an angle grinder after being secured in a vice. Bearings were press-fit into the weapon disc and aluminum mounting plate using an arbor press, and the assembly was secured with M5 bolts and locknuts.



Figure 78: Cutting the Weapon Shaft to Length Using an Angle Grinder

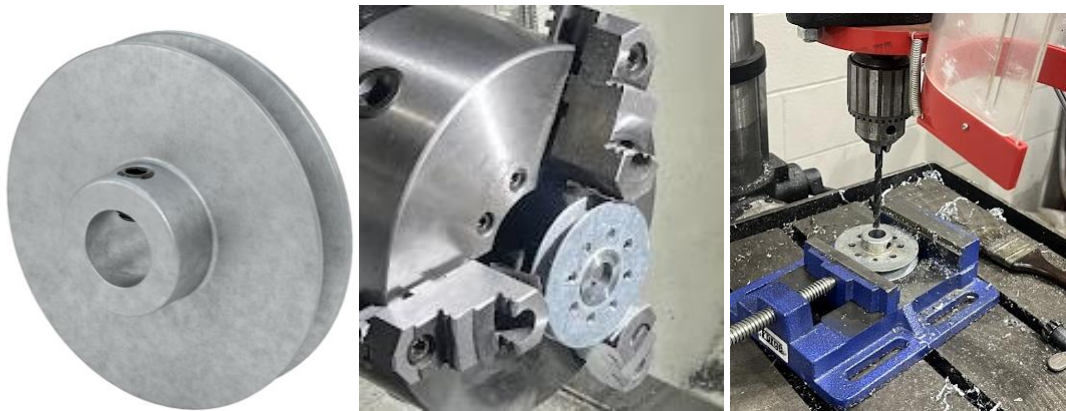


Figure 79: Driven Pulley Fabrication on Lathe & Drill Press



Figure 80: Completed Weapon Stack-up Assembly

### *Drive System*

Minimal fabrication was required for our drive system. The primary task was determining how to mount the gearboxes to the frame. We designed 3D-printed TPU sleeves that secured the gearboxes from the top and bottom. These sleeves also featured side holes, allowing direct mounting to the side plates using four M4 button-head screws. Eight M5 flat head screws were utilized to secure the sleeve to the top and bottom of the gearboxes.

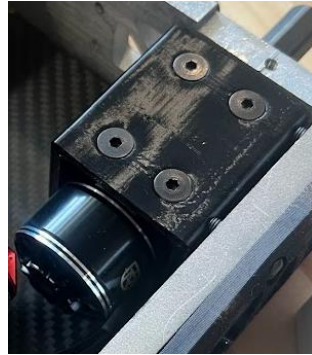


Figure 81: Gearbox Sleeve

### Electronics System

With the mechanical assembly complete, the team shifted focus to the electronics fabrication for the robot. The system includes a Turnigy nano-tech 1550mAh 6S 65~130C LiPo battery, two SoloGood FLYCOLOR Francy 2 50A brushless ESCs for the drive motors, a Castle Creations Sidewinder 8th Sport 1:8 waterproof brushless ESC for the weapon, a Kake power switch with ring connectors, and M5 bolts with lock nuts for secure connections. All wiring used stranded silicone-insulated cables, with 12 AWG for high-current connections (XT60 connectors) and 16 AWG for lower-current lines (MT60 connectors). The drive motors were connected to the ESCs using 18 AWG PWM cables, with red wires on “side 1” for consistent orientation. Two separate junctions used black as the primary hot wire and red as the secondary hot wire.

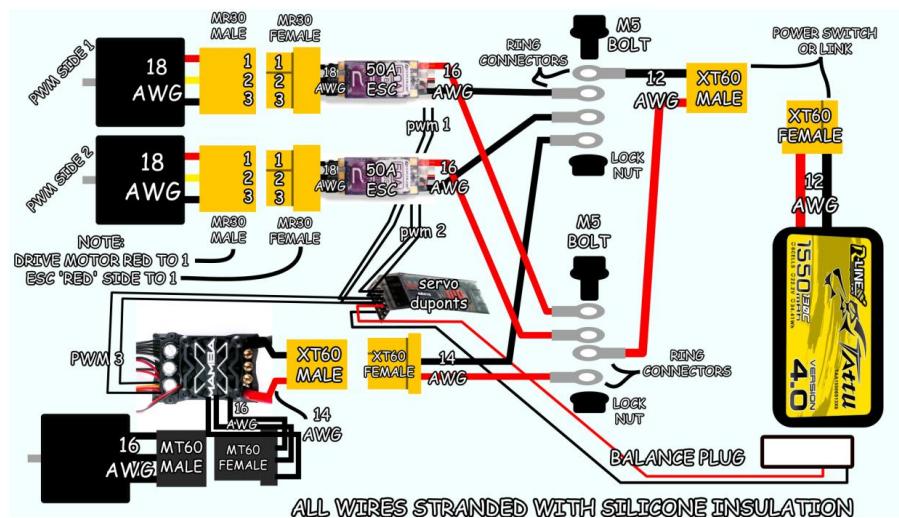


Figure 82: Electronics Wiring Diagram

The battery, ESCs, and weapon ESC were sourced pre-assembled, requiring no modification. Initially, the team crimped XT60 and MT60 connectors onto the wires using a crimping tool but later removed most crimped terminals and soldered the connections for improved reliability, except for the Kake power switch, which retained its crimped ring connectors. The Kake power switch was mounted to the bottom carbon fiber plate using a 3D-printed TPU insert and secured with superglue. All soldered connections were insulated with heat-shrink tubing to ensure durability in combat conditions.



Figure 83: Mounting Kake Power Switch

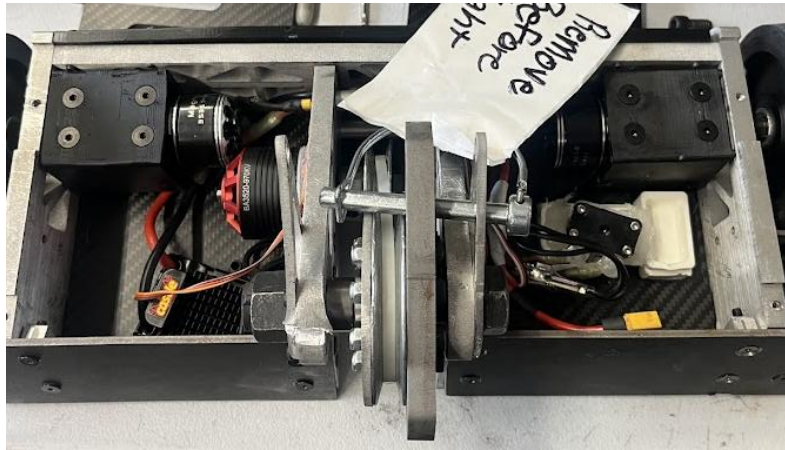


Figure 84: Completed Electronics Assembly Inside Bot

## 7. Final Assembly

### 1. Frame Assembly

The first step in assembly is constructing the robot's frame from 6061 aluminum. The frame includes the weapon uprights, side plates, back plate, support shafts, and nut strips. It also includes the top and bottom carbon fiber plates, but only the bottom will be installed in this step.

All major components are designed to key together, which strengthens the frame and helps prevent incorrect assembly. The side plates attach to either end of the back plate, while the uprights key into the rear face of the cross member. All frame components are fastened using M4 button head screws, except for those that secure into the nut strips, which use #8-32 UNC screws. The team used the XOOD 62-in-1 Precision Screwdriver and Electronics Repair Tool Kit for the frame assembly.

### 2. Motor Installation

Next, while there is still a good amount of working space inside the bot, the weapon and drive motors should be installed onto the frame. The weapon motor mounts to the left upright using four M3 x 12mm countersunk socket screws. After securing the motor, the 2" OD pulley for 3L V-Belts is fitted onto the motor shaft with an aluminum 6061 sleeve to ensure a secure fit.

Next, the drive motors—pre-attached to their gearboxes—are mounted to the side plates. These assemblies are seated in TPU sleeves that provide vibration damping and ensure proper alignment. Each motor-sleeve unit is fastened to the frame using four M4 x 18mm socket button head screws. Eight M5 screws are used to mount on the top and bottom of the gearboxes as well.

### 3. *Drive System Installation*

With the motors and gearboxes securely mounted to the frame, the two drive wheels can be installed onto their respective output shafts. Banebots T81 hubs for 1/2" hex shafts are slid onto the gearbox shafts and secured using set screws. The 3-7/8" x 0.8", 60A black Banebots wheels are then pressed onto the hubs and locked in place with snap rings. The gearboxes feature a 1/2" hex output shaft, which is compatible with common drivetrain accessories, making the T81 hubs a perfect fit.

### 4. *Electronics Installation*

With the mechanical systems in place, the next step is to install the electronics. Since all components have already been wired and tested, this step involves positioning each component within the bot and securing them to the bottom carbon fiber plate using superglue. Care is taken to ensure proper spacing inside the bot.

### 5. *Armor Installation*

The armor consists of 1/8" AR500 steel wedges, TPU deflectors, TPU shock absorbers, and a TPU backplate cover. The steel front wedge is bolted to the nut strips located at the front of the frame, while the side guards are mounted onto the TPU shock absorbers using M4 bolts. Once the wedge and side guards are secured, the only remaining vulnerable area is the rear of the robot. This is protected by the TPU backplate cover, which is fastened directly to the rear cross member using tapped holes in the frame and additional M4 bolts.

### 6. *Weapon Stack-Up Assembly*

The weapon stack-up consists of the weapon blade, an aluminum 6061 spacer plate, two high-speed ball bearings, and a custom 3" OD 3L V-belt pulley. The bearings are press-fit—one into the blade and the other into the spacer—for a secure and precise fit. The assembly is fastened using eight M5 socket head screws and M5 nylon insert lock nuts. M5 shoulder screws are used in this case to provide structural integrity and smooth rotation.

### 7. *Weapon Installation*

Once the weapon stack-up is assembled, it can be installed onto the weapon shaft. The shaft is a high-strength Class 10.9 steel hex head screw, sized M16 x 2.0 mm thread, 110 mm long, which spans a hole from one upright to the other.

To install the weapon, first loop the V-belt around the 3" pulley on the weapon stack-up, then wrap it around the 2" pulley on the weapon motor. With the belt in place, the entire stack-up can be slid between the uprights, and the weapon shaft inserted—starting from one upright, through the bearings in the weapon assembly, and exiting through the opposite upright. Needle thrust bearings and washers are placed in extra space during this process.

To secure the shaft, a Class 8 steel-insert locknut for extreme vibration (M16 x 2.0 mm thread) is tightened onto the end of the shaft, locking the assembly in place.

