ENR 281 Design Project Report (Spring 2024)

Freddy Skidd, Isaac Woodside, Mark Zepeda, Emmanuel Lopez, Megan Schimmel[1].

Abstract
This report documents the team's design work for the Marauders Cart project assigned in the sophomore level design courses ENR 280 (Fall) and ENR 281 (Spring). Each team was tasked to design a static and dynamic structure for the race course, as well as a remote controlled car to race. This team was assigned a series of turbines for the dynamic structure and a narrow bridge for the static structure. It was specified that the dynamic and static structure would combine to make one big structure. The design work performed utilized the engineering knowledge obtained in other courses and independent research. The designs required a knowledge of and an ability to apply mechanics of rigid and deformable bodies, motors, circuits, programming, and arduino controls. In addition to design work, this report documents the entire design process of this project including design specifications, necessary literature review, as well as management of budget and schedule.

[1] *School of Engineering, University of Mary, Bismarck, North Dakota*

Contents

Executive Summary

This report will outline the design process for the construction of a remote-controlled car, a dynamic structure and a static structure. The dynamic structure is a series of turbines, while the static structure is a curved bridge. The process begins with a set of specifications outlined by the team manager. This will then be followed by extensive research covering the major topics associated with constructing the car and obstacles. These topics include car components, material properties, bridge properties, and transferring torque. Important calculations and equations needed for both testing and construction are included as well.

After thorough research, this report outlines the initial ideas for the car and obstacles as well as the process to reach each final design. It will outline the thought process of the team and touch on why certain ideas were abandoned or adjusted. Within each design, CAD models and drawings were included to show the progress over time. After choosing the final design, the next step is prototyping and manufacturing. The next section outlines the process to construct the car and obstacles. It will include different tests that were conducted, and the flaws found in the system. Different solutions are introduced as well as the progress from start to finish. The challenges as well as the successes are highlighted throughout the whole process. The final product for the car, turbines, and bridge can be seen within prototyping and manufacturing section.

Overall, this report documents the entire design process from initial to final stages. It outlines the successes and failures of the team throughout the entire process, giving insight into information that is important when building a turbine, bridge and remote-controlled car.

1. Design Problem and Objectives

The problem presented in ENR 280/1 was to design and construct a remote-controlled car and a full race course to be located in Chick's Place. A map of the space the race course had to occupy is shown in Figure 1. The goal of this project was for each team to design the following: 1) A remote control car, 2) a dynamic structure, and 3) a static structure.

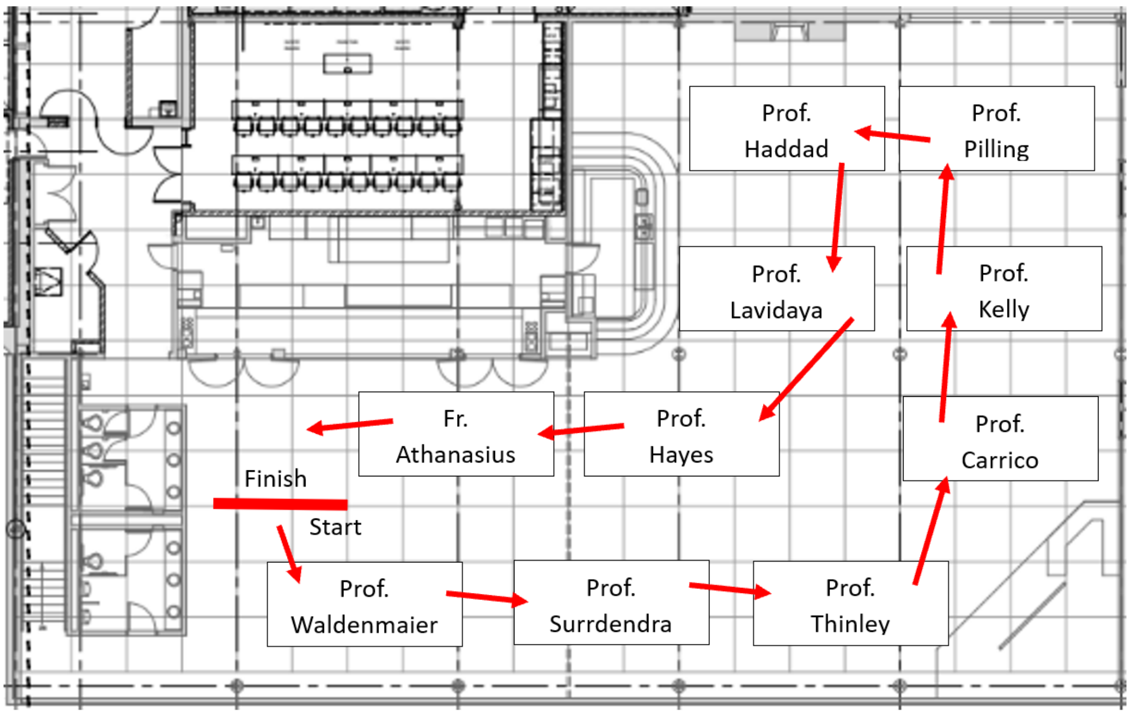

Figure 1. Map of the race course in Chick's Place

1.1 Design Specifications

Each of these designs had to satisfy the requirements given by the team manager, or Professor Waldenmaier. A breakdown of the specifications required for the design items are stated in Table 1.

