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MEMS 411: Just Putt It in Drive

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Mechanical Engineering Design Project
MEMS 411, Fall 2023

Just putt it in Drive

The goal of our senior design project was to design a vehicle that could have a golf striker attached in order to compete in the ASME Student Design Challenge. Our intended customers were Dr. Potter and the ASME. In order to do this, we examined existing designs, patents, and standards; interviewed our customer; created several concepts; and iterated through several prototypes. We also created three performance goals for our prototype: to be able to climb over a 2x4, to be able to climb over or under a sheet of plywood 3-1/2" off the ground, and to line up the first three shots of the course in under 1 minute. Our final prototype failed to meet any of the three goals.

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1 Introduction

The purpose and end goal of the design project is to build a moving vehicle that will act as the platform for a putting machine. In order for Dr. Potter to compete, he has tasked us to make this base. It needs to be able to transport the putting attachment and get over or around obstacles. This challenge has been put forth by the American Society for Mechanical Engineers(ASME). This is labeled as their annual design challenge.

There is a pre-described course that has has the putting machine drive from hole to hole and putt/chip the ball into particular areas. The base that is being designed must be able to withstand these forces. It also has to be able to move fine enough that the putter can hit the ball precisely and consistently. Dr. Potter is not very concerned with cost and portability. He is most concerned with the capabilities of the vehicle being able to complete the course precisely and efficiently.

2 Problem Understanding

2.1 Existing Devices

In doing research for this project, it can be seen that there are similar existing devices already out there in the world. The two listed below are different variations on pre-existing vehicles with tank treads. Though their designs are overall different, such as the way their treads are designed, they are roughly based upon the same central concept.

2.1.1 Existing Device #1:TP101 Tank Chassis Robot Frame Starter Kit

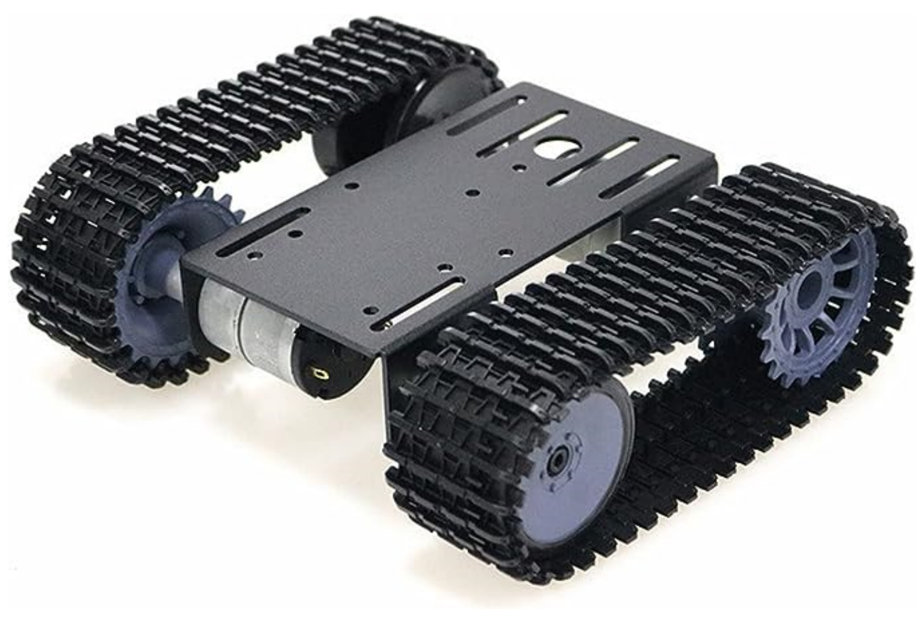


Figure 1: Small tank design

The TP101 Tank Chassis Robot Frame Starter Kit, shown in Figure 1, was designed as a starting point for budding robotics enthusiasts. The tank-style chassis is equipped with tracks and wide wheels, making it ideal for maneuvering through challenging terrains like grass, sand, and rocks.

The user can enter into the world of robotics with hands-on learning, covering mechanics, software, and hardware assembly using popular platforms like Arduino, Raspberry Pi, and Python. Crafted with a durable metal panel and budget-friendly pricing, it includes reference Arduino code for WiFi and Bluetooth control. Product Webpage: TP101 Tank Chassis Robot Frame Starter Kit

2.1.2 Existing Device #2: TS300 Robot Tank Chassis

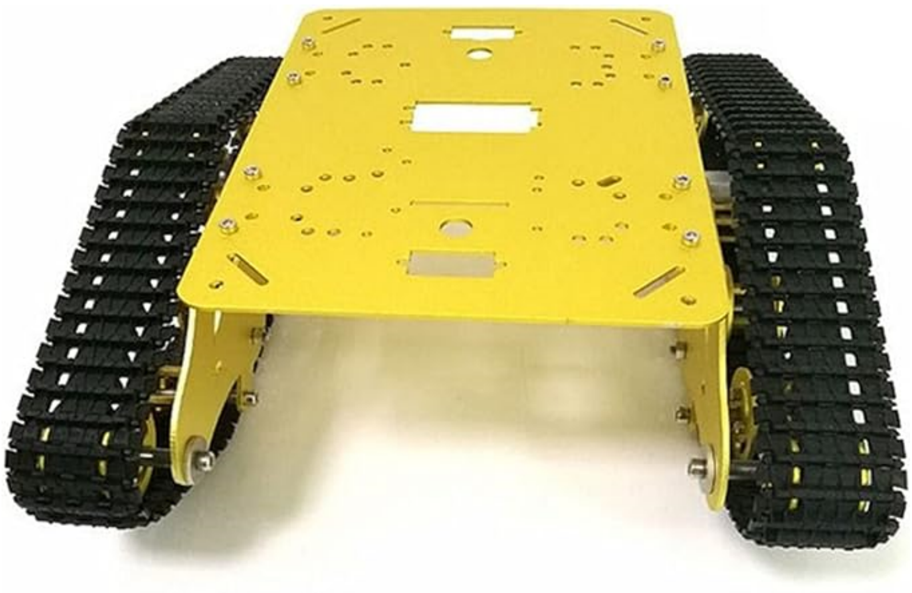


Figure 2: Tank Treads

The TS300 Robot Tank Chassis acts as a great introduction to the world of DIY robotics. This kit includes metal components like tracks, high-torque encoder DC motors, driving wheels, and bearing wheels, conveniently unassembled for shipping. Its advanced suspension system offers superb shock absorption, allowing it to navigate around obstacles effortlessly. Powered by high-torque DC motors, this chassis provides speed feedback through Arduino UNO R3, Raspberry Pi, or Micro-bit programming. Product Webpage: TS300 Robot Tank Chassis

2.1.3 Existing Device #3: Swaytail 4WD Metal Tank Chassis

Figure 3: Swaytail 4WD Metal Tank Chassis

The Swaytail 4WD Metal Tank Chassis kit includes 5 metal panels, 4 DC encoder motors with cables, 4 plastic tracks, 18 low-friction metal load wheels with bearings, 4 metal driving wheels, and necessary tools for assembly. Assembling is straightforward, provided the user follows the manual. The design allows for adjustable track lengths, reduces friction with double-bearing load wheels, and boasts an all-metal build (except for plastic tracks). While building, the user will learn about chassis structure and programming using Arduino, Raspberry Pi, or STM3. Product Webpage: Swaytail 4WD Metal Tank Chassis

2.2 Patents

2.2.1 Remote Controlled Toy Car with Controller (USD837307S1)

This patent was selected as it is the most similar to our project. Not only are they of similar size but they also use the same remote control, goals, and abilities. The goals being to travel from one location to another without being stopped, and in a timely manner. The similar abilities between the two are, being able to drive under the power of its own motors, having a wireless controller, and being able to climb over obstacles in its way.

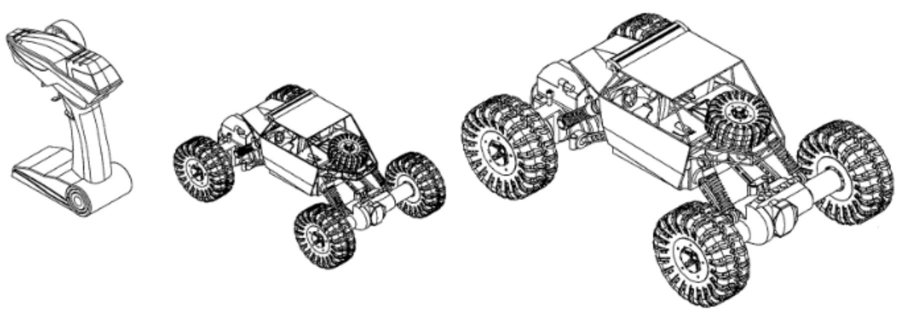


Figure 4: RC Car with wireless Remote Control

2.2.2 Tank track and method and apparatus for making some (US2375170A)

This patent was selected because when designing our current project. Tank treads were decided upon to act as the wheel base. This is due to them being able to give the vehicle a 0° turn radius, thus giving us the ability to adjust shots made by the striker unit without throwing off the shot by fully moving. The other reason that this course of thinking was chosen was due to the obstacles that the design will experience over the course. As it must be able to climb over obstacles, tank treads were chosen as they give many more points of contact rather then regular tires, while also giving the added benefit of keeping the center of mass close to the middle, keeping it from falling over.

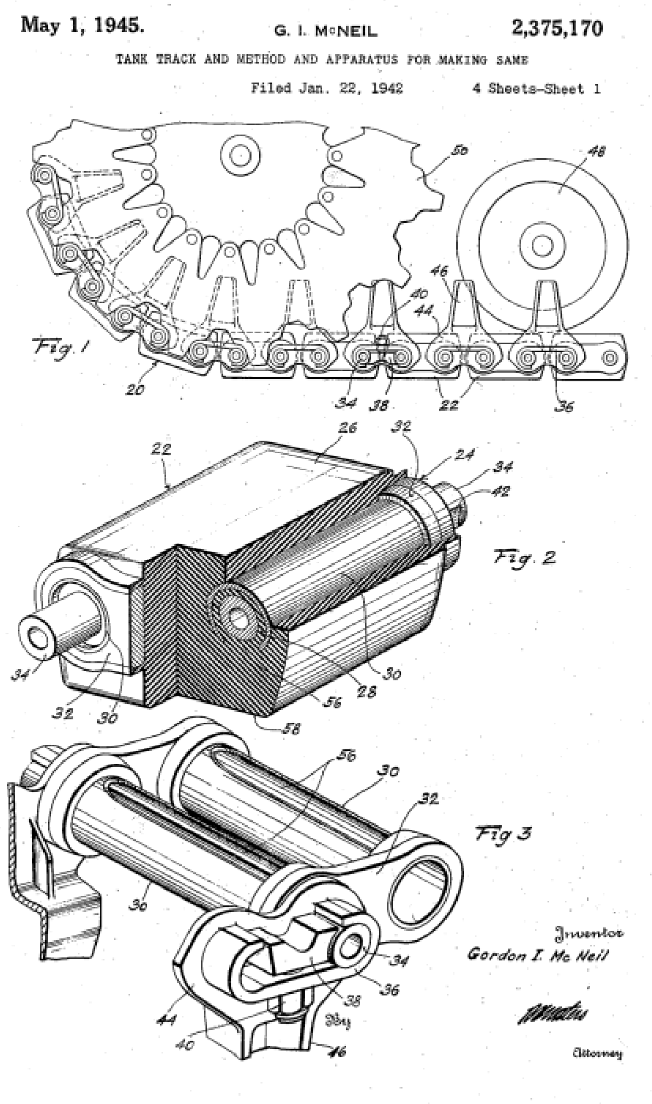


Figure 5: Tank Treads Creation

2.3 Codes & Standards

2.3.1 UL 1642

This standard pertains to the use of Lithium ion batteries, Meaning how they are used, their limitations as a power source, along with the restrictions that we need to be aware of when using them. This standard works well for our concept as these types of batteries are what we will use to not only power the motors on our vehicle, but also the controls for said vehicle. We need to be able to understand the limitations of the power source that we are using, so that we are able to know how far we can push them without having a catastrophic failure occur.