## 8. Top Cover Installation

The final and simplest step of the assembly process is fastening the top plates onto the robot's frame. Two carbon fiber top plates key into place and are held down using M4 button head screws that thread into tapped holes in the top of the frame. With this step complete the robot is ready to compete.

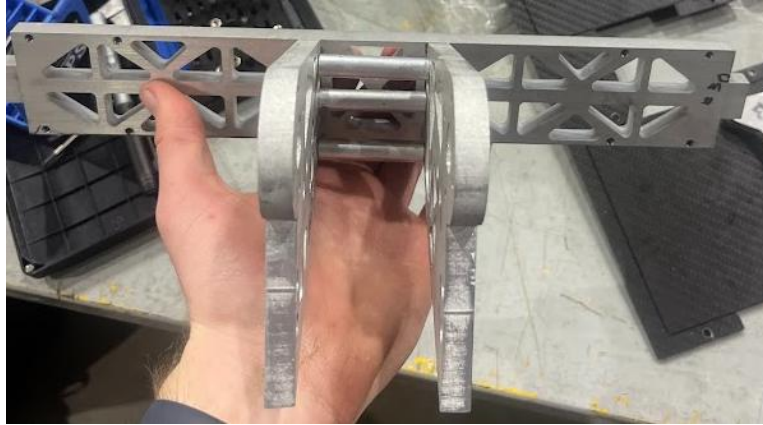


Figure 85: Beginning of Frame Assembly

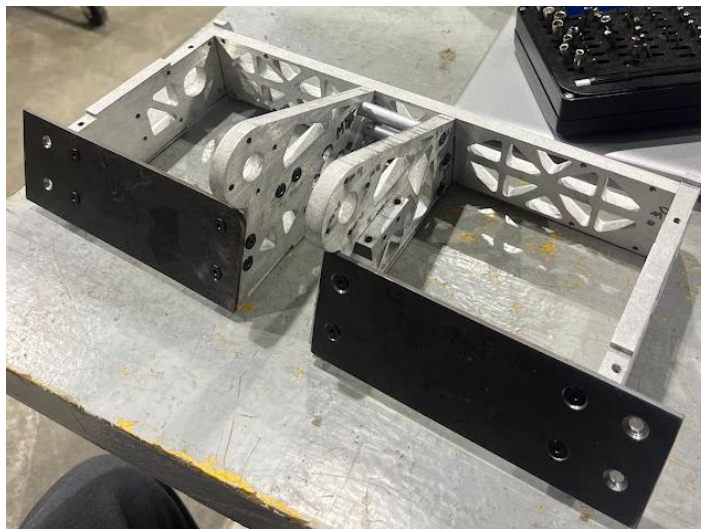


Figure 86: Frame Assembly

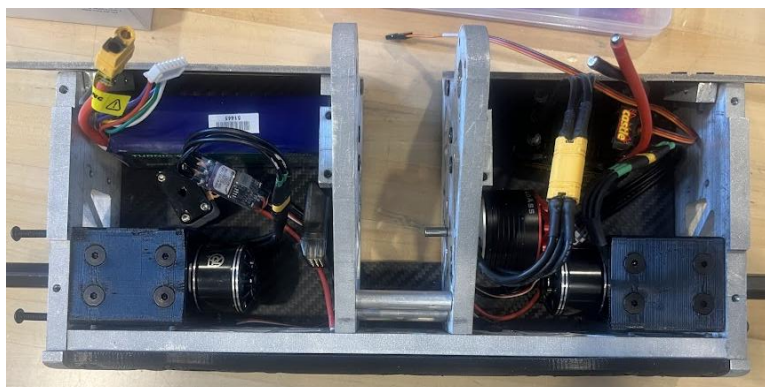


Figure 87: Electronics Assembly



Figure 88: Complete Frame Assembly



Figure 89: Fully Assembled Robot (NHRL Media Photo)

## 8. Testing and Competition

Our team's experience at the 2025 NHRL Open World Championship - Qualifier Round 3 in Norwalk, CT gave us a lot of valuable insight into how our bot performs in real competition.

In our first match against Torrent, we got our first experience fighting. Torrent did major damage within the first few moments, and we made the call to tap out early to avoid risking further harm that could hurt our chances in the actual qualifier rounds. It was a tough decision, but a strategic one.

Our second exhibition match was against Traiano, a bot from an MIT team. This time, things went in our favor. We landed a knockout win thanks to our powerful weapon system and smooth drive performance. Taking down a bot from a well-respected school like MIT gave us a confidence boost and confirmed our design choices.



Figure 90: La Machina vs Traiano

Our third scheduled fight was supposed to be against Carolina Reaper, but they forfeited before the match started, giving us a win by default. While we missed the chance to test our bot against a different opponent, the forfeit gave us a break to focus on repairs from the Torrent match and make sure we were ready for qualifiers.

Our final fight—the official qualifier match, was in the Round of 16 against Cherri, the 6th seed. Unfortunately, Cherri hit us with sustained, heavy damage that our bot couldn't recover from. The match ended in a technical knockout, and the damage was too extensive for us to continue. It was a tough way to go out, but it gave us a clear direction moving forward: we need to beef up our armor, strengthen the frame, and build in more redundancy to survive the high-level fights.



Figure 91: La Machina vs Cherri





Game History	
 vs Cherri TO - W 6th Seed Round of 16	 vs Carolina Reaper 0 - FF NP Seed Exhibition
 vs Traiano W - KO NP Seed Exhibition	 vs Torrent TO - W 4th Seed Exhibition

Figure 92: La Machina Fight Results

Overall, the event was a huge learning experience, and we left the event with a better understanding of what works—and what needs work—as we continue to improve our bot.

## 9. Project Management

### a. Team Members and Responsibilities

The team members of La Machina are John Gamble, Nguyen “Steven” Le, and Paul Jarvis, who are all Mechanical Engineering Technology students in their final year at the University of Cincinnati.

John Gamble is focused on the weapon and drive systems. He led the fabrication of weapon and drive components at the Victory Parkway Campus (VPC) and was responsible for creating all engineering drawings used during fabrication. John's contributions also include design and FEA analysis of the weapon and drive systems, programming electronics, and supporting the team's expo poster and video creation. His responsibilities span both design and hands-on build phases.

Nguyen “Steven” Le focuses on the frame and armor of La Machina. He managed the fabrication of the frame and armor at the VPC and coordinated 3D printing and waterjet jobs for armor and frame components at the 1819 Innovation Hub. In addition to designing and analyzing the chassis and armor systems, Steven also contributed to electronics programming and designed the team logo.

Paul Jarvis specializes in electronics and controls. He oversaw component manufacturing and was responsible for the wiring and integration of electronic systems across both the VPC and 1819 Hub. Paul managed the coding and electrical setup to ensure proper motor function, control system behavior, and effective integration with other subsystems.

All three members contributed to the robot’s electronics programming and maintained organized shared CAD folders in Fusion 360, the team’s primary design software. Steven led the CAD development for the entire bot, with support from John when needed, as John was primarily focused on project management tasks. Paul took the lead on fabrication, serving as the team’s manufacturing lead, ensuring high-quality execution of the physical build across all subsystems. While each member had a specialized focus, collaboration remained essential—each person contributed across disciplines to promote a deep understanding of the full robot system. Key design and integration decisions were made as a team to ensure seamless operation and performance.

Table 11: Team Members & Responsibilities

Team Member	Focus Area	Responsibility
John Gamble	Weapon & Drive Focus	<ul style="list-style-type: none"> <li>- Weapon design &amp; fabrication</li> <li>- Drive design &amp; fabrication</li> <li>- Created engineering drawings for fabrication</li> <li>- Expo poster &amp; video creation</li> <li>- Electronics programming</li> <li>- FEA analysis</li> </ul>
Nguyen “Steven” Le	Frame & Armor Focus	<ul style="list-style-type: none"> <li>- Frame design &amp; fabrication</li> <li>- Armor design &amp; fabrication</li> <li>- Submitted 3D printed armor and waterjet jobs</li> <li>- Electronics programming</li> <li>- Created team logo</li> </ul>
Paul Jarvis	Electronics & Controls Focus	<ul style="list-style-type: none"> <li>- Overall component manufacturing</li> <li>- Electronics &amp; wiring fabrication</li> <li>- Electronics programming</li> <li>- Manufacturing lead</li> </ul>

## b. Project Budget

### Proposed Project Budget

Table 12: Project Budget Overview

Total Budget	\$2000
Buffer for Errors	\$400 (20%)
Effective Working Budget	\$1600

The project will be entirely funded by the three members of Team La Machina. The total budget is set at \$2,000 and is divided into key categories: frame and armor, weapon system, drive system, electronics and controls, and miscellaneous items. To account for unexpected costs, we have allocated a critical 20% buffer (\$400) within the budget. This buffer is important for addressing potential design changes, part reorders due to failures or errors, and the purchase of additional materials to enhance the bot's durability and performance.

### Actual Budget

With the build now complete, the total cost of the robot—including all components, spares, and additional expenses—came out to \$1,691.52. This remained within our proposed budget, though it exceeded the base component cost of \$1,262 due to several necessary additions. Major costs included the weapon system (\$201.90), drive system (\$182.30), electronics (\$458.16), and frame (\$419.64). Additional expenses such as 3D printing, machining, taxes, and shipping fees accounted for the remaining balance. These costs were essential to the successful construction of the bot, particularly given the precision machining required for key components. The final cost per team member was \$563.84.