Table 1. Design Specifications

Need	Design	Specifications
Car	Arduino remote controlled car	Tires with good traction Easily controllable Tank-like Medium speed
Dynamic Structure	Series of Turbines	Three wheels (two in opposite direction) One slow moving, scoop-like blades One fast moving, high-damaging blades One of the team's choice Boundary so cars are forced to drive through the blades
Static Structure	Bridge	Wide enough for only one car Should be more difficult than a straight bridge Combined with dynamic structure

1.2 Project Objectives

The purpose and prime objective of the design project is for us to experience the entire design process and the putting together of a document that outlines the background, theory, ideas, methodology of the design process, proposed manufacturing techniques, prototypes, management, and analysis for the remote-control car and structures that will be designed and prototyped. The goal is to meet the team manager's specifications in creating a car that has good traction, is easily controllable, cannot be flipped, and ultimately functions properly. It also includes creating a working turbine that has three wheels, each with a different function. One that can flip a car, one that can cause significant damage and one of the team's choosing. Finally, the last goal is to create a bridge that has curves and can withstand the weight of an 8 lb car. The ultimate goal of the class is to win the race at the end of year.

From this design project, the desire is to be able to practically apply the material learned in technical engineering courses and from independent research, as well as to experience the process of designing and managing an engineering project.

2. Research

This section will discuss the different components needed for the remote-control car, the turbines and the bridge. It will outline the basic mechanics for a car to function. This includes parts such as motors, transmitters, batteries and tires. In addition, it will discuss torque, motor control, and a shut off system for a turbine. As for the bridge, it will discuss curvature, stability and slope as well as describe different materials for construction. The research outlines a basic understanding of what it takes to build each of these components.

2.1 Car

2.1.1 Motors

When researching the best motor to use in an RC car, there are two main types: AC and DC motors. AC motors are powered by alternating currents, while DC motors are powered by direct currents. Each has its advantages and disadvantages. While AC motors are more cost efficient, DC motors have better speed control and torque. DC motors provide a higher starting torque that produces quicker acceleration. This is beneficial for a car to be able to start and stop quickly. In addition, AC motors require a more complex system to control the speed, whereas only the voltage input needs to be changed to control the speed of a DC motor. This allows for better precision when controlling the car. An AC motor might have a longer life span; however, the durability of a DC motor is still good enough for the purpose of racing cars. AC motors are considered to be more powerful; however, DC motors are more efficient with their input energy. With the size and specifications of an RC car, DC motors are more advantageous. Overall, they create a more efficient use of energy and produce enough torque and speed to allow for more precise movements of the car.

After choosing a DC motor, the next step is determining what kind. There are multiple different types, including a servo motor, stepper motor, brush motor and brushless motor. Each has its own disadvantages and advantages.

To start, a servo motor allows for very precise motion control. It contains a sensor for positional feedback that will help control the rotational or linear speed. While this would allow for very accurate positioning of a car, it doesn't provide the needed power output. It is better used for machines dealing with dynamic load changes. In addition, the feedback mechanism will cause the motor to be unsteady. As it works to adjust to the desired position or speed, it will create a lot of twitching. It is used to rotate and push parts of a machine and therefore could be used to power the steering mechanism of an RC car.

Another type of motor is a stepper motor. This motor is not ideal for an RC car with its disadvantages outweighing any advantages. While it can be easily controlled with microcontrollers, it creates less torque at higher speeds. This reduces the acceleration of the car as it drives faster. In addition, it is very inefficient and becomes hot very fast. It has a slow response and overall, would not create the needed speed or precision required to race a car.

Finally, the two main motors to take note of are brushed versus brushless DC motors. They are the two most likely to be used in an RC car. Each has its own advantages depending on the situation. For the capabilities of an RC car, brushless motors tend to be too powerful. They might have a longer lifespan, making them more durable, but brushed motors can still hold enough power to race. Due to the fact that brushless motors are more powerful, a speed control system would be needed. These can make brushless motors very complex very fast. It would create a much higher torque and speed than the car could handle. This problem requires a more specialized knowledge to correctly apply the power to the car. This makes brushed motors more appealing. They are very simple to construct and tend to be more cost efficient than brushless. They do require more maintenance but create a higher torque at lower speeds. With the specification given, a brushed motor, while less powerful and durable, would still create enough speed. The goal of the car is not to go as fast as possible, but to create greater maneuverability. This is where the brushed motor better suits the functionality of the car.

In addition to the motor, an RC car needs an electronic speed controller (ESC). This takes voltage from the battery and controls how much the motor receives. It ensures the motors won't spin too fast and short circuit or overheat. It makes sure the motor maintains a certain speed no matter the driving condition. It also distributes power into the receiver. Overall, it controls the flow of power from the battery to the other parts of the car.