2.3.2 MIL-PRF-62195D

This standard dictates the creation of several vehicle types used by the U.S. Military. Specifically off-roading vehicles, which come in both tracked and normal wheel variations. This standard applies to our concept as our vehicle will use a track based system in order to clear the obstacles on the course. Though these machines are designed to be able to cross greater obstacles than those that we will face, we can use this as a guideline in how we approach the problem of crossing over obstacles with a much smaller vehicle.

2.4 User Needs

User needs are on of the most important considerations in creating a design. In order to determine user needs, our team interviewed Dr. Potter of Washington University in St. Louis's McKelvey School of Engineering. We also reviewed the posted rules for the ASME Student Design Challenge.

2.4.1 Customer Interview

Interviewee: Dr. James Jackson Potter
Location: Hillman 70, Washington University in St. Louis, Danforth Campus
Date: September 8^{th}, 2023
Setting: We met up and he brought an example portion of the course and vehicle/putter. I discussed how we would approach the different problems that the course provides. This interview was completed in our standard classroom and took ∼45 min.

Interview Notes:
How will the putter and vehicle connect?

- The vehicle teams need to leave room on the front or side of the device for the putting team to attach to. Based on the model the space should be about 6" wide and 4" deep.
- The connection should be able to slide onto the frame of the vehicle.

Should we try to go under one of the obstacles on the course?

- No, this would add to many constraints on both teams and would not be able to apply a more free design.
- Making the machine go under the obstacle would make it very difficult for the putter to fit if possible at all.

How heavy should the combined weight of the machine be?

- The weight does not matter that much. The vehicle should be heavy enough to not tip when the putter is attached. The putter should not weight more than 4-5 pounds, but this is not a hard cap.

What are the size constraints for the machine?

- The max size of the full assembly is 0.5m^3

What materials should be used?

- Material choice is up to the team. As long as the machine can get through the obstacles and putt the ball.

How will the final machine be combining the putter and the vehicle

- It is up to the individual groups if they want to form a super group from the beginning of the semester and communicate on a connection mechanism

– At the end of the semester groups will be combined and then attempt to do the full course together. They will be operated separately.

How portable should the device be and does it need to apply to flight standards

– Portability is not the focus of the device. Build something that works and worry about scaling it down later.

– It does not need to apply to flight safety standards. Battery size and other possible constraints should not apply.

How much should the device cost in total?

– There is a nominal budget of $400. Try to stay under that, but if the cost total is more talk to Dr. Potter.

Where are the rest of the rules located at?

– They are located at https://efests.asme.org/competitions/student-design-competition-(sdc).

2.4.2 Interpreted User Needs

From the customer interview, there were several key needs identified. Additionally, the rule set for the challenge identifies other needs for the vehicle platform. Further needs were identified by the design team.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The vehicle meets the size requirements	5
2	The vehicle provides a stable platform for a striker	5
3	The vehicle can successfully navigate the obstacles on the course	5
4	The vehicle uses a remote controller	5
5	THe vehicle is powered by rechargeable batteries	5
6	The vehicle can make precise turns and movements	4
7	The vehicle avoids tip-over risk	3
8	The vehicle is easy to operate	2
9	The vehicle is fairly cheap to produce	2
10	The vehicle is portable	1

Needs 1, 4, and 5 are all specific rules as given by the ASME SDC rule set. The other rules were identified either through the customer interview or by the design team.

2.5 Design Metrics

The following target specifications were created based on the Interpreted Customer Needs table.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1, 10	Length, width, and height	m	$\leq$0.5	$\leq$ 0.3
2	2	Designated striker platform	in, w x l	7.5 x 10.5	8 x 11
3	2	Platform stability	degrees from horizontal	$>$ 15	$>$ 5
4	3	Able to climb over platform supported by 2x4	Pass/Fail	Pass	Pass
5	4	Uses remote control	Pass/Fail	Pass	Pass
6	5	Powered by rechargeable batteries	Pass/Fail	Pass	Pass
7	6	Minimum turn angle	degrees	$<$ 5	$<$ 1
8	7	Rapid accelerations without tipover	m/s^2	$>$ 7	$>$ 14
9	8	Ease of control	Team member votes	3/4	4/4
10	9	Budget	USD	400	350
11	10	Total weight	lbs	$<$ 30	$<$ 20
12	5	Adheres to UL 1642 standards for use of rechargeable batteries	Pass/Fail	Pass	Pass

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.

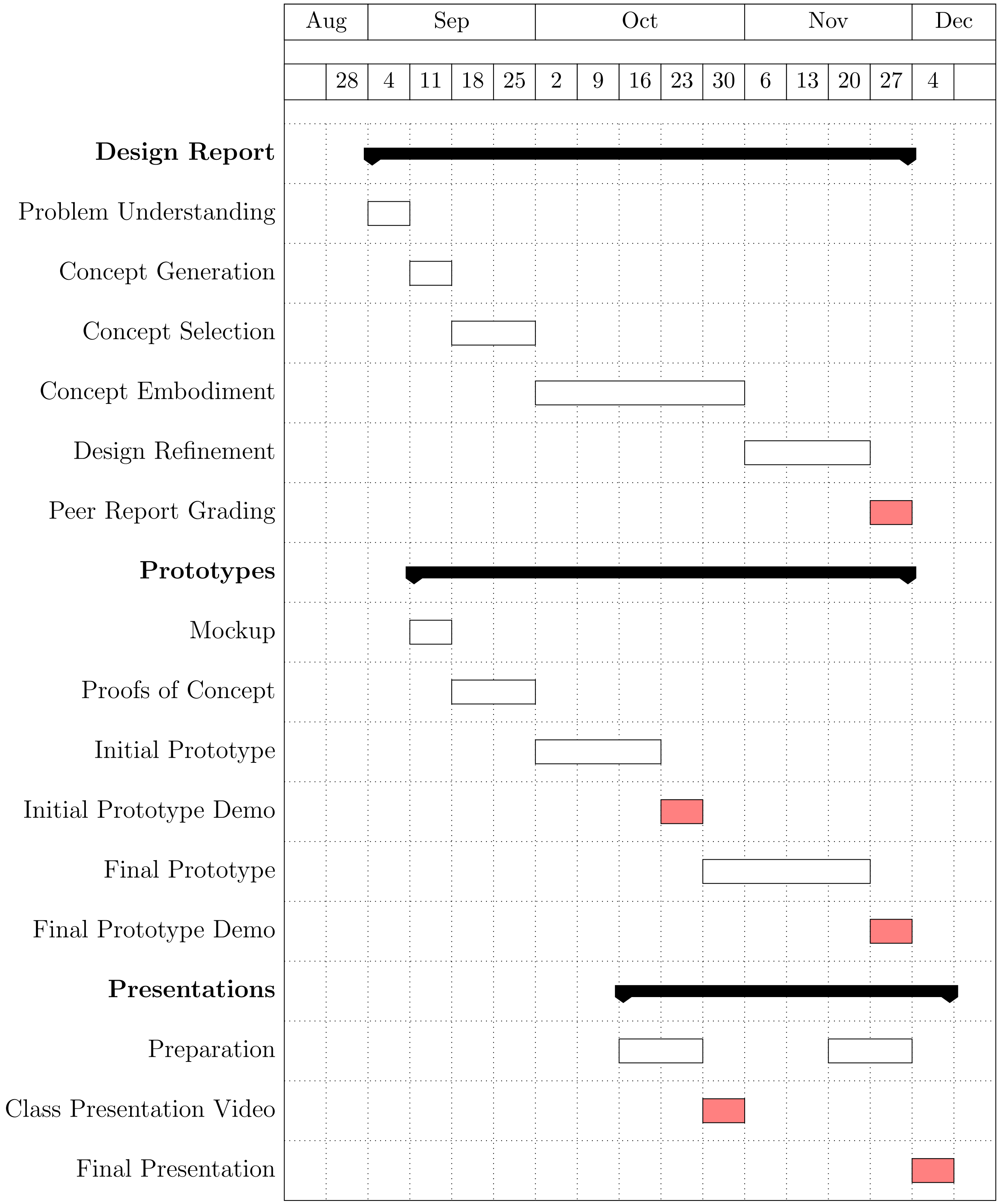


Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

We constructed a mockup prototype using several of the design elements we came up with during our concept generation. We included tank treads and a horizontal platform for the striker. We also designated space for controls, electronics, and batteries. We constructed the mockup using simple, cheap materials: cardboard, twine, and pencils. The mockup prototype is pictured in several different angles in Fig.s 7-10. After completing this mockup we feel that this could be a good design to scale up and test with our proof of concept. The only downside is that there is not a easy mounting point on the side of the vehicle. This would only work with a front mounted striker. Since the weight of the striker would be in the front it is necessary to attach the batteries and other essential components to the back of the vehicle to keep the center of mass balanced. We are discussing increasing the width of the platform so that we can move the tracks inward from the edge of the platform to account for a side mounted striker.

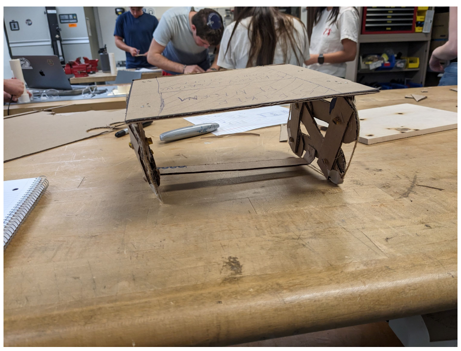


Figure 7: Front view of the mockup.

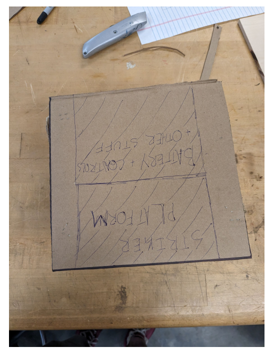


Figure 9: Top view of the mockup.

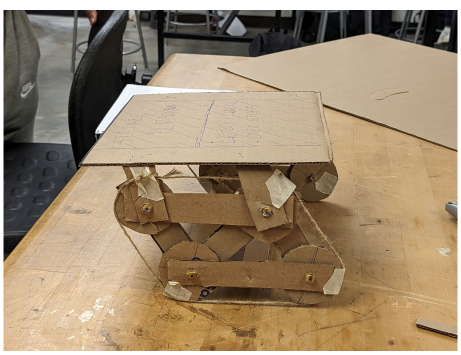


Figure 8: Side view of the mockup.

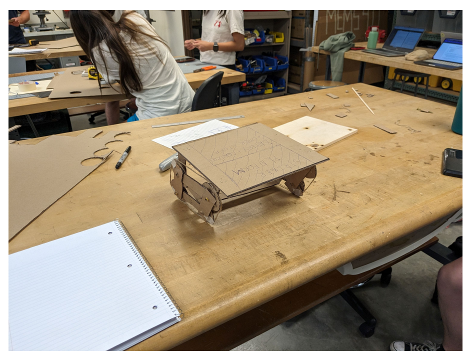


Figure 10: Angled view of the mockup.