Table 13: Updated Budget

Link	Vendor	Price	Qty	Spares	Total	Total Without Spare
V-Belt - McMaster	McMaster-Carr	10.02	4	0	40.08	40.08
Needle Bearing Link - McMaster	McMaster-Carr	3.91	6	0	23.46	23.46
Thrust Washer Link - McMaster	McMaster-Carr	1.3	6	2	10.4	7.8
Driven Pulley - McMaster	McMaster-Carr	11.64	1	0	11.64	11.64
Driver Pulley - McMaster	McMaster-Carr	9.14	1	0	9.14	9.14
Steel Hex Head Screw - McMaster	McMaster-Carr	19.24	1	0	19.24	19.24
Weapon Shaft Locknut Link - McMaster	McMaster-Carr	6.26	1	0	6.26	6.26
M3x12 Screws - ACCU	ACCU	0.23	4	8	2.76	0.92
Needle-Roller Bearing - McMaster	McMaster-Carr	7.8	1	0	7.8	7.8
Ball Bearing - McMaster	McMaster-Carr	7.87	3	0	23.61	23.61
M5x30 Flat Head Screws - McMaster	McMaster-Carr	8.01	1	0	8.01	8.01
10"x10" AR500 Plate - Shapiro Metal Supply	SMS	39.5	1	0	39.5	39.5
12"x12" AR500 Sheet - McMaster	McMaster-Carr	80.82	1	0	80.82	80.82
					<b>Weapon Total \$ 282.72</b>	<b>\$ 278.28</b>
Gearbox & Drive Motor Link	Repeat Robotics	80	2	0	160	160
Wheel Hubs - BaneBots	BaneBots	4.5	2	0	9	9
Wheels - BaneBots	BaneBots	4.25	2	0	8.5	8.5
M4x18 Motor Mount Screws - ACCU	ACCU	0.2	8	16	4.8	1.6
					<b>Drive Total \$ 182.30</b>	<b>\$ 179.10</b>
Brushless Motor Link - Innovative	Innovative Designs	74.99	1	0	74.99	74.99
Turnigy nano-tech 1500mah 6S 65-130C Lipo Pack	Hobby King	20.23	1	0	20.23	20.23
ESC Link - Amazon	Amazon	62.99	1	0	62.99	62.99
Weapon ESC Link - Ebay	Ebay	109.95	1	0	109.95	109.95
Power Switch Link - Maximzmer	Maximzmer	40	1	0	40	40
Receiver & Controller Link	Amazon	150	1	0	150	150
					<b>Electronics Total \$ 458.16</b>	<b>\$ 458.16</b>
Multipurpose 6061 Aluminum - Same as 3/8" Plate	McMaster-Carr		6	4		0
Chassis Button Head Screws Link - McMaster-Carr	McMaster-Carr	12.91	1	0	12.91	12.91
M4x2mm Button Head Screws - ACCU	ACCU	0.15	8	4	1.8	1.2
5/16" Thin Hex Nuts - McMaster	McMaster-Carr	3.77	1	0	3.77	3.77
5/16"x5/8" Socket Head Screws - Monster Bolts	Monster Bolts	1.73	1	0	1.73	1.73
Bunny Ear Ball Bearing Link - McMaster	McMaster-Carr	15.53	2	2	62.12	31.06
8-32x3/4" Flat Head Screws - ACCU	ACCU	0.3	36	14	15	10.8
Nut Strip Button Heads - ACCU	ACCU	0.49	4	8	5.88	1.96
TPU Protection Screw Link - McMaster	McMaster-Carr	15.81	1	0	15.81	15.81
Aluminum Rod - McMaster	McMaster-Carr	2	1	0	2	2
CFRP Sheets Link - Hobby King	Hobby King	51.95	2	0	103.9	103.9
1/8" Aluminum Plate - McMaster-Carr	McMaster-Carr	20.51	1	0	20.51	20.51
3/8" Aluminum Plate - McMaster-Carr	McMaster-Carr	93.39	1	0	93.39	93.39
					<b>Frame Total \$ 338.82</b>	<b>\$ 299.04</b>
					<b>Bot Total \$ 1,262.00</b>	<b>\$ 1,214.58</b>
\$	1,262.00					
\$	738.00					



## 10. Conclusion and Future Improvement

### *Switch to a Single Timing Belt System*

During testing at the NHRL competition, the V-belt system was troublesome because tolerances in the manufacture were inconsistent, making sizing tricky. The V-belts were bulky, and on fight day, it was slow and frustrating getting it attached to the weapon stack. Moving forward, we suggest moving to a single timing belt system. Timing belts have a precise fit, are simpler to size, and are thinner, making them less complicated. This would make assembly easier, reduce reliability concerns, and minimize technical difficulties at important times such as fight day.

### *Upgrade to BLHeli-32 Compatible ESCs*

The existing electronic speed controllers (ESCs) that our team bought were not compatible with stock BLHeliSuite32 software. It took our team several hours to discover alternative test software to view settings. This added considerable setup and tuning time. Moving forward, we suggest an upgrade to fully compatible ESCs with BLHeli-32. This would have saved our team a ton of time that we could have used to fine tune the settings.

### *Utilize TPU Covers and Mounts for Electronics*

Our first try at using individual inserts for mounting electronics didn't really work out—tolerances and wiring weren't considered, so they ended up being unusable and we had to scrap the idea. To fix that, we're recommending a single TPU floor insert instead. TPU is flexible enough to handle wiring and tolerance issues, plus it offers solid, lightweight protection. This one-piece solution also makes assembly way easier, and it's worked well for other battlebot teams. In theory, having a separate insert for each component could work, but it'd be a pain to design and build all of them.

### *Improve Manufacturability and Account for Tolerances*

The production process for this robot was laborious, with tolerances not properly addressed in the design phase. The assembly was very difficult, involving adjustments such as clearance holes once parts had been waterjet cut. To resolve this, we suggest that parts should be designed with tolerances incorporated into them, such as slotted holes or adjustable mounts to simplify assembly. The design should also be simplified to minimize the number of components with high precision requirements to expedite manufacturing and assembly, saving time and minimizing mistakes during build.

### *Conclusion*

La Machina reflects the relentless problem-solving, resilience, and teamwork in the face of adversity. Throughout the project, we encountered a multitude of design reiterations, unforeseen fitment issues, and tight timelines. Through all of these challenges, however, there remained a consistent and steadfast commitment from the team to deliver a working and competitive robot.

Many of the things we assumed were going to happen in the early stages were proved wrong in fabrication and assembly, and we were pushed to get creative and make decisions in a hurry. We redrafted parts, tightened tolerances, and optimized layouts in real time—all while keeping the project on deadline. Those situations demanded effective communication and hands-on problem-solving in the moment.

The best aspect of La Machina's success was the level of dedication of all team members. Every member of the team brought something unique to the table to enhance the success of the project, whether in CAD design, machine work, wiring, or testing. Hours of late nights redrawing designs, working long hours in the machine shop, and weekends trying to get things to work were all a regular occurrence. It was all a team effort that played a very significant role in building a dependable and competitive robot.

Through adaptability and functioning together as a team, we managed to finish La Machina and compete successfully at NHRL on April 5th. The robot performed as expected in combat and showed the durability and capability we aimed to attain. This project in the end reaffirmed the importance of iteration, planning, and engineering in the real world.

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## 12. Appendices

### a. NHRL Rules – 2025 (30)

#### Weight Classes

NHRL offers three weight classes: 3lb, 12lb, and 30lb. Robots must not exceed the maximum weight for their class at the start of a fight. Weight bonuses and exemptions may apply under certain conditions. The total weight of a robot, including bonuses, must not exceed  $1\frac{2}{3}$  times the base weight limit.

Weight bonuses are summarized in the following table:

Weight Class	Non-Traditional Locomotion Bonus	Multibot Bonus	Maximum Bot Weight
3lb	+1.5 lbs	+1 lb	5 lbs
12lb	+6 lbs	+3 lbs	20 lbs
30lb	+15 lbs	+12 lbs	50 lbs

NHRL has sole discretion in awarding bonuses.

#### Non-Traditional Locomotion Bonus

Robots that do not use traditional motion systems—such as wheels, tracks, or treads—may qualify for this bonus. This includes robots that use alternative methods of locomotion, like walking mechanisms or other innovative systems.

#### Multibot Bonus

Robots composed of multiple independent components (multibots) may qualify for this bonus. Each component must have independent control and be capable of influencing the fight. At least 51% of the total weight must be allocated to components with active weapons. The heaviest component of a multibot must not exceed 110% of the base weight limit for its class.

#### Weight Exemptions

- Flamethrower bots are weighed without fuel.
- Pneumatic and ICE systems have tanks removed for weigh-in.
- Hydraulic systems must declare fluid weight in advance; this weight is subtracted during weigh-in.
- Active cameras or recording equipment do not count toward robot weight but must be approved during inspection.

#### Size Requirements

- 3lb robots must fit within a 30 x 30 x 24-inch box.
- 12lb and 30lb robots must fit within a 36 x 36 x 36-inch box.
- Multibots must fit within the size limit collectively.
- Robots may expand or contract after the match begins.

#### Batteries and Power

- Robots must have an easily accessible master power cutoff, such as a switch or removable link, deactivatable within 15 seconds.
- Nominal battery voltage must not exceed 60V for 3lb bots and 75V for 12lb and 30lb bots.

- Systems producing voltages above these limits require prior NHRL approval.

### Robot Control Systems

- Control systems must pass a failsafe test: drive systems must stop within 30 seconds, and weapons within 60 seconds, upon signal loss.
- Each robot or multibot component must have a dedicated receiver.
- Autonomous robots must have a radio control module to activate/deactivate the robot remotely.

### Weapons

All robots must have an active weapon, defined as a mechanism operating independently from the drivetrain and designed to influence the opponent. In multibots, at least 51% of the weight must be on components with active weapons.

Exceptions include:

- "Mellybrains" and "Gyro Walkers" are exempt from the active weapon requirement.
- "Thwackbots" do not qualify as having an active weapon.

NHRL encourages competitors to consult with staff regarding unconventional weapon designs.

### Specific Weapon Classifications

- **Flame and Heat-Based Weapons:** Allowed with restrictions. Robots must self-light and self-extinguish. In case of signal loss, flames must extinguish within 30 seconds. Fuel limits are 6 ounces for 3lb bots and 16 ounces for 12lb and 30lb bots.
- **Internal Combustion Engines:** Allowed; must be started safely and not cause movement upon ignition.
- **Projectile Weapons:** Allowed with a maximum projectile speed of 300 mph. Tethered projectiles must not entangle opponents. Ramset charges and similar devices are prohibited.
- **Inductive Systems:** Allowed for self-heating purposes only; must not interfere with opponent's electronics or arena systems.
- **Magnetic Systems:** Externally mounted magnets intended to adhere to opponents are prohibited. Other magnetic systems require NHRL approval.
- **Other Restricted Systems:** Pneumatic and hydraulic systems, as well as components exceeding 300 mph, require prior NHRL approval.

### Weapon Locks

All weapons must have locks to prevent movement or activation outside of matches. Locks must not require placing fingers in the path of the weapon.

### Other Design Restrictions

- **Drones:** Allowed if compliant with FAA regulations and other design rules.
- **Entanglement Devices:** Prohibited.
- **Ablative Armor:** Allowed if not likely to cause entanglement.
- **Expelled Liquids:** Prohibited, except for bubbles or substances that become gaseous before contact.
- **Pneumatics, Hydraulics, Airbags:** Allowed with prior NHRL approval.

### **The NHRL Design Approval Process**

Designs involving restricted features must be approved by NHRL Safety Staff at least three weeks before the competition. Submit design details to [safety@nhrl.io](mailto:safety@nhrl.io) for review.