2.1.2 Tires

When choosing the best kind of tires, multiple properties, including material, tread pattern, and tire profile, need to be considered.

RC tires can be made of three different materials: foam, synthetic rubber, and natural rubber. Foam is a lightweight material and offers a substantial grip, however it is prone to "chunking." This means pieces of the tire will tear off while the car is in motion, making it too flimsy to use. If the car was for leisurely purposes, this might be a more applicable material.

The other options include synthetic and natural rubber. Synthetic rubber is softer than natural rubber, however it offers good traction. The rigidity of natural rubber decreases the traction but makes it very durable. Both tires have their advantages and disadvantages. When picking the best tire, it depends on the situation. A tire with better traction would be beneficial for a car traversing more difficult terrain such as slopes or ramps. In turn, a natural rubber or more durable tire would be better for a car traversing terrain that is uneven or is made of rough materials.

In addition, it is important to look at different tread patterns. This affects how fast or smoothly the car will turn, increases the car's ability to climb obstacles and increases versatility. There are multiple different tread patterns, as seen in Figure 2. A slick tire tread is a smooth tire that allows for higher speeds on smooth tracks. They work best for roads that could wear down any raised tread on other kinds of tires. On the other hand, raised tread can include spike or pin tread. This kind of tread makes it easier for cars to travel across rough or loosely packed terrain. Finally, a V-shape tread is a tire that has raised stripes pointing towards the middle of the tire, creating a "v." This kind of tread gives the car better traction and can help prevent hydroplaning. The v-shape allows for water to be displaced faster when the car is traveling at higher speeds.

Figure 2. (Left) V-Shape, (Center) Slick, and (Right) Spike Tire Treads [8, 9, 10]

Finally, the tire profile refers to the part of the tire that contacts the surface. The different profiles can be seen in Figure 3. They can be either square or rounded with the square profile's width covering a larger surface area and a round profile's width covering less. A square tire will offer good forward traction while a round profile is good at driving through rough conditions. This means a square profile is better for climbing objects in a straight line while a round profile tire is better for making fast turns and covering uneven ground.

Figure 3. The difference between round and square tire profiles [17]

2.1.3 Transmitters

Transmitters in RC cars use radio frequency, or alternating currents carrying radio signals. These waves normally oscillate anywhere from 3 kHz to 300 GHz. The range of the transmitter is dependent on the power and frequency. They are normally powered by a 9-volt battery, but increasing the voltage can increase the power of the signal. If there is more power going to the transmitter and it has a higher frequency, it can reach a larger distance. Radio frequency allows the user to choose their level of penetration based on the frequency, making it very versatile. Transmitters enable real-time, wireless communication and are simple to install.

The process for sending a signal from the transmitter to the receiver is very simple. The transmitter sends radio waves that oscillate at a very specific frequency (normally 27 MHz or 49 MHz for typical RC cars), and when the receiver picks up these bursts, it sends out another signal to block out any other frequency. The remaining signal is then converted into an electrical pulse sequence. This sequence is decoded and will cause the appropriate motor to turn on. The correct action is determined by the number of pulses in the sequence and each function has a different number of pulses. These radio signals can tell a car to either move forward, reverse, move forward left and right, or reverse left and right.

2.1.4 Batteries

There are a few basics that are important to understand when picking a battery for an RC car. A battery's capacity is measured in milliamp hours (mAh). This means that if a battery has 5000 mAh, it can hold a 5-amp load for one hour. If the load is lighter than the amp rating on the battery, then it will run for a longer period. This is vice versa for a load greater than the battery rating. For example, if a 10-amp load is placed on the battery in the example above, the power will take a half hour to deplete. The main point to understand is that the higher the capacity, the longer the car can run. In addition, it's important to note the voltage of the battery, or the power output being supplied. When the voltage exceeds what is safe for the speed controller, the car will short circuit. Making sure the other parts of the car can handle the voltage of the battery is crucial for success.

In addition, the voltage in a battery is usually measured in either cells or volts. A single cell in a nickel-metal hydride (NiMH) battery holds about 1.2V carrying around 6 to 7 cells. This means it has a voltage of about 7.2 or 8.4 volts. On the other hand, a single cell in a lithium polymer (LiPo) battery holds about 3.7 V carrying 2 to 3 cells. This means it has a voltage of about 7.4 or 11.1 V [13].

As mentioned above, two kinds of batteries compatible for an RC car are nickel-metal hydride (NiMH) batteries and Lithium Polymer (LiPo) batteries. NiMH batteries are the generic batteries found in most RC cars and are known for the best performance. They have a large range of life spans, tend to be very cheap and are fairly heavy. For example, a 3600 mAh battery can weigh about 380 grams. In addition, nickel-metal hydride batteries deplete slowly but give off less power as the charge decreases. On the other hand, LiPo batteries give off the same amount of power even as the battery depletes. Its output is more advantageous than that of a NiMH battery. They are longer lasting, lighter and hold a steady voltage compared to NiMH batteries. The downside of a LiPo battery is they tend to be more expensive and require more care as they get older.