3.2 Functional Decomposition

A function tree, or functional decomposition, allowed us to look at each problem or need we had for our design. This tool is useful for breaking up a large design challenge into much smaller, more manageable problems.

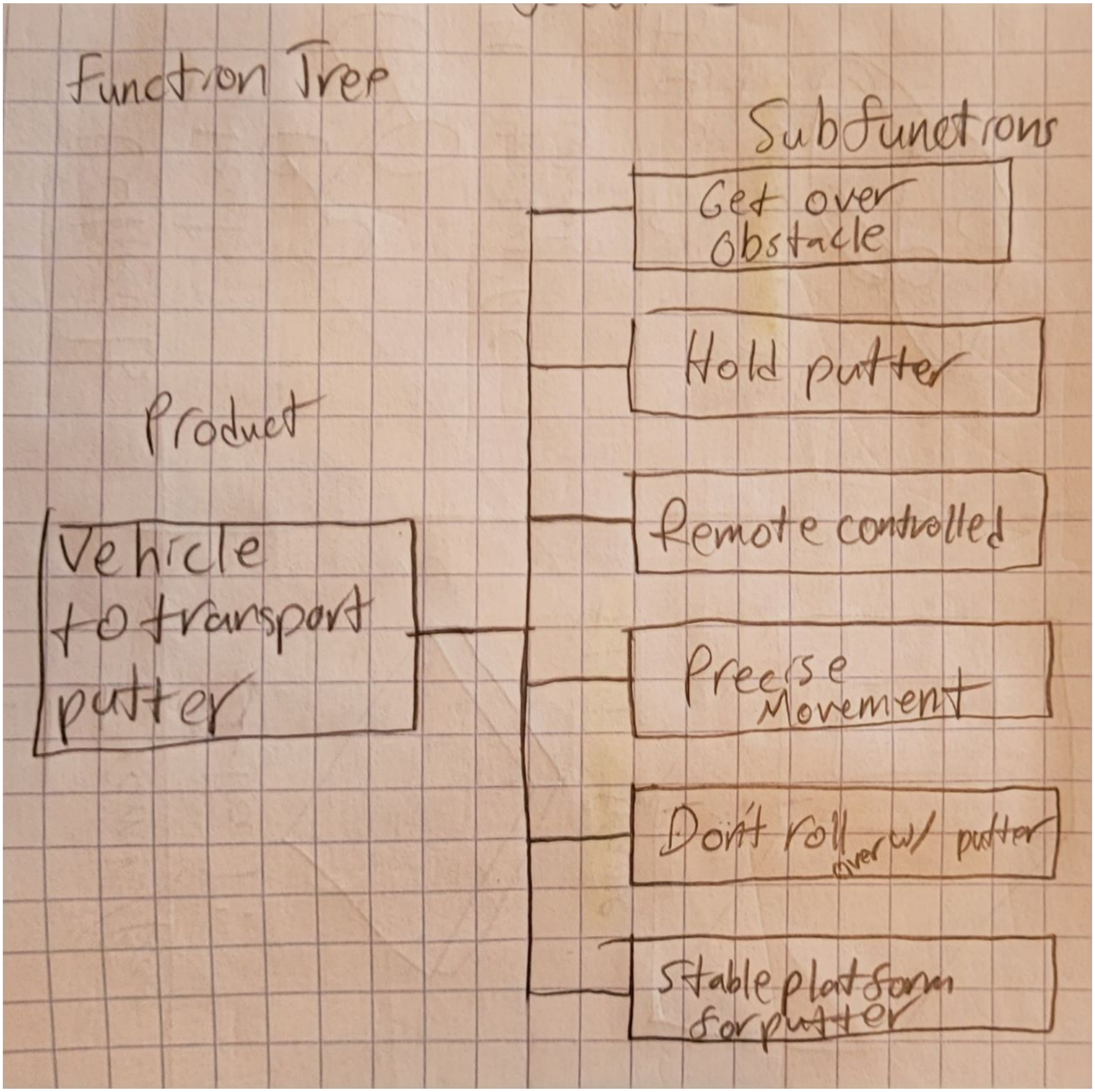


Figure 11: Function tree for ASME design challenge vehicle, hand-drawn and scanned

3.3 Morphological Chart

The morphological chart, or morph chart, is a concept generation tool that focuses on generating many solutions for each of the functions identified in the function tree. It allows us to address each design challenge independently of each other, rather than as an interconnected giant problem. Morph charts are a very helpful tool for getting creative and generating as many concepts as possible early in the design process.

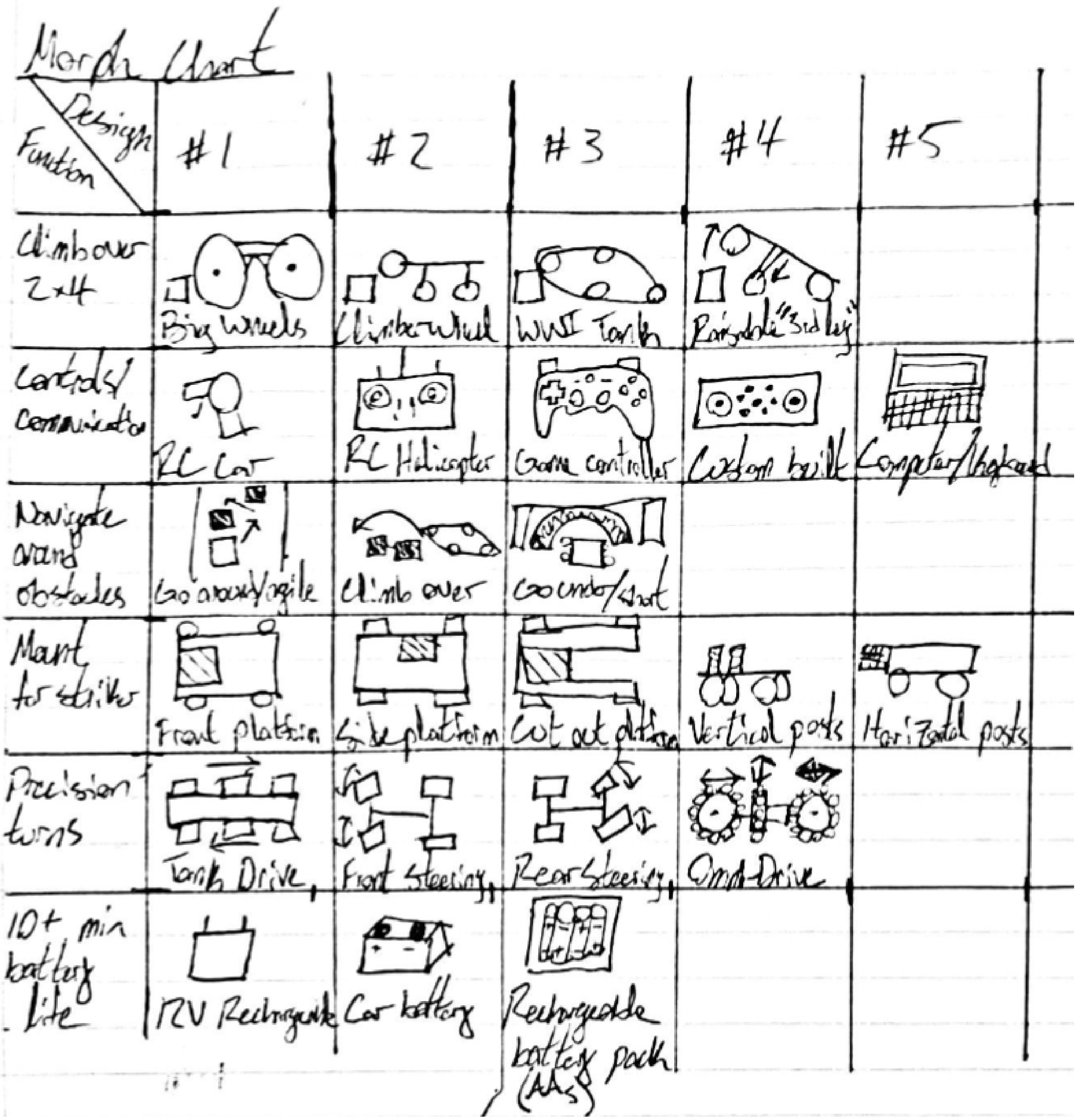


Figure 12: Morphological Chart for ASME Student Design Challenge Vehicle

3.4 Alternative Design Concepts

3.4.1 Concept #1: Third Leg

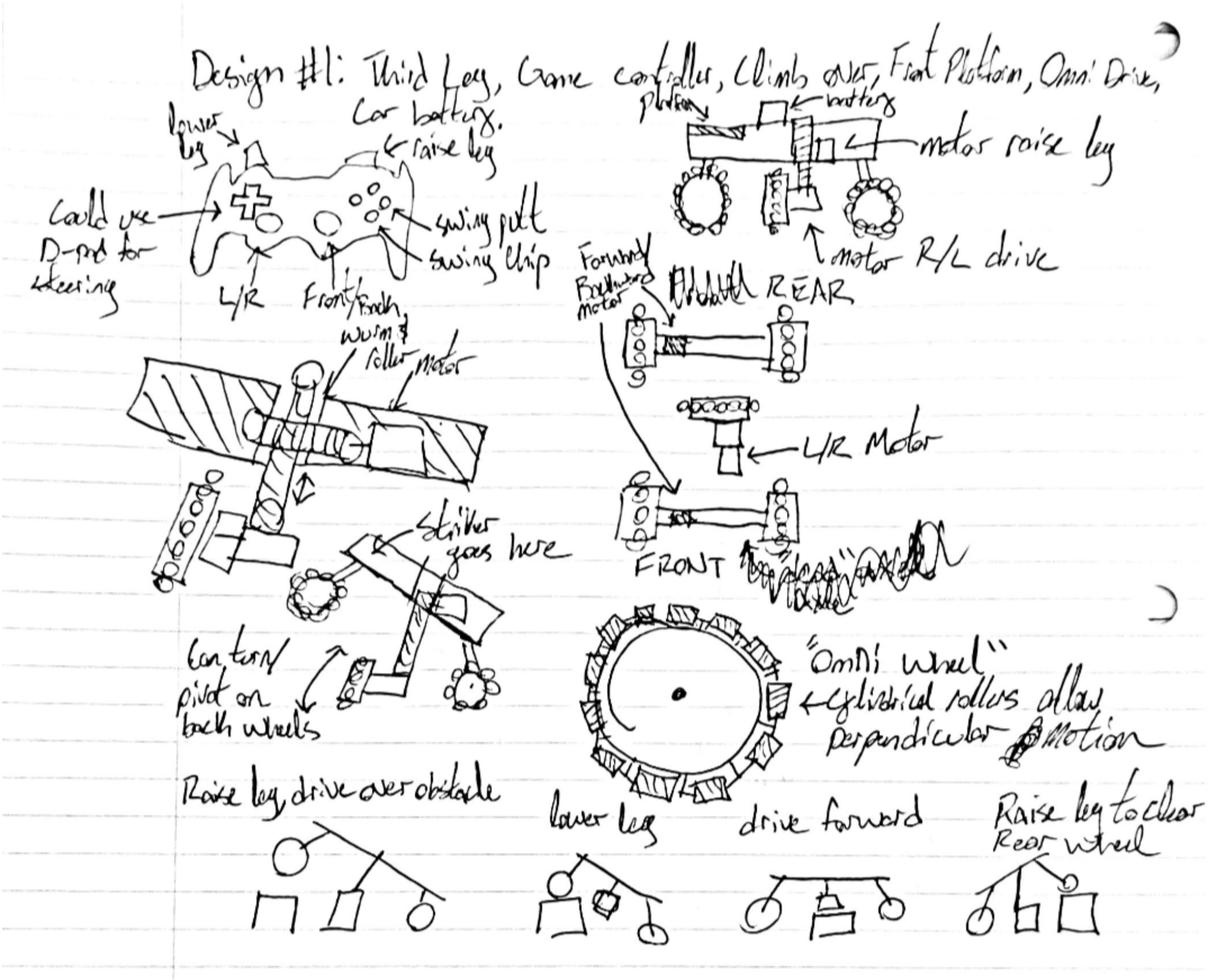


Figure 13: Sketches of a "Third Leg" concept

Description: This design uses a "third leg" to raise the front wheels above obstacles in order to drive over them. The raising and lowering of the leg is done via a worm and roller method. All 5 wheels are Omnidrive wheels, with rollers on the outside perpendicular to the direction of rotation for the wheels, allowing the wheels to roll in any direction. There is a frontally located platform for the striking apparatus. The vehicle would be controlled via a common video game controller, like X Box or PlayStation. The vehicle would be powered by a car battery.