### **Spare Robots and Batteries**

Competitors may bring multiple copies of their robot, provided they are nearly identical and pass inspection. Spare robots must be compatible with all modular systems and armor configurations.



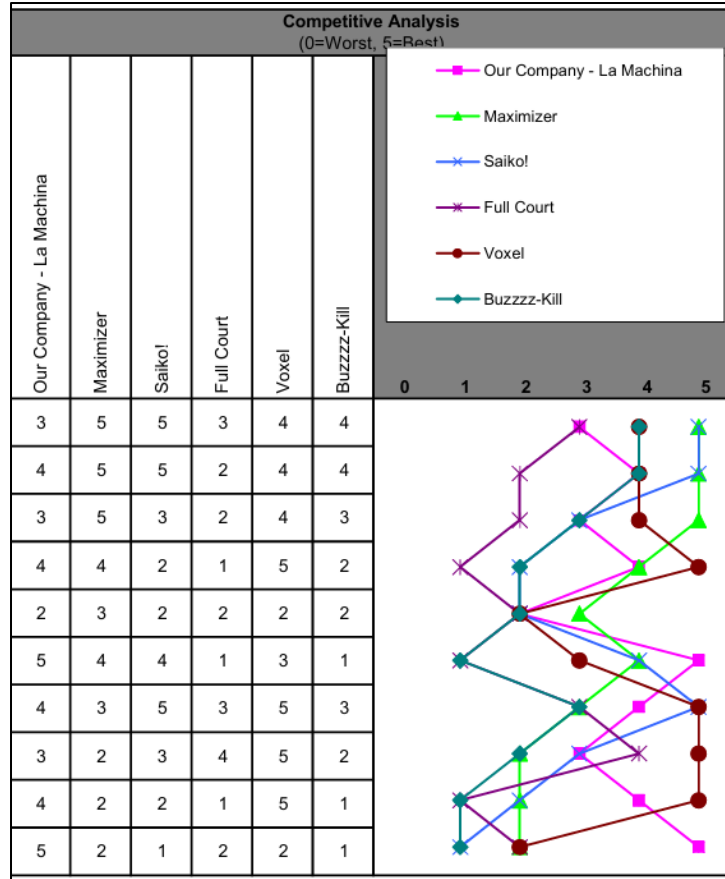


Figure 95: HOQ Room 5, Benchmark Satisfaction

### c. Survey Questions

#### Battle Bot Feature Survey (La Machina: John, Paul, and Steven)

Hey there! We need your help to make our battle bot design the best it can be. Your feedback will guide us in building a better bot, so please take a few minutes to answer the following questions based on your experience and what you think is most important.

1. Importance of Battle Bot Features: Rate how important the following features are to you when it comes to a battle bot. Use a scale from 1-10, with 1 being "Not Important" and 10 being "Extremely Important."

- Damage Delivery
- Weapon Durability
- Weapon Effectiveness
- Maneuverability
- Safety Features
- Maintenance & Repairability
- Traction
- Wheel Protection
- Total Cost
- Ease of Use
- Weapon Design
- Weapon Size
- Weapon Motor Speed
- Total Weight
- Interesting Design

2. Feature Preferences: For each pair of features, pick which one you think is more important for a successful battle bot.

- Damage Delivery vs. Maneuverability
- Weapon Durability vs. Ease of Use
- Weapon Effectiveness vs. Total Cost
- Safety Features vs. Cool Design
- Maintenance & Repairability vs. Weapon Size
- Visual Appearance vs. Total Weight
- Traction vs. Weapon Motor Speed
- Wheel Protection vs. Maneuverability

3. Short Answer Questions - We'd love to hear your thoughts! Please answer the following: In your opinion, what's the most important feature for a battle bot?

- Describe a feature that's often overlooked but is super important.
- If you could improve one thing about battle bots, what would it be?
- How does a battle bot's visual design affect how strong or effective you think it is?

4. Additional Comments: Anything else you'd like to share about what makes a battle bot great in competition. Let us know!

## d. Calculations and Analysis

### Weapon Performance

Motor KV	970 KV	Battery Voltage	Throttle 0-1
Voltage	22.2 Volts	22.2	1
Driven Gear Dia	3 any unit		
Driving Gear Dia	2 any unit		
Diameter	4.834 in		
Weapon RPM	14356 rpm		
Weapon Deg/s	86136 Deg/s		
rad/sec	1503.356804 Rad/s		
tip speed	206.4553066 mph		
MOI Weapon	1853000 g/mm <sup>2</sup>		
MOI Weapon	0.001853 kg/m <sup>2</sup>		
Weapon Energy	2094.0 J		
Weapon Energy	2.09 KJ		

Figure 96: Weapon Performance Calculator

### *Inputs*

$$\text{Battery Voltage} = 6s \text{ Lipo Voltage} = 22.2 V$$

$$\text{Weapon Diameter} = 4.834 \text{ in}$$

$$\text{Weapon MOI} = 1853000 \text{ gmm}^2 = 0.001853 \text{ kgm}^2$$

$$\text{Driven Pulley Dia} = 3 \text{ in}$$

$$\text{Driver Pulley Dia} = 2 \text{ in}$$

$$\text{Pulley Ratio} = \frac{\text{Driven}}{\text{Driver}} = \frac{3}{2} = 1.5$$

### *Motor RPM*

$$\text{Motor RPM} = \text{KV} * \text{Voltage} = 970 * 22.2 = \mathbf{21,534 RPM}$$

### *Weapon RPM*

$$\text{Weapon RPM} = \frac{\text{Motor RPM}}{\text{Pulley Ratio}} = \frac{21,534}{1.5} = \mathbf{14,356 RPM}$$

### *Weapon Angular Speed*

- *Deg/s:*

$$= 14,356 * 6 = \mathbf{86,136 \text{ deg/s}}$$

- *Rad/s:*

$$= 86,136 * \left(\frac{\pi}{180}\right) \approx \mathbf{1503.36 \text{ rad/s}}$$

### *Tip Speed*

$$\text{Tip Speed (mph)} = (124.834) * \pi * 14,356 * (52801) * 60 \approx \mathbf{206.46 \text{ mph}}$$

*Weapon Energy*

$$\begin{aligned} \text{Weapon Energy} &= (0.5) * (\text{Weapon MOI}) * \left(\text{Weapon} \frac{\text{Rad}}{\text{s}}\right)^2 \\ &= (0.5) * (0.001853 \text{ kgm}^2) * \left(1503.36 \frac{\text{rad}}{\text{s}}\right)^2 \approx \mathbf{2094 \text{ J}} \end{aligned}$$

*Minimum Motor Wattage*

$$\text{Minimum Motor Wattage} = \frac{\text{Weapon Energy}}{\text{Spin up time}} = \frac{2094 \text{ J}}{0.9\text{s}} \approx \mathbf{2,327 \text{ W}}$$

*Drive Performance*

Table 17: Drive Inputs

Component	Value
<b>Battery</b>	6S LiPo = 22.2 V nominal
<b>Drive Motor KV</b>	1400 KV
<b>Gear Ratio</b>	19:1
<b>Wheel Diameter</b>	3.875 in
<b>Arena Travel Distance</b>	16 ft
<b>Target Time</b>	1.5 seconds

*Required Drivetrain Speed to cross 16 ft in 1.5 seconds:*

$$\text{Speed} = \frac{16 \text{ ft}}{1.5 \text{ s}} = 10.67 \frac{\text{ft}}{\text{s}} \approx \mathbf{7.3 \text{ mph}}$$

*Required Wheel RPM*

$$\text{Wheel Circumference} = \pi * 3.875 \text{ in} = 12.17 \text{ in} = \mathbf{1.014 \text{ ft}}$$

$$\text{RPS} = \frac{10.67 \text{ ft/s}}{1.014 \text{ ft/rev}} = 10.52 \frac{\text{rev}}{\text{s}} \rightarrow \text{RPM} = 10.52 * 60 = \mathbf{631.3 \text{ RPM}}$$

*Required Motor RPM*

$$\text{Motor RPM} = \text{Wheel RPM} * \text{Gear Ratio} = 631.3 * 19 = \mathbf{11,995 \text{ RPM}}$$

*Minimum Motor KV Required*

$$\text{KV Required} = \frac{11,995 \text{ RPM}}{22.2 \text{ V}} = \mathbf{540 \text{ KV}}$$

Table 18: Drive Required vs Actual

Parameter	Required	Actual
<b>Motor KV</b>	540 KV	1400 KV ✓
<b>Gear Ratio</b>	19:1	19:1 ✓
<b>Motor RPM Available</b>	1400 × 22.2 = 31,080 RPM	Required = 11,995 ✓
<b>Drivetrain Speed</b>	~7.3 mph target	Available speed is much higher

*Maximum Speed*

Given motor RPM = 31,080

Wheel RPM (after 19:1 reduction) =  $31,080 / 19 = 1,636$  RPM

$$\text{Wheel RPS} = \frac{1636}{60} = 27.27 \frac{\text{rev}}{\text{s}} \rightarrow \text{Speed} = 27.27 * 1.014 \text{ ft} = 27.65 \frac{\text{ft}}{\text{s}} \approx 18.85 \text{ mph}$$

*Final Outputs:*

- Required Drivetrain Speed: 7.3 mph
- Required Wheel RPM: 631
- Required Motor RPM: ~12,000
- Required Motor KV: 540 KV
- Actual KV: 1400 KV
- Max Speed: ~18.85 mph

**e. BOM and Cost**

**Estimated BOM & Total Cost:**

*Weapon System:*

Part	Link	Vendor	Price	Qty	Spares	Total	Total Without Spare		
<b>Weapon System</b>									
V-Belt	<a href="#">V-Belt - McMaster</a>	McMaster-Carr	10.02	4	0	40.08	40.08		
Needle-Roller Thrust Bearings	<a href="#">Needle Bearing Link - McMaster</a>	McMaster-Carr	3.91	6	0	23.46	23.46		
Thrust Washers	<a href="#">Thrust Washer Link - McMaster</a>	McMaster-Carr	1.3	6	2	10.4	7.8		
Driven Pulley	<a href="#">Driven Pulley - McMaster</a>	McMaster-Carr	11.64	1	0	11.64	11.64		
Driver Pulley	<a href="#">Driver Pulley - McMaster</a>	McMaster-Carr	9.14	1	0	9.14	9.14		
Weapon Shaft	<a href="#">Steel Hex Head Screw - McMaster</a>	McMaster-Carr	19.24	1	0	19.24	19.24		
Shaft Locknut	<a href="#">Weapon Shaft Locknut Link - McMaster</a>	McMaster-Carr	6.26	1	0	6.26	6.26		
Weapon Motor Mounting Screws	<a href="#">M3x12 Screws - ACCU</a>	ACCU	0.23	4	8	2.76	0.92		
Needle-Roller Bearing	<a href="#">Needle-Roller Bearing - McMaster</a>	McMaster-Carr	7.8	1	0	7.8	7.8		
Ball Bearing	<a href="#">Ball Bearing - McMaster</a>	McMaster-Carr	7.87	3	0	23.61	23.61		
M5x30 Flat Head Screws	<a href="#">M5x30 Flat Head Screws - McMaster</a>	McMaster-Carr	8.01	1	0	8.01	8.01		
3/8" Thick AR 500	<a href="#">10"x10" AR500 Plate - Shapiro Metal Supply</a>	SMS	39.5	1	0	39.5	39.5		
						<b>Weapon Total: \$</b>	<b>201.90</b>	<b>\$</b>	<b>197.46</b>