2.2 Turbines

2.2.1 Torque and Motors

The motors for each turbine would have to meet certain specifications in order for every function to be carried out successfully. A slow-moving, scoop-like turbine would need a motor with high torque and low RPM. This would allow the turbines enough power to flip cars caught in between the blades. On the other hand, the fast moving, high-damage turbine would need a motor with low torque and high RPM. The blades would be made of relatively light material and therefore wouldn't need as much force to spin. The high RPM would ensure the blades still make optimal damage to the cars passing through. The equation for torque is

$$\tau = r(F \sin\theta) \tag{1}$$

- r is the radius from the pivot point
- F is the force acting on the object
- θ angle between the force and position vector

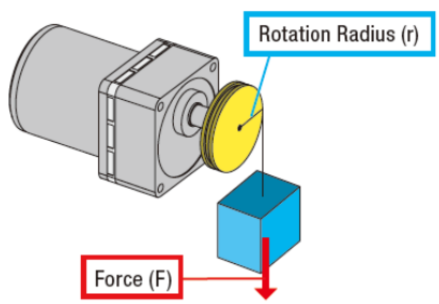

Figure 4. Diagram showing the force of the object acting downwards on the motor and the rotation radius [12]

For example, if a turbine has a blade of about 1 ft and is moving a force of about 9lbs, the torque needed would be 9 ft lbs.

One such motor that applies a large amount of torque is a DC gear motor. These have increased torque at lower speeds which allows it to assist in moving a heavy object. In addition, it has an efficient power transfer and comes in variable sizes. It has a high temperature resistance and can reduce the chance of overheating.

Gears, belts or a direct line can transfer torque from the motor to the blades. A belt-drive system uses a belt and pulley to help smaller motors generate more torque. It is helpful when pushing a less powerful motor to output a larger amount of torque. However, the friction from the belt causes a loss in efficiency. The pulley system adds more weight for the motor to overcome and could add more wear to the system. Overall, this way of transferring torque is efficient in assisting a cheaper motor but affects the relay of information. On the other hand, a gear system consists of two gears rotating between the motor and turbine. The gear attached to the motor is the driver (input gear) and the gear attached to the turbine is the driven (output gear). The gear ratio is the number of teeth on the input gear to the output gear. This ratio and the torque from the motor can be used to find the torque applied to the wheel. The equation to find this is

$$\tau_w = \tau_m * \frac{output}{input} \tag{2}$$

- τ_w is the torque of the wheel
- τ_m is the torque of the motor

The above equation shows that the output gear should be larger than the input gear. Utilizing a gear system helps to increase the torque on the wheel when the motor output isn't as strong. This method, however, requires more maintenance than other methods. The final method of transferring torque is a direct transfer, or when the turbine is connected straight to the motor. This means the power output of the motor needs to be greater in order to spin the blade without any help. In this method, the motor has no extra mass to overcome and therefore does not lose any generated torque. In addition, there is less maintenance needed for the system because there are no belts or gears. It is the most efficient way to transfer torque to a system when the motor has enough power to support the system.

2.2.2 Emergency Shut Off System

Sensor: A sensor is one component needed to create an emergency stop system in case a wheel gets caught or malfunctions. The best kind of sensor to use is an ultrasonic sensor because it can detect the distance of any solid object within a certain range. The reliability of this sensor is a major aspect because it can detect pretty much any hard material, regardless of the transparency.

The sensor is made up of two parts, a sound transmitter and sound receiver. The transmitter sends out the wave, while the receiver catches the wave travelling back from the target. The process is similar to echolocation. When an electrical signal is sent to the sound transmitter it produces an ultrasonic wave. When this wave hits an object, it bounces off and travels back to the receiver. Once the receiver detects this wave, a second electrical signal is produced. From this information, the sensor calculates the distance from the object by using the speed of sound and the time the wave took to return to the receiver. The formula is

$$D = \frac{1}{2}T * C \tag{3}$$

- D is the distance
- T is the time
- C is the speed of sound (343 m/s)

Avoiding interference is very important when using an ultrasonic sensor, whether that's from other sensors or the obstruction of the sensor itself. The sensor cannot be blocked in a way that the ultrasonic signals cannot bounce back. An illustration of how the ultrasonic sensor works is shown below.

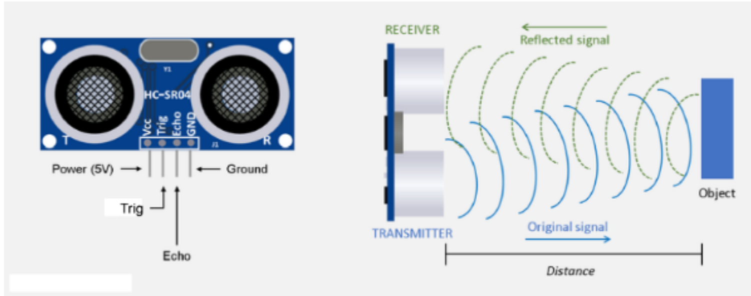

Figure 5. An ultrasonic sensor and how the transmitter and receiver work to detect ulstrasonic signals [1]

Power Relay: In addition to a sensor, a power relay system will be needed. A power relay is a circuit element that allows one circuit to control another while being completely isolated. A lower power circuit will control a higher power circuit in order to prevent any damage between the two circuits.