3.4.2 Concept #2: Just Putt it

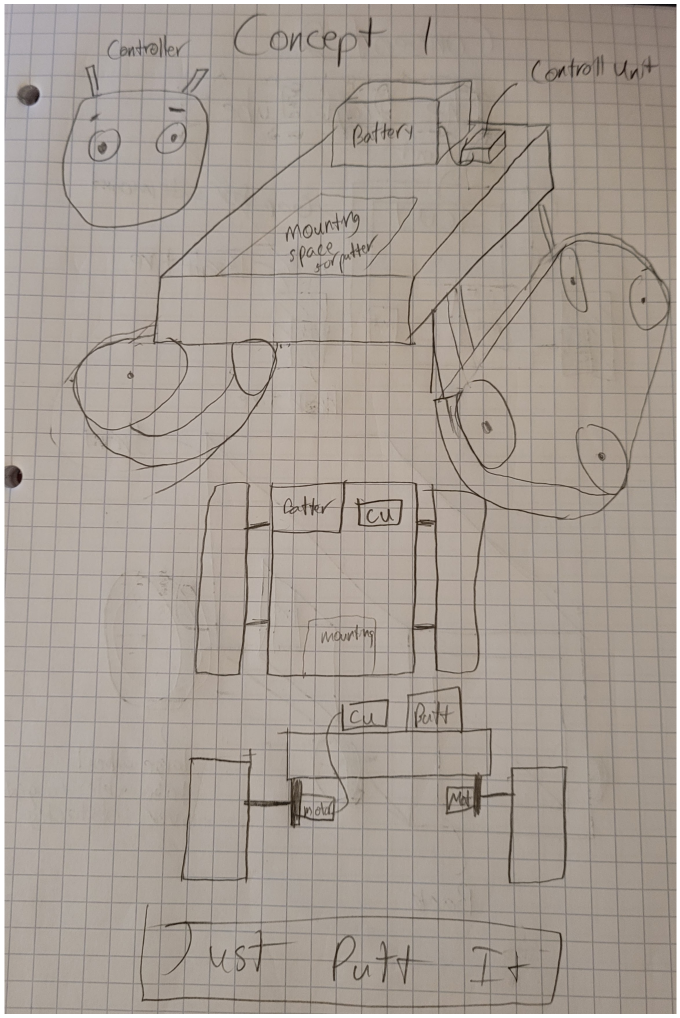


Figure 14: Sketches of a "Just Putt It" concept

Description: In the figure above a few sketches show a flat platform that is transported via motors attached to tank treads on either side of the vehicle. There is a large space on the front and space on the side where the putting mechanism can be mounted. In the back of the plate there is the battery and the receiver. These are in the back both because they need to be out of the way and they can act as a counterbalance to the putter. For movement there are tank tracks below the main frame of the vehicle. The motors are directly attached to the tracks for simplicity. Since the motors are attached to electronic speed controllers that are then connected to both the batteries and the receiver. In order for all of the components to get input there is a six channel controller in order to move the vehicle around.

3.4.3 Concept #3: Power Box

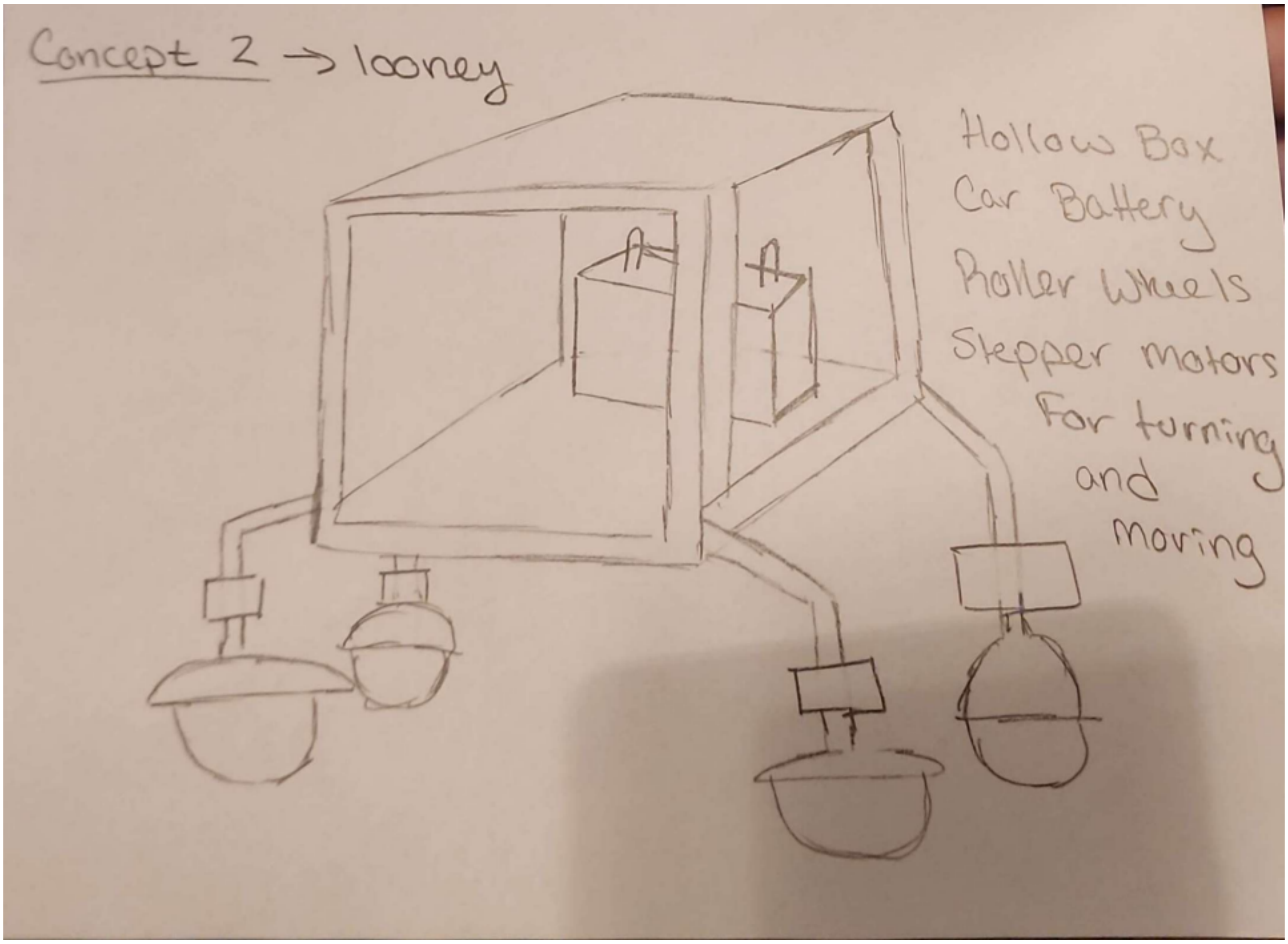


Figure 15: Sketches of a "Power Box" concept

Description: This design uses a hollow box that contains all major components of the vehicle. It contains a large battery towards the back in order to give it enough power. The wheels are roller balls, capable of omni-directional motion. It leaves the space open in the front of the hollow box to house the striker unit when it is done. Finally the motors are located in each of the legs of the vehicle. There would be 2 motors per each leg, one turning the direction we want to move and the other being the propulsion motor that actually moves the wheels.

3.4.4 Concept #4: Arrowhead

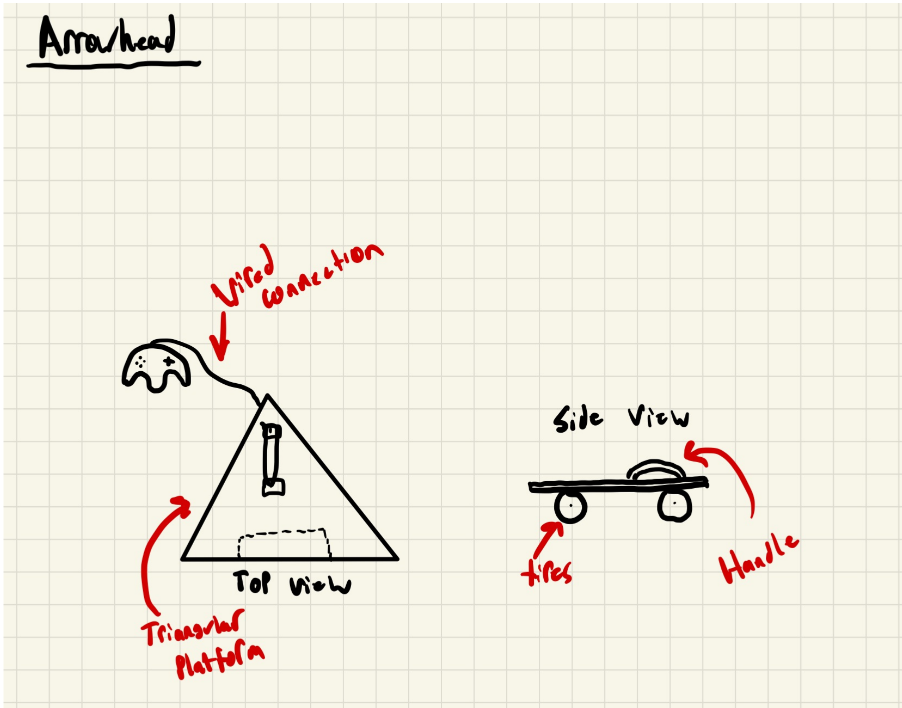


Figure 16: Sketches of ”Arrowhead” concept

Description: This design uses a triangular platform for its base, on top of which all the major components will be secured.The vehicle will have two wheels towards the front and two wheels at the rear, with motors mounted by each set of wheels. The vehicle is operated by a handheld controller that is connected via wire. On the open space towards the back of the vehicle there is a small handle that helps to increase the portability.

4 Concept Selection

4.1 Selection Criteria

In order to properly select a design concept, we considered a number of our design needs. We analyzed what we considered to be the most important design needs using an analytic hierarchy process (AHP). We considered cost, ease of construction, precision turning ability, ability to climb over obstacles, and ease of operation. These needs were ranked comparatively in order to develop an quantitative weight for each need.

