Final Report: BattleBot - BattleDuck

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Table of Contents

Chapter 1: Proposal

I. Introduction

The Battlebots competition has grown in popularity over recent years, as competitors have designed hundreds of combat robots in multiple weight classes. This semester, we have been tasked with designing and building a 3 lb battlebot that emphasizes durability, mobility, damage, safety, and cost. To create this battlebot, we will conduct research on existing battlebots to compile the most important features for our battlebot, assemble our customer needs into a House of Quality, create a list of engineering specifications, and design a Gantt chart to lay out a timeline for the project.

II. Background Research

For our research, we gathered information on the judging guidelines, construction specifications, existing battlebots, electronics, gear ratios, and interviews with experts to learn different strategies and builds commonly used.

An important part of our background research was gathering information from the SPARC Judging Guidelines and the SPARC Robot Construction Specifications. We learned that battlebots are judged on 3 categories: damage, control, and aggression (*SPARC Judging Guidelines v1.1*, 2015). The damage category awards points based on the relative amount of damage dealt by each robot that affects their opponent's functionality, control is based on the relative amount of time each robot spends in control of the fight, and aggression is the relative amount of time spent attacking the opponent. The battlebot that obtains the most points wins the battle. Along with the judging criteria, safety is another important category to consider when designing a battlebot. The construction specifications included many safety specifications, such as fail-safe mechanisms, power indicators, grounding, manual disconnects, and visible locking devices. Including these features in our battlebot is integral to ensuring the safety and success of our design.

As part of our background research, we looked into the documentation of other battlebots, hoping to learn from their successes and failures. One of the most important aspects is the weapon assembly on a robot, and we realized there are multiple weapon types. We explored the most common weapons- vertical and horizontal spinners, ring spinners, and lifters, outlining the advantages and disadvantages of each *(Garnache, 2022)*. The most feasible weapon given the time frame is the spinners. Overall, spinners are great for beginners as they are easier to design for, especially with electronics, and have a fairly high damage output *(Garnache, 2022)*. The main difference between the horizontal and vertical spinner is that a horizontal spinner must extend out to avoid hitting itself with its weapon (*3LB Beginner's Guide*). One advantage of a vertical spinner is that it can be combined with a wedge, allowing for your battlebot to have a backup weapon in the case that your spinner fails (*Types of Battlebots, 2018)*. Wedges are often used to affect the opponent's mobility and can sometimes flip the opponents (*Robot Basics*). This type of multi weapon battlebot is seen in multiple high performing battlebots, such as Horns of Fury, as the robot can utilize the wedge to drive opponents into the vertical spinner as well (*Texas Combat Robotics*).

Another important aspect of the research we looked into was the electronics as buying the correctly rated motors, controllers, and batteries is important. The "3 lb Beginner's Guide" gave us a wiring diagram and list of all the necessary electronics, such as a battery, switch, electronic speed controllers (ESC), drive motors, weapon motor, controller, and receiver. From this, we looked into various battlebots and the recommended brands and components used (*3LB*

Beginner's Guide). Expert builders recommended brushless drive motors, such as the Hyperlite or DYS. In addition, DYS sells ESCs that are also available to pair with the respective motor. For weight reduction, many expert builders recommend PCBs that integrate multiple functions into one component such as a single board for the power switch and power distribution. When speccing out electronics it's important to match the voltage ratings and to look at the KV as an output of the RPM.

We also researched the design aspect of the robot. One key design principle is the gear ratio. To determine the ideal weapon RPM (2000-5000), we can backtrack to find the ideal gear ratio by coupling this with the power and torque of the motor. In addition, the kinetic energy in the weapon can also be calculated to get a theoretical output energy and torque generated from our spinner (*3LB Beginner's Guide*). These calculations, although theoretical, will guide our design choices and make our engineering process more efficient.

Learning the different types of material we could potentially choose for our battlebot was also an important part of our research. For armor, we could potentially use metal, wood, plastic, fiber, or rubber (*Armor: Battlebots Wiki*). Titanium is a popular material for battlebots as it is commonly used in thin sheets over plastic and polymer armor. This can allow the titanium to absorb the energy of the hits (*Combat Robotics: Weapons & Armor*). HDPE is suitable for disposable and replaceable armor pieces as it's cheap, easy to manufacture, and light. Lastly, steel is excellent for fasteners and weapons as it's strong and resists deformation (*3LB Beginner's Guide*). However, steel is heavy, so we want to use it sparingly. Researching these materials gave us a better understanding of what materials to use to create our battlebots and how to apply them, so that we use them effectively.

To gain a better understanding of the nuances of the battlebot as a competition, we pulled on virtual interviews previously conducted by the group to gather insight into various aspects of the competition. These interviews were done earlier in the year for a 15-lb battlebot competition part of our group participated in, but much of the information provided is relevant to the current project. First, we interviewed Jordan Neal, a veteran combat roboticist and driver, who competed at the national stage for battlebots with Wild Side Robotics. Jordan Neal worked on Dragon Slayer, which competed at the Battlebots World Championship, with its main weapon being an asymmetrical vertical spinner. (*Dragon Slayer*). Jordan provided insights into the design of the robot, giving us a practical overview with recommendations on how to make our bot more efficient and lethal. Some key components to include in our design are guards to protect our wheels and forks to guide opposing robots into our weapon. Materials such as HDPE can provide security for our wheels with little weight added, and be easily replaceable. He also mentioned that aiming for the opponent's wheels in a battle is a solid strategy as immobilizing the opposing bot can score points and allow for more damage dealt. Lastly, Jordan recommended spending ample time driving and practicing as there is generally a learning curve for driving a battlebot with the gyroscopic effect. The group also talked with Ian Macmahon, a seasoned combat roboticist with many years of experience. Ian focused on tips for electronics and suggested we research and buy quality ESCs as these are crucial for the control of the robot. In addition, he mentioned designing the bot to have easy access to electronics for replacing parts as using backup parts may be necessary. Ian cautioned us against high-discharge batteries and recommended adding some slack to the belt system for the weapon to reduce current spikes from back-driving the motor. These interviews were helpful and provided us with insights on how to better design and build our robot from an insider perspective.

Another aspect of the battlebot we conducted research on was the controller and receiver. These components will be given to us as part of the class, and it is important for us to understand how they work and how they can be integrated into our system. Utilizing the manual for the controller provides a great resource to order electronic components that are compatible, how to connect the receiver, and how to program the controller to output the functions. The receiver has 6 channels for motor control and one that routes to a switch. Furthermore, the controller has endpoints for each channel that allow the user to control the range of output given to each motor, and a sub trim function that can change the midpoint for the range of each channel (*Fly Sky, 2016*). This research is very useful in multiple aspects; it can frame what electronic components we buy, thus also guiding our designs for any parts interacting with these components. We can also build upon this research later in the manufacturing process to tune our motors and controls when preparing for the competition.

Another phenomenal resource we discovered during our research process was a thesis from the University of Cincinnati submitted on battlebots. This thesis provided an in depth dive into multiple aspects of their battlebot design and assembly. Some key information we picked up focused on the component selection aspect of the battlebot. The first helpful resource was a section that detailed different weapon drive configurations. Many spinner battlebots often use some sort of pulley system, and this gave us their recommendations from various tests and trials. The two methods they compared were a belt drive and chain drive system. Although the chain drive is more rigid and theoretically will allow for more energy to be transmitted and a higher damage output from the weapon, this is exactly what is a huge disadvantage as well. The belt drive has more “give”, or slip, which enables the weapon to also take impact as it gets hit by an opponent (*Ahluwalia, 2013*). This slight slip will ensure our weapon does not fracture or reduces the impact taken by the weapon system as whole. This resource taught us a new aspect of component selection and the weapon system as a whole and will definitely guide some of the future design decisions we make. We learned a great deal about both drive systems, as well as material properties under heavy impact like our battlebot, will be taking.

III. Gantt Chart and Task List

We created a Gantt chart and task list to act as constantly changing documents that help us keep track of deadlines and work distribution. The Gantt chart's primary focus is keeping us on track to start tasks and hit deadlines on time. Our task list's main focus was breaking down large tasks and distributing them evenly among us. The finalized Gantt chart can be found in Appendix A, and the task list can be found in Appendix B.

IV. Customer Needs Analysis

Since the battlebot project does not have an end consumer that will be purchasing it, the customer needs analysis is a bit non-traditional. Instead, we focused on identifying customers in terms of users and anyone related to scoring and judging the battlebot. Through this, the customers we identified were the people completing the safety checks, the judges, and the driver. We began by reading through the rules to identify the needs that must be achieved to pass safety checks to compete. Once these needs were identified we moved on to the scoring guidelines and then finally the end user which is the driver.

Since the safety requirements in the rules document are mandatory, they are our primary customer need. The main areas of scope for safety involve the electrical system, control system, and weapon system. These areas were chosen because of specific, non-negotiable rules given to us that are related to the systems. To accomplish these requirements any other aspect of the customer needs must also satisfy the guidelines set for us.

The scoring guidelines are the main metric for the success of our battlebot since it is how the performance of our robot is judged. The main focuses of the scoring are aggression, control, and damage. When analyzing these areas we noticed that many of the descriptors for scoring guidelines mentioned the ability of the robot to maneuver well and to inflict damage. Due to the emphasis on these two areas of combat most of the customer needs related to scoring guidelines have to do with the driving ability of the robot and the effectiveness of the weapon against our opponents.

Finally, we discussed the last customer which will be one of our team members who drives the robot. The customer needs coming from the driver primarily relate to the control structure of the robot since the controller is how the driver interfaces with the rest of the system. When discussing control structure we noticed most of our needs were for different features implemented on the controller such as tank steering, weapon throttle, and a button for reversing all controls of the battlebot in case we get flipped. Some of these controls might be confusing for a new user to use however we chose to exclude simplicity of controls from our customer needs as the driver will have time to familiarize themselves with the controller and control structure during the prototyping and testing process. Another factor of driving the robot is the mitigation of gyroscopic precession which causes the robot to flip on its side when turning too fast. By using force balance equations we determined that an open-loop control can be implemented to mitigate this. *(Smith, David, et.al., 2014)*

We decided our battlebot must be safe, highly maneuverable, and have high amounts of damage in each hit. These categories were obtained from our customer needs analysis list in

Appendix C. Focusing on these needs and categories will allow us to design and manufacture a safe robot that follows all regulations and is successful in combat. In order of importance, our customer needs are safety, maneuverability, and attack ability. These are listed in this order due to not being able to compete without passing safety checks and maneuverability playing a larger role in the judging guidelines than attack does.

V. House of Quality and Engineering Requirements

After establishing the customer needs through background research and interviews, we began to translate these values into our House of Quality as a weighted customer needs analysis. For each of the customer needs, we assigned a value from 1-5 to indicate the relative importance of each of the customer needs, with 1 representing the least important and 5 the most important. We assigned these values based on the emphasis each of our customers placed for the needs, as well as how often we encountered the need in our background research. For example, one of our most essential customer needs was incorporating a physical weapon lock, which correlates to safety. This is a need that was heavily important to many of our customers, such as the driver and other competitors as this will be an area of concern during competition. In addition, this is a higher need due to the fact that the addition of this can increase our points in the competition, In a similar vein, requirements given to us by the professor, one of our customers, such as the weight and cost limit also had a high importance to satisfy these needs and earn points for the competition. Lastly, some of the other higher ranking weighted customer needs came from background research and prior knowledge. Having a structurally sound frame and chassis is critical to our robot. This was determined to be a high important need due to research which pointed to many battlebots not having enough “defense” In addition, this need impacts others such as maneuverability as many of the motors and drive systems can be affected negatively if the frame and chassis are not well designed. Some of the customer needs were ranked lower due to customers not placing heavy emphasis on these needs. For example, although prioritizing campus resources is important for the team to minimize cost, sourcing materials and machines outside of the UT resources can still be feasible within the given budget and timeline. This process gives us a clear idea of which aspects of the battlebot are important to our various customers and guides us on which needs to prioritize when designing and manufacturing.

The next part of the House of Quality included establishing the engineering requirements. Based on the customer needs analysis we conducted, we created engineering requirements that correlated to the wants of the customers. We created an engineering specifications sheet as shown in Appendix D to showcase this. To formulate these engineering requirements, we translated each of the customer needs into a requirement that can be incorporated into our design. These requirements also needed to be quantifiably verified, however, this proved to be more difficult for some of the requirements than others, thus we used some yes/no type questions for a simpler specification. An example of this is the engineering requirement of whether our robot can turn, which corresponds directly to the need of “the robot can turn in place”. The specification sheet also included our quantified target value for each of the quantified requirements and a method of verification for this. For example, to quantify the force our chassis can take, we decided that a chassis design that can withhold 1 kN of force was ideal for our battlebot, and we can verify this through FEA and physical tests. Doing this gives us clear guidelines on which requirements we need to incorporate into our design and how we can aptly test and validate our battlebot is meeting the standards we set. This will be key later on in our design and manufacturing process to test the full capabilities of our battlebot and maximize its performance from a quantitative standpoint. Using both the engineering spec sheet and the weighted customer needs, we will ensure the more important needs such as our weight limit, and the protection of our electronics are upheld as we design our battlebot.

To analyze the relevance between the customer needs and the engineering specifications, we included calculated importance for all the engineering specifications based on how relevant each one is to the customer needs. We used a circle dot, triangle, circle, or no symbol to indicate the relevance on a grid between the customer needs and the engineering requirements with 9, 3, 1, and 0 points respectively. Using these point values, we were able to calculate the absolute importance of each of the requirements by multiplying the points by the value of relative importance assigned earlier. After, the relative importance could be calculated by dividing each of the absolute importance by their sum. This allowed us to analyze how important some of the customer needs and engineering specifications are and reevaluate their integration into our design. The most important is weight, which adheres to our design methodology as weight has a heavy effect on mobility and durability. Other important engineering specifications were having secured electronics and cost, both of which are important qualities to increase durability and fulfill project requirements. Surprisingly, the lowest-ranked engineering specification was speed, demonstrating that it was not as important to the needs of the customers. The group analyzed the absolute and relative importances to gain a more in depth and qualitative understanding of the emphasis we needed to place on each of the parameters when it comes to designing. It is important to keep all the requirements in mind, however the importance gives us a concrete method of determining which specifications to prioritize.

Based on these engineering specifications, the group made metrics to more thoroughly express the requirements. To create these metrics, we assigned each engineering requirement a unit and target values to specifically gauge how to measure the requirements and what the goal measurement should be, shown in Appendix D. For example, the units and target value for the “amount of force the chassis can take” is 1 kN, which we can measure through FEA, and verify through stress tests. For some of the requirements, we were able to assign units and values and used yes/no if the feature was unable to be easily quantified, or a percentage to gauge some attributes such as “how much of the wheels are covered/protected”. Many of these metrics were derived from material properties, as well as previous battlebots and their performance and concerns as shown primarily by Horns of Fury and the RoboJackets.

The next step in the House of Quality were two sections that related to comparisons to other products. We evaluated our battlebot design against three other battlebots over a variety of weights and weapon assemblies. We compared our robot against Scampi by RoboJackets, Horns of Fury by Texas Combat Robotics, and Tombstone by Hardcore Robotics *(Tombstone)*. Utilizing the metrics we created in the previous section, we gauged how our battlebot compared to others by identifying as many values for each of the other robots as we could. For example, Horns of Fury, a 15 lb battlebot, had good documentation, allowing us to gauge our engineering specifications with a successful robot. Some of the similarities included the weapon type and the covering of the electronics, and the ability to drive while flipped over *(Texas Combat Robotics, 2024)*. Another bot we compared our battlebot to was Scampi, another 3 lb battlebot. There were some differences between our designs. Scampi had exposed wheels, and the target speed for Scampi was nearly half of our target value. This data supported the relative importance of the speed requirement being one of the lowest, but the wheels seemed to be an oversight in durability from the engineers *(Scampi)*. From the House of Quality, we can gain takeaways by looking at similar battlebots to see what has previously worked, and other common themes. As shown by some of the comparisons mentioned above, attributes such as speed were not very important, in addition, almost all of the high performing battlebots had some common concepts like wheels for a mobility system and protection for the structure and wheels. We can utilize these ideas in our design to bolster our battlebot concept generation in the coming stages.

Our last addition to the House of Quality was our roof. The roof is a way for us to visualize our metric conflicts and synergies. The metrics are connected at the point they meet diagonally. An example of a design conflict (negative symbol) would be trying to meet our weight requirement while also trying to have our robot be as armored as possible to meet the percent damage our robot can take. Since the robot would be heavier with the more armor we add, it goes against us trying to be lightweight. A synergy (positive symbol) example would again have to do with our lightweight requirement and the desired minimum speed we want to meet. Being lightweight allows us to move faster. Upon completion of our roof, we were able to learn what we are going to have to design around in the future and how we should better prioritize certain aspects of our battlebot.

VI. Problem Statement

The goal of this project is to design and fabricate a safe, functional 3-lb combat robot within the $300 budget that is structurally durable, physically mobile, and capable of dealing damage to opponents. With the given requirements, an important aspect of our project is to adhere to the specific SPARC safety guidelines, and stay within the $300 budget. In addition, the customer needs and background research showed us that our robot needs to be designed to be able to withstand, as well as deal, damage, and move efficiently in the arena to be successful in battle.

VII. Conclusion

Through our background research, customer needs, and engineering specification constraints, our team began to understand what type of battlebot design would be the most optimal. Through our background research of battlebot champions and interviews with experts, we were able to settle on a vertical spinner for our weapon type. Given our project timeframe, vertical spinners are simpler to design for, compared to other high damage output weapons and can be more deadly when using a ramp to guide opponents into our vertical spinner. From our customer needs, we decided that our battlebot needed to be safe, maneuverable, and inflict high amounts of damage. From our House of Quality and engineering specifications, we gathered that weight, secure electronics, and cost were the most important qualities to design for. With all of these qualities, we will focus on creating a battlebot that follows the competition constraints, is mobile, structurally sound, and capable of inflicting high amounts of damage.

Chapter 2: Design Review

I. Introduction

The goal of our project is to design a 3 lb battlebot that emphasizes durability, mobility, damage, safety, and cost. To achieve this, we created functional models and used concept generation methods, such as 6-3-5, design by analogy, and a mind map, to brainstorm possible designs and solutions for our battlebot. We then used a morphological matrix to come up with 4 concept variants and then used a Pugh chart to evaluate these variants to come up with a leading concept.

II. Functional Models

To define the goals and specific functions of our battlebot, we created two functional models: a black box diagram and a function tree. The black box diagram (Figure E1) illustrates the primary function of battling bots, while the function tree (Figure E2) displays the main functions and subfunctions of our battlebot.

Our black box model provides a clear visualization of how our battlebot processes inputs and produces outputs in terms of energy, materials, and information. For energy, the input was our battery, and the outputs included thermal energy, sound, rotational kinetic energy, and translational kinetic energy. For materials, the input was our hand to drive and control the robot, and the outputs were our hand and the deformation of our opponent's parts. For information, the inputs were speed, the on/off status of our battlebot, and the controller, while the outputs were indicators and visual feedback.

The function tree's main function was to battle robots, from which we identified three subfunctions: maneuvering the robot, withstanding impacts, and operating the weapon. By breaking down these subfunctions into simpler components and actions, we gained a deeper understanding of the task and function of our product. This approach helped us systematically analyze and refine our design, rather than merely generating ideas. It served as a tool to deconstruct the task, which was battling other robots, ensuring that each aspect of our battlebot's functionality was thoroughly considered and optimized.

III. Concept Generation

To generate distinct ideas that will help us design our battlebot, we performed three different methods of concept generation, mindmapping, 6-3-5, and design by analogy. These generation methods allowed us to compare all our ideas and then weigh the feasibility and strength of each.

The first method we chose was mindmapping. We decided to do this generation method first as it gave us the freedom to brainstorm any and all ideas without restriction. Utilizing research from the customer needs and the function tree we established previously, we created 6 sub functions - weapons, drive, materials, electronics, durability, and safety (Figure F1). Our mind map covered as many aspects of the battlebot as possible, from various electronic components needed, to different ideas for a drive system, to different materials and where they can be used in the battlebot (Figure F1). Having a comprehensive, visual map of all our ideas aided us in organizing our concepts and we heavily utilized this for the rest of the concept generation methods

The next generation method the group conducted was 6-3-5 (Figures F2-F9). To better visualize and collaborate on designs, each group member spent time drawing sketches of various battlebot designs within a given time limit. Then, the rest of the team spent time adding details and feedback, rotating the sketches. Doing this practice was very helpful in allowing a collaborative design where each of us could provide input and features that we thought were important and could increase our chances of designing a successful battlebot. In addition, sketching the designs allowed us to start brainstorming and thinking about the designs we had in our minds from a more realistic standpoint. Sketching out some of the ideas, such as the horizontal spinners or the tank tracks for the drive system shows how complex and not feasible these can be when compared to other designs. Some common themes throughout all the designs that we could incorporate into the final concept were adding sharp edges or spikes to our weapon to increase damage done to opponents, adding wedges or forks to push opponents to our weapons, and adding protection to our wheels and internal components. These ideas persisted through each design we sketched, showcasing their importance and why they should be included in the final design.

The last concept generation method we used was the design by analogy (Figure F10). To bring about new, fresh ideas, we took some inspiration from nature, identifying animals and products we thought were implicative of designs we could incorporate into our battlebot. As a group, we brainstormed problem areas in our battlebot design that needed to be addressed and researched analogies in nature that could help spark similar concepts and designs for our battlebot. We put this in our table - noting down the problems, the analogy, and the solution that we created based on the analogy (Figure F10). Some of the concepts that we came up with through this concept generation method included designing the front and back of our battlebot to be shaped similar to a bird's beak as this is known to increase aerodynamics to help our bot move quicker. Another problem is ensuring that internal structures and components are protected. The spiny mouse provided a great analogy as these animals have spines that serve as protection, but if under too much pressure they fall off and are regrown. With that context, we thought about having guards around our robot made from plastic that act as protection and take most of our damage, but these can be replaced in between each match to maximize the protection. From this concept generation method overall, we were able to gain a better understanding of how to approach some of the problems we had. Writing down our problems was very helpful, and basing our solutions off of analogies that have proven to work was a big takeaway and provided us with a higher quantity of creative ideas to implement on our battlebot in the design process.