*Drive System:*

<b>Drive System</b>									
Gearbox & Drive Motors	<a href="#">Gearbox &amp; Drive Motor Link</a>	Repeat Robotics	80	2	0	160	160		
Wheel Hub	<a href="#">Wheel Hubs - BaneBots</a>	BaneBots	4.5	2	0	9	9		
Wheels	<a href="#">Wheels - BaneBots</a>	BaneBots	4.25	2	0	8.5	8.5		
Motor Mount Screws	<a href="#">M4x18 Motor Mount Screws - ACCU</a>	ACCU	0.2	8	16	4.8	1.6		
						<b>Drive Total: \$</b>	<b>182.30</b>	<b>\$</b>	<b>179.10</b>

*Electronics System:*

<b>Electronics</b>									
BA 3520 970 KV	<a href="#">Brushless Motor Link - Innov8tive</a>	Innov8tive Design	74.99	1	0	74.99	74.99		
Battery	<a href="#">Turnigy nano-tech 1550mah 6S 65-</a>	Hobby King	20.23	1	0	20.23	20.23		
Default ESC	<a href="#">ESC Link - Amazon</a>	Amazon	62.99	1	0	62.99	62.99		
Castle Sidewinder 8th	<a href="#">Weapon ESC Link - Ebay</a>	Ebay	109.95	1	0	109.95	109.95		
Kake Switch	<a href="#">Power Switch Link - Maximizer</a>	Maximizermerch	40	1	0	40	40		
ar410 & controller	<a href="#">Receiver &amp; Controller Link</a>	Amazon	150	1	0	150	150		
						<b>Electronics Total: \$</b>	<b>458.16</b>	<b>\$</b>	<b>458.16</b>

*Frame and Armor System:*

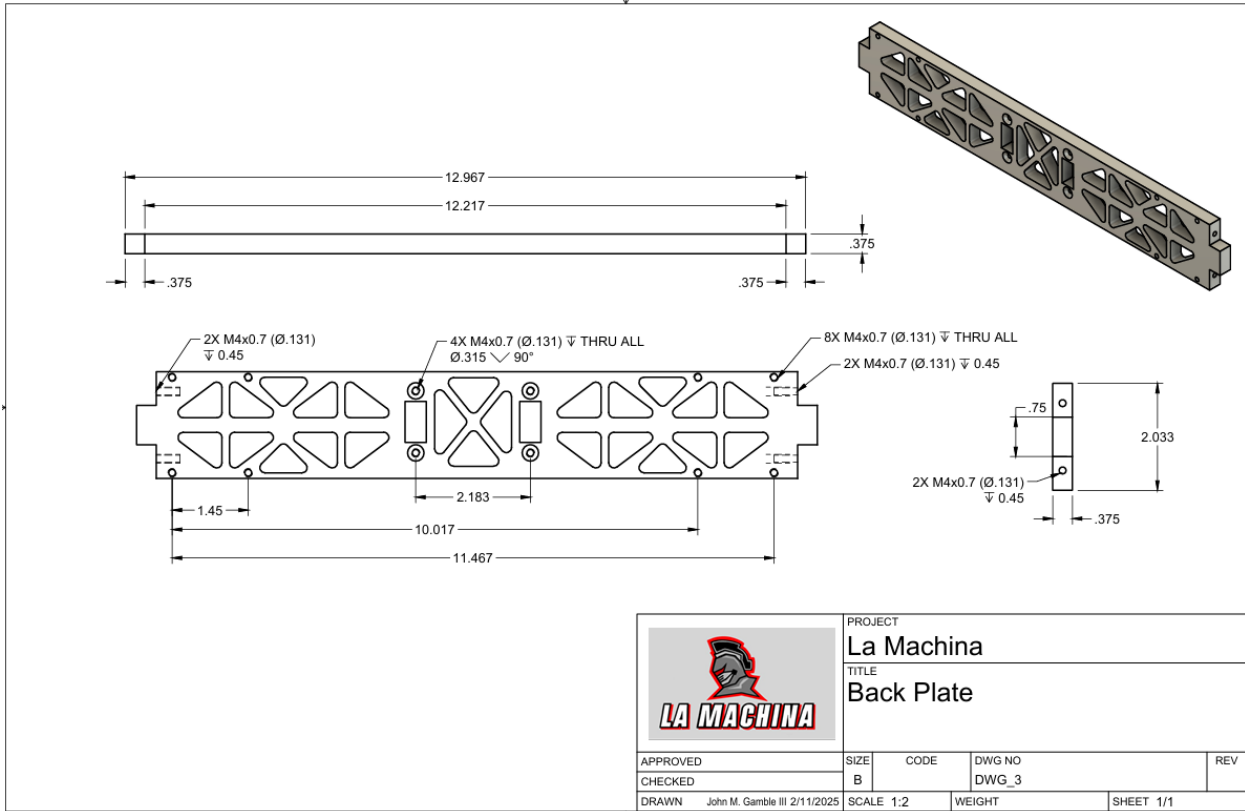
<b>Frame and Armor System</b>									
Nut Strips (4x4)	<a href="#">Multipurpose 6061 Aluminum - Same as 3/8" Plate</a>	McMaster-Carr		6	4		0		
Chassis Button Head Screws	<a href="#">Chassis Button Head Screws Link - McMaster-Carr</a>	McMaster-Carr	12.91	1	0	12.91	12.91		
Bunny Ear Screws	<a href="#">M4x12mm Button Head Screws - ACCU</a>	ACCU	0.15	8	4	1.8	1.2		
Bunny Ear Bearing Hex Nuts	<a href="#">5/16" Thin Hex Nuts - McMaster</a>	McMaster-Carr	3.77	1	0	3.77	3.77		
Bunny Ear Bearing Screws (10 Pack)	<a href="#">5/16"x5/8" Socket Head Screws - Monster Bolts</a>	Monster Bolts	1.73	1	0	1.73	1.73		
Bunny Ear Ball Bearings	<a href="#">Bunny Ear Ball Bearing Link - McMaster</a>	McMaster-Carr	15.53	2	2	62.12	31.06		
Nut Strip/Support Shaft Flat Head Screws	<a href="#">8-32 x 3/4" Flat Head Screws - ACCU</a>	ACCU	0.3	36	14	15	10.8		
Nut Strip Button Head Screws	<a href="#">Nut Strip Button Heads - ACCU</a>	ACCU	0.49	4	8	5.88	1.96		
TPU Protection Screws	<a href="#">TPU Protection Screw Link - McMaster</a>	McMaster-Carr	15.81	1	0	15.81	15.81		
Aluminum Support Shafts	<a href="#">Aluminum Rod - McMaster</a>	McMaster-Carr	2	1	0	2	2		
CFRP (3mm x 400mm x 300mm)	<a href="#">CFRP Sheets Link - Hobby King</a>	Hobby King	51.95	2	0	103.9	103.9		
ALUMINUM 6061	<a href="#">1/8" Aluminum Plate - McMaster-Carr</a>	McMaster-Carr	20.51	1	0	20.51	20.51		
	<a href="#">3/8" Aluminum Plate - McMaster-Carr</a>	McMaster-Carr	93.39	1	0	93.39	93.39		
1/8" Thick AR 500	<a href="#">12"x12" AR500 Sheet - McMaster</a>	McMaster-Carr	80.82	1	0	80.82	80.82		
						<b>Frame Total: \$</b>	<b>419.64</b>	<b>\$</b>	<b>379.86</b>