In an electrical relay, the wire of the low-power circuit is coiled inside the relay. Next to this wire is a lever that will open or close the high-power circuit. Each of these components is electrically insulated from the other. When power is sent into the lower circuit, it produces a magnetic field that essentially pulls on the lever closing or opening the circuit.

Microcontroller: An Arduino nano controller is a simple computer that executes inputted instructions and is connected to sensors and other electronic components. Based on the given instructions, it can input and output different signals to activate devices.

Microcontrollers are made up of four parts. The first is the processor which reads the instructions and decides what to do with them or which components to send them to. It determines what action the arduino should carry out. The second part is memory, consisting of program and data memory. Program memory is long term and will not be erased from the microcontroller, thus storing given commands. On the other hand, data memory gets erased every time the microcontroller is turned on. This is used to hold data collected from sensors or calculated values. The third part is the I/O pins. These connect the microcontroller to the other electrical devices and allow them to send out or receive signals. Finally, the last part of a microcontroller is the serial port. This is used to send instructions in the form of programs to the microcontroller and is used as a port for power.

Power Converter: In order to transfer power from a wall outlet to a low voltage system, a full wave bridge rectifier (or AC to DC converter) is needed. This converter is used to convert high voltage AC to low voltage DC and is made of two assemblies: the transformer (Figure 6) and the rectifier (Figure 7).

The transformer converts the AC voltage coming from the wall to a lower level for the device the converter is connected to. Wall outlets have about 110-240 volts coming from them, so a transformer is needed to step down this voltage considerably. For this to work, transformers have wires from the lower and higher circuit coiled next to each other but not electrically connected. The current from the wall generates a magnetic field in the main coil that then generates current in the neighboring coil. These wires are often around a core that improves the connection of the magnetic field. To make the wall circuit voltage lower than the receiver circuit, the wires simply need to be coiled less. The equation to find this coil is given by

$$\frac{V_2}{V_{source}} = \frac{n_2}{n_1} \tag{4}$$

- V_2 is the voltage from the secondary source
- V_{source} is the votlage from the primary source

- n_2 is the number of turns in wire 2
- n_1 is the number of turns in wire 1

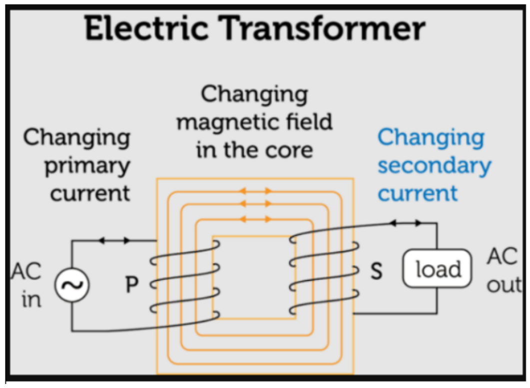

Figure 6. Transformer [3]

The second part is the rectifier circuit. This takes the AC wall current and converts it to a DC current after the transformer lowers it to a usable level. This circuit is made up of diodes that only allow the current to flow one way. This is useful because of the alternating nature of AC currents. They are constantly shifting from positive to negative in a sine wave pattern. It happens at about 60 Hz or 60 times a second. The conversion to DC is done by putting the diodes in a formation that forces AC current to travel in different directions depending on the positive or negative current. If the current is positive, the positive DC node will allow it through whereas if the current is negative, the diodes redirect it to the negative DC node.

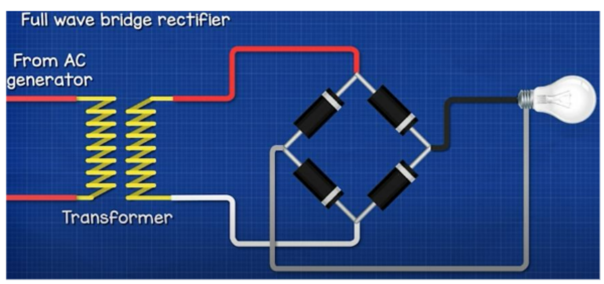

Figure 7. Rectifier circuit [5]

2.3 Bridge

When building a stable bridge, it is important to note the best kind of support. There are two functional designs that provide possible support, beams and triangles. Triangular supports are the strongest because they distribute force from a single point across a wider base. The force exerted on the bridge can be spread more evenly across the base. However, this is difficult to do with a curvy bridge. This is where beam support can be helpful. Multiple columns are placed underneath the bridge at spaced out intervals. This is best for bridges that span a smaller distance. The load can be distributed among each of the beams. For a bridge that has more curves, it is more advantageous to use beams because they can be spaced better than triangular supports.