To generate some more concepts and ideas we can draw upon, we conducted some research into prior work, looking specifically at previous battlebots and patents to identify additional candidate solutions for any functions we needed to flesh out. Pulling on a resource from our background research, we utilized Tombstone, a successful 250-lb battlebot that has competed in multiple world championships. The design of the chassis is straightforward and intuitive, which we can adopt and scale down for our battlebot. The shape of the chassis is a box constructed from heavier, durable side frames with thinner panels for the top and the bottom. In addition, adding vents can be critical for the design as many electronic components that produce heat will be in close proximity *(Tombstone)*. Another innovative function of Tombstone is the two-wheel drive system. Having only two wheels greatly minimizes the points of failure and decreases our risk for technical development, and this drive system allows for quick turning and decreased weight due to fewer materials. Although Tombstone is very different as a battlebot concept than what we are looking into, many of the different sub functions are creative and have thorough designs that we can look to learn from and incorporate into our battlebot concept (*Tombstone*).

Another source of idea generation can be from patents. Patents provide a clear view of the various systems included in a device, as well as, insights into the novel, fresh technology portrayed in the patent. One of the patents we looked at was a United States Patent by Rehkemper et.al. titled “INTERACTIVE BATTLING ROBOTS WITH UNIVERSAL VEHICLE CHASSIS“. This patent was focused on the idea of modularity within robotics, specifically using a robot chassis as a framework for showcasing clever, modular design. Although this is not something we can adopt directly, the idea of a modular design is very useful for a battlebot. A key topic in the patent, and shown in the many detailed drawings, was the assembly process and the emphasis on minimizing assembly time and complexity to achieve a more modular design. This simple idea is what can guide us in our design from the standpoint of modular parts. As mentioned previously, some of the parts we intend to utilize on the outside of the battlebot for armor and protection are designed to take damage and be replaced in between matches *(Rehkemper)*. Having a clear plan for assembly like the patent articulates, and putting the mounting in critical places that are easy to attach and remove will greatly increase the modularity of our design and allow for quick and simple fixes during our competition.

IV. Morph Matrix

We started our Morph Matrix (Appendix G) by listing the different subfunctions of a typical battlebot, derived from the lowest level of our function tree: method of guiding the opponent to our weapon, securing electronics, chassis material, type of drive system, and chassis structure. These subfunctions provided enough detail to begin organizing our ideas.

We filled the matrix with practical solutions for each subfunction, focusing on one subfunction at a time to maximize different effective concept variants. We drew inspiration from several robots in our background research, utilized our ideas from the previous concept generation methods, and considered cost and weight requirements from our customer needs to keep our ideas and design aligned with our goals.

After populating the Morph Matrix with potential solutions for each subfunction, we combined different ideas to generate unique concepts and variations. Our past experience and research gave us insight into how certain components could integrate to form complete subsystems, so we focused on those combinations. This process resulted in four distinct concept variants.

V. Concept Variants

For our Morph Matrix, we created four concept variants for our battlebot. Sketches and labels of each are found in Figures H1 - H8 in Appendix H. They are defined as follows:

Concept A: A battlebot shaped like a rectangular prism with tank tracks that has an aluminum chassis (Figure H1 and Figure H2). The weapon is a beater bar that has fixed forks to guide the opponent into the weapon. Electronics are secured using zip ties.

Our first concept is a battlebot that utilizes a beater bar, tank tracks, and a rectangular chassis. The weapon is a beater bar that acts with the fixed forks to guide opponents into the weapon with the beater bar allowing the battlebot to have a large area of attack. The chassis is manufactured out of aluminum and is shaped as a rectangular prism for ease of manufacturing. The aluminum chassis will make this battlebot resistant to high-impact attacks and thus, a more durable option. The tank tracks will provide better mobility and traction when battling against other components, allowing it to be more stable. The electronics will be secured with zip ties, providing a secure, but cost-effective solution for securing the electronics within the chassis of the battlebot.

While this battlebot has many advantages when compared to other concept variants, many things could be improved. The tank tracks are excellent for translational movement, but quick rotational movement would prove to be more difficult with the tank tracks. Another con would be that the tank tracks would also make this design significantly more expensive and more complicated to design. The fixed forks are stable and a good addition to our weapon, but in the case that our battlebot gets flipped, the forks are rendered useless.

Concept B: A battlebot shaped like a wedge with two wheels that has an aluminum and HDPE chassis. The weapon is a vertical spinner that has pivoted forks to guide the opponent into the weapon. Electronics are secured using plastic mounting screws (Figure H3 and H4).

This battlebot functions as a vertical spinner with a two-wheel drive system. The weapon is a thin vertical spinner with mass on the outside of the weapon system to generate more energy, The weapon system will also utilize pivoting forks to guide the opponent into the weapon. The shape of the bot is a wedge, or a triangular prism, with aluminum frames and HDPE plates that will provide structure and protection for the internal components. The wheels will have clearance on both the top and the bottom to allow for driving while flipped over. To provide additional protection, guards of HDPE will be mounted around the wheels on the sides of the chassis. Lastly, the electronics will be secured through plastic mounting screws to ensure they stay in place during battle.

This battlebot concept has many advantages. Utilizing a 2 wheel drive system and a thinner vertical spinner greatly increases the mobility of our battlebot. Having a vertical spinner minimizes the gyroscopic effect compared to a shell spinner or horizontal spinner, allowing the driver to better control the robot. In addition, having 2 wheels allows the robot to turn in while still having a high-speed output. This can be pivotal during battles to outmaneuver our opponent.

This battlebot also has relatively low technical development risks. This concept design has fewer points of failure when compared to features included in other designs such as a tank track drive system or a chassis shell that spins. Using aluminum and HDPE for the chassis will also bolster the durability of the frame of the chassis, allowing the battlebot to take more damage from opponents without sacrificing form or functionality. The guards around the wheels will only further increase the durability. A clear disadvantage to this concept is the damage output from the weapon. A vertical spinner is not as effective as dealing damage to opponents, potentially lowering our score in the competition.

Concept C: A battlebot shaped like a disk with two wheels that has a HDPE chassis. The robot is a full-body spinner that has a wedge to guide the opponent into itself. Electronics are secured using zip ties.

This concept has a disk-shaped design with two wheels and a HDPE chassis, making it lightweight and agile. Its full-body spinner, where the entire shell of the chassis can spin to deliver powerful, all-around attacks, while the wedge helps guide opponents into the spinner for maximum damage. In addition, the design has a 2 wheel drive system. The use of zip ties to secure electronics offers a simple, flexible solution for component placement.

However, there are some potential downsides. With only two wheels, the robot may struggle with stability and control, especially after a hit. The HDPE chassis, while durable, could be vulnerable to heavy impacts. Additionally, securing electronics with zip ties may not provide enough protection against strong shocks or vibrations during combat.

Concept D: A battlebot shaped like a hexagon with four wheels that has a HDPE chassis. The robot has a horizontal spinner that has nothing to guide the opponent into itself. Electronics are secured inside a black box.

This concept has a focus on being mobile and able to take and give large hits. Unlike concepts A-C, this robot doesn't have a guiding mechanism to push opponents into its weapon since there isn't an easy way to implicate one without adding lots of weight. It also is the only concept that has four wheels. It would likely need at least three motors, two for wheels and one for the weapon. The chassis will also be multi-pieced and screwed together.

This battlebot design offers several advantages. The hexagonal shape provides stability and omnidirectional defense, while the four-wheel setup ensures good traction and mobility. The HDPE chassis is lightweight and impact-resistant, adding durability without compromising speed. The horizontal spinner covers a wide area in combat, delivering powerful hits, and the black box secures the electronics, protecting them from damage.

However, there are some drawbacks. The hexagonal shape lacks the aerodynamics and pushing power of more angled designs, and the four wheels are vulnerable to attack. The HDPE chassis, while durable, can be susceptible to heat damage, and the horizontal spinner, without guidance for opponents, may miss its target. Additionally, the black box could complicate quick repairs and add unnecessary weight.

VI. Back of Envelope Calculations

In order to compare our various design concepts we performed quick back of envelope calculations to assess the performance in various metrics for each design. Based on the criteria in our Pugh Charts in Appendix J, we decided upon metrics that would let us quickly and roughly compare each of the following criteria: durability, mobility, damage, safety, cost, and technical development risk.

For durability, we looked at the various material properties of each of the materials we selected. While there are many qualities we could look at and lots of in-depth calculations that could be done we wanted to keep our back of envelope calculations rather simple. Ultimately we decided that tensile strength would be a good basis for comparison between the different frame materials. Tensile strength provides an accurate metric of the overall endurance of our battle bot and we compiled a list of the potential materials and their various strengths through some research *(Armor) (3 Lb Beginner's Guide).*

In terms of mobility, the two metrics we looked at were maximum rotational velocity and maximum linear velocity. For the most part, it is assumed that the motors used to drive each wheel and the motor to drive the weapons would be standardized among the various concepts. The only concept that uses a different motor is the whole-body spinner. The program in Figure I1 was used to quickly generate values for the above metrics. The equations used by the program are simple equations of motion for transforming motor RPM to linear and angular velocity based on wheel radius and distance between wheels.

To compare the damage we decided to look at the tip speeds of our concept weapons. In general the higher the tip speed the more effective the weapon. These calculations were obtained from the same program as was used for the mobility calculations. The outputs from this function are shown in Figure I2. The equation used to calculate tip speed simply transforms the RPM of the motor to a linear velocity at the tip of the weapon. This tip speed is directly related to the energy of the weapon which shows how much damage is dealt.

For safety, we talked through the steps required to take each robot from its combat-ready state and back to its transport state where someone could safely pick it up. This was a quick way of analyzing roughly a comparison between the safety of our concepts, and using requirements such as weapon lock, and even how to restrict other dynamic components gave us a good idea of this.

Quantifying cost and technical development risk are dependent on each other. With increased levels of technical development, the cost tends to go up as well. For cost we mainly compared designs by the amounts of components that could be needed and for technical development we based our comparison on an estimate of the time of experimentation. The technical development risk also lends itself to complexity and points of failure. Oftentimes, over engineered designs can have more potential to fail and a balance is necessary to ensure the systems we use are functioning and able to be fabricated and assembled in the timeline given.

VII. Pugh Chart and Leading Concept

In order to compare our design concepts and decide upon a leading concept we used a Pugh Chart. The criteria we selected for our Pugh chart were durability, mobility, damage, safety, cost, and technical development risk.

To compare the criteria in our Pugh chart we used the back of envelope calculations mentioned in the previous section. These allowed us to quickly assess which concept was relatively better in each of the criteria. With the criteria selected, we created 4 Pugh charts, each with one of the concept sketches as the datum, allowing us to use this as a base or reference to gauge the others in comparison and evaluate the relative values. As we went through each Pugh Chart, we discussed the advantages and disadvantages, using our research, back of envelope calculations, and prior knowledge to justify these comparisons.

A strong negative trend we saw throughout the Pugh charts was the low mobility score of concepts C and D, a shell spinner and a horizontal spinner respectively. These concepts were determined to have low mobility due to their weapons causing massive gyroscopic effects. Another similar trend was the safety factor. Once again, due to the nature of a shell spinner and horizontal spinner, these weapon designs are more difficult to control and often take more levels of safety to lock. These are key requirements for the competition and to ensure the safety of the team, thus an important criterion to take into consideration. A positive trend that helped guide us toward our final leading concept was the high durability rating of Concept B. Many of the other concepts incorporated design aspects that had exposed and vulnerable systems without any protections, such as the tank drive system in Concept A, the shell spinner being vulnerable to damage in Concept C, and the extended supports for the spinner in Concept D. With these in mind, it set a clear favorite for this criteria. Another important aspect was the technical development risk. This requirement translated to maximizing the feasibility of our build and minimizing liabilities. As a team, we determined that this is very important due to the tight design and manufacturing timeframe given to us. Various components of the concepts were taken into account and thoroughly explored to fully understand the design and measures needed to actualize these ideas. For example, the tank treads and 4-wheel drive system can increase traction, however, both these drive systems require significantly more parts and assembly than a 2-wheel drive system. This adds unnecessary complexity, weight, cost, and, most importantly, points of failure to our robot. Another risk that could be gauged with technical development incorporates the securing of electronics. Although ideas such as mounting screws and black boxes are ideal and provide the most protection, implementing these can be tricky and often more time-consuming than rewarding. A simple solution such as zip ties as shown in Concept A can achieve the same result. All these various comparisons and analyses of our concepts allowed us to holistically think about our final concept and choose different ideas to corroborate into a final, leading sketch.

From the Pugh Chart, we were able to identify and incorporate the leading concept into one final battle bot concept sketch. As shown through the Pugh Chart, Concept B had a lot of advantages in the criteria we defined. Although the amount of damage this battlebot concept delivers to its opponents is a con, the durability, mobility, and feasibility, as showcased through technical development risks, of this concept was superior to the other concepts and we borrowed some of these concepts for our final, or leading, sketch. For the leading concept, we chose to implement a 2 wheel drive system. We chose this system due to the high range of mobility given by two wheels, and the ability to turn in place, one of our engineering requirements. Also, as shown through the technical development risks, having only two wheels decreases the complexity and weight when compared to a tread drive system or a 4 wheel system. For the chassis, we decided to adopt the wedge-shaped design from Concept B. Originally planning to use a box-shaped chassis, we realized that narrowing one of the sides could save us weight while still allowing proper function. In addition, we decided to incorporate our wheel guards into the design of our chassis as seen in Concept C and D. The frames we use for structure will sit outside the wheels, minimizing any weight from external wheel guards needed, while still protecting the wheels. The materials for the chassis is something we also included in our leading concept. Based on a combination of Concept B and Concept C, the frames and chassis will be made out of both aluminum and HDPE. For the weapon system, we chose a vertical spinner as shown in concept B. As mentioned above in the Pugh Chart section, this weapon type is one of the most feasible to design and manufacture in the given time frame and allows for a higher level of control than the weapon types in Concepts C and D due to gyroscopic effects. A vertical spinner is also safer for the team and audience of the competition, adhering to the SPARC safety guidelines and potentially earning us points as well. The last concept we thought out was a method for securing the electronics. Once again, a combination of multiple concepts proved to be a better solution. Utilizing the mounting screws from Concept B, and zip ties as labeled in

Concept A. Securing the electronics was an engineering requirement we placed heavy importance on, so having these two methods combined will ensure our electronics are safe and can withstand the impacts that come with combat.

VIII. Conclusion

Through the making of our functional models, concept generation activities, Morph Matrix, and Pugh Chart, we were able to decide on a leading concept that emphasizes durability, mobility, damage, safety, and cost. From our functional models, we were able to clearly define the functions we would need our battlebot to perform and the specific components needed. Our concept generation activities, such as mind mapping, 6-3-5, design by analogy, and researching previous successful battlebots and patents, allowed us to brainstorm all ideas without restriction. From this, we defined our subfunctions: weapon, drive system, chassis material, electronics, durability, and safety. Through our Morph Matrix, we clearly defined the subfunctions we outlined from our concept generation activities and generated multiple ideas for each subfunction. Then using our Morph Matrix we came up with four concept variants for our battlebot. We evaluated each of these utilizing our Pugh Chart and back of the envelope calculations. From the evaluations, we outlined our leading concept which has a 2-wheel drive system, wedge-shaped chassis that is made out of a combination of aluminum and HDPE, a vertical spinner weapon, and securing our electronics using zip ties and mounting screws.

Chapter 3: Final Report

I. Introduction

The Battlebots competition has grown in popularity in recent years, with competitors crafting hundreds of combat robots across various weight classes. This semester, our challenge was to design and build a 3 lb battlebot, focusing on durability, mobility, damage, safety, and cost. To achieve this, we began by researching existing battlebots and compiling our customer needs into a House of Quality. We then developed a list of engineering specifications and created a Gantt chart to outline our project timeline. For idea generation and organization, we employed functional models and concept generation methods such as 6-3-5, design by analogy, and mind mapping. Using a morphological matrix, we generated four concept variants and evaluated them with a Pugh chart to identify the leading concept. After selecting the leading concept, we refined it to develop our final design. We then assessed this design through simulations, experimentation, and design for manufacturing analysis, making final adjustments in preparation for the battlebot competition.

II. Final Design

The final design of the battlebot incorporates many of the design aspects previously discussed in the methodology for concept selection. The CAD assembly for the final design can be found in Appendix L.

The primary structure of the battlebot was designed as metal panels. The bottom panel, back panel, and inner and outer side panels are 6061 aluminum. These plates are held together with 6-32 nut strips at the edges, and M3 standoffs acting as crossbeams. These panels also contain features that allow for the mounting of the drive and weapon motors and some of the electronics.

The weapon assembly consists of an AR-500 steel weapon body with four M3 mounting holes and a 17mm hole in the middle for a bearing. The mounting holes are used to secure the weapon body to a timing pulley that is connected to the weapon motor through a belt system, where a smaller timing pulley interfaces with the weapon D-shaft through two set screws. The large timing pulley and the weapon body are press-fitted with bearings that sit on the 6mm weapon shaft. The weapon shaft goes through designed 6mm holes in the inner side panels for tighter clearance and uses shaft collars to maintain structure and limit translational motion. The wheel assembly is pretty simple. The Banebots wheels have off-the-shelf hubs that set screw into the drive motor shafts, and the wheels press fit over the machined hubs and use snap rings to keep them in place.

To close any gaps in the front, we used 3D-printed wedged wheel guards that sit around the inner and outer side panels on each side and mount with the fasteners on the outside of the battlebot. These also included steel shims fastened on top for extra protection. In addition, another 3D-printed cover was added to the inside of the battlebot, using heat-set inserts. This component kept the wiring on the inside from being exposed and added structural support to keep the small timing pulley in place. Lastly, the top cover is a 3D printed pocketed piece that allows for easy assembly and access to all the inner components, such as the electronics sitting on the inside, for more height for these components to sit in. The plate has counterbored-through holes that fasten to the nut strips and mount the panel, and an extruded Longhorn logo to showcase school spirit.

Our assembly plan was structured around easily putting together each component and being able to properly tighten each screw used. We started with mounting each motor to its corresponding panel and then began assembling the whole bot from the middle. The middle panels were attached first with all crossbeams and nut blocks mounted as well. From here we assembled the outer panels and then the bottom plate. Finally, we put in the rest of the electronics and connected all of the wiring. Once it was all assembled and ready for combat the battery was plugged in and the top plate was secured.

III. Bill of Materials

The Bill of Materials (BOM) for the battlebot gives a list of all components required for the design and assembly of the system. The BOM is categorized into four subsystems: Weapon, Drive, Chassis, and Electronics. Each part is identified by a Part # following the format of the subsystem's first letter, a dash, and a double-digit number indicating the order in which the part was added (e.g., "W-12"). For each part, the Part Name, Function, Source, Properties (material, dimensions, voltage, etc.), Quantity, Price per Unit, and Total Price are listed. This format helps to track the weight, cost, and properties of the components. The BOM also helps to keep track of our weight constraint and budget. As stated before, we must maintain a maximum weight of 3 lbs and a total budget of $300. The complete BOM, detailing all parts and associated costs, can be found in Appendix M below.

IV. Failure Modes and Effects Analysis (FMEA)

The FMEA for our battlebot goes over anticipated failure modes that could be experienced during assembly and battle in Appendix N, Figure N1. Since the objective of this competition is to cause damage to another battlebot it is expected that teams will also attempt to damage ours. This means that it is difficult to fully prevent any failure and that we must try to mitigate the effects of it. This also means that a majority of our failure causes our impacts and the majority of the failure modes are material yield or deformation. For the electrical components, a major failure cause is an improper installation that could short or burn out electrical components. The effect of most of our failures is a lack of functional subsystems such as the weapon or drive systems.

To lower our risk we chose to make a component to decrease the risk of the weapon motor pulley slipping off the axle since this was one of our largest RPNs. We made a piece that constrained the motion of the pulley and completely removed the chance of it coming off the axle. This improvement is reflected in a drastic reduction in occurrences and is shown in the risk assessment in Appendix N, Figure N2.

V. Simulation

To determine the optimal material for our battlebot's chassis wall, we conducted Finite Element Analysis (FEA) in SolidWorks. Our objective was to identify a material capable of withstanding a 1 kN impact from an opposing battlebot's weapon, as specified in our engineering requirements. The analysis was performed on three materials — 6061-T6 Aluminum, Baltic Birch Plywood, and ABS — each with a uniform thickness of 0.125 inches. For each material, the same boundary conditions and impact location were applied to ensure consistency in testing.

The first simulation was performed on the 6061-T6 Aluminum panel, which produced a maximum deformation of 0.457 mm, as shown in Appendix O, Figure O1. This minimal deformation suggests that the aluminum panel would maintain its structural integrity under impact, allowing the robot to remain functional. Given the low level of deformation, we determined that 6061-T6 Aluminum would be a favorable material.

The second material tested was Baltic Birch Plywood, with a maximum deformation of 9.69 mm, as shown in Appendix O, Figure O2. Such a high deformation indicates that the material would likely fracture rather than bend. Given this result, we concluded that plywood would not be a reliable option for chassis protection. A fractured panel would expose internal components, such as electronics, to potential damage, which would likely render the robot inoperable during competition.

The final simulation was conducted on an ABS plastic panel, which exhibited the largest deformation of 12.89 mm, as shown in Appendix O, Figure O3. Similar to the plywood, the significant deformation suggests that the ABS panel would likely fracture. This level of displacement, combined with its lower impact resistance, led us to eliminate ABS as a viable option for the chassis material.

Based on the simulation results, 6061-T6 Aluminum is the clear choice for our chassis wall material. While real-world impacts may be less severe than simulated ones due to energy dissipation through the overall movement of the robot, we prioritized material failure prevention. Although Baltic Birch Plywood and ABS are cheaper and could be replaced during competition, relying on their ability to survive impact is risky. If either material were to fail during a match, the robot's internal components would be exposed, potentially leading to a critical system failure and loss of the match. By contrast, the 6061-T6 Aluminum offers consistent protection without the need for mid-competition replacements. Therefore, we have selected 6061-T6 Aluminum as the material for the chassis wall to ensure maximum durability and maintain competitiveness throughout the event.

VI. Experimentation

In our experiment, we examined how wheel size, weapon RPM, and electronic calibration influence both the distance offset during continuous rotation and the speed of our battlebot. We tested two wheel sizes: 4 inches and 2 inches in diameter. The weapon RPM settings were either 8000 RPM or off, and the electronics were either calibrated or uncalibrated, the back of the envelope calculations are located in Appendix P, Figure P1. The uncalibrated setting uses the stock setting on the controller for sending tank drive PWM signals to both motors. The calibrated setting was obtained by driving straight forward and backward with the controller stick and changing the max PWM signal on the right wheel until the robot drove in straight lines. This ended up being approximately a 10% increase in the signal sent to the right drive motor. By measuring the distance offset while rotating in place, we aimed to identify which settings enhance driver control, helping us strategize for battles. We placed the battlebot on a piece of tape in the arena and rotated it in place for 10 seconds. Afterward, we measured the distance it moved using a measuring tape and divided this distance by time. Additionally, to evaluate speed, we sought to determine the optimal settings for maximizing our battlebot's maneuverability. We placed the battlebot on a piece of tape and drove it in a straight line for 1 second, then measured the distance it traveled with a measuring tape.