	Cost	Ease of Construction	Precise Turns	Ability to climb over obstacles	Ease of operation		Row Total	Weight Value	Weight (%)
Cost	1.00	1.00	0.33	0.20	3.00		5.53	0.11	10.60
Ease of Construction	1.00	1.00	0.33	0.20	5.00		7.53	0.14	14.44
Precise Turns	3.00	3.00	1.00	0.33	7.00		14.33	0.27	27.47
Ability to Climb Obstacles	5.00	5.00	3.00	1.00	9.00		23.00	0.44	44.07
Ease of Operation	0.33	0.20	0.14	0.11	1.00		1.79	0.03	3.42
						Column Total:	**52.19**	**1.00**	**100.00**

Figure 17: The resulting AHP table. A score of greater than 1 indicates that the row item is more important than the column, while a score of less than one indicates that the column is more important. A score of one indicates equal importance.

4.2 Concept Evaluation

Each team member created two concept designs, and then chose one of those designs to contribute to our design selection process. We chose "Just Putt It" as our reference design for cost, ease of construction, and ease of operation since the majority of our members made a similar tank-like design. Third Leg was chosen as the reference for precise turns and climbing obstacles because we agreed that it would be "average" at both of those things. We rated each of the chosen designs from 1 to 5 in each need and applied the weights developed using the AHP to create a Weighted Scoring Matrix (WSM). These designs were then ranked using the scores resulting from the WSM.

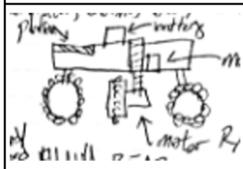
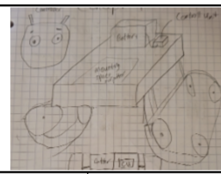
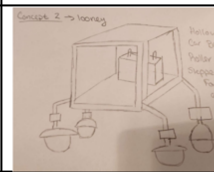
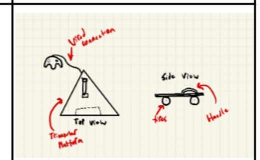
Alternative Design Concepts		Third Leg		Just Putt It		Power Box		Arrowhead	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Cost	11	3	0.32	3	0.32	4	0.42	5	0.53
Ease of Construction	14	2	0.29	3	0.43	4	0.58	4	0.58
Precise Turns	27	3	0.82	5	1.37	3	0.82	1	0.27
Ability to Climb Obstacles	44	3	1.32	5	2.20	2	0.88	3	1.32
Ease of Operation	3	2	0.07	3	0.10	1	0.03	5	0.17
	Total score	**2.821**		**4.431**		**2.741**		**2.876**	
	Rank	**3**		**1**		**4**		**2**	

Figure 18: Weighted Scoring Matrix (WSM) that was applied to choose our design concept.

4.3 Evaluation Results

From our WSM, we decided to move forward with the "Just Putt It" design. This design scored significantly higher than any of the other designs, beating the second place by more than 1 point. Just Putt It had perfect scores in the precise turns and ability to climb obstacles categories, which combined made up 71% of the total score. It also scored comparatively high on ease of operation. The angled tank treads will be able to easily conquer tall obstacles. We believe that using two separate joysticks, one for each tread, will make this design fairly easy to operate, while also giving us the ability to make zero radius turns with a high degree of precision. However, Just Putt It did score comparatively very low in cost and ease of construction. We will have to plan carefully to keep our budget under control and make sure that our design can be constructed with the available tools and resources. We intentionally weighted these categories lower because the challenges they present can be more easily overcome by carefulness.

4.4 Engineering Models/Relationships

We also considered several important physical relationships that would constrain our design. We mostly considered

4.4.1 Model 1: Battery Longevity

In order to see if the selected battery has enough power to complete the trials set in front of it, the battery life must be calculated. To do so we take the battery life and divide it by the current load applied to the battery as it is running. The equation for that is listed below.

$$B_l = \frac{B_c}{I}$$

B_l is the variable that represents battery life, B_c represents the battery's capacity (how much charge it can hold at one time), and I stands for the load charge that is being applied to the system. With this value calculated, it can be determined if the current power source has enough power to get us through the course and over the obstacles without any issue.

4.4.2 Model 2: Friction Coefficient

Throughout the course of the ASME challenge, the vehicle that is being designed will have to complete several climbing challenges set up. In order to accurately know if the design will succeed in climbing over the obstacles, the coefficient of friction needs to be calculated. Knowing the force outputted by the device, and the force exerted on the tract when successfully getting over the obstacle, the friction coefficient can be calculated. To do this the following equation is needed.

$$F_f = \mu N$$

Once these coefficients are calculated, we can be able to determine if the vehicle will be able to have enough friction to succeed.

4.4.3 Model 3: Frame Support Designs

The last of the models that were looked at was the model for looking at where to place the supports on the chassis so that the frame does not crumble in on itself. The equation to find the length of the wheel base is relatively straight forward with it being the distance from the front wheels axle to the back wheels axle. Then in order to find the most optimal support location a series of solid works analysis are then run to find the points of the weakness within the frame.

Though this model does not have equations, it is a series of engineering tests in order to find the week points in the structure. An example of this model testing can be seen below.

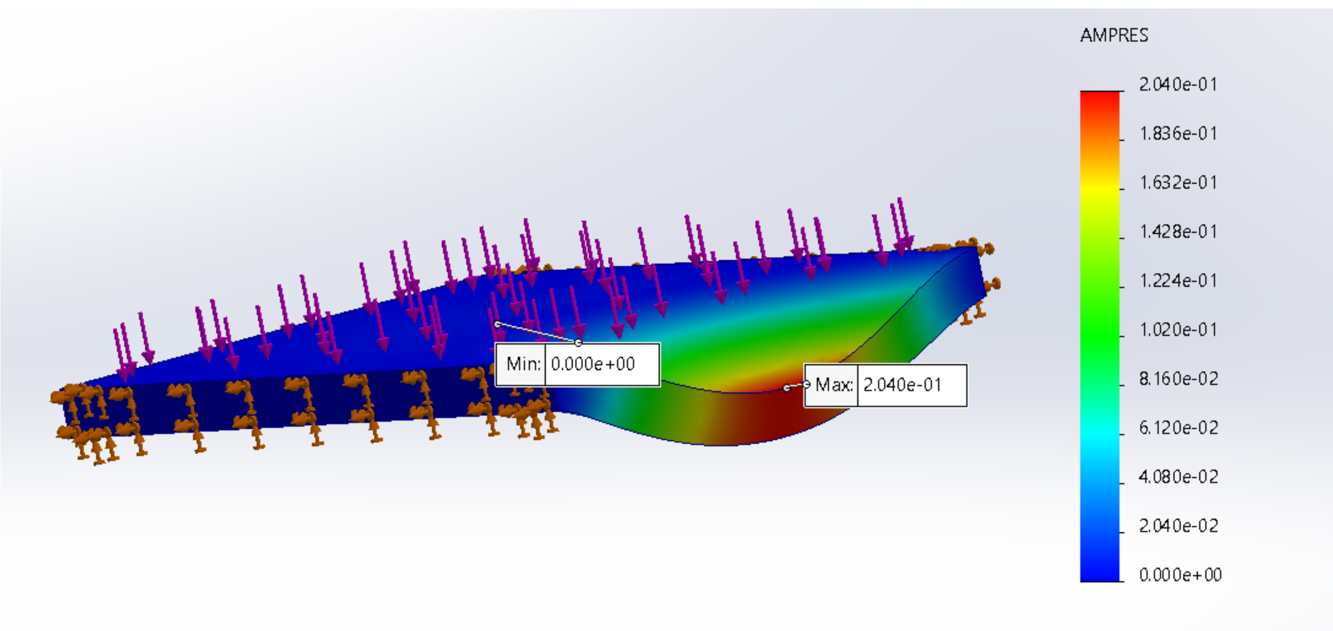


Figure 19: Support Analysis

By looking at this image, it can be seen that there is an applied load on the top of the plate with it being held firm along the sides. As a result of this the internal section starts to buckle. From this it can be seen that a support needs to be placed in the front middle section of the base plate to stop the plate from deforming and still be usable.

5 Concept Embodiment

5.1 Initial Embodiment

The initial concept embodiment was heavily rooted in our concept selection results. One of our first steps was to create a CAD rendering of our concept.