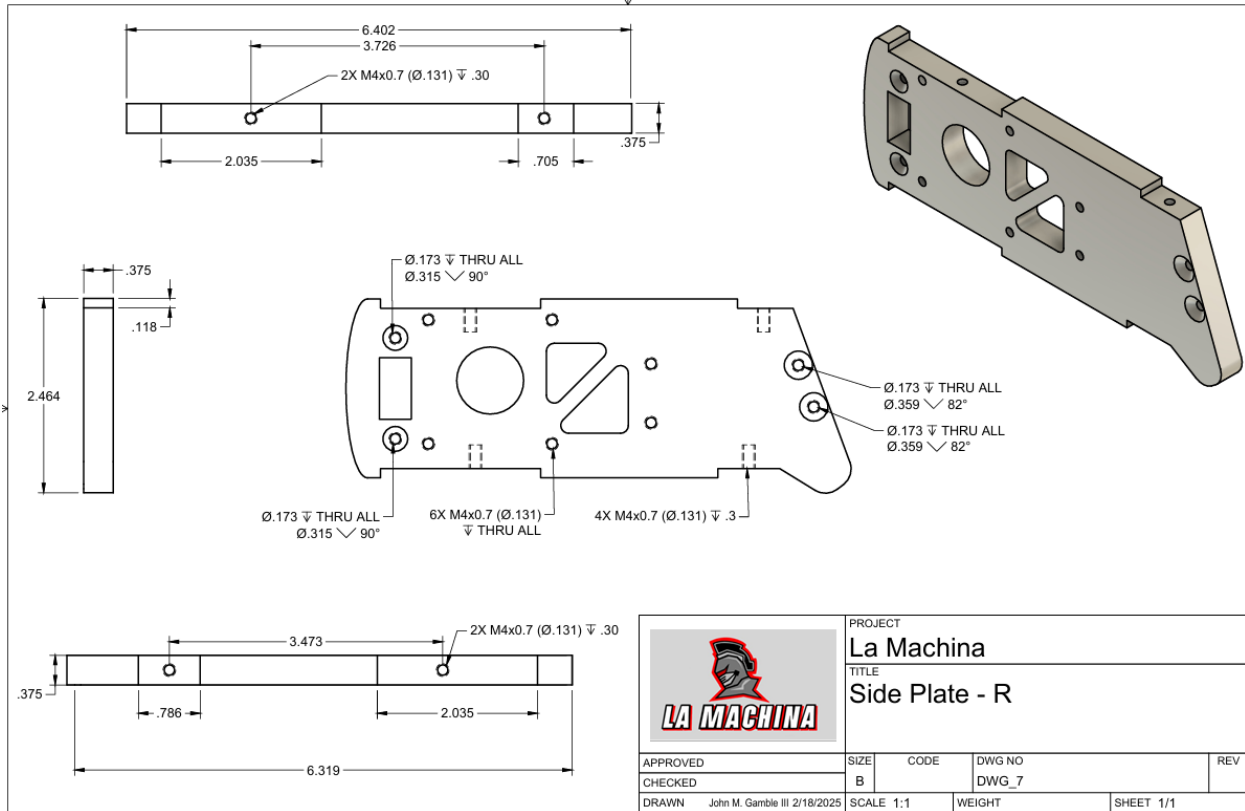
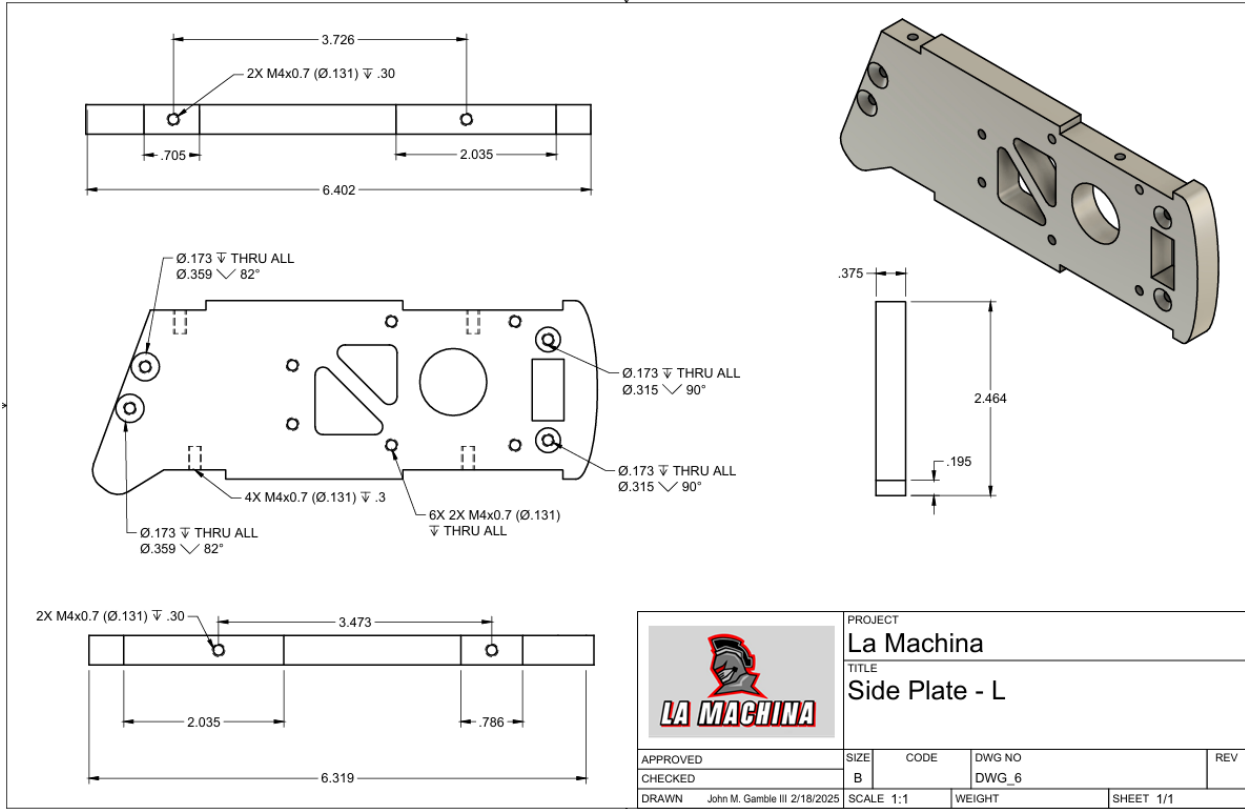
**Total Cost After Non-BOM Transactions (Shipping, Taxes, Machining – e.g., 3D Printing, Waterjet):**

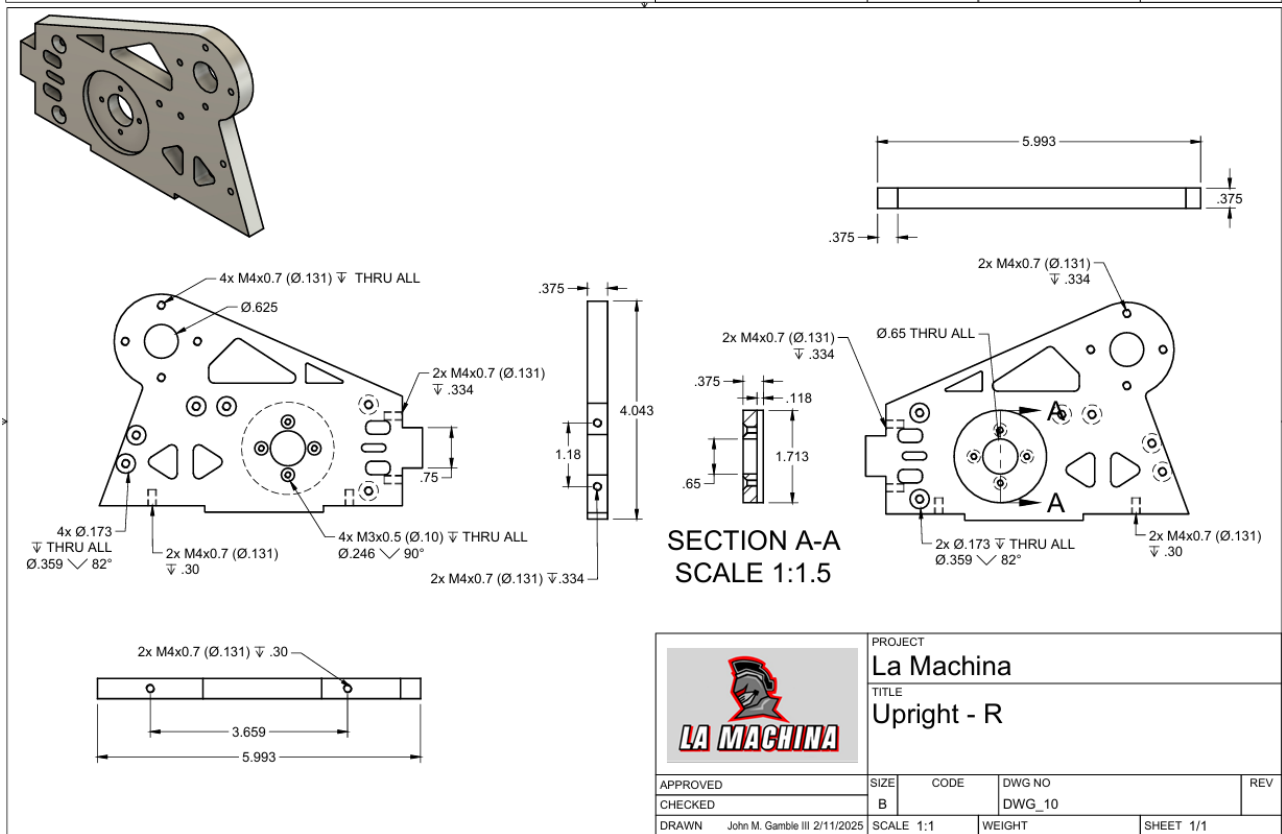
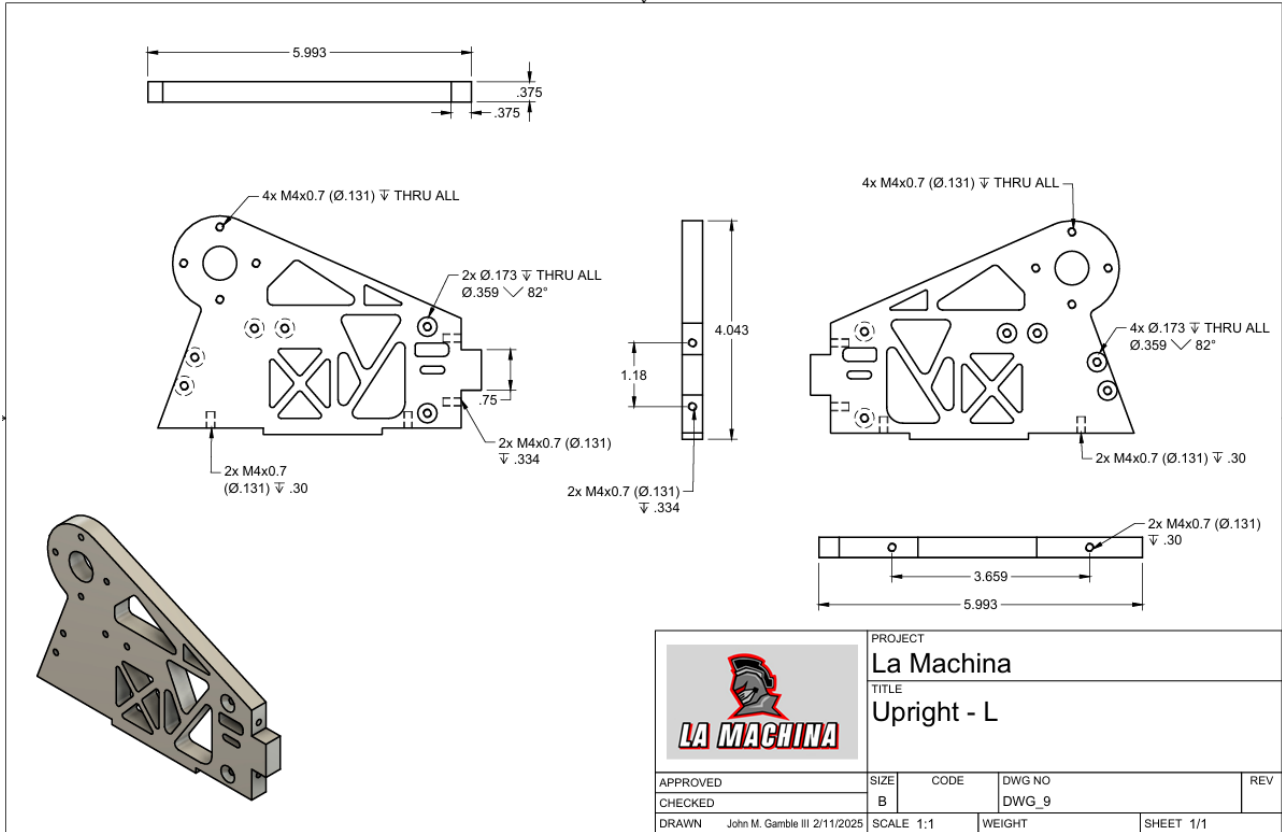
Order Date	Qty	Company	Total Price	Total Spent
1/16/2025	19	McMaster-Carr	477.96	1691.52
1/16/2025	110	ACCU	51.81	
1/16/2025	1	Moster Bolts	6.8	
1/16/2025	1	Kake Switch	45.9	
1/16/2025	1	SMS	76.29	
1/16/2025	4	Hobby King	113.73	
1/23/2025	2	Repeat Robotics	160	
1/23/2025	4	BaneBots	27.3	
1/23/2025	1	Innov8tive Designs	80.98	
1/23/2025	2	Amazon	229.59	
1/23/2025	1	Ebay	118.53	
2/7/2025	2	McMaster-Carr	43.92	
2/13/2025	2	1819 (3d print)	144.54	
3/6/2025	3	1819 (water jet)	36	
3/6/2025	1	1819 (water jet)	24	
3/9/2025	1	Amazon	30.17	
3/10/2025	1	1819 (water jet)	12	
3/25/2025	1	1819 (water jet)	12	