Appendix P, Figure P2 presents the raw data collected from our experiments. Using this data, we created a cube plot by assigning the values from the three trials for each combination of variables to their respective vertices. This provided an intuitive visual representation of the results, though it lacked detailed analysis. To gain deeper insights, we performed a regression analysis on both the distance offset and speed data to determine the statistical significance of each variable. For the distance offset results, the coefficients of all three variables were low. The largest coefficient in magnitude was for wheel size, followed by calibration, and lastly, weapon RPM. The p-values indicated the statistical significance of these variables; however, none had p-values below 0.05, meaning none were statistically significant. For the speed results, the largest coefficient in magnitude was again for wheel size, followed by calibration, and weapon RPM. Unlike the distance offset, all these variables had p-values below 0.05, indicating that they were statistically significant for speed. The interaction plots are shown in Appendix P, Figures P6-11.

From the linear regression and interaction plots, we determined that wheel size had the largest effect on both distance offset and speed. This was confirmed by the wheel sizes having the coefficients with the largest magnitudes for both tests. For speed, it was evident that larger wheels resulted in faster speeds. However, the results from the distance offset tests showed no clear correlation between wheel size and distance offset, despite wheel size having the largest coefficient. Weapon RPM also affected speed; with the weapon off, we gained a few more inches per second compared to when the weapon was on. Interestingly, weapon RPM had a direct correlation with distance offset, with the weapon being on causing less offset than when it was off. Calibration did not seem to significantly impact either speed or distance offset. If we were to redo the experiment, we would increase the number of seconds we measured for speed to allow for both wheels to fully accelerate and get a more accurate speed calculation for both sets of wheels.

VII. Design for Manufacturing and Assembly

While designing our final CAD assembly for our battlebot, we kept in mind many of the DfMA rules and tips learned in class. The main constraints we needed to adhere to were the resources available to us, the total $300 budget for our project, and the 3 lb weight limit. With these in mind, we made some critical design decisions that allowed for ease of manufacturing and assembly within these limitations.

With one of our main criteria for overall design being durability, we wanted to utilize a strong material that could withstand impact during our battles. To stay within budget, the timeline, and the weight limit, we chose 6061 aluminum for the majority of our chassis, and AR-500 steel for the weapon. Aluminum provides a structurally sound, yet lightweight metal while steel is used for the weapon only as this is the part that will take the most impact. Using these materials, we made sure to design parts with a uniform 2D profile, making them suitable for sheet metal fabrication, such as laser cutting or water jetting. This was done to cut costs as much as possible as making any 3D object out of metal would require a CNC and wasted stock material. Manufacturing it through these methods also ensures higher tolerances and more accurate dimensions. As shown in our final CAD assembly and part drawings in Appendix L, the inner side panels, outer side panels, bottom panel, back panel, and weapon body were all designed with these requirements in mind. Furthermore, the hole patterns and any mounting features were designed to adhere to specific requirements such as the edge edge distance, and minimum hole size, to allow these parts to be manufacturable. To further simplify the design, both the left and right inner and outer side panels were designed to be symmetrical. This allowed for a more robust method of manufacturing and allowed for ease of assembly when putting the battlebot together. Using 2D paneling introduces the problem of joining or assembling these panels securely. To overcome this, the main structure of the chassis was joined together with nut strips and standoffs. The nut strips allowed for the mounting of perpendicular panels at edges or vertices, while the standoffs allowed for structural integrity and distance between the side panels.

Utilizing these off-the-shelf components also allowed for easier manufacturing as all the panels and pieces designed simply had clearance holes. In addition, using these components simplified assembly drastically as nearly all the screws used fastened from the outside to one of these joining components allowing for screws to be easily accessible.

Another aspect of the design that allowed for easier assembly was the mounting of the motors. All three motors, the two drive motors and the weapon motor, were wall-mounted, or fastened through one of the side panels to threaded holes on the face of the motor. This allowed for fairly easy access to the motor screws for assembly and disassembly and did not require extraneous pieces to hold or clamp the motor down.

The most complex subsystem in the assembly was the weapon system. The weapon motor was connected to a small timing pulley which used a belt system to spin a larger timing pulley. This timing pulley was mounted to the weapon body using 4 clearance holes made through both the weapon body and the pulley. The weapon body and the pulley were both also designed to press fit around a 6mm bearing that fit on the weapon shift. This dead-axle weapon system ensured a smoother assembly process and fewer points of failure.

The last part of the design that we focused on to allow for better assembly was to create a thorough and detailed CAD. In the CAD assembly, we included all the parts for every subassembly, including off-the-shelf parts such as standoffs, nut strips, and fasteners. This allowed us to account for specific attributes such as the placements of certain components based on the ability to reach those components, the length of fasteners needed for different parts, and the interference of fasteners with any existing components.

VIII. Final Discussion And Recommendations

Our project for this battlebot encompassed significant design and research. We started with background research into battlebots, focusing on in-depth articles on both the hardware, electronics, and key design strategies that go into manufacturing successful battlebots. We also used guidance from experienced professionals with significant battlebots experience. Conducting interviews with these seasoned roboticists provided us with insight into specific features to incorporate into our bot such as speccing out high-quality ESCs or designing built-in slack-to-belt systems to allow it to take impact. With this research, we were able to form in-depth customer needs and then transform these into engineering requirements. We formed these customer needs and engineering requirements by implementing the most common guidelines and suggestions from our research while also taking into account the parameters given to us in the form of cost, weight, safety, and competition grading. These engineering specifications were detailed requirements needed from our robot with qualitative or quantitative target metrics, and a test for us to achieve these metrics. (Appendix D) This key design tool not only guided us in our final design but allowed us to systematically prove that our robot was up to specific standards and identify any customer needs we did not meet.

When comparing our final battlebot to the engineering requirements we established earlier, we conducted tests as specified in the table to verify that we met the specifications. Overall, we satisfied the majority of the engineering specifications but did fail to meet some due to specific design choices and restrictions. In the mobility section of Appendix D, we verified with external tools the max mobile capabilities of our robot, such as the max turning and weapon speed and the overall maximum linear speed. Due to the significant budget spent on speccing out high-quality electronics, we surpassed these metrics by far and this gave us a significant advantage in the competition. An interesting metric was the ability to drive upside down. With the initial design of 2” wheels and the weapon slightly offset in the vertical direction, we were unable to drive upside down and shifted our strategy to use our weapon to knock us upright. However, with the 3⅞” wheels, we were able to drive upside due to the higher ground clearance. This change is something we made to support a more wedge-like shape of the battlebot but also helped us meet this criteria. For the durability section, we met all the parameters set up for the battlebot. Primarily tested through FEA analysis on SolidWorks, our chassis and main structure were mainly manufactured from aluminum to allow us to meet these durability requirements, especially the force the chassis can take as this was critical to the performance of our bot. This also proved itself in the competitions as we were able to last multiple battles and took a significant amount of hits with little deformation. However, we did not meet the requirement to have our wheels covered. This was a design choice made as we chose higher quality more durable wheels that could take an impact. This allowed us to shift away from wheel guards to save weight and decreased the chance of an opponent using the geometry of a wheel guard to flip us. Similarly, we met all the safety requirements that allowed us to compete, such as the use of a manual disconnect and weapon safety lock. One parameter we did meet, but potentially needed to be reworked as a metric was the distance between the battery and the outermost wall. This shortcoming is discussed later in this section. Although we maintained our overall cost, we did not manufacture most of the battlebot in-house, which was a design choice made due to the material of most of our structure being metal. This allowed us to get many of the paneling and the weapon professionally made and allow for higher tolerances. Lastly, the battlebot overachieved for the damaged section. As seen in the battles we faced, we were able to inflict significant damage to many of the bots faced, disassembling structures and using the AR-500 weapon to shear other metal structures.

Overall, the battlebot performed remarkably well in the competition. The high torque drive motors allowed for increased speed and control of the battlebot, and the high speed of the weapon assembly caused a formidable vertical spinning weapon that earned us a bye in the first round. The quarter-finals and semi-finals of the competition went very well as the battlebot’s aluminum frame was able to take impact from the other battlebots with minimal damage. The bot won both of these rounds in under 25 seconds, delivering quick and fatal blows to significant parts of the other bot to disable motion on the opponent. The quick controls and spin-up of the weapon allowed us to take a more offensive approach and use our compact design and steel weapon to inflict damage while taking nearly no damage ourselves on the recoil. In the finals, we lost due to our battery being exposed, a prominent safety hazard. This revealed a major flaw in our design. Although the battery placement met the engineering requirements, the metric should have been set higher and the battery should have been placed in a more secure and less exposed location. In addition, the use of PLA and steel shims was designed to minimize the weight of the bot, but could have been switched to an aluminum wheel guard as the calculated weight was severely overestimated when compared to the real battlebot. For future improvements, this is a necessary feature we can include to ensure the safety of the bot and the bystanders and would have allowed us to potentially win the competition. In conclusion, we performed exceptionally well, with some key oversights that we can learn and improve from.

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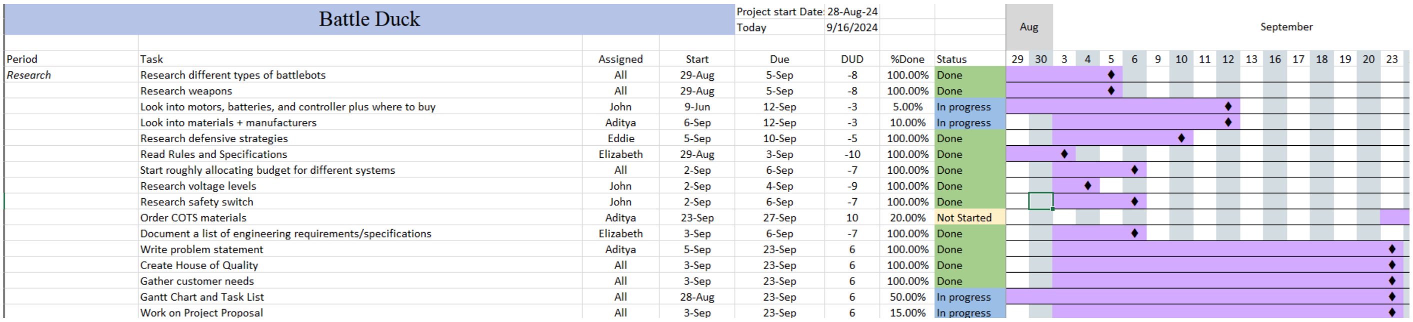
Appendix A:

Gantt Chart

Figure A1

Phase 1: Research Gantt Chart



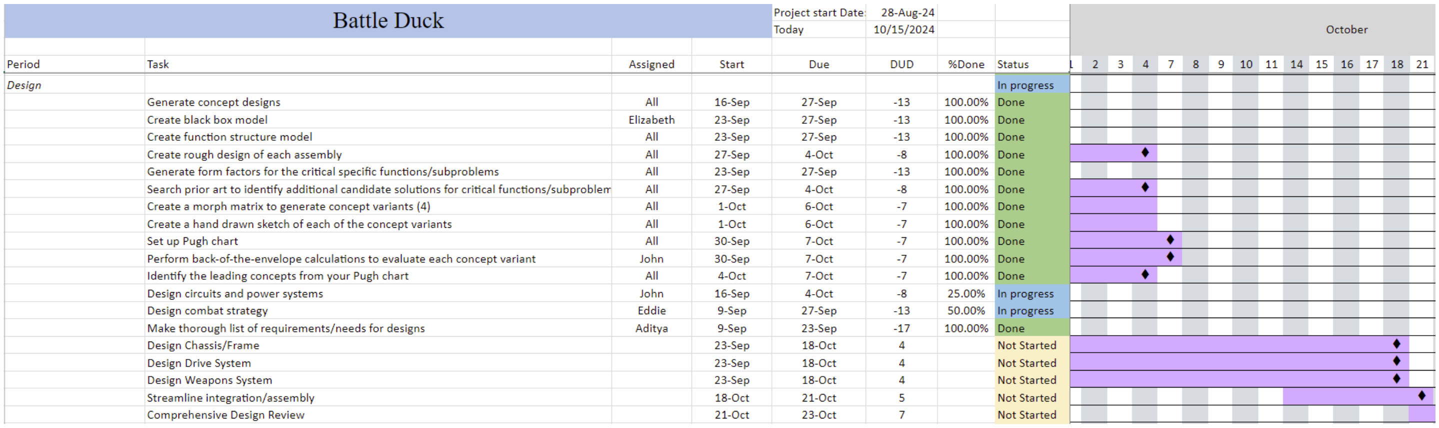
Battle Duck

Project start Date: 28-Aug-24
Today 9/16/2024

Period	Task	Assigned	Start	Due	DUD	%Done	Status
Research	Research different types of battlebots	All	29-Aug	5-Sep	-8	100.00%	Done
	Research weapons	All	29-Aug	5-Sep	-8	100.00%	Done
	Look into motors, batteries, and controller plus where to buy	John	9-Jun	12-Sep	-3	5.00%	In progress
	Look into materials + manufacturers	Aditya	6-Sep	12-Sep	-3	10.00%	In progress
	Research defensive strategies	Eddie	5-Sep	10-Sep	-5	100.00%	Done
	Read Rules and Specifications	Elizabeth	29-Aug	3-Sep	-10	100.00%	Done
	Start roughly allocating budget for different systems	All	2-Sep	6-Sep	-7	100.00%	Done
	Research voltage levels	John	2-Sep	4-Sep	-9	100.00%	Done
	Research safety switch	John	2-Sep	6-Sep	-7	100.00%	Done
	Order COTS materials	Aditya	23-Sep	27-Sep	10	20.00%	Not Started
	Document a list of engineering requirements/specifications	Elizabeth	3-Sep	6-Sep	-7	100.00%	Done
	Write problem statement	Aditya	5-Sep	23-Sep	6	100.00%	Done
	Create House of Quality	All	3-Sep	23-Sep	6	100.00%	Done
	Gather customer needs	All	3-Sep	23-Sep	6	100.00%	Done
	Gantt Chart and Task List	All	28-Aug	23-Sep	6	50.00%	In progress
	Work on Project Proposal	All	3-Sep	23-Sep	6	15.00%	In progress

Figure A2

Phase 2: Design Gantt Chart



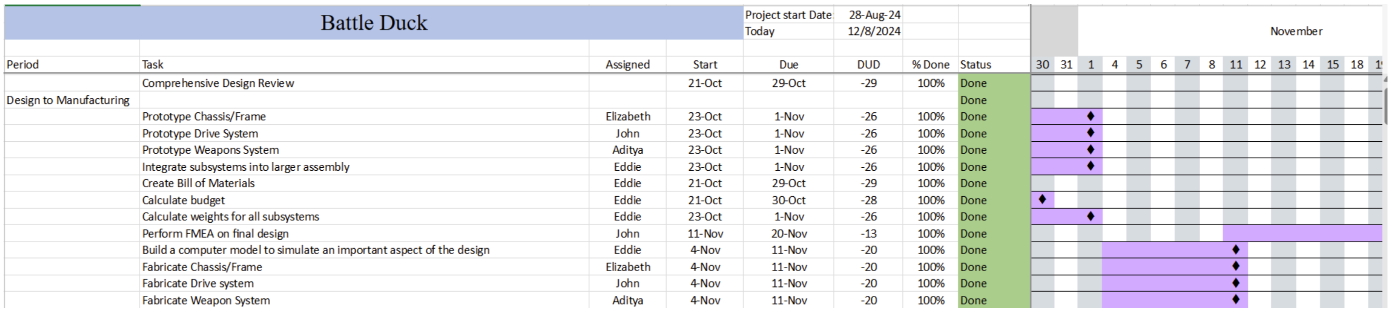
Battle Duck

Project start Date: 28-Aug-24
Today 10/15/2024

Period	Task	Assigned	Start	Due	DUD	%Done	Status
Design							In progress
	Generate concept designs	All	16-Sep	27-Sep	-13	100.00%	Done
	Create black box model	Elizabeth	23-Sep	27-Sep	-13	100.00%	Done
	Create function structure model	All	23-Sep	27-Sep	-13	100.00%	Done
	Create rough design of each assembly	All	27-Sep	4-Oct	-8	100.00%	Done
	Generate form factors for the critical specific functions/subproblems	All	23-Sep	27-Sep	-13	100.00%	Done
	Search prior art to identify additional candidate solutions for critical functions/subproblem	All	27-Sep	4-Oct	-8	100.00%	Done
	Create a morph matrix to generate concept variants (4)	All	1-Oct	6-Oct	-7	100.00%	Done
	Create a hand drawn sketch of each of the concept variants	All	1-Oct	6-Oct	-7	100.00%	Done
	Set up Pugh chart	All	30-Sep	7-Oct	-7	100.00%	Done
	Perform back-of-the-envelope calculations to evaluate each concept variant	John	30-Sep	7-Oct	-7	100.00%	Done
	Identify the leading concepts from your Pugh chart	All	4-Oct	7-Oct	-7	100.00%	Done
	Design circuits and power systems	John	16-Sep	4-Oct	-8	25.00%	In progress
	Design combat strategy	Eddie	9-Sep	27-Sep	-13	50.00%	In progress
	Make thorough list of requirements/needs for designs	Aditya	9-Sep	23-Sep	-17	100.00%	Done
	Design Chassis/Frame		23-Sep	18-Oct	4		Not Started
	Design Drive System		23-Sep	18-Oct	4		Not Started
	Design Weapons System		23-Sep	18-Oct	4		Not Started
	Streamline integration/assembly		18-Oct	21-Oct	5		Not Started
	Comprehensive Design Review		21-Oct	23-Oct	7		Not Started

Figure A3

Phase 3: Design to Manufacturing Gantt Chart



Battle Duck

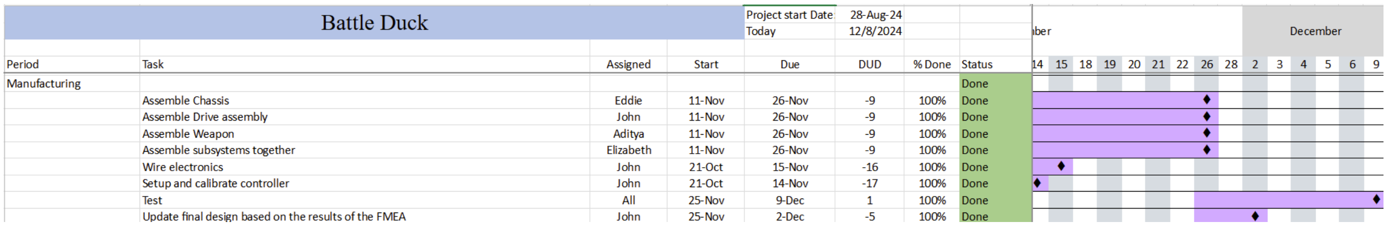
Project start Date 28-Aug-24
Today 12/8/2024

November
30 31 1 4 5 6 7 8 11 12 13 14 15 18 1

Period	Task	Assigned	Start	Due	DUD	% Done	Status
	Comprehensive Design Review		21-Oct	29-Oct	-29	100%	Done
Design to Manufacturing							Done
	Prototype Chassis/Frame	Elizabeth	23-Oct	1-Nov	-26	100%	Done
	Prototype Drive System	John	23-Oct	1-Nov	-26	100%	Done
	Prototype Weapons System	Aditya	23-Oct	1-Nov	-26	100%	Done
	Integrate subsystems into larger assembly	Eddie	23-Oct	1-Nov	-26	100%	Done
	Create Bill of Materials	Eddie	21-Oct	29-Oct	-29	100%	Done
	Calculate budget	Eddie	21-Oct	30-Oct	-28	100%	Done
	Calculate weights for all subsystems	Eddie	23-Oct	1-Nov	-26	100%	Done
	Perform FMEA on final design	John	11-Nov	20-Nov	-13	100%	Done
	Build a computer model to simulate an important aspect of the design	Eddie	4-Nov	11-Nov	-20	100%	Done
	Fabricate Chassis/Frame	Elizabeth	4-Nov	11-Nov	-20	100%	Done
	Fabricate Drive system	John	4-Nov	11-Nov	-20	100%	Done
	Fabricate Weapon System	Aditya	4-Nov	11-Nov	-20	100%	Done

Figure A4

Phase 4: Manufacturing Gantt Chart



Battle Duck

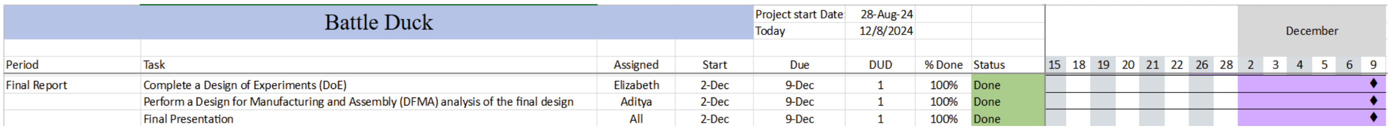
Project start Date 28-Aug-24
Today 12/8/2024

ber
December
14 15 18 19 20 21 22 26 28 2 3 4 5 6 9

Period	Task	Assigned	Start	Due	DUD	% Done	Status
Manufacturing							Done
	Assemble Chassis	Eddie	11-Nov	26-Nov	-9	100%	Done
	Assemble Drive assembly	John	11-Nov	26-Nov	-9	100%	Done
	Assemble Weapon	Aditya	11-Nov	26-Nov	-9	100%	Done
	Assemble subsystems together	Elizabeth	11-Nov	26-Nov	-9	100%	Done
	Wire electronics	John	21-Oct	15-Nov	-16	100%	Done
	Setup and calibrate controller	John	21-Oct	14-Nov	-17	100%	Done
	Test	All	25-Nov	9-Dec	1	100%	Done
	Update final design based on the results of the FMEA	John	25-Nov	2-Dec	-5	100%	Done

Figure A5

Phase 5: Final Report Gantt Chart



Battle Duck

Project start Date 28-Aug-24
Today 12/8/2024

December
15 18 19 20 21 22 26 28 2 3 4 5 6 9

Period	Task	Assigned	Start	Due	DUD	% Done	Status
Final Report	Complete a Design of Experiments (DoE)	Elizabeth	2-Dec	9-Dec	1	100%	Done
	Perform a Design for Manufacturing and Assembly (DFMA) analysis of the final design	Aditya	2-Dec	9-Dec	1	100%	Done
	Final Presentation	All	2-Dec	9-Dec	1	100%	Done