Individual Parts

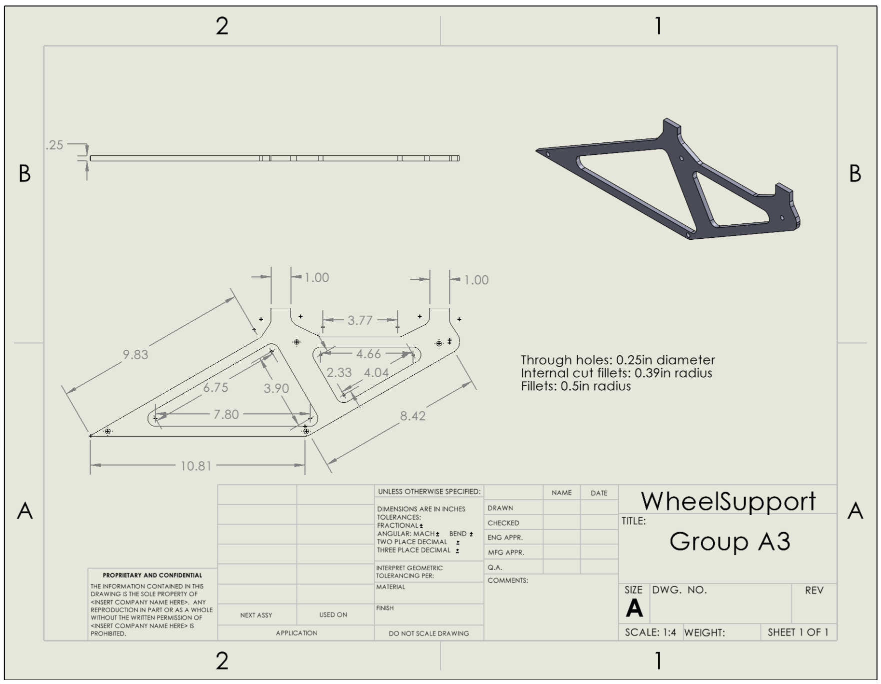


Figure 20: Wheel Supports

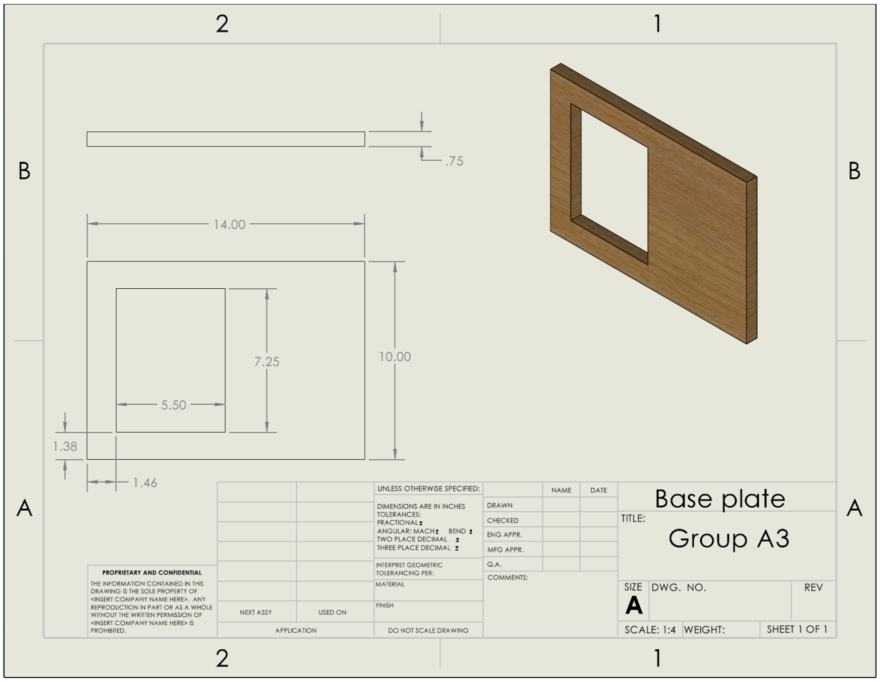


Figure 21: Base Plate

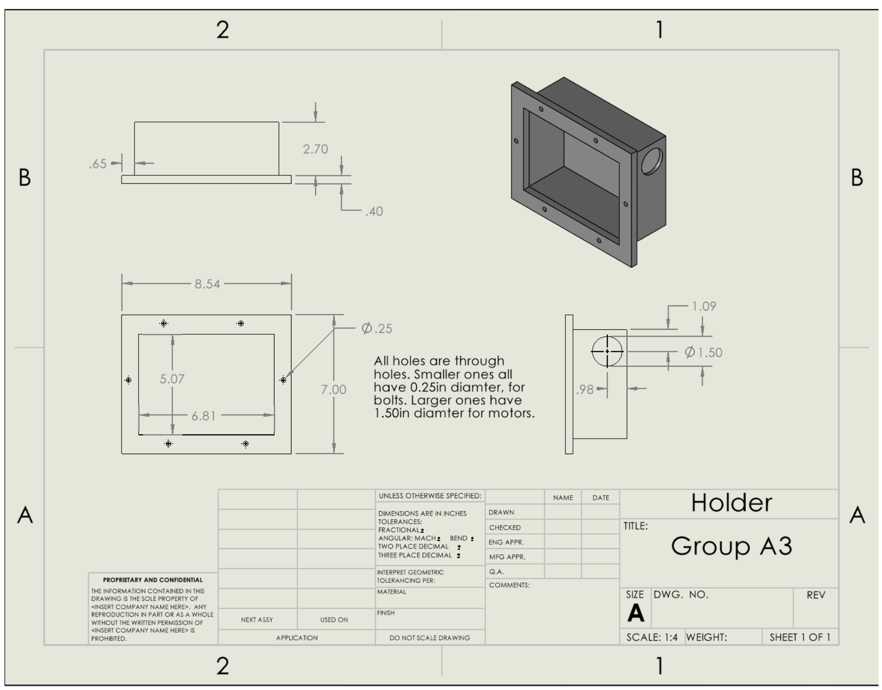


Figure 22: Component Holder

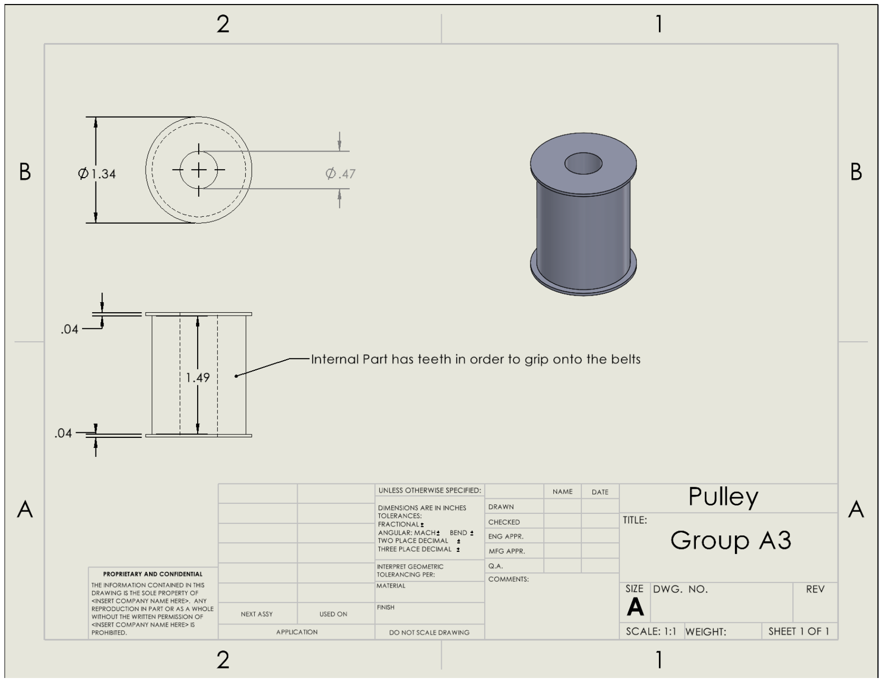


Figure 23: Pulley

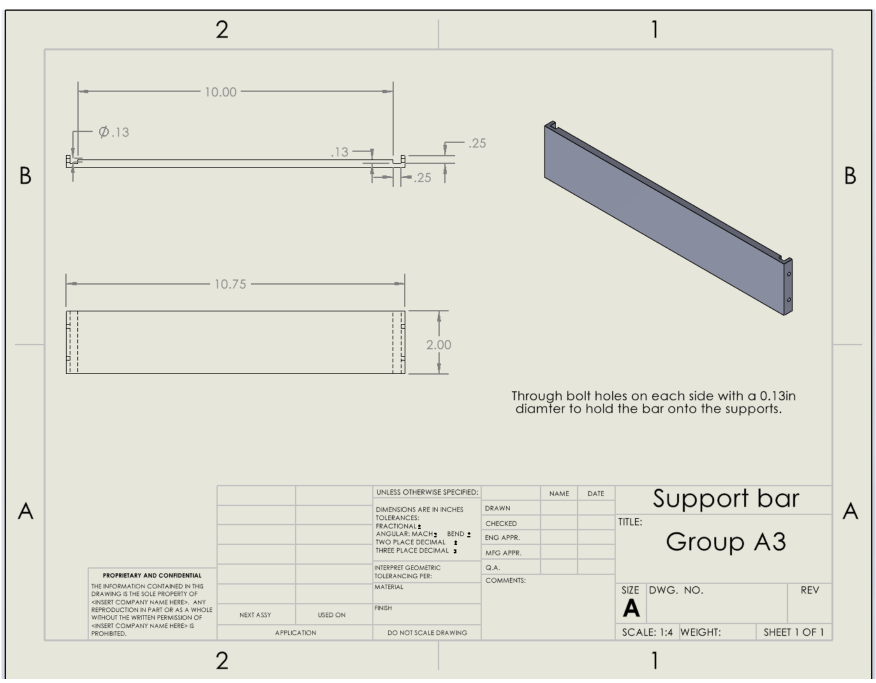


Figure 24: Bottom Support Bar

Isometric Assembly

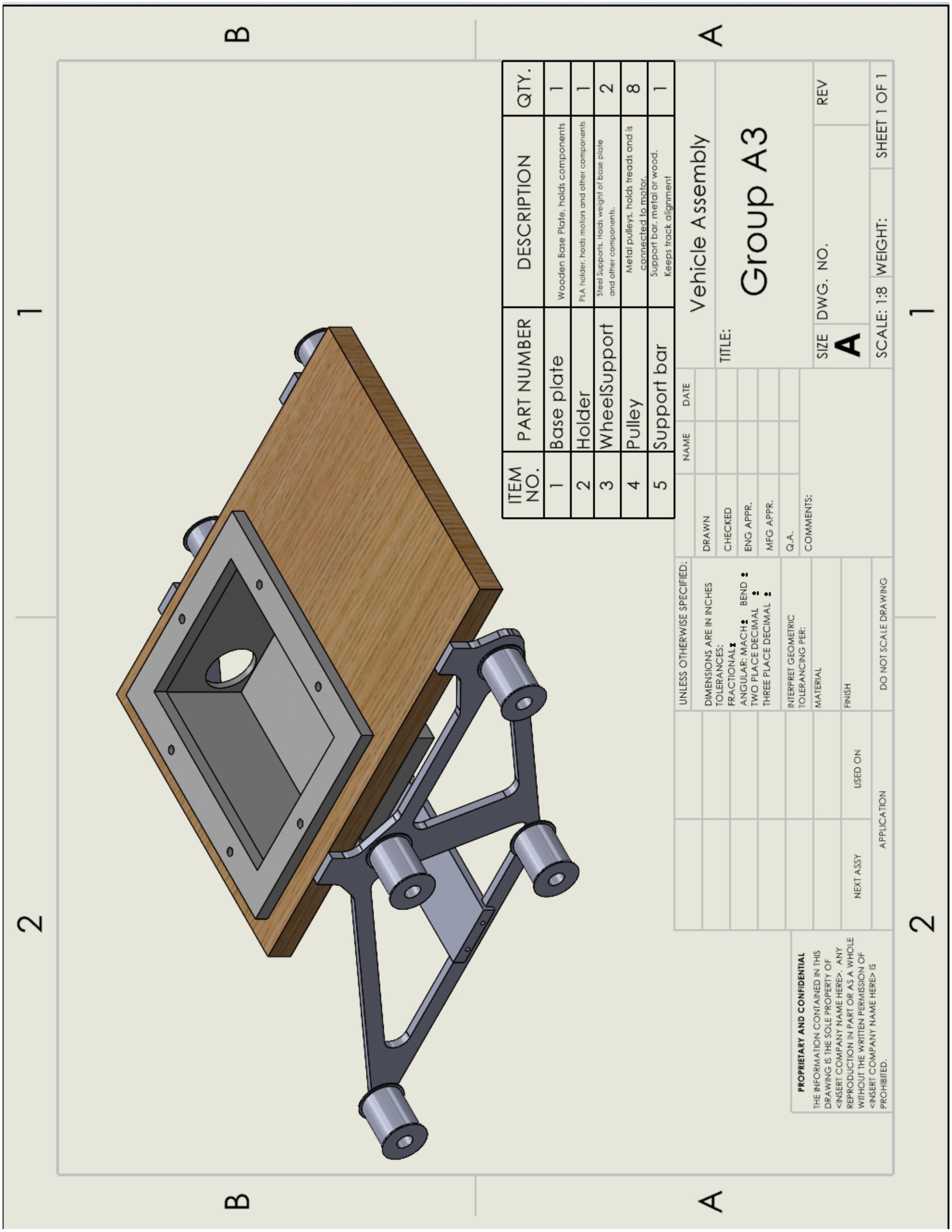


Figure 25: Assembled isometric view with bill of materials (BOM)