In order to determine the slope of incline of a bridge or ramp, basic trigonometry functions can be used. For example, if the run length of the bridge and height is known, the following equation can be used

$$\tan\theta = h/b \tag{5}$$

- b is the run distance
- h is the height of the bridge

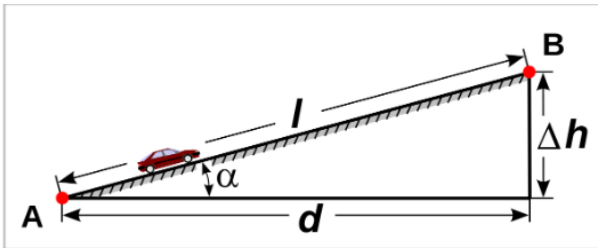

Figure 8. Finding angle of incline for a sloped road [11]

The angle of incline will increase or decrease depending on the length the bridge covers as well as the height it travels upwards. For example, a greater height will need a longer ramp length in order to avoid a steep incline. The lower the height, the smaller the ramp length needs to be. In addition, to find the slope grade, the following equation can be used

$$grade = (rise/run) * 100 \tag{6}$$

For example, a bridge with a height of 1 ft and a length of 3 ft will have a slope grade of 33%. A bridge with a higher slope grade and a greater angle of inclination will be harder to climb. The cars will be required to use more power in order to drive all the way up. Essentially, the greater the slope, the greater the difficulty.

When building a bridge with curves, it is important to determine the curve radius to ensure cars can still make the turn. A larger curve radius means cars can more easily maneuver around the bend. This radius is dependent on multiple factors. The equation to find the curve radius of a turn is

$$R = V^2/g(e + F_s) \tag{7}$$

- R is the radius
- V is the velocity of the car
- g is the constant of gravity (9.81 m/s^2 or 32.2 ft/s^2)
- e is the super elevation or banking angle
- F_s is the static friction coefficient

When finding the curve of a ramp, the super elevation is negligible because the incline is so small. In addition, the coefficient of static friction refers to the contact between the wheel and the bridge, which depends on the surface or in this case, how sanded the wood is. Neglecting both the coefficient of static friction and the super elevation leaves only gravity and velocity affecting the radius. As a quick example, if a car is traveling at 4 ft/s, the radius of curvature would need to be a minimum of about 0.5 feet.

2.4 Materials

Many different factors contribute to choosing certain materials including strength, density and cost. Different situations will mean using different materials.

To build a stable structure capable of holding a decent amount of weight and withstanding the force of a moving object, the concept of stress and strain must be applied. The strength of the wood is defined by how much force it can resist, or the stress. The equation is

$$stress = L/A \tag{8}$$

- L is the load on an object (lbs)
- A is the area of the surface (sq ft)

The equation shows that the more force a piece of wood can withstand the stronger the material. Half inch plywood can hold roughly 35 lbs per square foot. This makes it a durable material that is more than capable of picking up an 8 lb car without breaking. The downside of using wood to build a structure is the cost. It is expensive to purchase wood and therefore isn't budget friendly.

This is where PVC pipe might be more efficient. It is less expensive than wood but isn't as strong. The average strength of a half inch diameter pipe spanning one foot is 18 lbs, and as the length increases the strength decreases. Over a longer stretch, PVC pipe becomes less durable. While it is still strong enough to withstand an 8 lb car, wood is more reliable.

For the turbine that is intended to cause maximal damage, vinyl tubing and rubber tubing are two viable options. Vinyl is a flexible and lightweight material that can be purchased in varying lengths. It is durable, inexpensive, and easy to work with. On the other hand, rubber is a highly flexible material that is very versatile. It is mildly heavy to extremely heavy, lasts for an extended time, and is very durable. However, rubber is somewhat expensive and the material itself is hard to work with.

Rubber would weigh enough to cause a lot of damage at a rapid pace, tearing light plastic structures to shreds. On the other hand, even though vinyl is lightweight, the damage to cars can still be substantial without completely destroying them.

3. Design Conceptualization, Initial Ideas, Process and Decisions

3.1 Design Concepts and Initial Ideas

3.1.1 Turbines

The initial design concept in Figure 9 was generated by Professor Waldenmaier when he gave his specifications. He wanted a series of turbines with a bridge traveling across the top. The idea was a combined dynamic and static structure.

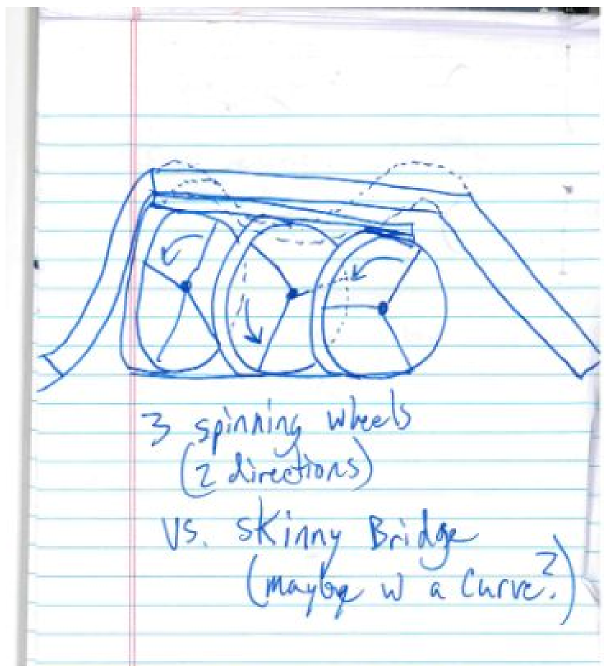

Figure 9. Preliminary structure design drawn by Professor Waldenmaier. It details three turbines with a bridge going over the top

The initial idea was to have three different kinds of blades with circular rims around them. The rim shape was quickly changed to a rectangular frame because there wasn't enough available materials to create a circular design. In addition, rectangular frames would provide more stability. This change can be seen in the initial CAD model in Figure 10. As for the blades, the first would be a scoop designed to pick up and flip cars, the second would be designed to cause a lot of damage, and the third blade would be chosen by the team.