Appendix B:

Task List

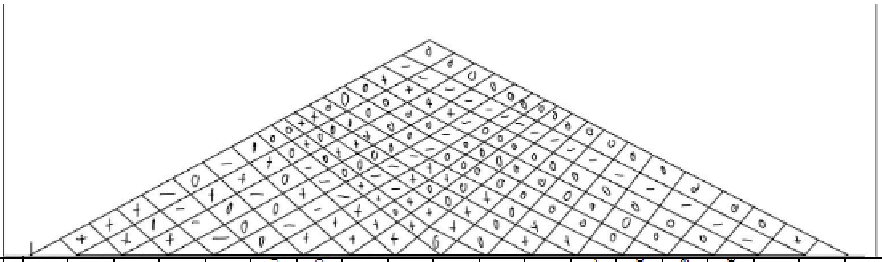
Task	Responsibility
Research	
Research different types of battlebots	All
Research weapons	All
Look into motors, batteries, and controller plus where to buy	John
Look into materials + manufacturers	Aditya
Research defensive strategies	Eddie
Read Rules and Specifications	Elizabeth
Start roughly allocating budget for different systems	All
Research voltage levels	John
Research safety switch	John
Order COTS materials	Aditya
Document a list of engineering requirements/specifications	Elizabeth
Write problem statement	Aditya
Create House of Quality	All
Gather customer needs	All
Gantt Chart and Task List	All
Work on Project Proposal	All
Design	
Generate concept designs	All

Create black box model	Elizabeth
Create function structure model	All
Create rough design of each assembly	All
Generate form factors for the critical specific functions/subproblems	All
Search prior art to identify additional candidate solutions for critical functions/subproblems	All
Create a morph matrix to generate concept variants (4)	All
Create a hand drawn sketch of each of the concept variants	All
Set up Pugh chart	All
Perform back-of-the-envelope calculations to evaluate each concept variant	John
Identify the leading concepts from your Pugh chart	All
Design circuits and power systems	John
Design combat strategy	Eddie
Make thorough list of requirements/needs for designs	Aditya
Design Chassis/Frame	Elizabeth
Design Drive System	John
Design Weapons System	Aditya
Streamline integration/assembly	Eddie
Comprehensive Design Review	All
Design to Manufacturing	
Prototype Chassis/Frame	Elizabeth
Prototype Drive System	John
Prototype Weapons System	Aditya
Integrate subsystems into larger assembly	Eddie
Create Bill of Materials	Eddie
Calculate budget	Eddie
Calculate weights for all subsystems	Eddie
Perform FMEA on final design	John

Build a computer model to simulate an important aspect of the design	Eddie
Fabricate Chassis/Frame	Elizabeth
Fabricate Drive system	John
Fabricate Weapon System	Aditya
Manufacturing	
Assemble Chassis	Eddie
Assemble Drive assembly	John
Assemble Weapon	Aditya
Assemble subsystems together	Elizabeth
Wire electronics	John
Setup and calibrate controller	John
Test	All
Update final design based on the results of the FMEA	John
Final Report	
Complete a Design of Experiments (DoE)	Elizabeth
Perform a Design for Manufacturing and Assembly (DFMA) analysis of the final design	Aditya
Final Presentation	All

Appendix C:

House of Quality



			Relative Importance	Force the chassis can take	Are electronics secured	Damage robot can take	Wheel covered	Weight	Latency between controll	Max turning speed/weapo	Can turn	Max speed	Can drive upside down?	Damage caused?	Can flip opponent	Percent damage caused?	Quantity of manual dis	Quantity of physical we	Distance between batt	Cost	Made on campus	Competitor A: Competitor B: Competitor C: Our Desired Product*		
		Direction of Improvement		↑	⊙	↑	↑	↓	↓	↑	⊙	↑	⊙	↑	⊙	↑	⊙	⊙	↑	↓	↑	Horns of Fury	Tombstone	Scampi
Customer Needs	Durability	Frame/chassis is structural sound	5	⊙	⊙	⊙	△	△		△	△		△					△		⊙		5	5	2
		Electronics are secured	4	△	⊙	⊙		△	○	△			△				△		⊙			3	3	4
		Take damage witout sacrificing function	4	⊙	⊙	⊙	⊙	⊙	△					○		△			⊙	⊙		5	3	3
		Wheels protected	3	○		△	⊙	△		○	⊙		⊙							△		5	1	1
		Light weight	5	○				⊙		△	△						△	△		△	△	2	2	5
	Mobility	Responds to controller	3			○			⊙	⊙	△	○	△		⊙	△						2	2	3
		Minimize gyroscopic effect	4					⊙		⊙	△	△										2	4	3
		Turn in place	2		△		○			⊙	⊙	△	⊙		△					○		4	4	3
		Out maneuver opponent	2		△	△	○	⊙	⊙	⊙	⊙	⊙	△	△	⊙	⊙						3	3	2
		Can drive upside down	3		⊙				△		⊙		⊙							○		5	1	1
	Damage	Damage mobility systems	4					△			○		○	⊙		⊙						4	5	4
		Flips other robot	4					⊙			○		○	△	⊙	⊙						3	5	3
		Damage weapons system	2					△			○	○	○	⊙		⊙						2	5	4
	Safety	Has a manual disconnect for electricity	4		○			○									⊙			○		5	3	5
		Has physical weapon lock	5					○										⊙	⊙	○		5	3	4
		Protect battery	5		⊙			△											⊙	○		3	3	2
	Cost	Under $300	5	△																⊙	△	1	1	4
		Prioritize campus resources	2																	⊙	⊙	3	1	4
		Units		KN	Y/N	%	%	lbs	ms	rps	Y/N	m/s	Y/N	%	Y/N	%	Num	Num	mm	$	%			
		Target Value		1	Y	30	80	3	500	2	Y	2.5	Y	70	Y	70	1	1	5	300	50			
		Horns of Fury			N		100	15	50		Y	5	Y	50	Y		7	1	3	15k				
		Tombstone					0	250			Y		N	99	Y					15K				
		Scampi			Y	20	0	3		20	Y	1.22	N		Y							Max Sum		
		Absolute Importance		132	205	135	82	249	70	144	151	41	124	76	87	129	63	75	167	187	48	2165		
		Relative Importance		0.06	0.09	0.06	0.04	0.12	0.03	0.07	0.07	0.02	0.06	0.04	0.04	0	0.03	0.03	0.08	0.09	0.02			
		Ranked Importance		8	2	7	12	1	15	6	5	18	10	13	11	9	16	14	4	3	17			

Appendix D:

Engineering Requirements

Date	**Imp.**	**Specification**	**Target**	**Resp.**	**Test/Verification**	**Source**
	Durability					
10/21	5	Force the chassis can take	1 KN	EF	Verify with FEA	RoboJackets Guide
10/21	4	Are electronics secured	Yes	JL	Shake robot	Team
10/23	4	Damage robot can take	30%	EC	Verify with FEA	Interviewee
10/30	3	Wheel covered	80%	AR	Verify with engineering drawings	Interviewee
10/30	5	Weight	3 lbs	EC	Verify with scale	SPARC
	Mobility					
	3	Latency between controller and robot	500 ms	JL	Verify with timer	Interviewee
	4	Max turning speed/weapon speed ratio	2 rps	JL	Verify with tachometer	RoboJackets Guide
	2	Can turn	Yes	EF	Verify during drive testing	Team
	2	Max speed	2.5 m/s	EC	Verify with a time/distance test	Combat Robot Field Guide
	3	Can drive upside down?	Yes	EC	Verify by drive testing the robot upside down	Texas Combat Robotics
	Damage					
	4	Damage caused?	70%	AR	Verify in combat	RoboJackets Guide
	4	Can flip opponent	Yes	AR	Verify in combat	Interviewe

						e
	2	Percent damage caused?	70%	EF	Verify in combat	Team
	Safety					
	4	Quantity of manual disconnects	1	JL	Count disconnects	SPARC
	5	Quantity of physical weapon locks	1	JL	Count weapon locks	SPARC
	5	Distance between battery and outermost wall	5mm	JL	Verify with calipers	SPARC/Team
	Cost					
	5	Cost	$300	AR	Verify with BOM	Professor Schauer
	2	Made on campus	50%	EF	Verify during manufacturing	Team

EF = Eddie Flores
JL = John Lyle
EC = Elizabeth Cazes
AR = Aditya Rao

Appendix E:

Functional Models

Figure E1:

Black Box Model

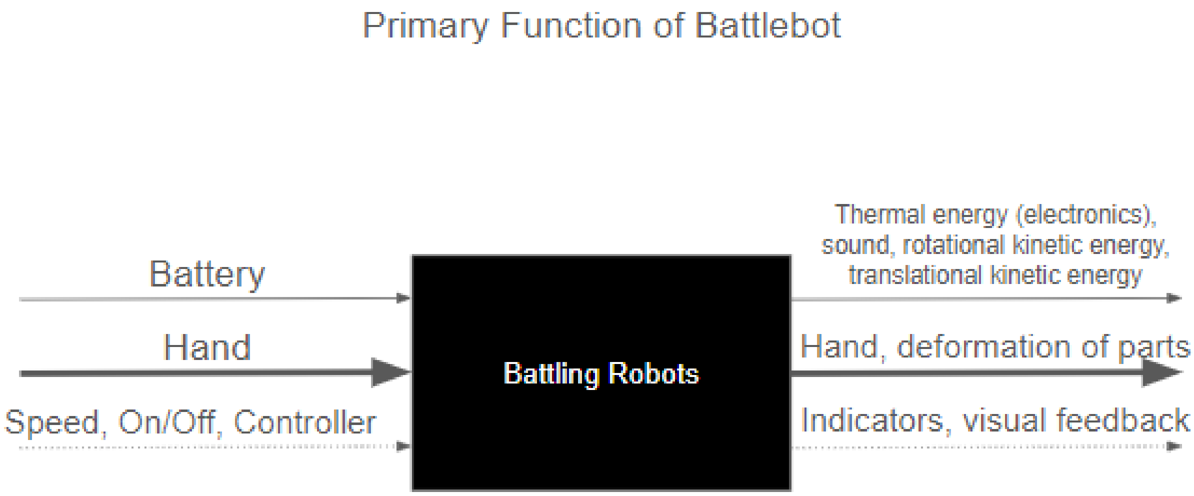
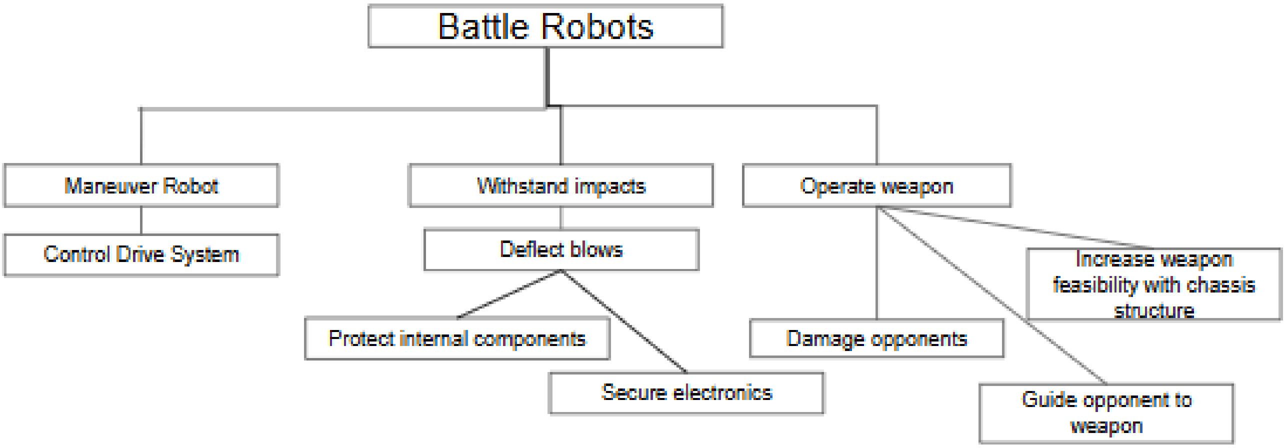


Figure E2:

Function Tree



Appendix F:

Concept generation

Figure F1:

Mindmap

Figure F2:

6-3-5 method 1

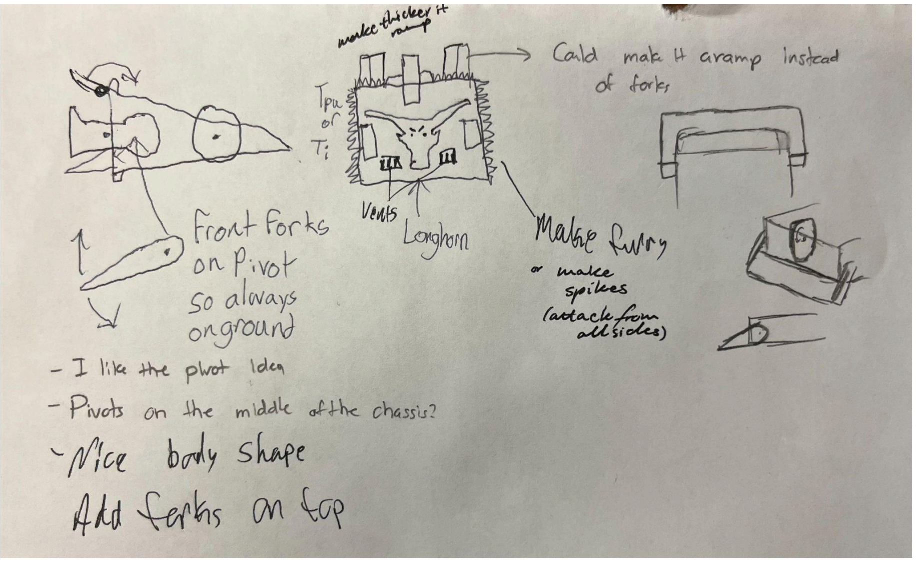


Figure F3:

6-3-5 method 2 & 3

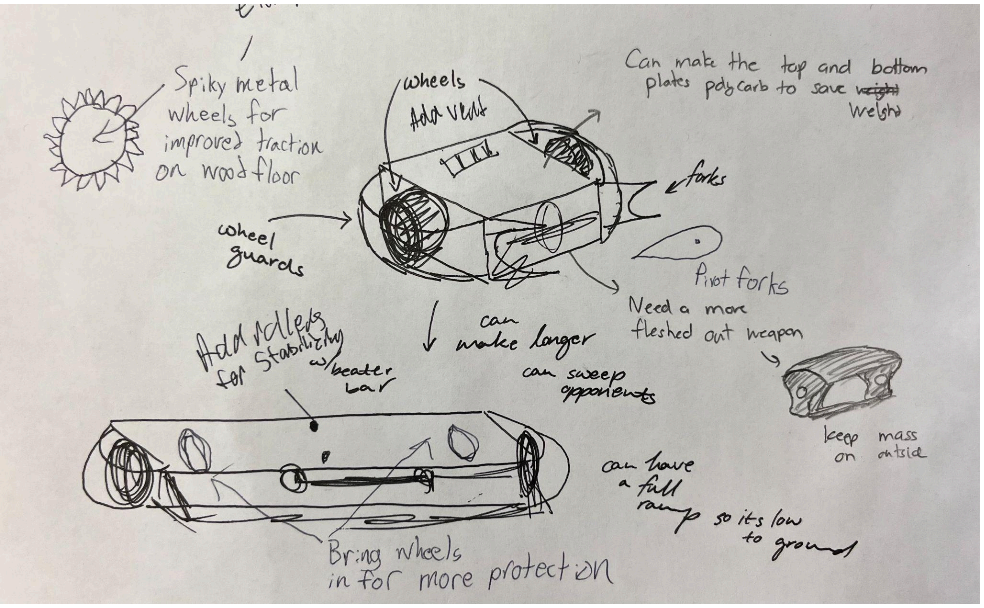


Figure F4:

6-3-5 method 4

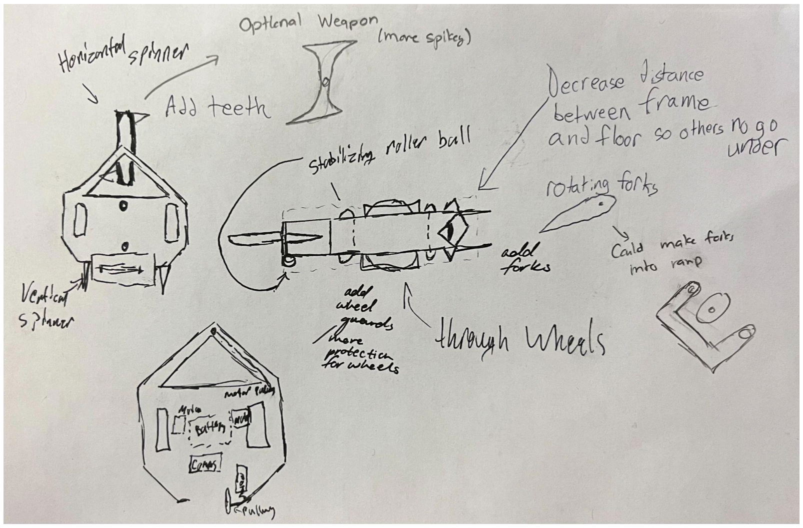


Figure F5:

6-3-5 method 5

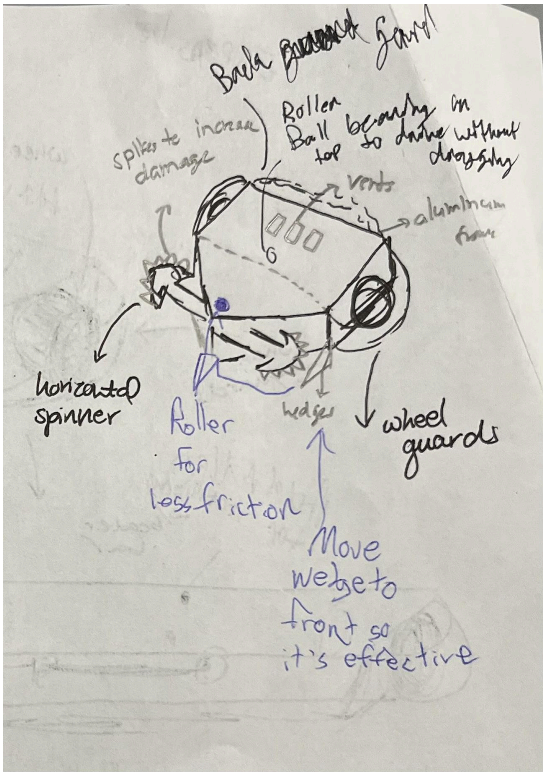


Figure F6:

6-3-5 method 6 & 7

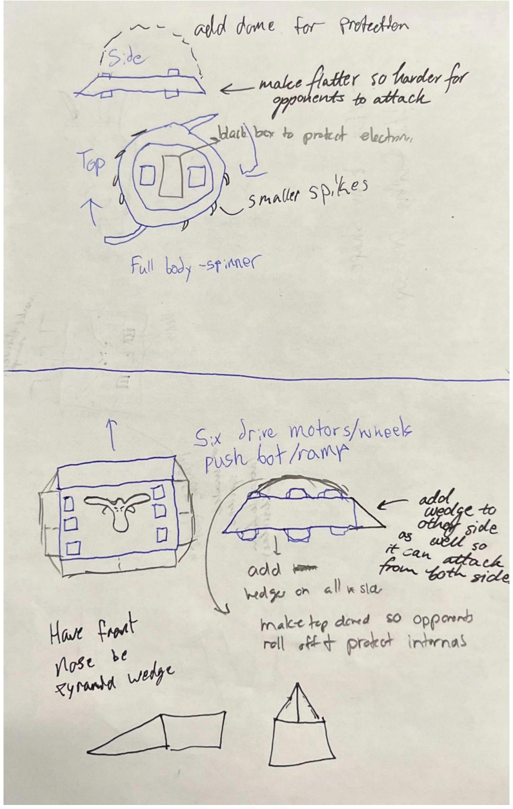


Figure F7:

6-3-5 method 8 & 9

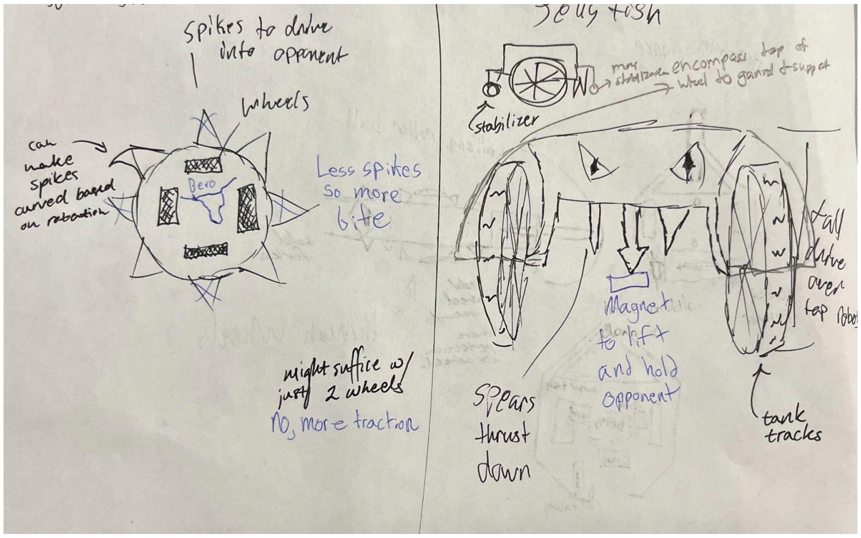


Figure F8:

6-3-5 method 10 & 11

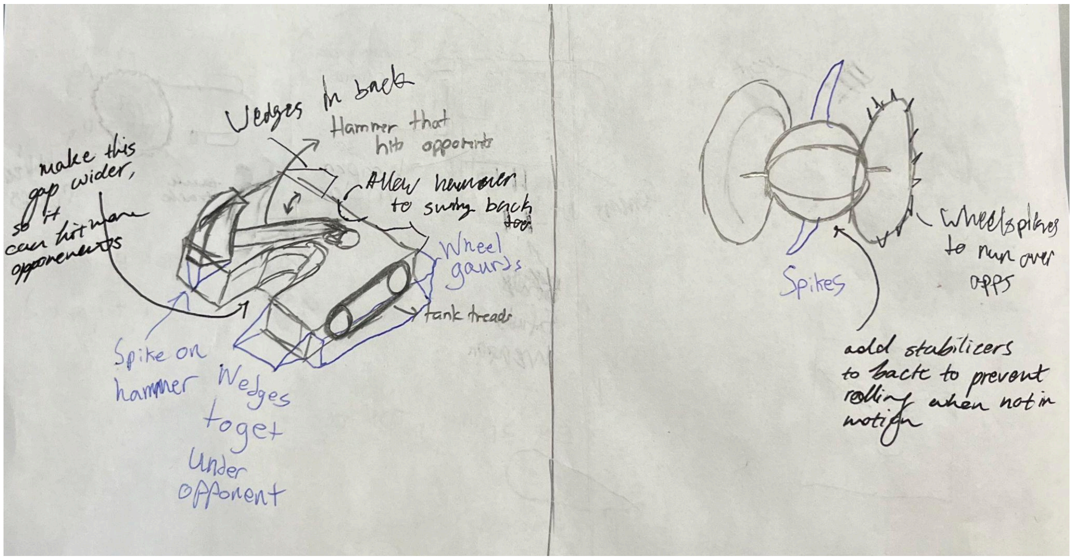


Figure F9:

6-3-5 method 12

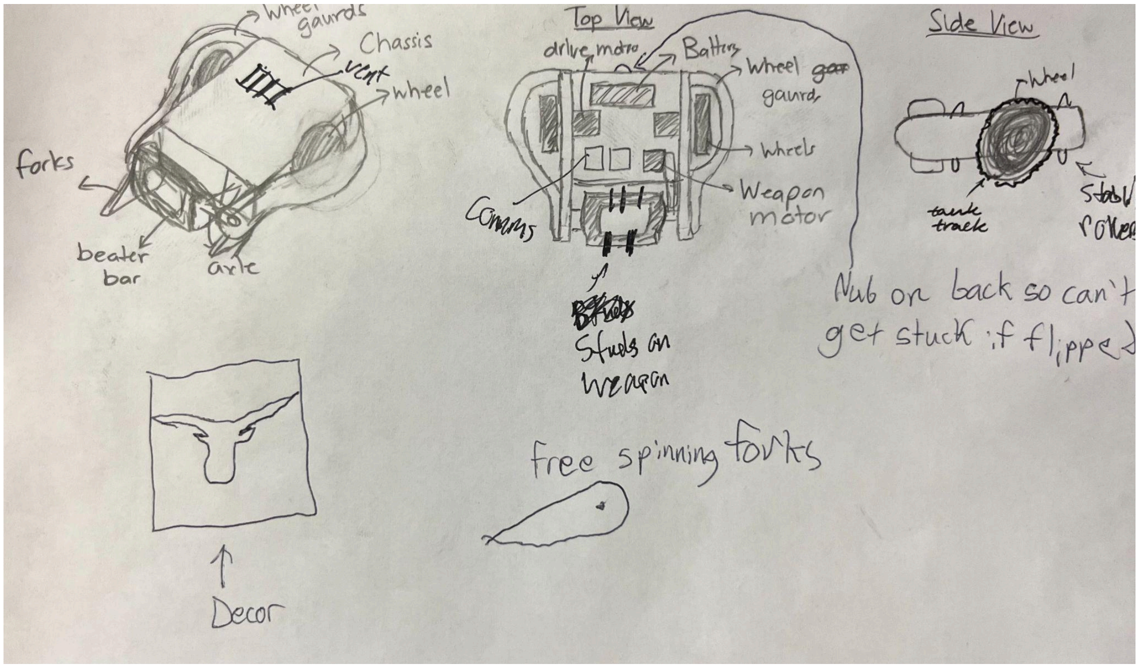
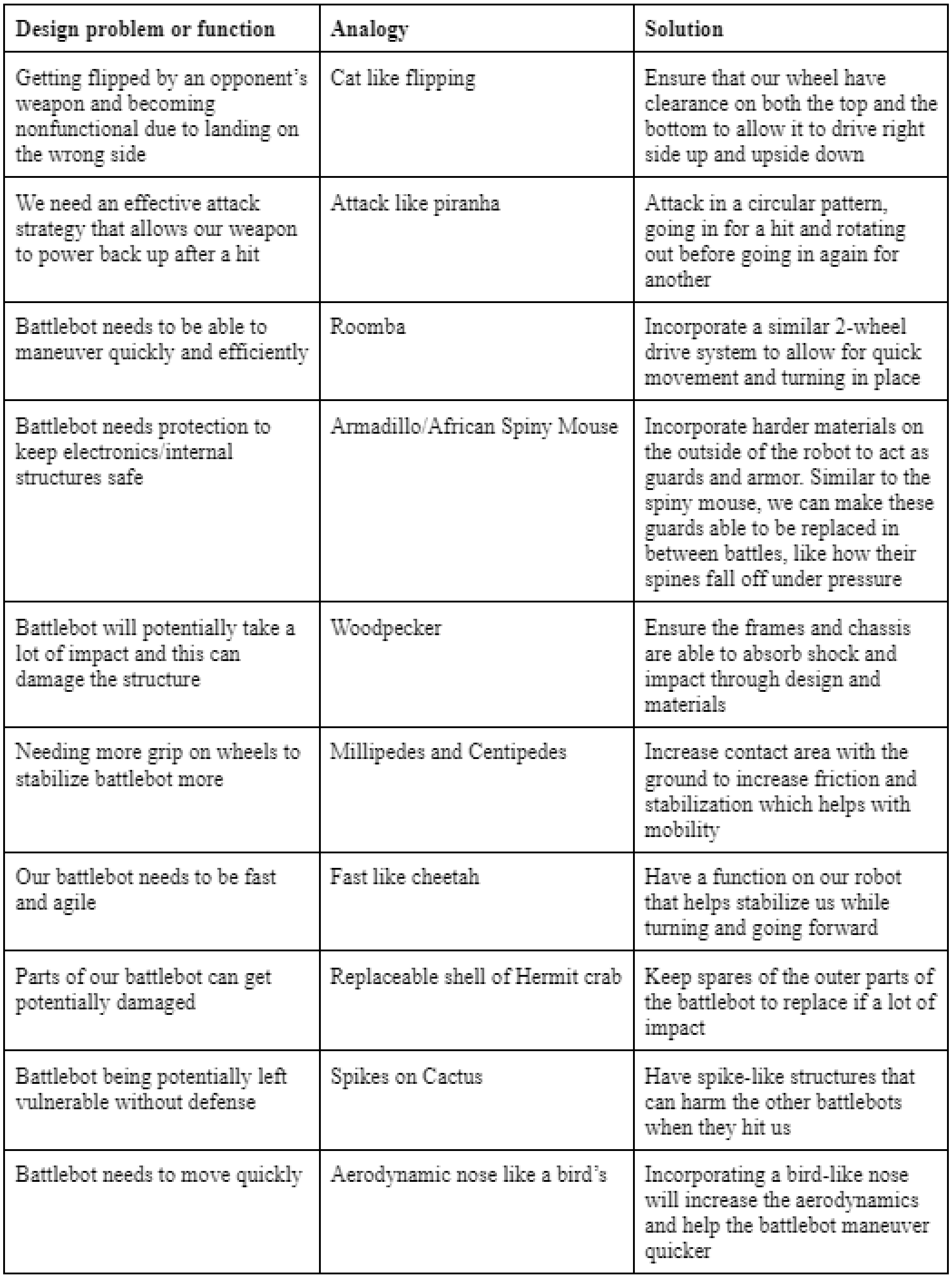


Figure F10:

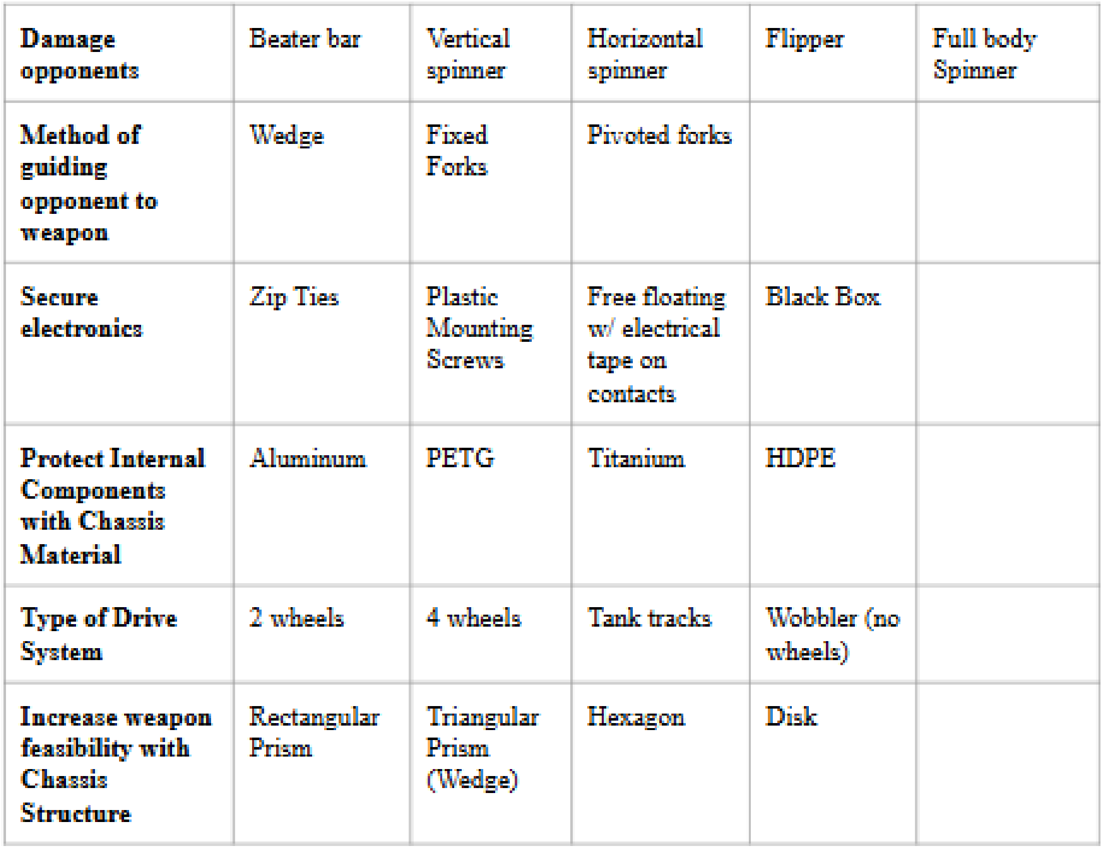
Design by Analogy



Design problem or function	Analogy	Solution
Getting flipped by an opponent's weapon and becoming nonfunctional due to landing on the wrong side	Cat like flipping	Ensure that our wheel have clearance on both the top and the bottom to allow it to drive right side up and upside down
We need an effective attack strategy that allows our weapon to power back up after a hit	Attack like piranha	Attack in a circular pattern, going in for a hit and rotating out before going in again for another
Battlebot needs to be able to maneuver quickly and efficiently	Roomba	Incorporate a similar 2-wheel drive system to allow for quick movement and turning in place
Battlebot needs protection to keep electronics/internal structures safe	Armadillo/African Spiny Mouse	Incorporate harder materials on the outside of the robot to act as guards and armor. Similar to the spiny mouse, we can make these guards able to be replaced in between battles, like how their spines fall off under pressure
Battlebot will potentially take a lot of impact and this can damage the structure	Woodpecker	Ensure the frames and chassis are able to absorb shock and impact through design and materials
Needing more grip on wheels to stabilize battlebot more	Millipedes and Centipedes	Increase contact area with the ground to increase friction and stabilization which helps with mobility
Our battlebot needs to be fast and agile	Fast like cheetah	Have a function on our robot that helps stabilize us while turning and going forward
Parts of our battlebot can get potentially damaged	Replaceable shell of Hermit crab	Keep spares of the outer parts of the battlebot to replace if a lot of impact
Battlebot being potentially left vulnerable without defense	Spikes on Cactus	Have spike-like structures that can harm the other battlebots when they hit us
Battlebot needs to move quickly	Aerodynamic nose like a bird's	Incorporating a bird-like nose will increase the aerodynamics and help the battlebot maneuver quicker

Appendix G:

Morph Matrix



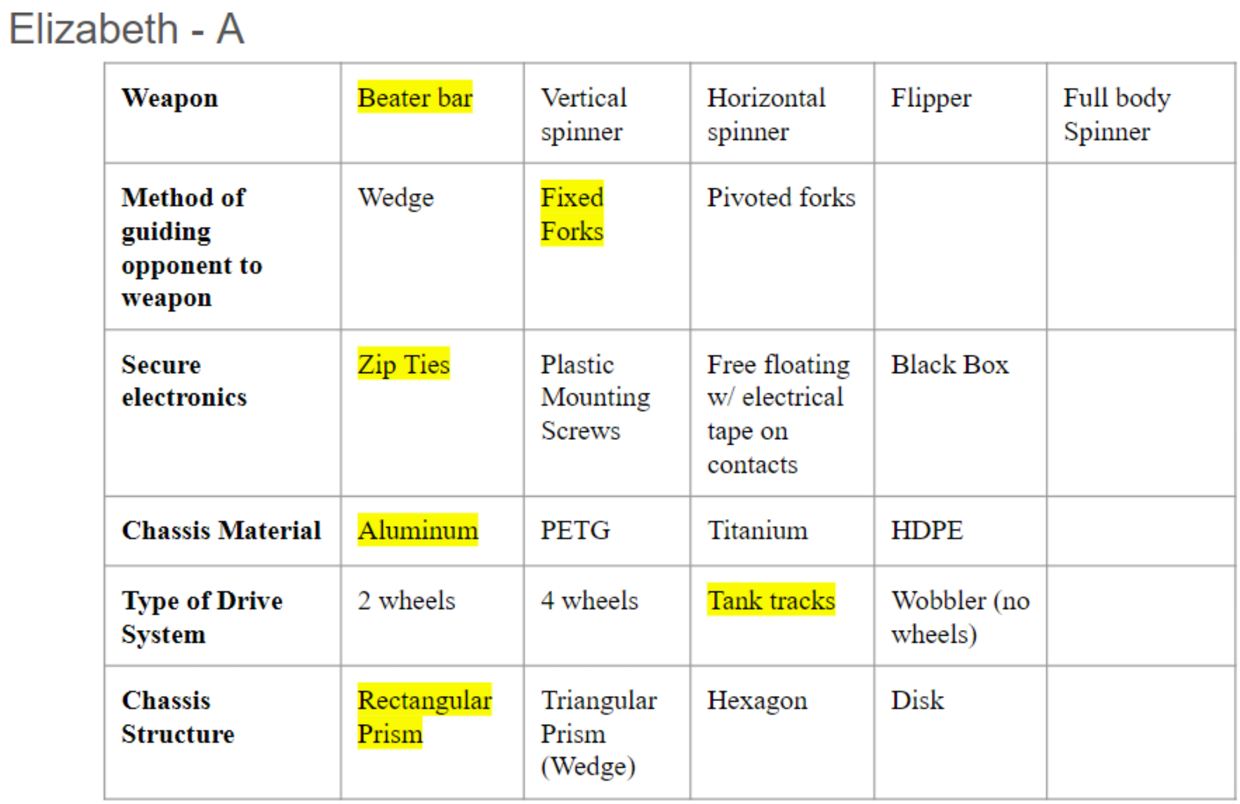
Damage opponents	Beater bar	Vertical spinner	Horizontal spinner	Flipper	Full body Spinner
Method of guiding opponent to weapon	Wedge	Fixed Forks	Pivoted forks		
Secure electronics	Zip Ties	Plastic Mounting Screws	Free floating w/ electrical tape on contacts	Black Box	
Protect Internal Components with Chassis Material	Aluminum	PETG	Titanium	HDPE	
Type of Drive System	2 wheels	4 wheels	Tank tracks	Wobbler (no wheels)	
Increase weapon feasibility with Chassis Structure	Rectangular Prism	Triangular Prism (Wedge)	Hexagon	Disk	

Appendix H:

Distinct Morph Matrix Concepts

Figure H1:

Morph Matrix - Elizabeth



Elizabeth - A

Weapon	Beater bar	Vertical spinner	Horizontal spinner	Flipper	Full body Spinner
Method of guiding opponent to weapon	Wedge	Fixed Forks	Pivoted forks		
Secure electronics	Zip Ties	Plastic Mounting Screws	Free floating w/ electrical tape on contacts	Black Box	
Chassis Material	Aluminum	PETG	Titanium	HDPE	
Type of Drive System	2 wheels	4 wheels	Tank tracks	Wobbler (no wheels)	
Chassis Structure	Rectangular Prism	Triangular Prism (Wedge)	Hexagon	Disk	

Figure H2:

Concept Drawing - Elizabeth

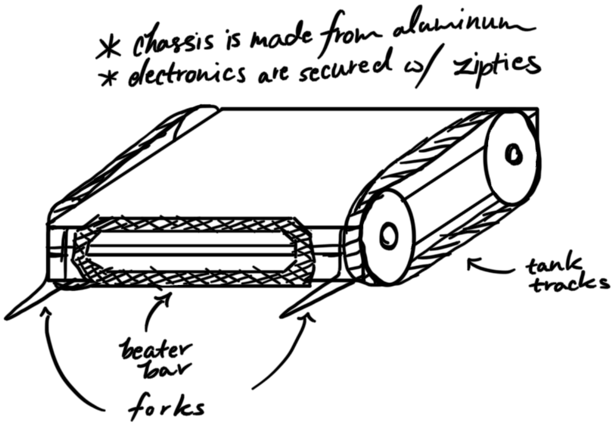


Figure H3:

Morph Matrix - Aditya

Aditya - B

Weapon	Beater bar	Vertical spinner	Horizontal spinner	Flipper	Shell spinner
Method of guiding opponent to weapon	Wedge	Fixed Forks	Pivoted forks		
Secure electronics	Zip Ties	Plastic Mounting Screws	Free floating w/ electrical tape on contacts	Black Box	
Chassis Material	Aluminum	PETG	Titanium	HDPE	
Type of Drive System	2 wheels	4 wheels	Tank tracks	Wobbler (no wheels)	
Chassis Structure	Rectangular Prism	Triangular Prism (Wedge)	Hexagon	Disk	

Figure H4:

Concept Drawing - Aditya

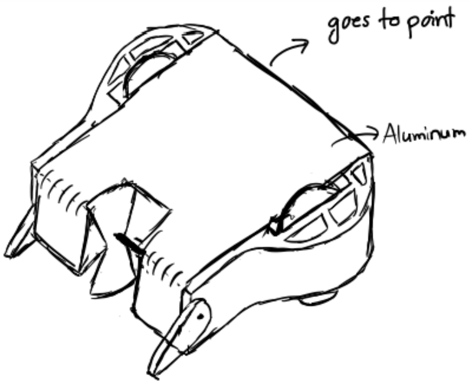
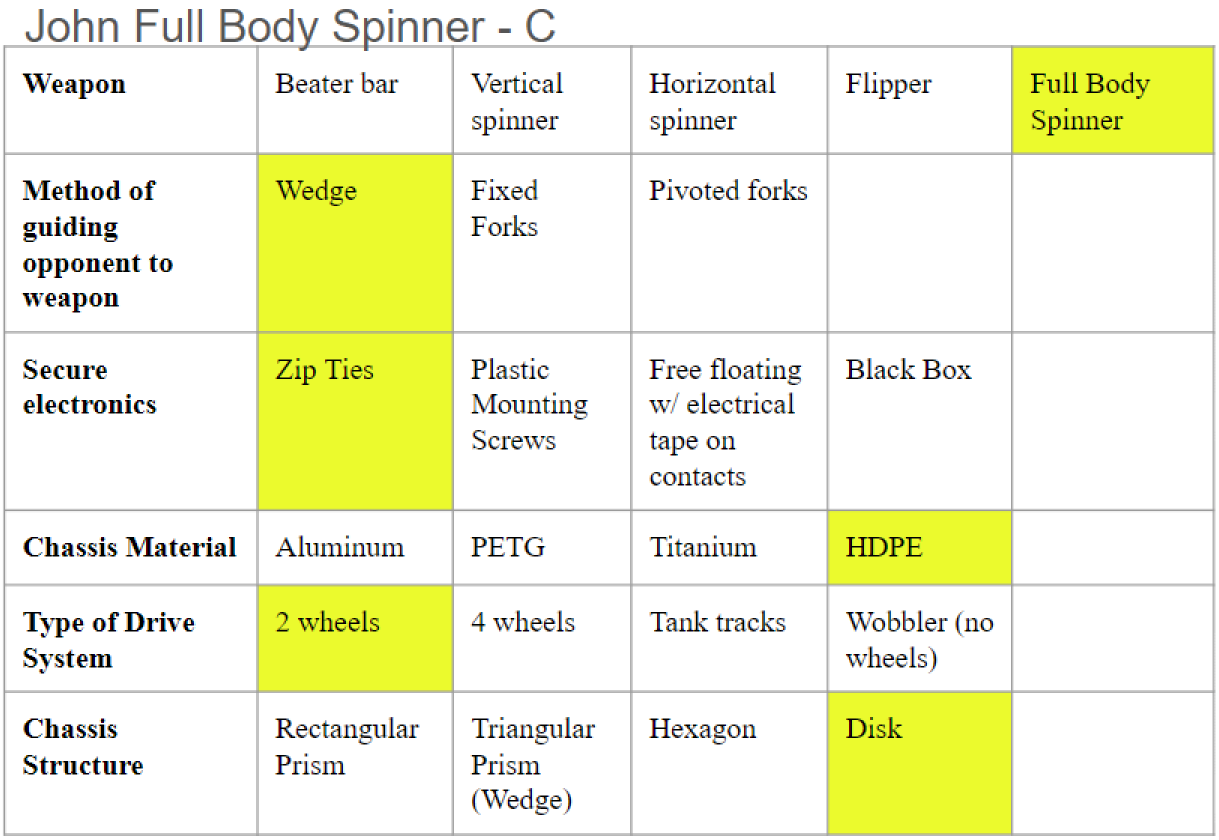


Figure H5:

Morph Matrix - John



John Full Body Spinner - C

Weapon	Beater bar	Vertical spinner	Horizontal spinner	Flipper	Full Body Spinner
Method of guiding opponent to weapon	Wedge	Fixed Forks	Pivoted forks		
Secure electronics	Zip Ties	Plastic Mounting Screws	Free floating w/ electrical tape on contacts	Black Box	
Chassis Material	Aluminum	PETG	Titanium	HDPE	
Type of Drive System	2 wheels	4 wheels	Tank tracks	Wobbler (no wheels)	
Chassis Structure	Rectangular Prism	Triangular Prism (Wedge)	Hexagon	Disk	