Exploded View of Assembly

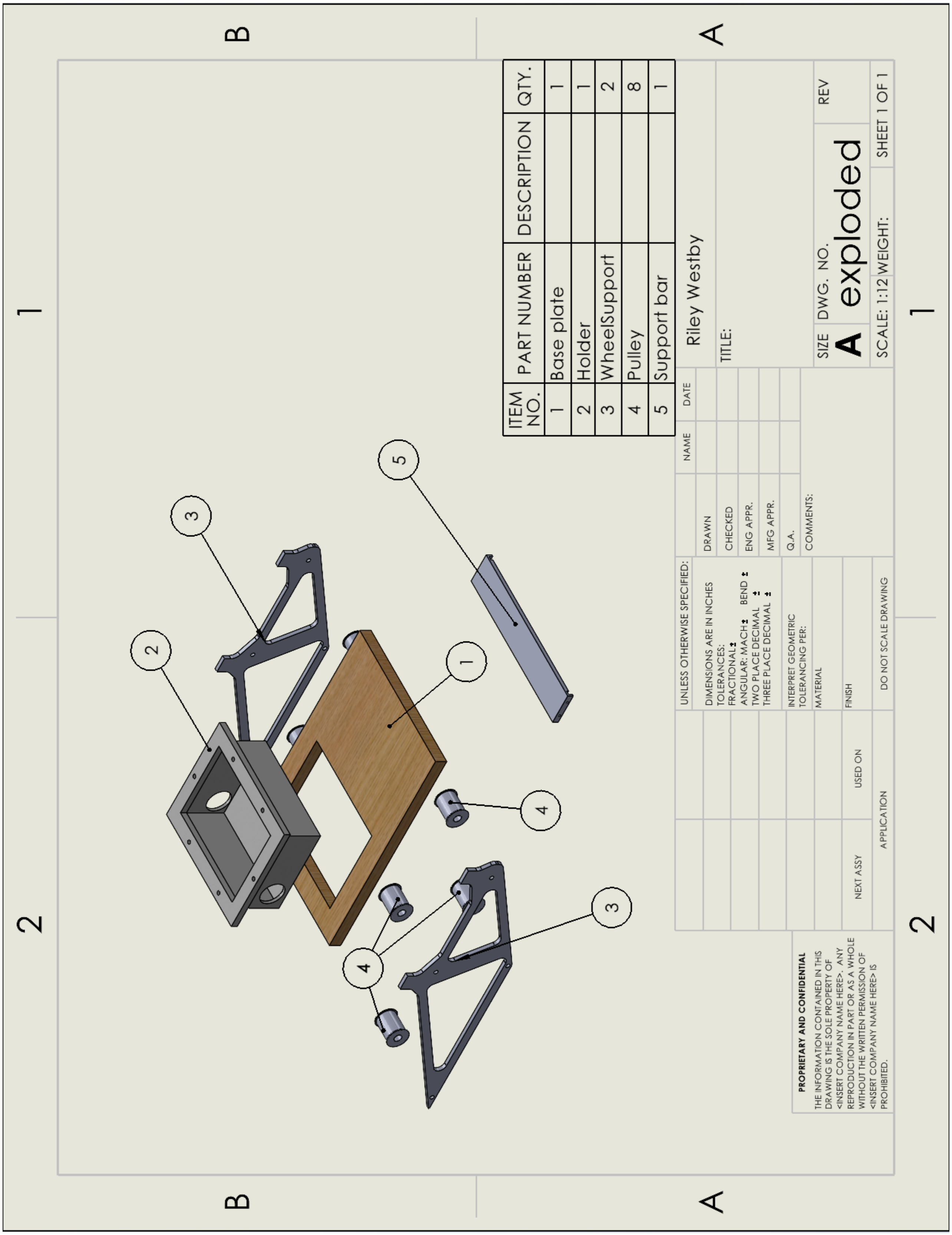


Figure 26: Exploded view with callout to BOM

This version of the concept was designed in order to meet the prototype goals that were agreed upon for all the ASME Student Design Challenge vehicles. Thes prototype goals were:

1. While carrying an extra weight*, the vehicle can climb over a long wooden board that is 3.5" tall and 1.5" thick.

2. While carrying an extra weight*, the device can climb onto, over, and back down from a sheet of 1/2"-thick plywood whose bottom surface is 3.5" above the ground.

3. While carrying an extra weight*, the device can position itself next to three golf balls (without disturbing them) and "aim" in a specified direction before removing the ball and continuing to the next ball, in ¡ 1 minute. The ball locations, aiming directions, and position of obstacles will be based on Holes 1, 2, and 3 of the design challenge.

*The extra weight will be approximately 3lbs, the esitmated weight of the striker unit.

5.2 Proofs-of-Concept

From our CAD rendering of our chosen concept, an initial prototype was constructed. The wheel supports were made using thin steel and aluminum beams that were cut to the needed length and then fastened together with bolts. Wood from the Jolley basement was used for the baseplate. A rectangular hole was then cut through the plate to hold the housing for the electronic components. The component holder was 3D printed and bolted into its slot in the baseplate. From there, the needed pulleys, treads, and electronic components were ordered from online sources and utilized to finish the initial prototype

Figure 27: Prototype

Figure 28: Prototype

5.3 Design Changes

In order to make our vehicle more functional numerous changes are being made. Starting with the main base plate that everything is attached to. We are remaking this with a more flat piece of wood, so that it is easier to work with and flat on the sides for the side frame to be attached to. Most of the updates to the newer design pertain to the lower framework and the treads. Previously many strips of metal were bolted together to form a framework for the treads to attach to. This was not very successful because different components sat out at different distances. To improve this we are transitioning to a solid piece of metal it will have the base framework cut out of it and then be mounted to the base plate. This also makes it easier to line up the angles for the treads.

Transitioning to the treads there are a few points of improvement. To start, we are planning on tightening tolerances so that the axles will not be able to bend around as freely. This will allow us to properly mount the treads and drive around. If this does not work, then we can add framing so that the axles are supported on either side of the treads. If that does not work, then we can add a dummy wheel made of wood on the other side of the framing to keep the bottom pulleys from having too large of an angle. We are also changing out our axles. One issue we had was that the axles we could find were too small for our pulleys. We remedied this with duct tape, but getting properly sized axles will help improve the design.

One of the base things we were missing from our initial prototype was two working motors so that we can drive the vehicle with both treads. Now that both of our motors have come in we can add both of the motors to the circuit and run both treads from the controller. To better hold these motors in place. We are 3-D printing mounts for them to sit in and not allow any movement other than the axle.

6 Design Refinement

6.1 Model-Based Design Decisions

Using the same CAD model from section 5.1 the center of mass is located at the front edge of the drop-down box, which is the middle of the model. From this an assumption about the balance of the model can be made. This assumption is about the balance of the model, stating that the model should be able to sit upright without the possibility off rolling over. This is due to the fact that the center of mass is centralized meaning that the design is symmetrical on the sides and the addition of the drop-down box acts as a counter weight to the front of the design. Then using the buckling analysis from section 4.4. it can be seen where the buckling occurs is towards the central part of the base plate. This has been fixed by the addition of the drop-down box as it lowers the amount of force acting on the top of the plate, instead switching it to a force acting on the inside structure of the base plate. Another way of solving this buckling analysis is with the addition of structural bars. This addition can be seen in the cad assembly in section 5.1. By adding these bars they add structural support to the base plate as well as the wheel supports. When designing the treads for the model, the use of rubberized belts was decided upon. This is due to the friction coefficients that can be seen between the materials. With the connection between the rubberized belt to the pulleys it can be seen as a connection between a material with a coefficient of friction of 0.4 (rubber) and a material with a coefficient of 0.61 (aluminum). From these values it can be seen that with the addition of the teeth of the belt and the teeth of the pulley, which increases the amount of friction present, that these should be able to act upon one another with minimal slipping. Then when it comes to the treads versus the wooden obstacles, they have roughly the same relationship as wood has a coefficient of friction of 0.6. This relationship shows that all parts should be able to act upon themselves and each other with minimal slipping.

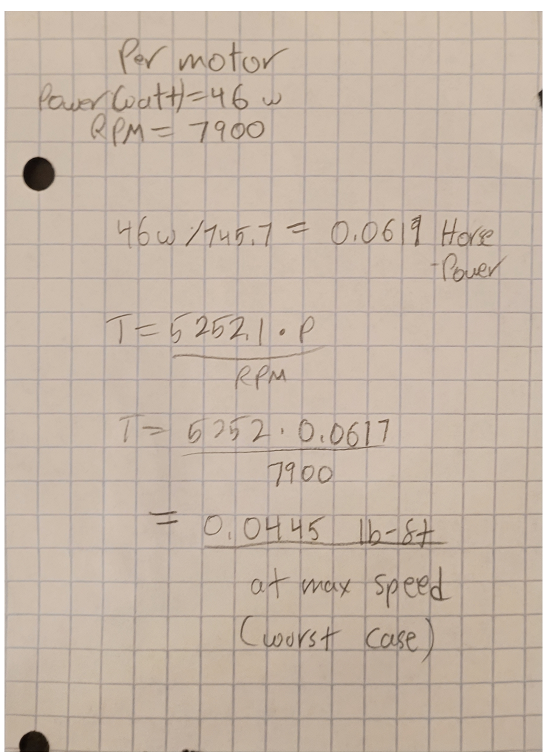


Figure 29: Torque Calculations

From the image above, the calculations for the expected torque for each motor has been found.

These calculations show the worst case scenario, that being when the motor is running at its full potential, thus lowering the amount of torque output. From this it can be assumed that the motor will need to be held to a constant low output to maximize the torque, thus resulting in keeping the motor from slipping and allowing the model to be drivable. Finally the last design decision was based on the battery longevity equations, that can be found in the section 4.4. This was then cross referenced with the motor selection. Making sure that the motor that was selected also had the correct corresponding battery. Capable of driving the motor when needed.

6.2 Design for Safety

When designing this project safety was an important thing to consider. There are different deliberate actions in the design to maximize the safety of the device. Some of our main safety goals were ensuring that the components did their job without placing the operator in any type of distress. This includes making the handling of the vehicle easy to understand, so that the driver does not lose control and drive it into an area with a large amount of people thus preventing injury. Along with this is making sure our components did not overheat / break thus resulting in possible injury. In order to make sure these issues were handled steps were taken to ensure that the components were given enough space in order for them to dissipate their collected heat, along with adding housings or supports to keep the parts from moving or breaking due to the stress placed upon them. Once these goals were understood, they were among some of the top focus of the group when designing the vehicle, so that moving forward safety would be a key factor amongst our designs.

6.2.1 Risk #1: Battery Overload

Description:
When using the internal connections of the battery to the ESC to the motors, there is always some worry of the battery overloading. When the battery overloads it starts to generate heat and expand. From this expansion, the battery can cause fire or even the possibility of exploding if it expands enough.

Severity:
This is one of the most severe failures that can happen. If this produces a large amount of heat the battery could potentially catch fire and in the most extreme cases explode.

Probability:
Though the possibility of this is rather slim as the components attached to the battery are rated for the level of charge outputted from the battery. This failure can still occur if we stress the battery too much. This can happen from overcharging, overworking the battery, or by simply placing the battery in a location that the heat is not easily dissipated.

Mitigating Steps:
Steps to ensure that this does not happen are as follows. Place the battery in a well ventilated area, ensuring that the heat built up by the batteries is able to dissipate into the surrounding air. Make sure to take the batteries off the charger when they have reached the appropriate level of charge, making sure they do not stay on the charger longer than recommended. Finally making sure the battery is not overworked, meaning placing all the components to run off the power of the same battery. By splitting up the need for each battery, it will lower the chance they have of internally building up heat.

6.2.2 Risk #2: Tank Treads Break

Description:
When running the treads over various terrains it is possible that the tank treads that we created could break or come apart. Seeing as we made our own treads out of a timing belt rather than buying prefabricated treads this is an issue that could arise. In this the treads and become unable to move the vehicle.

Severity:
The severity of this issue is roughly in the middle, as it is important in that if it happens the tank will not be able to move, but it is an issue that can be fixed relatively easily. Thus the severity of this issue would reside more towards the middle ground on importance.

Probability:
The probability of this happening is rather small if the tank treads were properly made. With ours being made out of a timing belt and then fused together the chance of this issue increases and becomes more likely for our treads when comparing them to the other group's treads.

Mitigating Steps:
Making sure that the treads are properly fused together and that they can hold up under stress. This stress that we will test it with can be made in order to replicate the forces that the treads will undergo when the vehicle is being driven.

6.2.3 Risk #3: Rolling Over

Description:
This is when the tank rolls over onto one of its sides and becomes unable to move due to being flipped. This can occur when climbing obstacles or even when shifting the weight around within the vehicle thus changing the center of gravity that is needed to keep upright.

Severity:
The severity of this is not determined to be not that high as by rolling over the components should not be able to shift around and this can be fixed by just manually flipping the vehicle back over.