The initial design for the first blade was to use wooden spoons or some object that had an actual scoop on it, while the first design for the second blade included having rubber strands moving at high speeds. Finally, the first idea for the third blade was swinging sledgehammers, however the weight would be too great, and that idea was quickly eliminated. After brainstorming, the third blade was decided to be a wheel with two openings for the cars to drive through.

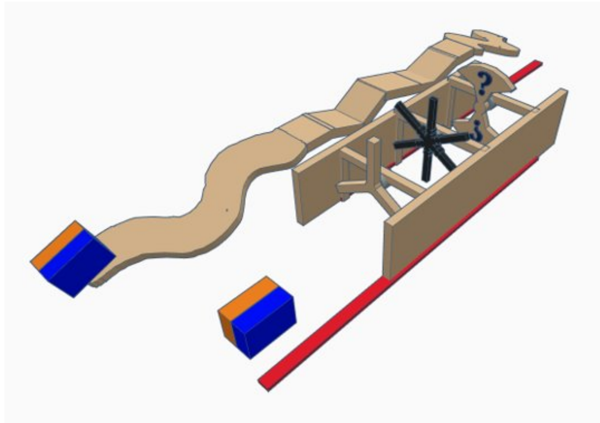

Figure 10. Initial CAD model for the structure. It details the rectangular frames, the three kinds of blades, and the bridge running along the side

3.1.2 Bridge

The initial idea for the bridge can also be seen in Figure 9. Professor Waldenmaier's original specifications for the bridge were that it must be narrow and difficult to traverse. This came in the form of curves along the ramps and the top of the bridge. In addition, the bridge would also travel up over the top of the turbines. The original design for the curves can be seen in Figure 11.

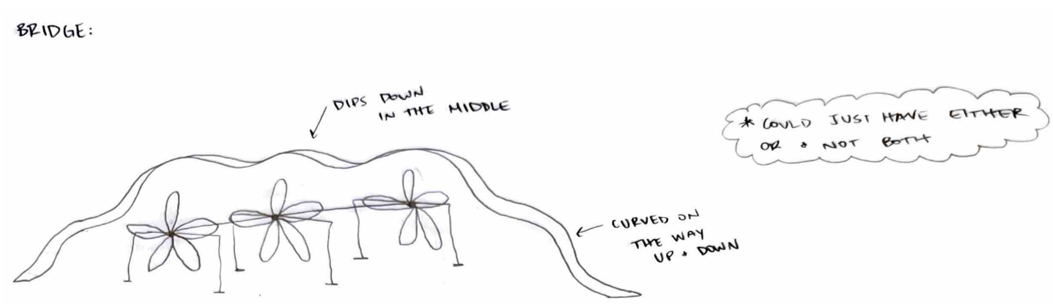

Figure 11. Bridge design emphasizing curves. The picture shows up and down curves on the ramp and dips down the middle of the bridge

3.1.3 Car

There were a few intial design ideas for the car. Since the focus was concentrated more towards manueverability rather than speed, the initial design was a tank-like car seen in Figure 12. The treads provided good traction, however the idea for greater mobility was to have a car with both wheels and treads as seen in Figure 13. The second initial design would give the car more versatility, and provided a fail safe in case the treads fell off. In addition, by utilizing tread it would allow the car to be able to drive on both sides and meet the specification of an unflippable car. While these were good initial ideas, after research and discussion, the team settled on a car with four wheels. These ideas will be explored further in the Process and Decisions section.

Figure 12. Preliminary car design emphasizing a tank-like structure and utilizing treads instead of wheels

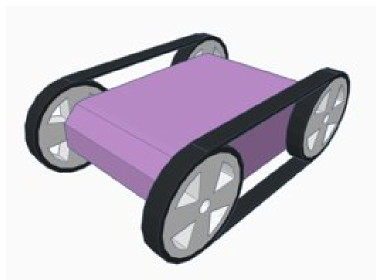

Figure 13. Car design with an alternative tread design. This design has both wheels and tread to create more versatility. It also provides a failsafe in case the treads fall off

3.2 Process and Decisions

3.2.1 Turbines

The process started with Professor Waldenmaier's initial design shown earlier in Figure 9. The shape surrounding the blades was originally circular, however after some research, that idea was quickly modified. The design was changed to have a rectangular base to account for better stability and to make construction more manageable. The researched material was also not suitable to execute a circular design. The next step was to choose between PVC pipes and wood for the base. While PVC pipe would be easy to put together and less expensive, it isn't as strong as wood. Extra stability would be needed to ensure the structure could hold the weight of the blades without falling over as the cars drove through.