Figure H6:

Concept Drawing: John

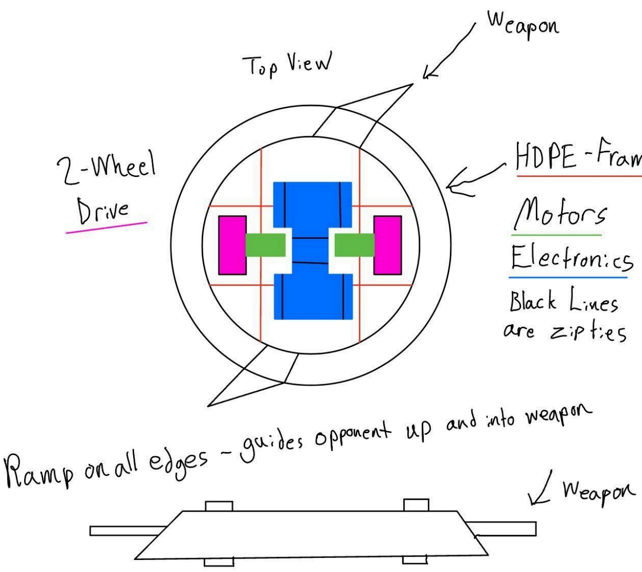
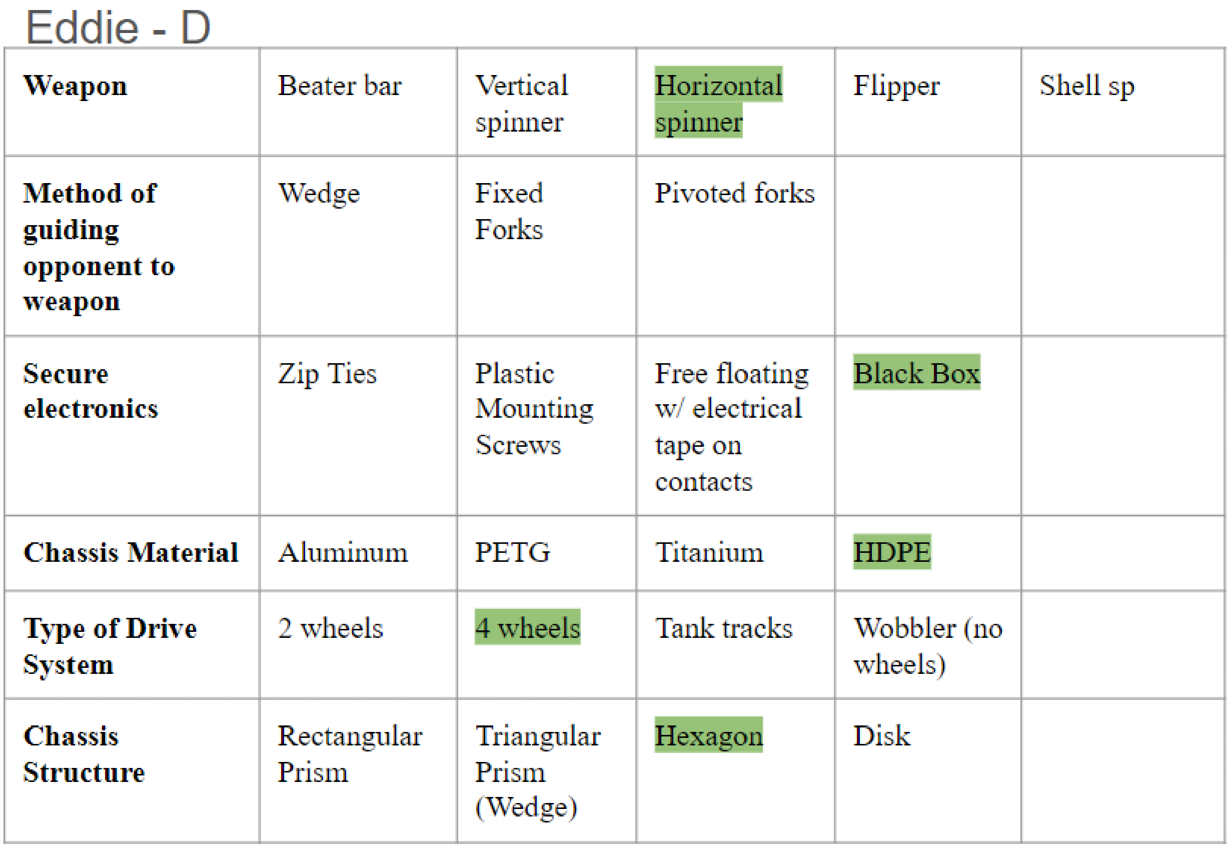


Figure H7:

Morph Matrix - Edd



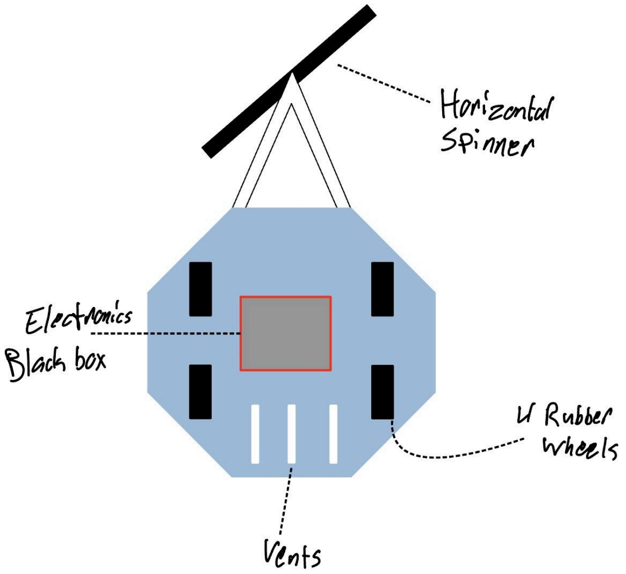
Eddie - D

Weapon	Beater bar	Vertical spinner	Horizontal spinner	Flipper	Shell sp
Method of guiding opponent to weapon	Wedge	Fixed Forks	Pivoted forks		
Secure electronics	Zip Ties	Plastic Mounting Screws	Free floating w/ electrical tape on contacts	Black Box	
Chassis Material	Aluminum	PETG	Titanium	HDPE	
Type of Drive System	2 wheels	4 wheels	Tank tracks	Wobbler (no wheels)	
Chassis Structure	Rectangular Prism	Triangular Prism (Wedge)	Hexagon	Disk	

ie

Figure H8:

Concept Drawing: Eddie



Appendix I:

Back of Envelope Calculations

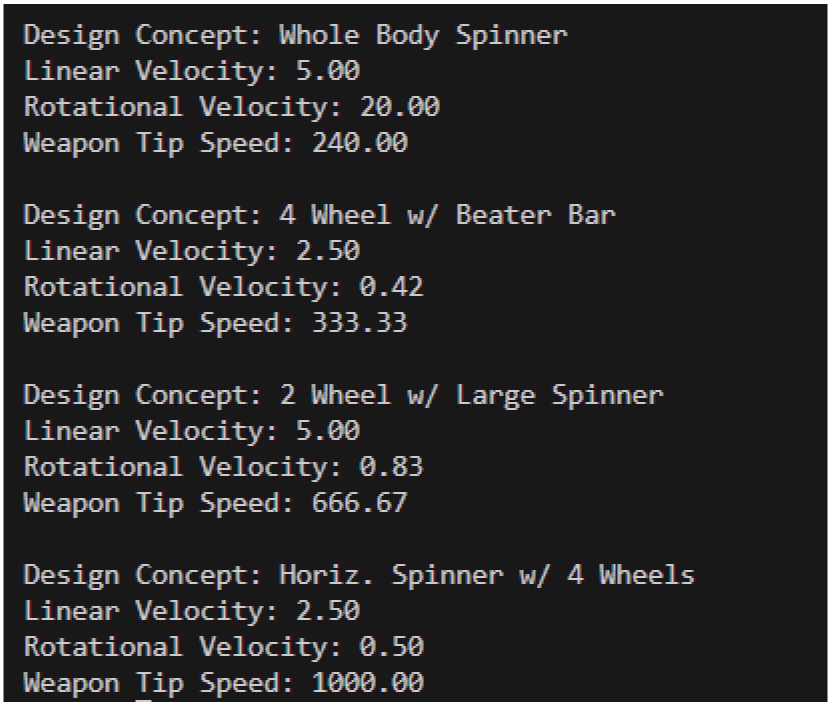
Figure I1:

Calculation Code

```python
# Design Variables
twoWheelRad = 3
fourWheelRad = 1.5
wholeBodyRad = 12
bBarRad = 2
bigSpinRad = 4
horizSpinnerRad = 6

# Common Design Variables

driveRPM = 100
weaponRPM = 10000
wholeDriveRPM = 2000

# Conversion Factors

def linearVelo(rpm, radius):
    return rpm * radius / 60
def rotationalVelo(rpm, radius, w2wdist):
    return rpm * radius / (w2wdist * 60)
def tipSpeed(radius, rpm):
    return radius * rpm / 60

wholeBody = ["Whole Body Spinner", twoWheelRad, wholeBodyRad, 5]
fourWheelBeaterBar = ["4 Wheel w/ Beater Bar", fourWheelRad, bBarRad, 6]
twoWheelBigSpinner = ["2 Wheel w/ Large Spinner", twoWheelRad, bigSpinRad, 6]
horizontalSpinner = ["Horiz. Spinner w/ 4 Wheels", fourWheelRad, horizSpinnerRad, 5]
types = [wholeBody, fourWheelBeaterBar, twoWheelBigSpinner, horizontalSpinner]

for i in types:
    linVelo = linearVelo(driveRPM, i[1])

    if i[0] == "Whole Body Spinner":
        rotVelo = rotationalVelo(wholeDriveRPM, i[1], i[3])
        tSpeed = tipSpeed(i[2], rotVelo * 60)
    else:
        rotVelo = rotationalVelo(driveRPM, i[1], i[3])
        tSpeed = tipSpeed(i[2], weaponRPM)
    print("\nDesign Concept: " + i[0])
    print("Linear Velocity: " + f"{linVelo:.2f}")
    print("Rotational Velocity: " + f"{rotVelo:.2f}")
    print("Weapon Tip Speed: " + f"{tSpeed:.2f}")
```

Figure I2:

Calculation Results



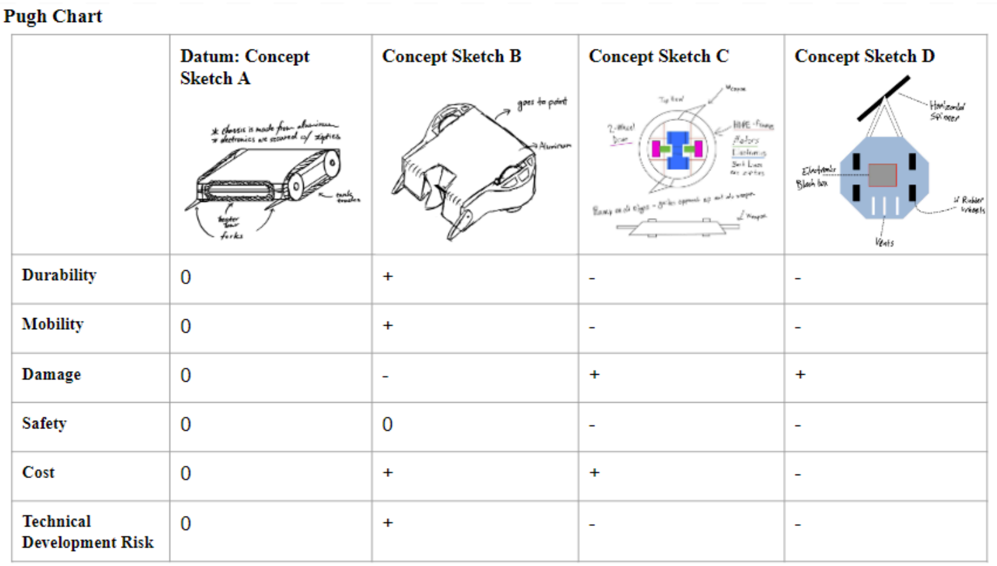
```
Design Concept: Whole Body Spinner
Linear Velocity: 5.00
Rotational Velocity: 20.00
Weapon Tip Speed: 240.00

Design Concept: 4 Wheel w/ Beater Bar
Linear Velocity: 2.50
Rotational Velocity: 0.42
Weapon Tip Speed: 333.33

Design Concept: 2 Wheel w/ Large Spinner
Linear Velocity: 5.00
Rotational Velocity: 0.83
Weapon Tip Speed: 666.67

Design Concept: Horiz. Spinner w/ 4 Wheels
Linear Velocity: 2.50
Rotational Velocity: 0.50
Weapon Tip Speed: 1000.00
```

Appendix J:

Pugh Charts

Figure J1:

Pugh chart: Datum of Concept A

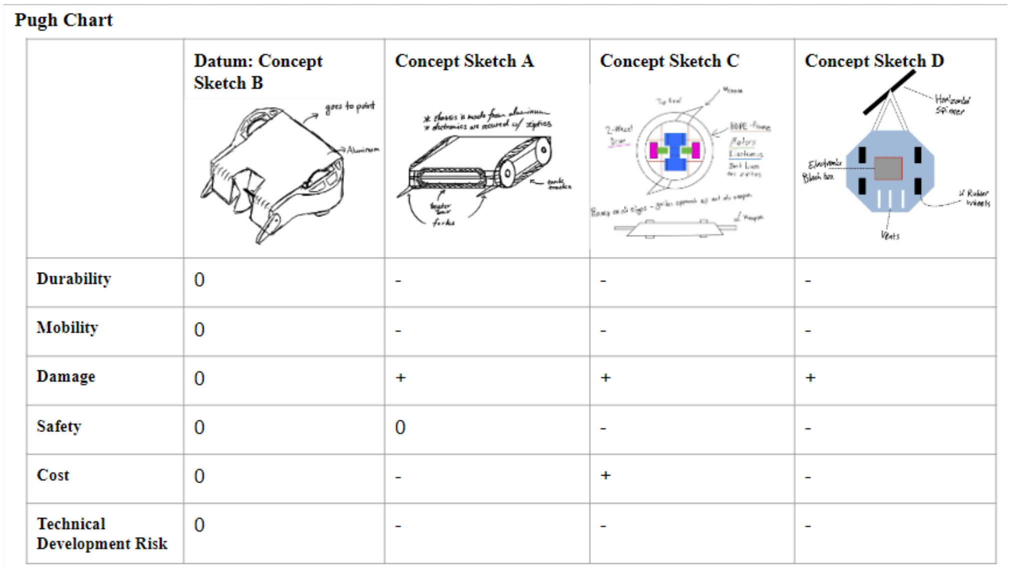


Pugh Chart

	Datum: Concept Sketch A	**Concept Sketch B**	**Concept Sketch C**	**Concept Sketch D**
Durability	0	+	-	-
Mobility	0	+	-	-
Damage	0	-	+	+
Safety	0	0	-	-
Cost	0	+	+	-
Technical Development Risk	0	+	-	-

Figure J2:

Pugh chart: Datum of Concept B



Pugh Chart

	Datum: Concept Sketch B	**Concept Sketch A**	**Concept Sketch C**	**Concept Sketch D**
Durability	0	-	-	-
Mobility	0	-	-	-
Damage	0	+	+	+
Safety	0	0	-	-
Cost	0	-	+	-
Technical Development Risk	0	-	-	-

Figure J3:

Pugh chart: Datum of Concept C

Pugh Chart

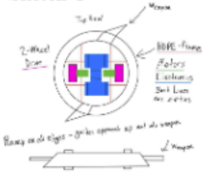
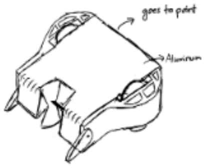
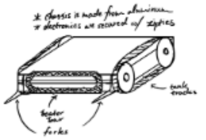
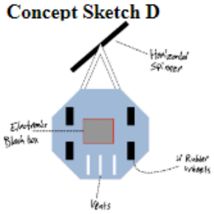
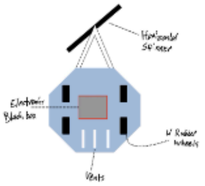
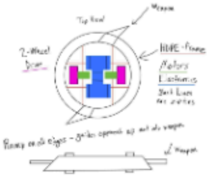
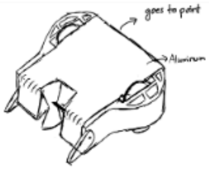
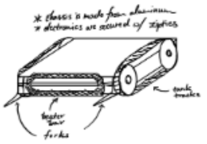
	Datum: Concept Sketch C 	**Concept Sketch B** 	**Concept Sketch A** 	**Concept Sketch D** 
Durability	0	+	+	-
Mobility	0	+	+	+
Damage	0	-	-	+
Safety	0	+	+	-
Cost	0	-	-	-
Technical Development Risk	0	+	+	+

Figure J4:

Pugh chart: Datum of Concept D

Pugh Chart

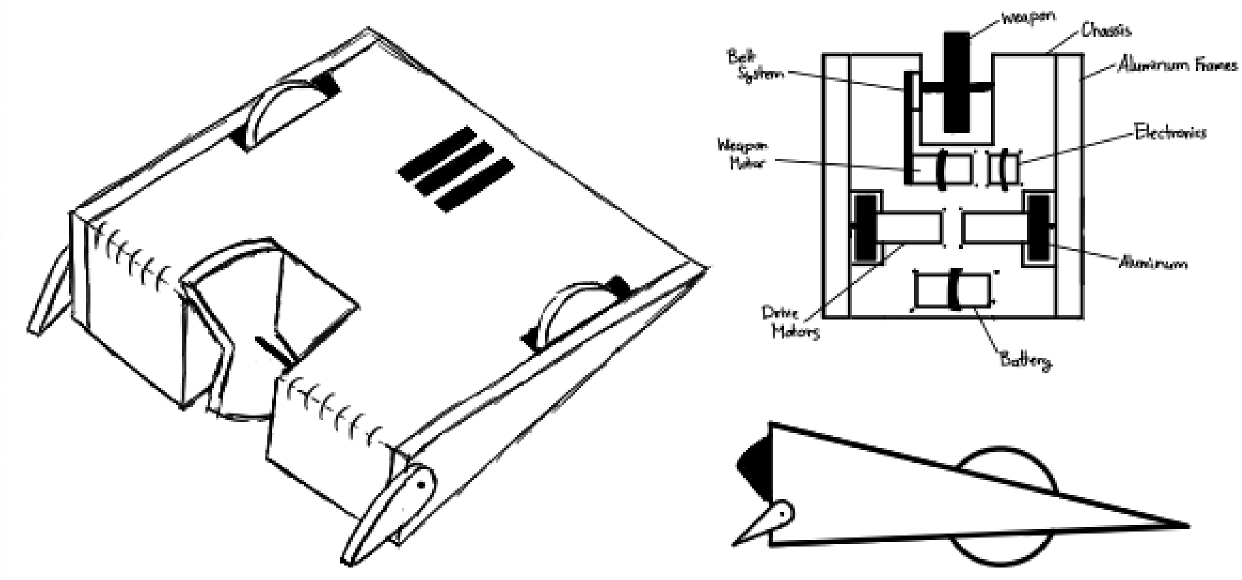
	Datum: Concept Sketch D 	**Concept Sketch C** 	**Concept Sketch B** 	**Concept Sketch A** 
Durability	0	+	+	+
Mobility	0	-	+	+
Damage	0	-	-	-
Safety	0	+	+	+
Cost	0	+	+	+
Technical Development Risk	0	-	+	+

Appendix K:

Leading Concept Sketch

Figure K1:

Leading Concept Sketch



Appendix L:

CAD and CAD Drawings

Figure L1

Isometric View of CAD

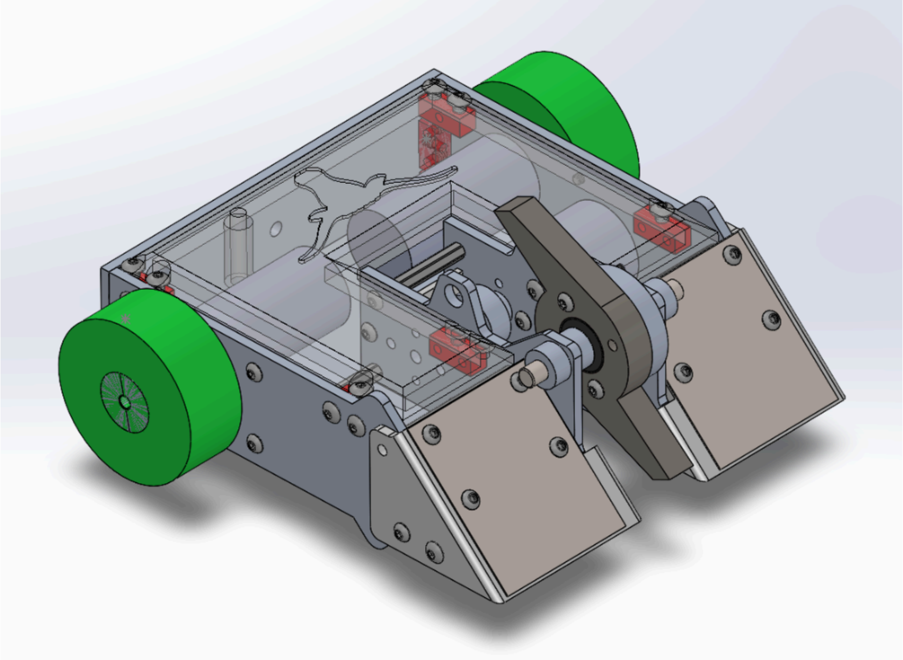


Figure L2

Side View of CAD

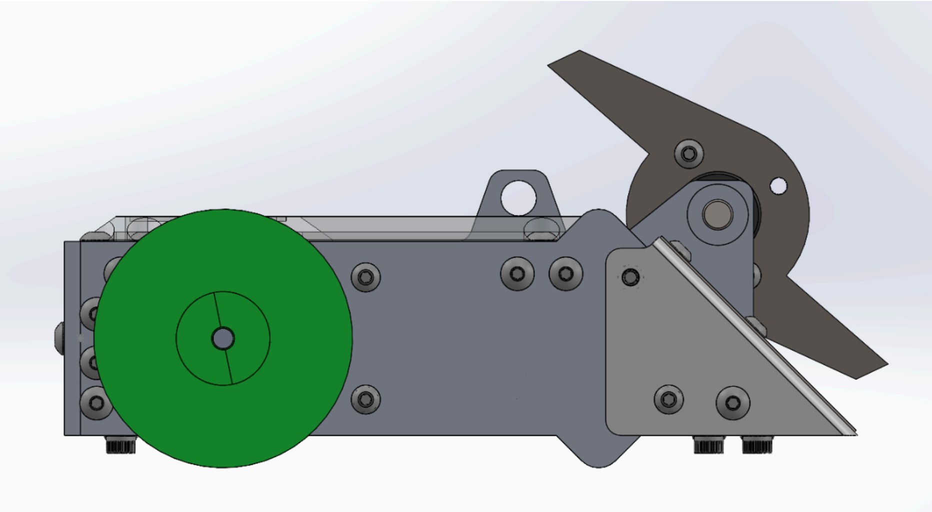


Figure L3

Front View of CAD

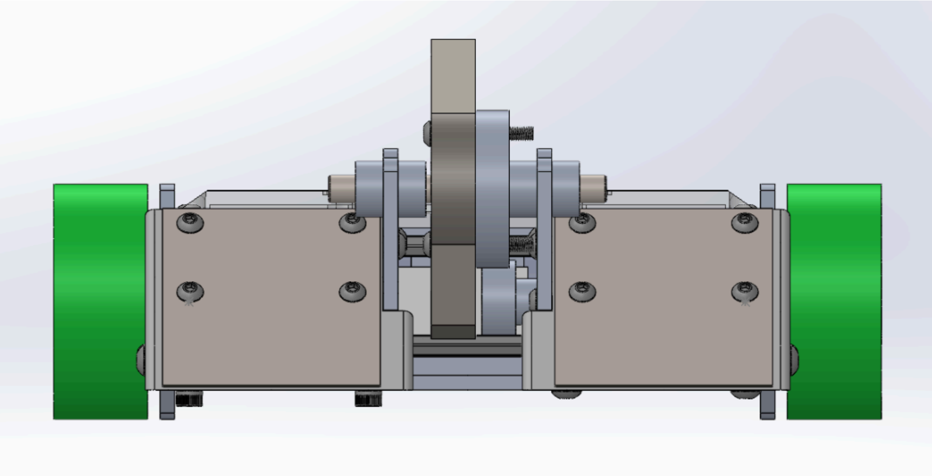


Figure L4

Back View of CAD

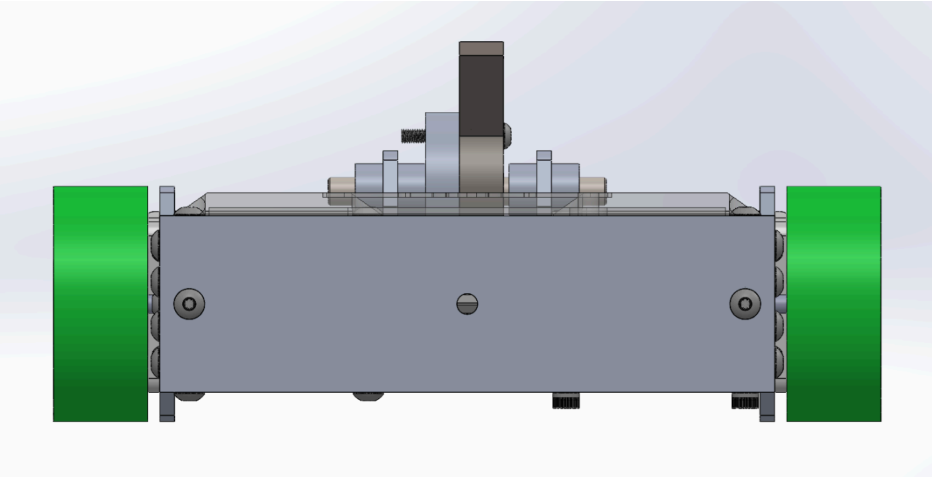


Figure L5

Top View of CAD

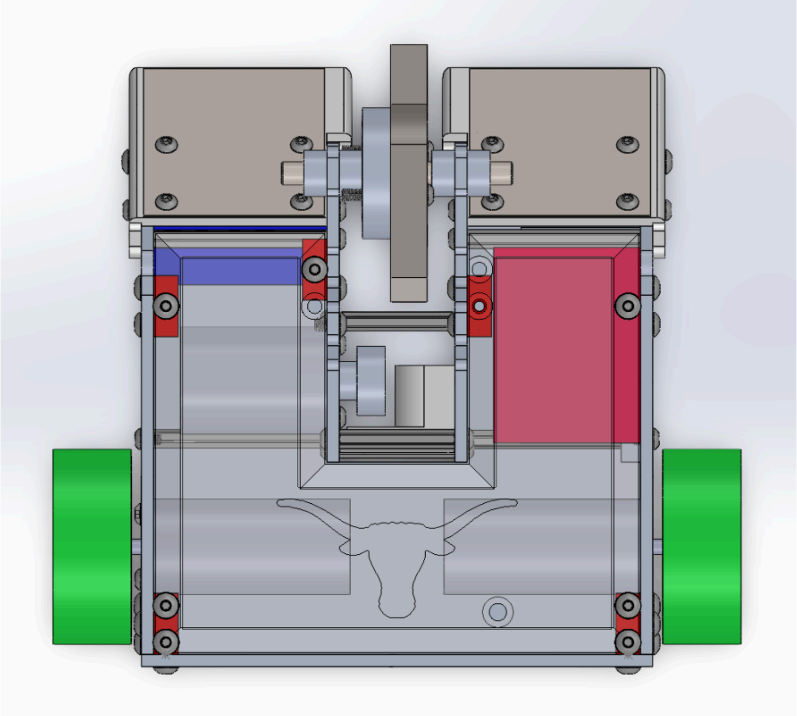


Figure L6

CAD Drawing of Assembly

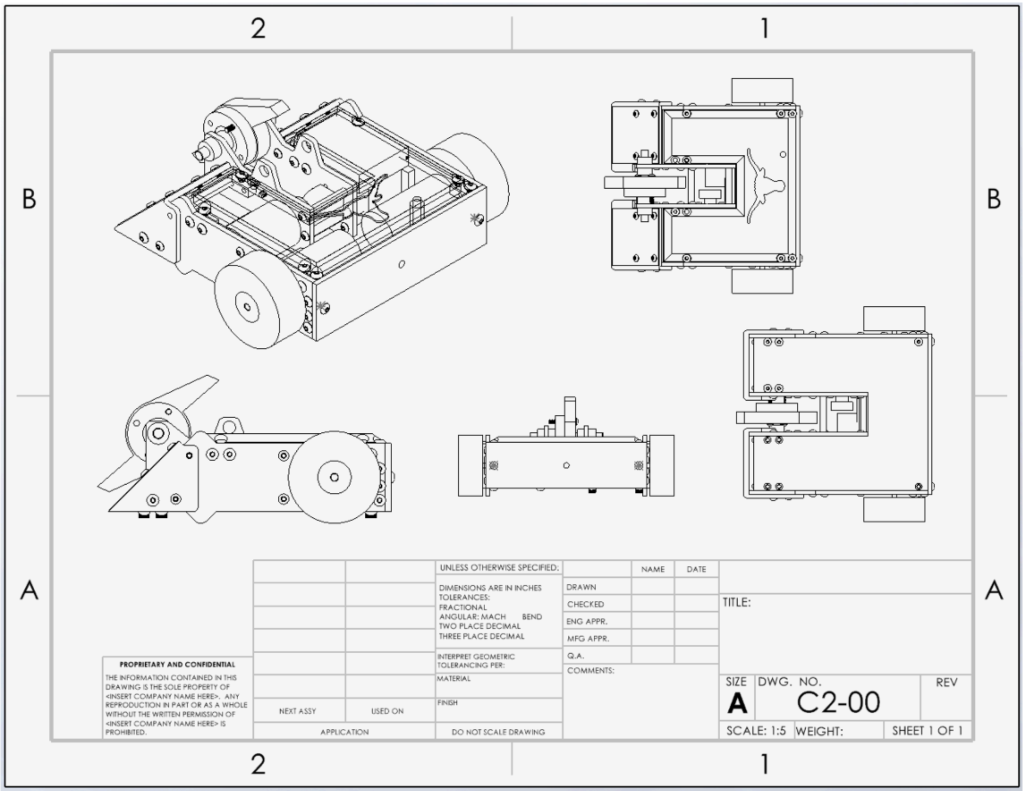


Figure L7

CAD Drawing of Chassis

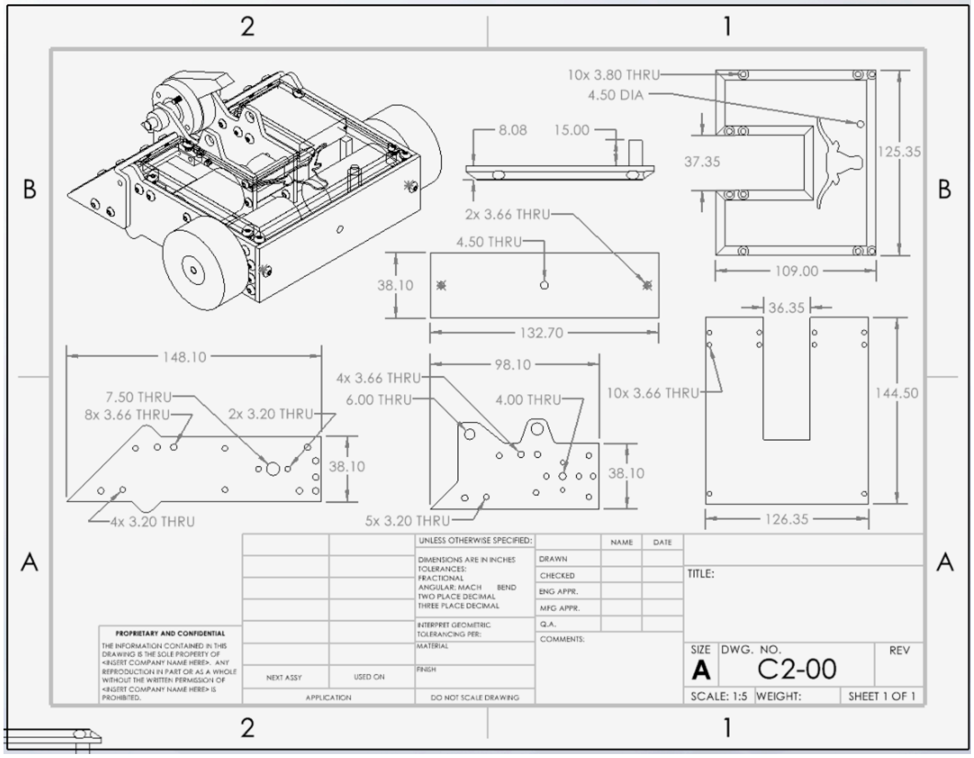
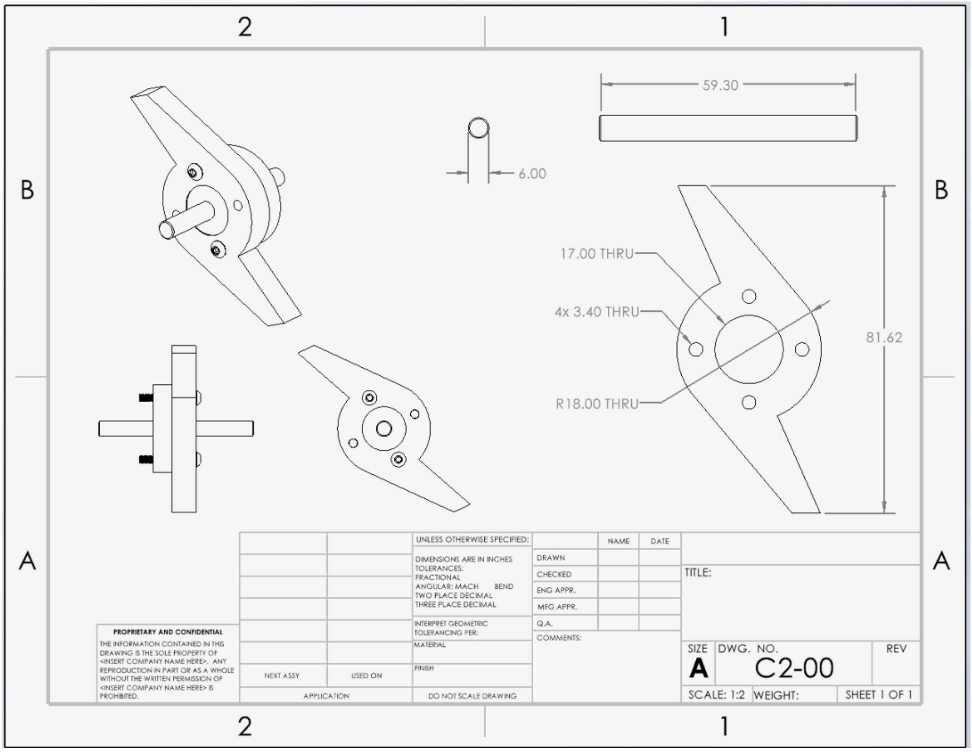


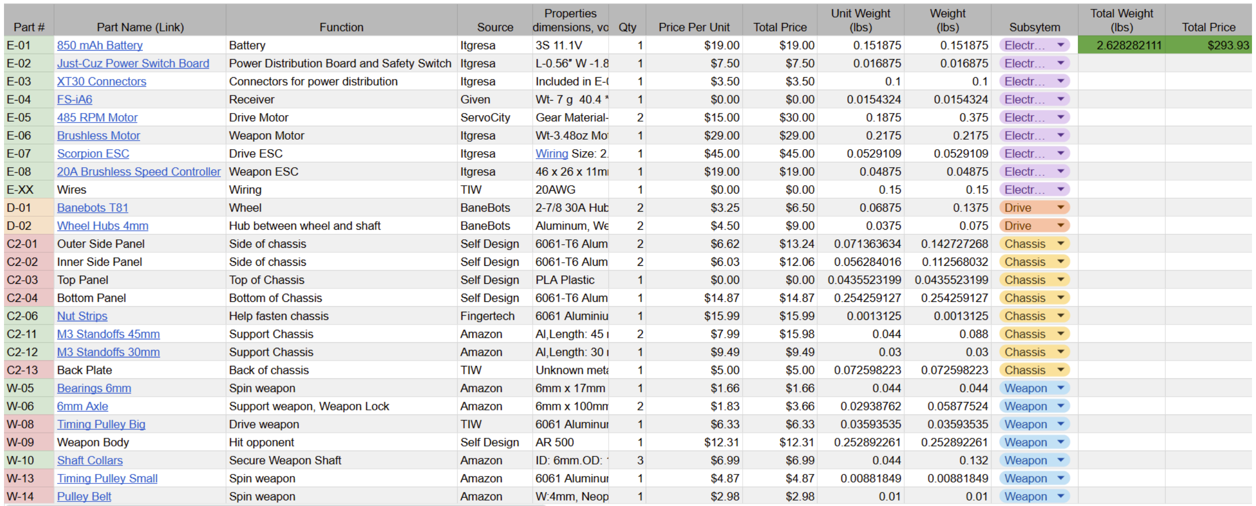
Figure L8

CAD Drawing of Weapon Assembly



Appendix M:

Bill of Materials



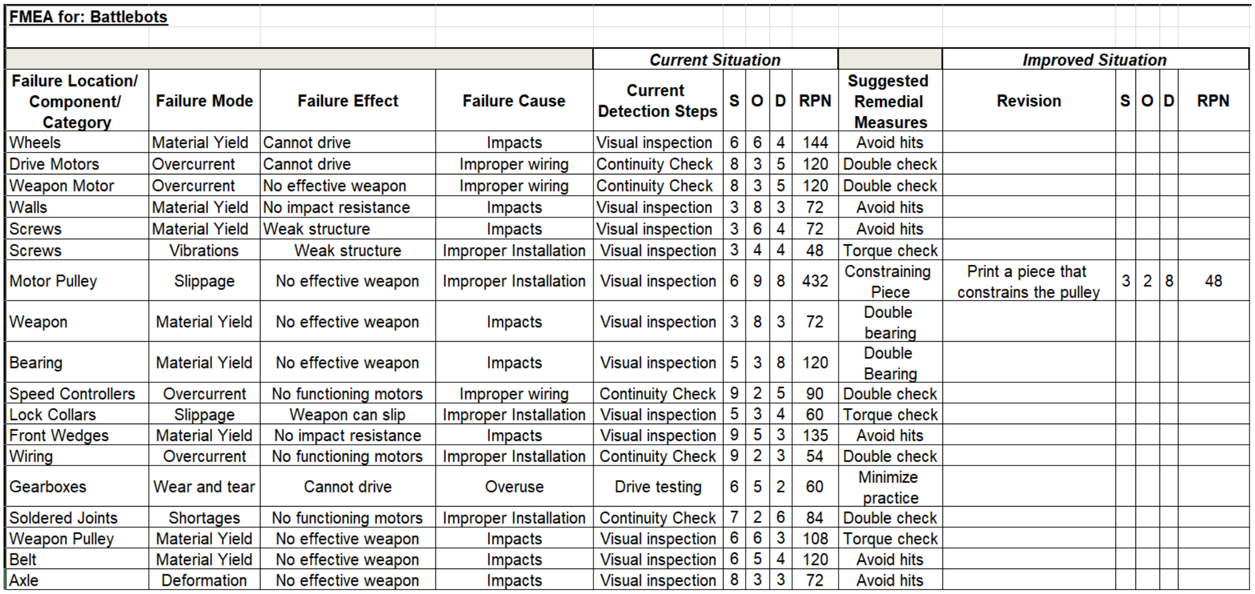
Part #	Part Name (Link)	Function	Source	Properties dimensions, vo	Qty	Price Per Unit	Total Price	Unit Weight (lbs)	Weight (lbs)	Subsytem	Total Weight (lbs)	Total Price
E-01	850 mAh Battery	Battery	Itgresa	3S 11.1V	1	$19.00	$19.00	0.151875	0.151875	Electr…	2.628282111	$293.93
E-02	Just-Cuz Power Switch Board	Power Distribution Board and Safety Switch	Itgresa	L-0.56" W -1.8	1	$7.50	$7.50	0.016875	0.016875	Electr…		
E-03	XT30 Connectors	Connectors for power distribution	Itgresa	Included in E-	1	$3.50	$3.50	0.1	0.1	Electr…		
E-04	FS-iA6	Receiver	Given	Wt- 7 g 40.4 *	1	$0.00	$0.00	0.0154324	0.0154324	Electr…		
E-05	485 RPM Motor	Drive Motor	ServoCity	Gear Material-	2	$15.00	$30.00	0.1875	0.375	Electr…		
E-06	Brushless Motor	Weapon Motor	Itgresa	Wt-3.48oz Mo	1	$29.00	$29.00	0.2175	0.2175	Electr…		
E-07	Scorpion ESC	Drive ESC	Itgresa	Wiring Size: 2.	1	$45.00	$45.00	0.0529109	0.0529109	Electr…		
E-08	20A Brushless Speed Controller	Weapon ESC	Itgresa	46 x 26 x 11m	1	$19.00	$19.00	0.04875	0.04875	Electr…		
E-XX	Wires	Wiring	TIW	20AWG	1	$0.00	$0.00	0.15	0.15	Electr…		
D-01	Banebots T81	Wheel	BaneBots	2-7/8 30A Hub	2	$3.25	$6.50	0.06875	0.1375	Drive		
D-02	Wheel Hubs 4mm	Hub between wheel and shaft	BaneBots	Aluminum, We	2	$4.50	$9.00	0.0375	0.075	Drive		
C2-01	Outer Side Panel	Side of chassis	Self Design	6061-T6 Alum	2	$6.62	$13.24	0.071363634	0.142727268	Chassis		
C2-02	Inner Side Panel	Side of chassis	Self Design	6061-T6 Alum	2	$6.03	$12.06	0.056284016	0.112568032	Chassis		
C2-03	Top Panel	Top of Chassis	Self Design	PLA Plastic	1	$0.00	$0.00	0.0435523199	0.0435523199	Chassis		
C2-04	Bottom Panel	Bottom of Chassis	Self Design	6061-T6 Alum	1	$14.87	$14.87	0.254259127	0.254259127	Chassis		
C2-06	Nut Strips	Help fasten chassis	Fingertech	6061 Aluminiu	1	$15.99	$15.99	0.0013125	0.0013125	Chassis		
C2-11	M3 Standoffs 45mm	Support Chassis	Amazon	Al,Length: 45	2	$7.99	$15.98	0.044	0.088	Chassis		
C2-12	M3 Standoffs 30mm	Support Chassis	Amazon	Al,Length: 30	1	$9.49	$9.49	0.03	0.03	Chassis		
C2-13	Back Plate	Back of chassis	TIW	Unknown meta	1	$5.00	$5.00	0.072598223	0.072598223	Chassis		
W-05	Bearings 6mm	Spin weapon	Amazon	6mm x 17mm	1	$1.66	$1.66	0.044	0.044	Weapon		
W-06	6mm Axle	Support weapon, Weapon Lock	Amazon	6mm x 100mm	2	$1.83	$3.66	0.02938762	0.05877524	Weapon		
W-08	Timing Pulley Big	Drive weapon	TIW	6061 Aluminu	1	$6.33	$6.33	0.03593535	0.03593535	Weapon		
W-09	Weapon Body	Hit opponent	Self Design	AR 500	1	$12.31	$12.31	0.252892261	0.252892261	Weapon		
W-10	Shaft Collars	Secure Weapon Shaft	Amazon	ID: 6mm.OD:	3	$6.99	$6.99	0.044	0.132	Weapon		
W-13	Timing Pulley Small	Spin weapon	Amazon	6061 Aluminu	1	$4.87	$4.87	0.00881849	0.00881849	Weapon		
W-14	Pulley Belt	Spin weapon	Amazon	W:4mm, Neop	1	$2.98	$2.98	0.01	0.01	Weapon		

Appendix N:

FMEA

Figure N1

FMEA for Battleduck

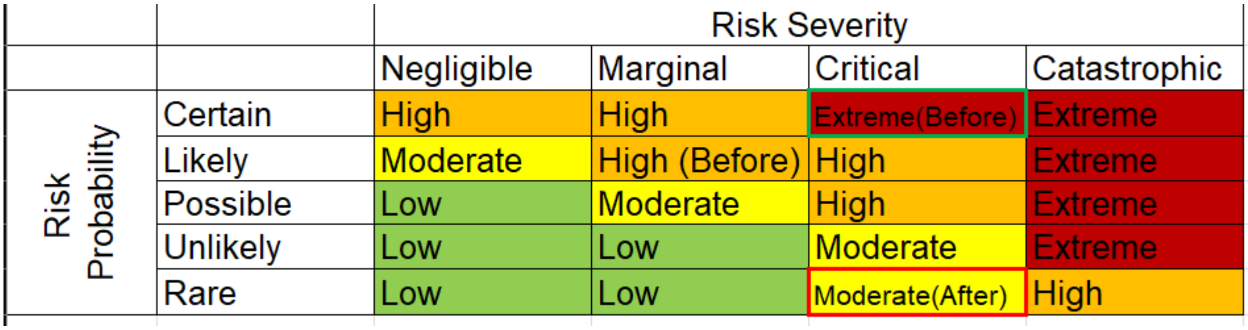


FMEA for: Battlebots

				Current Situation						Improved Situation				
Failure Location/ Component/ Category	**Failure Mode**	**Failure Effect**	**Failure Cause**	**Current Detection Steps**	**S**	**O**	**D**	**RPN**	**Suggested Remedial Measures**	**Revision**	**S**	**O**	**D**	**RPN**
Wheels	Material Yield	Cannot drive	Impacts	Visual inspection	6	6	4	144	Avoid hits					
Drive Motors	Overcurrent	Cannot drive	Improper wiring	Continuity Check	8	3	5	120	Double check					
Weapon Motor	Overcurrent	No effective weapon	Improper wiring	Continuity Check	8	3	5	120	Double check					
Walls	Material Yield	No impact resistance	Impacts	Visual inspection	3	8	3	72	Avoid hits					
Screws	Material Yield	Weak structure	Impacts	Visual inspection	3	6	4	72	Avoid hits					
Screws	Vibrations	Weak structure	Improper Installation	Visual inspection	3	4	4	48	Torque check					
Motor Pulley	Slippage	No effective weapon	Improper Installation	Visual inspection	6	9	8	432	Constraining Piece	Print a piece that constrains the pulley	3	2	8	48
Weapon	Material Yield	No effective weapon	Impacts	Visual inspection	3	8	3	72	Double bearing					
Bearing	Material Yield	No effective weapon	Impacts	Visual inspection	5	3	8	120	Double Bearing					
Speed Controllers	Overcurrent	No functioning motors	Improper wiring	Continuity Check	9	2	5	90	Double check					
Lock Collars	Slippage	Weapon can slip	Improper Installation	Visual inspection	5	3	4	60	Torque check					
Front Wedges	Material Yield	No impact resistance	Impacts	Visual inspection	9	5	3	135	Avoid hits					
Wiring	Overcurrent	No functioning motors	Improper Installation	Continuity Check	9	2	3	54	Double check					
Gearboxes	Wear and tear	Cannot drive	Overuse	Drive testing	6	5	2	60	Minimize practice					
Soldered Joints	Shortages	No functioning motors	Improper Installation	Continuity Check	7	2	6	84	Double check					
Weapon Pulley	Material Yield	No effective weapon	Impacts	Visual inspection	6	6	3	108	Torque check					
Belt	Material Yield	No effective weapon	Impacts	Visual inspection	6	5	4	120	Avoid hits					
Axle	Deformation	No effective weapon	Impacts	Visual inspection	8	3	3	72	Avoid hits					

Figure N2

Risk Severity Table



		Risk Severity			
		Negligible	Marginal	Critical	Catastrophic
Risk Probability	Certain	High	High	Extreme(Before)	Extreme
	Likely	Moderate	High (Before)	High	Extreme
	Possible	Low	Moderate	High	Extreme
	Unlikely	Low	Low	Moderate	Extreme
	Rare	Low	Low	Moderate(After)	High

Appendix O:

Simulation

Figure O1

Simulation 1: 6061-T6 Aluminum

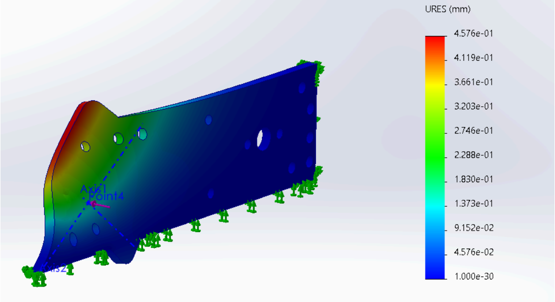


Figure O2

Simulation 2: Baltic Birch Plywood

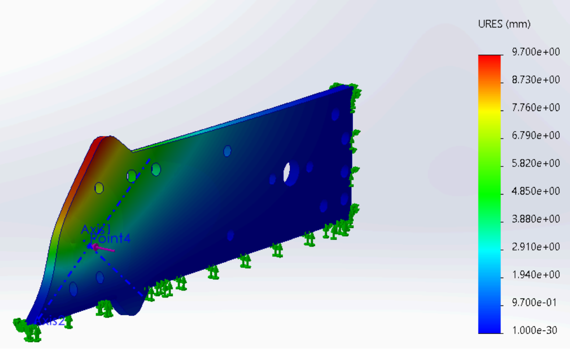
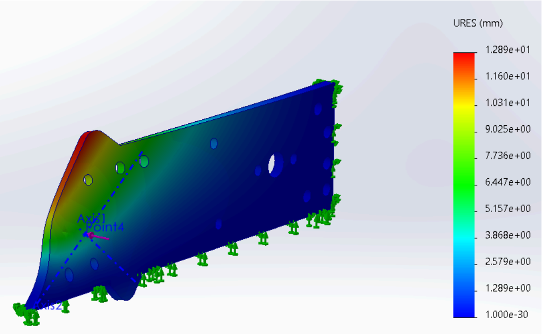


Figure O3

Simulation 3: ABS

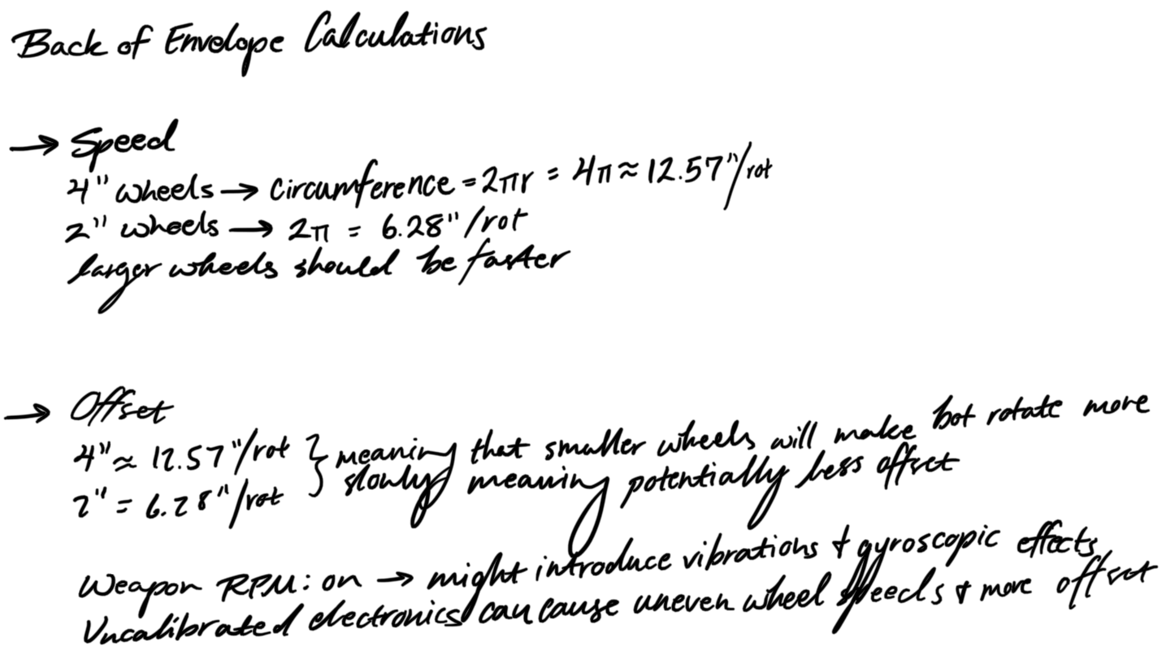


Appendix P:

Experimentation

Figure P1:

Back of Envelope Calculations



Back of Envelope Calculations

→ Speed
4" wheels → circumference = $2\pi r = 4\pi \approx 12.57"/\text{rot}$
2" wheels → $2\pi = 6.28"/\text{rot}$
larger wheels should be faster

→ Offset
$4" \approx 12.57"/\text{rot}$
$2" = 6.28"/\text{rot}$
} meaning that smaller wheels will make bot rotate more slowly meaning potentially less offset

Weapon RPM: on → might introduce vibrations & gyroscopic effects
Uncalibrated electronics can cause uneven wheel speeds & more offset

Figure P2:
Data Table

Run	Wheel Size	Weapon RPM	Calibration	Result of Distance Moved (in/sec)	Result of Speed (in/sec)
1	-1	1	1	.275	12
2	-1	-1	1	.325	15
3	-1	1	-1	.35	10
4	-1	-1	-1	.3	13
5	1	1	1	.15	20
6	1	-1	1	.325	25

7	1	1	-1	.25	18
8	1	-1	-1	.425	22

Figure P3:

Cube Plot

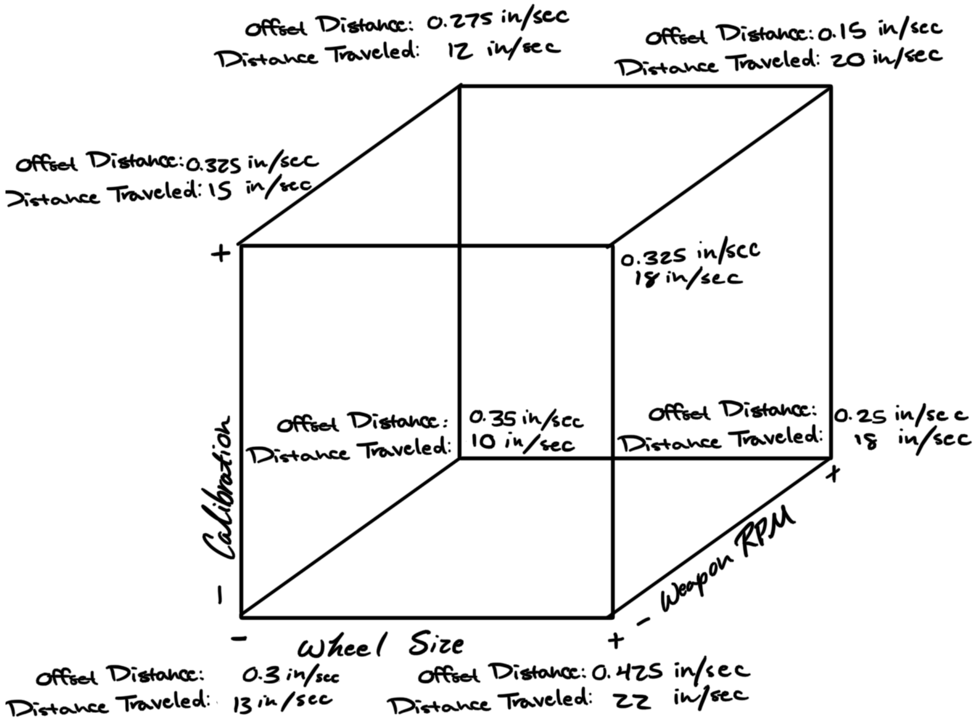
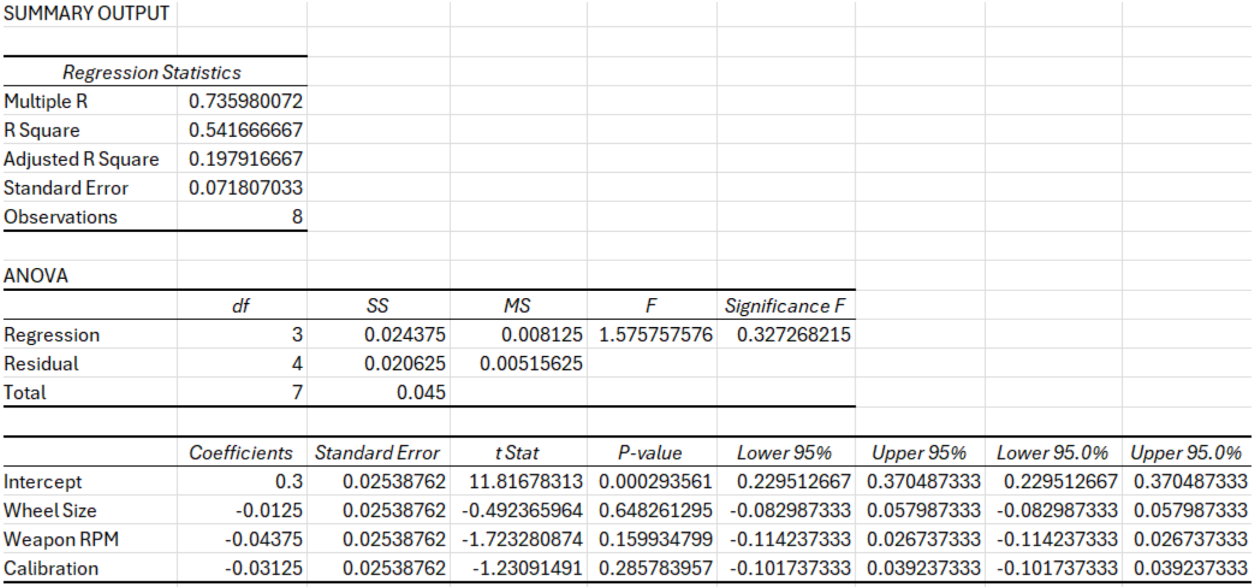


Figure P4:

For Result of Distance Offset:



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.735980072
R Square	0.541666667
Adjusted R Square	0.197916667
Standard Error	0.071807033
Observations	8

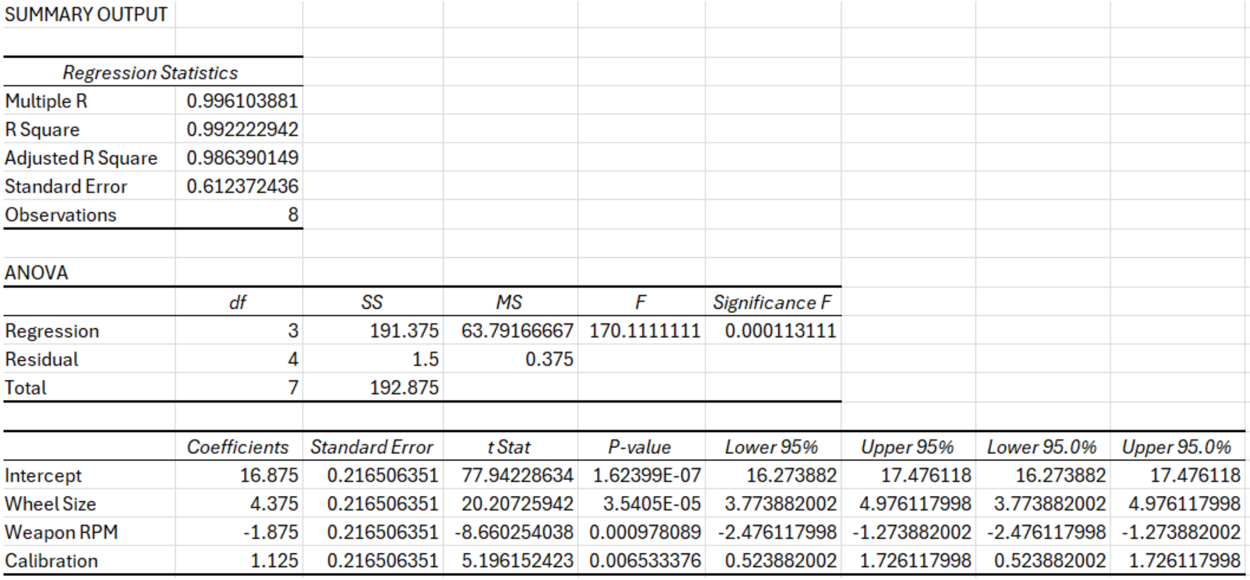
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.024375	0.008125	1.575757576	0.327268215
Residual	4	0.020625	0.00515625		
Total	7	0.045			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.3	0.02538762	11.81678313	0.000293561	0.229512667	0.370487333	0.229512667	0.370487333
Wheel Size	-0.0125	0.02538762	-0.492365964	0.648261295	-0.082987333	0.057987333	-0.082987333	0.057987333
Weapon RPM	-0.04375	0.02538762	-1.723280874	0.159934799	-0.114237333	0.026737333	-0.114237333	0.026737333
Calibration	-0.03125	0.02538762	-1.23091491	0.285783957	-0.101737333	0.039237333	-0.101737333	0.039237333

Figure P5:

For Result of Speed:



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.996103881
R Square	0.992222942
Adjusted R Square	0.986390149
Standard Error	0.612372436
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	191.375	63.79166667	170.1111111	0.000113111
Residual	4	1.5	0.375		
Total	7	192.875			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	16.875	0.216506351	77.94228634	1.62399E-07	16.273882	17.476118	16.273882	17.476118
Wheel Size	4.375	0.216506351	20.20725942	3.5405E-05	3.773882002	4.976117998	3.773882002	4.976117998
Weapon RPM	-1.875	0.216506351	-8.660254038	0.000978089	-2.476117998	-1.273882002	-2.476117998	-1.273882002
Calibration	1.125	0.216506351	5.196152423	0.006533376	0.523882002	1.726117998	0.523882002	1.726117998

Figure P6:

Interaction Plot of Wheel Size vs. Weapon RPM for Result of Distance Offset

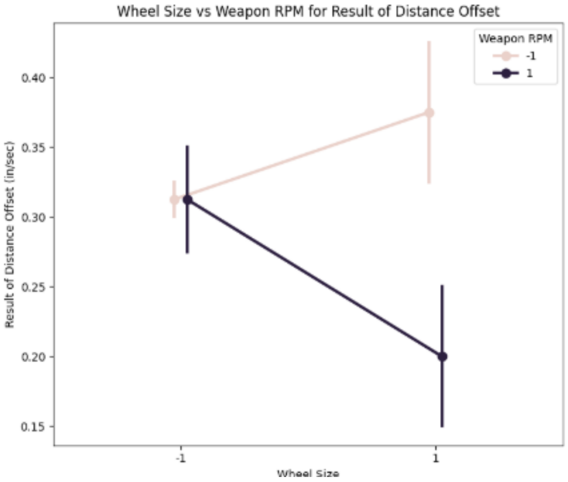


Figure P7:

Interaction Plot of Wheel Size vs. Calibration for Result of Distance Offset

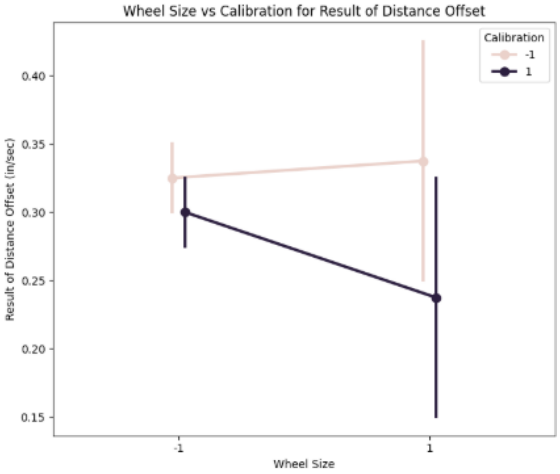


Figure P8:

Interaction Plot of Weapon RPM vs. Calibration for Result of Distance Offset

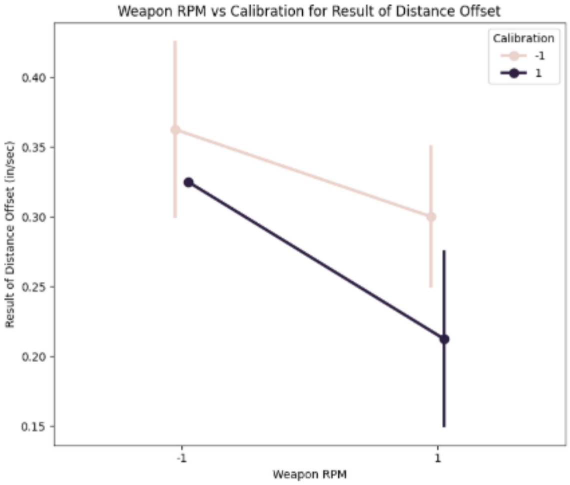


Figure P9:

Interaction Plot of Wheel Size vs. Weapon RPM for Result of Speed

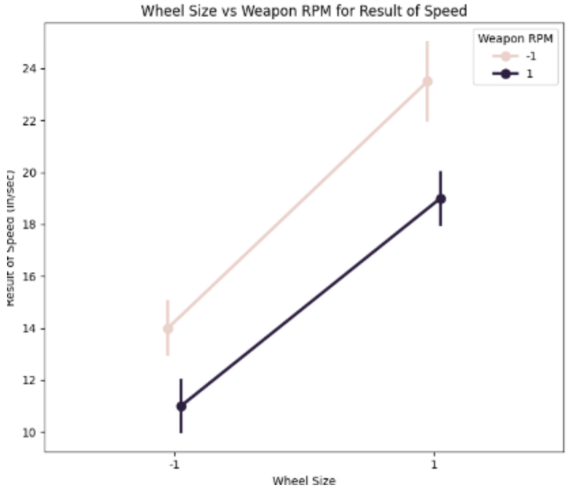


Figure P10:

Interaction Plot of Wheel Size vs. Calibration for Result of Speed

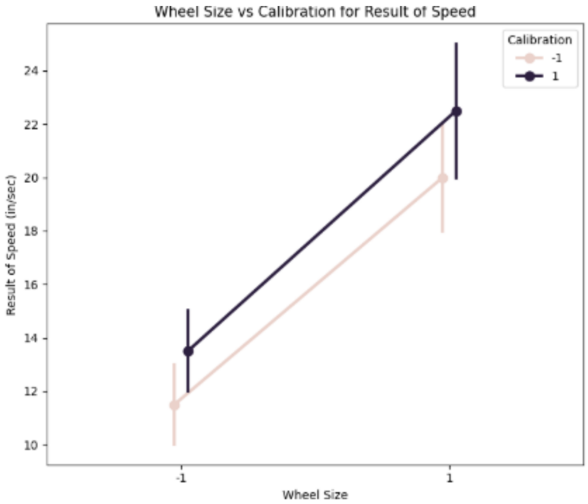


Figure P11:

Interaction Plot of Weapon RPM vs. Calibration for Result of Speed