Probability:
The probability of this is rather low as the width of the design keeps it from rolling left to right. And the center of mass is placed in the middle of the design so that shows that the vehicle design should be nicely balanced when trying to roll over either forwards or backwards.

Mitigating Steps:
Make sure that the base is wide enough so that the vehicle cannot roll over on its side. And place the center of mass in the middle of the design so that it is nicely balanced out. In addition, counterweights might be added to help keep the vehicle upright.

6.3 Design for Manufacturing

Total current components: 30
Total Current threaded fasteners: 28
Theoretically Necessary Components:

- Combined chassis, electronics tray, and wheel supports
  - This part cannot be combined any further, as the electronics need to be removable from the base for maintenance and battery charging, while the other parts must be able to freely move relative to the chassis.

- Axles and wheels (x8)
  - These must be separate components because the tread must be able to move freely along the wheels, while the axles must be free to rotate in the wheel supports.
- Treads (x2)
  - The treads must be separate parts from the wheels because they move relative to the wheels, and will be made out of a different material. The treads would need to be a flexible material, while the wheels need to be hard and sturdy.
- Motors (x2)
  - The motors in and of themselves are fairly complex components, made of several different sub-components and materials. There is no way to make a motor that could be combined with the wheel-axle assembly while still fitting into the wheel supports, or to combine the motors with a plastic chassis/electronics tray.
- Two channel motor controller
- Battery
- Controller
- Receiver

A combined chassis could include the electronics tray and both wheel supports all in one part. None of these components must move relative to each other and combining them would eliminate many of the threaded fasteners. This part could be 3-D printed or molded from plastic. Combining axles and wheels into one part would eliminate the need for the set screws that hold our wheels onto the axles. It would also eliminate any slipping between the drive wheels and the drive axles that may occur. These could be made by casting metal, powder metal additive manufacturing, or with a 4 axis CNC machine. Due to their independently moving nature, the two treads and two motors would all have to remain separate components. We could eliminate the need for two ESCs on board by using a two channel motor controller or an Arduino set up that could receive and send two independent signals from the controller. We could also consolidate our power supply down to a single batter rather than two separate batteries. The controller and receiver are both essential components. The controller must, by the rules of the competition, remain separated from the rest of the vehicle. The receiver cannot be further combined into any other components, since it may need it be removed for maintenance or to replace the controller.

6.4 Design for Usability

When designing this project many different aspects were taken into account. One thing was the usability of the device. Usability can mean a variety of different things. These things can be is it prohibitively expensive, usable to all or most people, and complexity.

There are different ways we could have taken this project. Most of which would pertain obtaining expensive parts and then just assembling them together. We decided to not go this route and use as many simple parts you can get at a hardware store as possible. One example is that we are using timing belts from a car along with pulleys that can also be from a car or other vehicle. This is different from most other designs because the tread setup in most other designs would become the biggest cost of the entire design. We also used wood and 3D printing for the rest of the support and structure of the part. These can easily be bought at a hardware store and printed at a maker space. Most of the components do not cost that much and are accessible to most people. We also reduced the complexity of as many components as possible. By doing this is it more usable and understandable to more people. The main components for this was the circuitry which just had the batteries, receiver, electronic speed controllers, and the motors. The other component that was simplified was the treads. Having just one driving pulley and then simple holes for the other pulleys and axles to attach in creates a simple design.

In order to make this device usable by most people it would need to be light and easy to control. This is done by a few design choices throughout the design. The entire framing and structure is made of light wood and plastic. This makes is weigh less than five pounds and easy to carry. We also attached eye hooks and a rope at the top for easy carrying. To control the device we use a radio transmitter and receiver. These are easy to use by most people Due to the difference between the left and right stick on the controller we used a rubber band to return the left stick to the original position after being pushed up or down, so that it would mimic the right stick. There are also two switches glued to the top of the plastic structure that can easily turn the motors on or off. These design decisions help contribute to a more usable prototype.

Many of the design considerations took into account the usability of the device. This is partially because none of us have previous remote controlling experience before this and want to make it easier for us to understand and for others as well. We succeeded in making it usable by other people. Some of these considerations made the vehicle less functional.

6.5 Design Considerations

Table 3: Factors considered for design solution

Design Factor	Applicable	Not Applicable
Public Health		X
Safety	X	
Welfare		X
Global		X
Cultural		X
Societal		X
Environmental		X
Economic	X	

Table 4: Contexts considered for ethical judgments

Situation	Applicable	Not Applicable
Global context		X
Economic context	X	
Environmental context		X
Societal context		X

7 Final Prototype

7.1 Overview

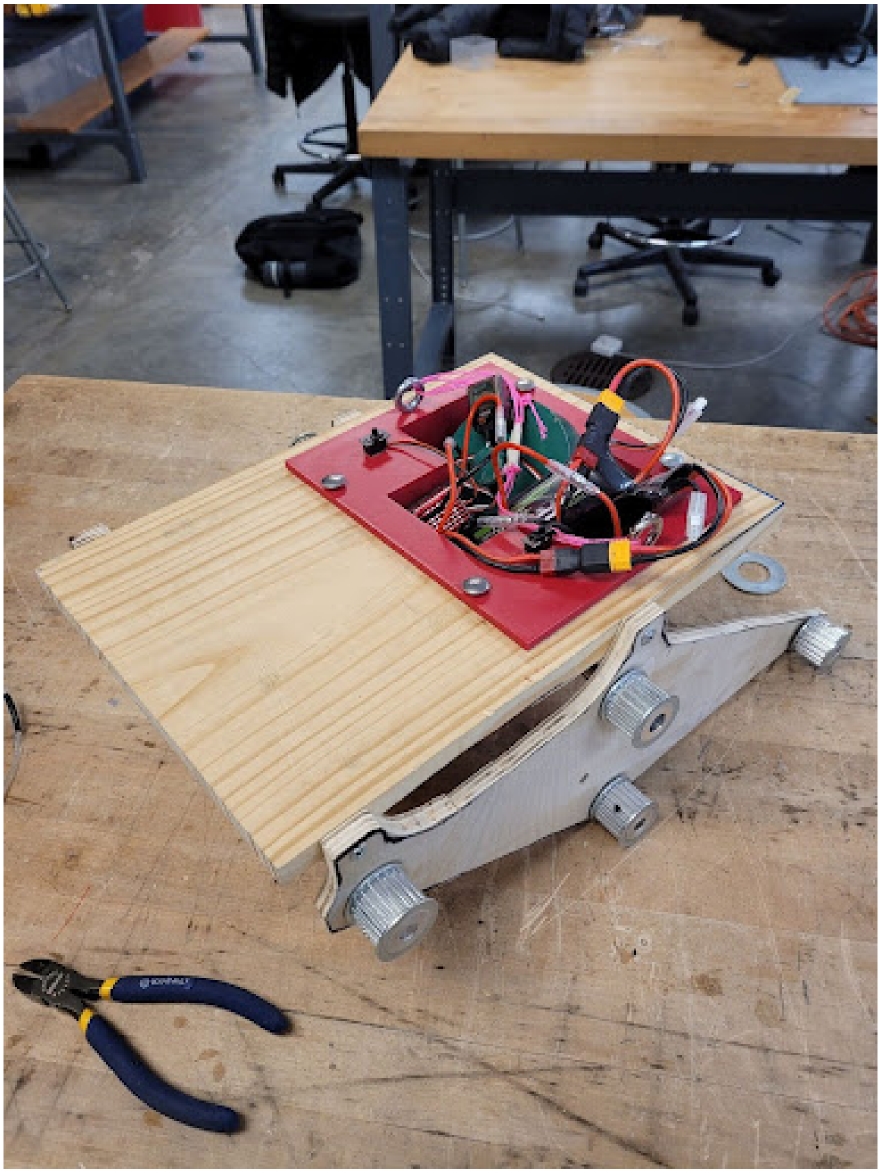


Figure 30: The final prototype iteration.

Our final prototype faced a number of design issues. First, the treads would slip off the drive wheels when the motor exceeded the desired rpm, allowing the wheels to spin while the tread remained stationary. Additionally, while the motor was within the desired rpm range, the torque of the motor was not enough to turn the treads. This is likely due to the underestimation of the friction between our axles and the wheel supports. These two issues caused our vehicle to be completely immobile. Additionally, a change of materials moved the center of gravity too far forward compared to our SOLIDWORKS model, leading to the addition of counterweights in our drop down tray.

7.2 Performance Assessment

Our performance goals were:

1. While carrying an extra weight, the device can climb over a long wooden board that is 3.5" tall and 1.5" thick.
2. While carrying an extra weight, the device can climb onto, over, and back down from a sheet of 1/2"-thick plywood whose bottom surface is 3.5" above the ground.
3. While carrying an extra weight, the device can position itself next to three golf balls (without disturbing them) and "aim" in a specified direction before removing the ball and continuing to the next ball, in ¡ 1 minute. The ball locations, aiming directions, and position of obstacles are based on Holes 1, 2, and 3.

Due to our vehicle's complete immobility, none of the goals were achieved.

7.3 Future Work

We have many ideas for potential future work that may improve our prototype's performance. Adding bearings to the wheel support structure would reduce the friction on the axles. Using higher torque motors would also help to overcome the issues with the vehicle's treads. Similarly, we could create a gearing system from the motors to the drive wheels rather than applying the power directly to decrease our RPM and increase our torque. Changing the shape of the treads so that the drive wheels have a larger wrap angle might help to reduce slip between the treads and the wheels. Using a premade tread system instead of building our own from scratch would help to alleviate the issues we had with keeping enough tension in the tread and keeping our treads in one piece.

A Parts List

	Part	Source Link	Supplier Part Number	Color	Unit Price	Tax	Shipping	Quantity	Total Price
1	1/2-2-2 Birch Hardwood	Lowes	6199	light wood	$ 11.98	$ 2.51	$ -	2	$ 26.47
2	ISPG PLA 1.75mm black	MicroCenter	407452	black	$ 11.01	$ 1.18	$ -	1	$ 12.19
3	uxcell Aluminum 20 Teeth 12mm Bore 5mm Pitch Timing Belt Pulley for 20mm Belt	Amazon	a17042100ux1 220	silver	$ 9.99	$ 5.40	$ -	8	$ 85.32
4	OVONIC 3S Lipo Battery 25C 2200mAh 11.1V Lipo Battery with XT60 (2 Packs)	Amazon	B07DGSVNP5	Black	$ 34.99	$ 4.01	$ -	1	$ 39.00
5	GoolRC 550 35T Brushed Motor with 60A Brushed ESC Electric Speed Controller (T Male Plug) Replacement for 1/10 Axial SCX10 RC4WD D90	Amazon	B08KG1W9PY	black	$ 27.99	$ 5.04	$ -	2	$ 62.02
6	POWGE 5Meters 3M-20mm HTD 3M Open Ended Timing Belt Width 20mm	Amazon	B0C2QCQGJ4	black	$ 39.99	$ 3.60	$ -	1	$ 43.59
7	HTRC LiPo Battery Charger 2S-3S RC Balance Charger	Amazon	B09ZP5P85B	black	$ 11.97	$ 1.31	$ -	1	$ 13.28
8	GLOBACT 550 Brushed Motor 12T and 80A ESC Brushed Motor ESC Combo ESC Dual Mode BEC 5A 7.4V/6.4V	Amazon	B09CKQWM7D	black	$ 31.77	$ 2.63	$ -	1	$ 34.40
9	Base Board	Jolley 110		wood	$ -	$ -	$ -	1	$ -
10	6 channel radio transmitter/reciever	Jolley 110		black	$ -	$ -	$ -	1	$ -
Total:									$ 316.23