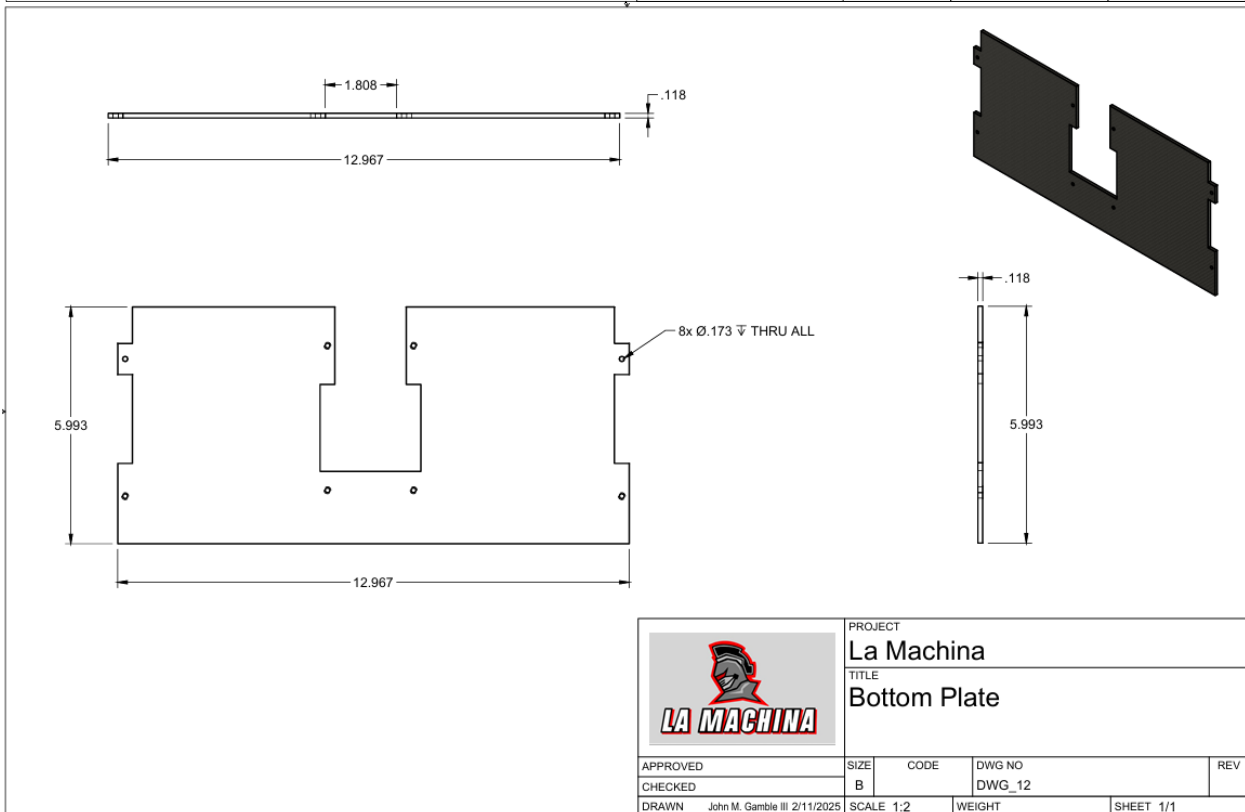
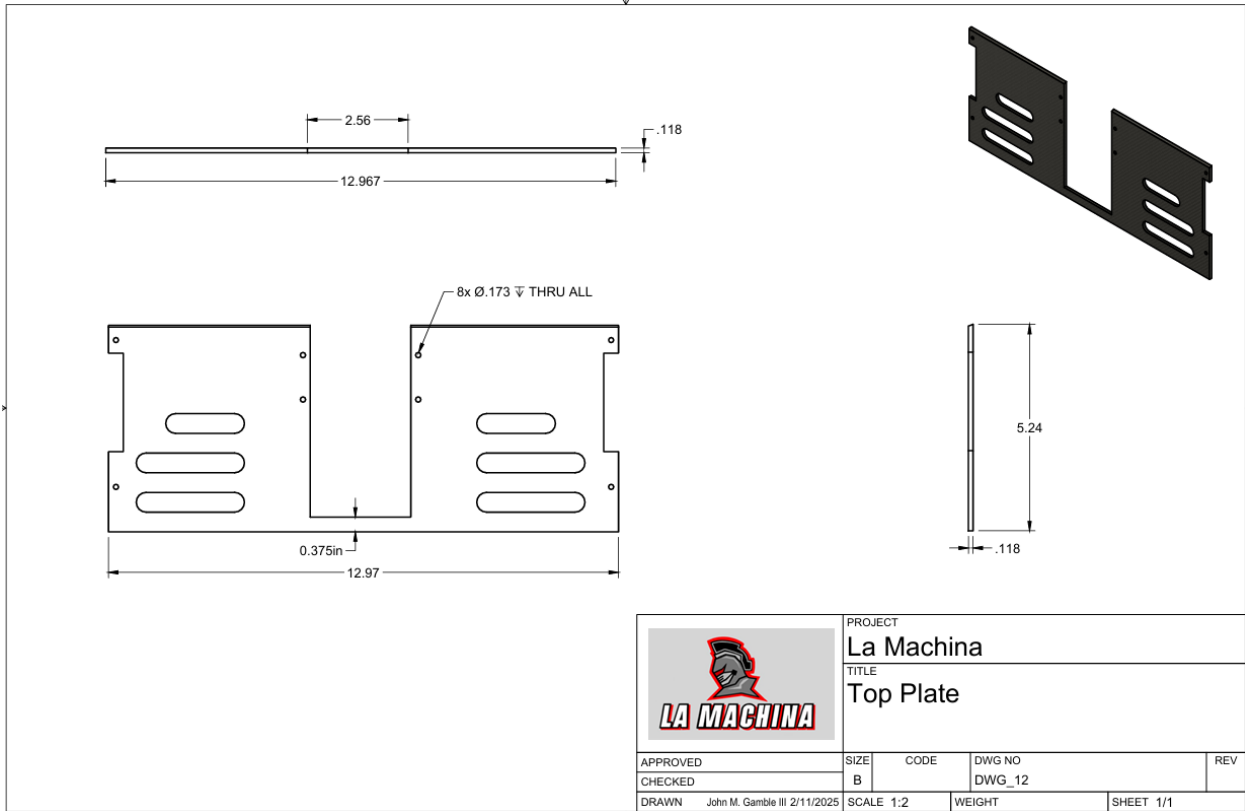
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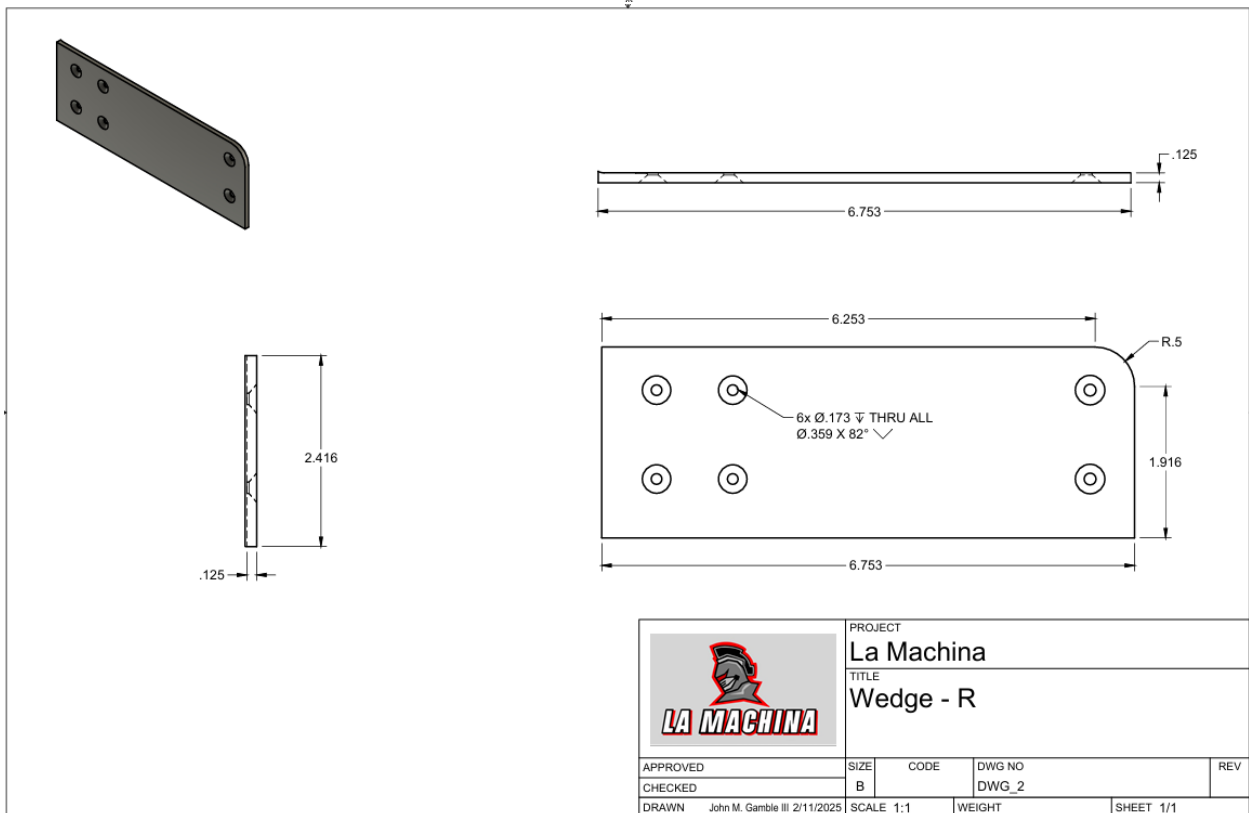
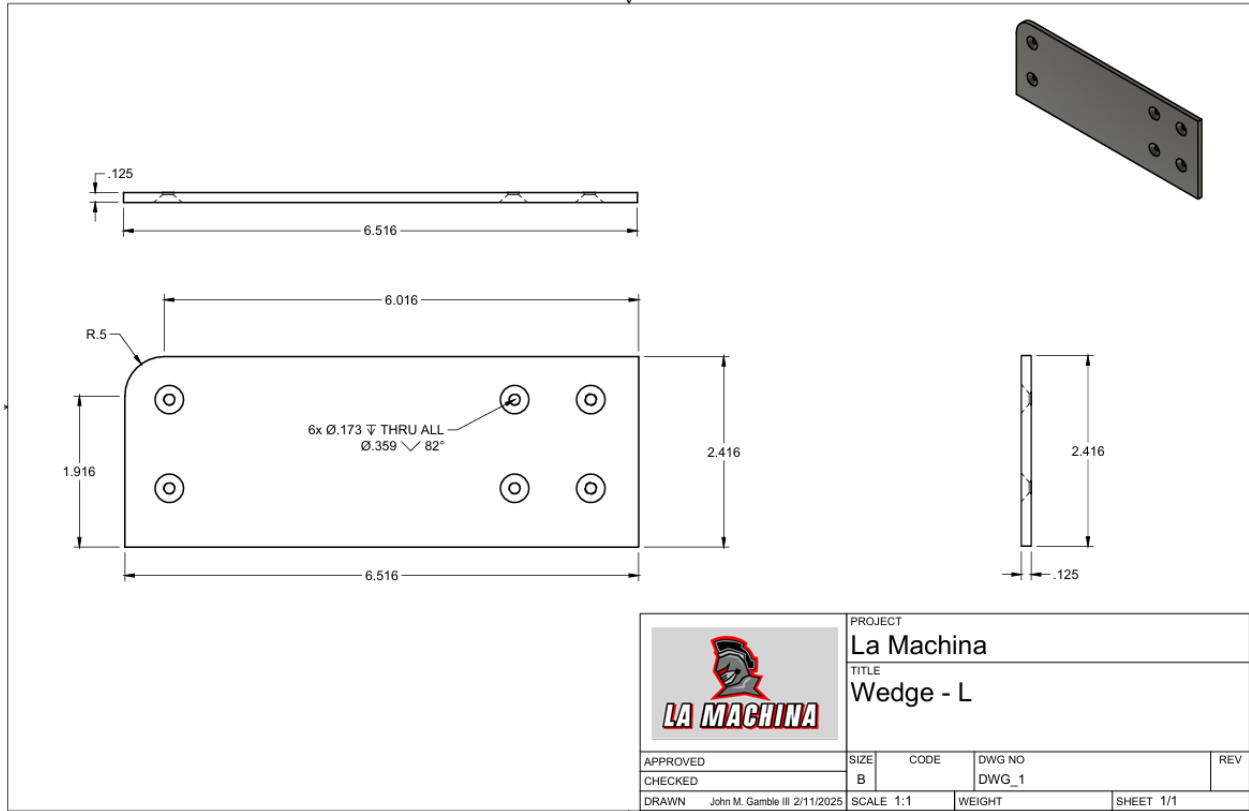
Frame & Armor:

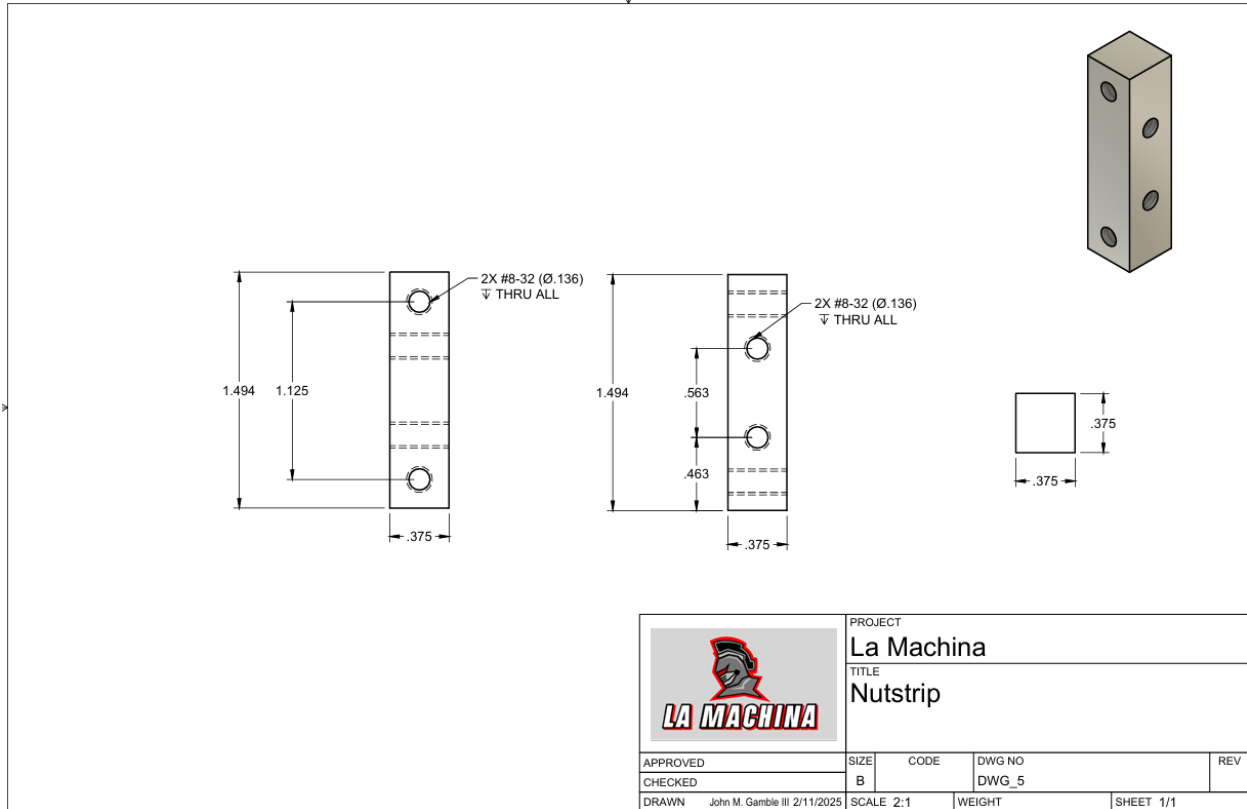
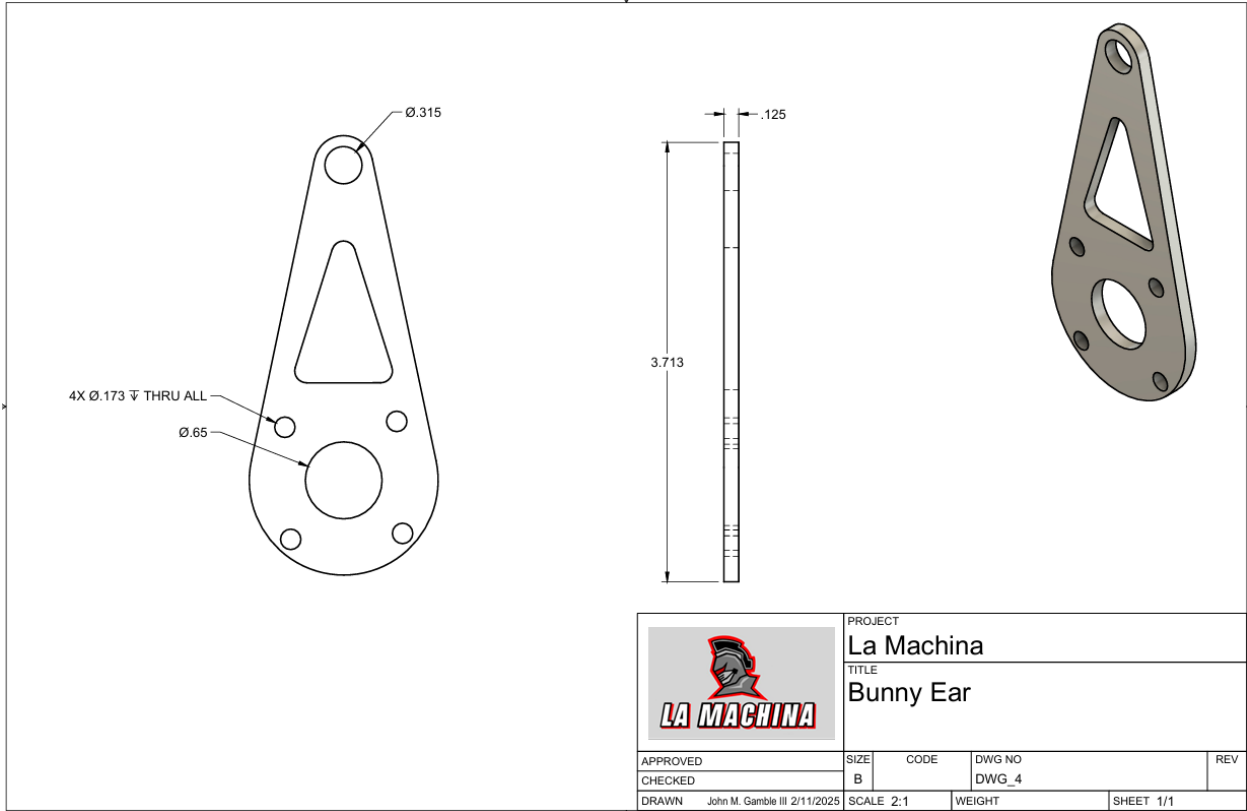












		PROJECT		
		La Machina		
		TITLE		
		Support Shaft		
APPROVED	SIZE	CODE	DWG NO	REV
CHECKED	B		DWG_8	
DRAWN	John M. Gamble III 2/11/2025	SCALE 5:1	WEIGHT	SHEET 1/1

Weapon:

		PROJECT		
		La Machina		
		TITLE		
		Weapon Disc		
APPROVED	SIZE	CODE	DWG NO	REV
CHECKED	B		DWG_16	
DRAWN	John M. Gamble III 2/11/2025	SCALE 1:1	WEIGHT	SHEET 1/1