Then, the team brainstormed different blade ideas. For the first blade, a scoop design was chosen. This would hopefully pick up cars if they weren't fast enough to go through. A couple of ideas regarding materials were considered, including wooden spoons, but the best idea was to form an arc-like shape out of plywood. This would essentially be able to get up underneath the cars while also being strong enough to lift 8 lbs.

For the second turbine, it needed to cause significant damage to the cars. The first thought was rubber. This would be a hard, durable material that can be bought in bulk for very little money, however, it would cause too much damage. When whipped at high speeds the damage to cars would be fatal, therefore the next option was to use clear vinyl tubing instead. This is also a very durable material and is still inexpensive, however it won't inflict as much damage. Cars would potentially experience some casualties, but could make it through still functioning. These initial ideas for the first two blades can be seen in Figure 14.

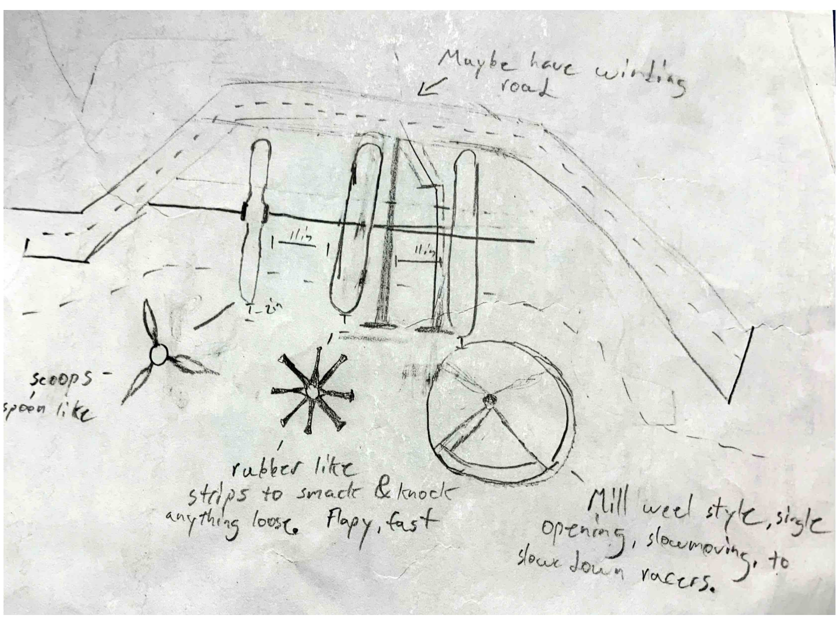

Figure 14. Turbine design emphasizing blade type. The picture shows a scoop blade possibly made of spoons, a blade made of rubber strips, and an open wheel

The first idea for the third turbine was swinging sledgehammers. While this would have caused a lot of damage, the weight was too big of a constraint. Other designs, like in Figure 15, suggested using wood or other materials to add spikes to the third blade, however the final decision was something more unique. The third turbine would be a wheel with small openings, as shown above in Figure 14. This would make it more difficult to traverse because the cars would have to time when to go to avoid getting flipped. The idea was to create a more strategic obstacle for cars rather than just getting hit. In addition, the gaps between the turbines were designed to be smaller than a foot so cars were more pressured to move quicker through the next wheel. The danger from the past wheel will make the obstacle more difficult. The final model for the turbine design can be seen in Figure 16.

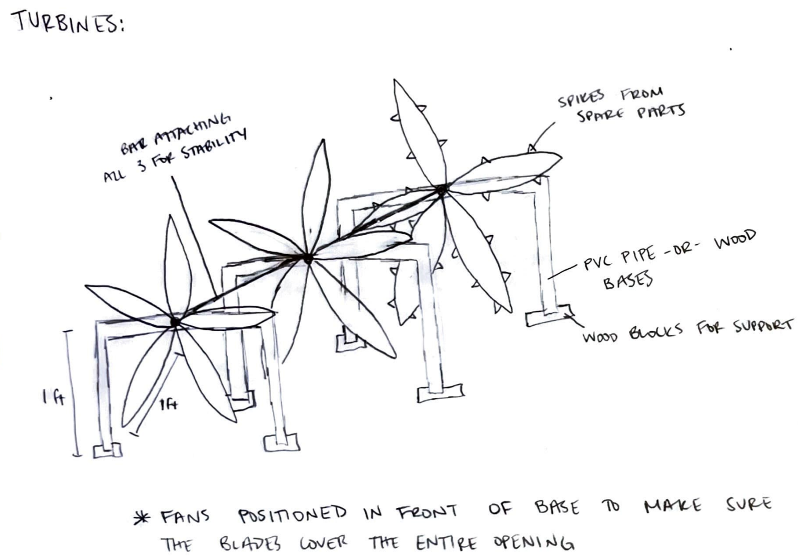

Figure 15. A turbine design showing rectangular frames with a bar attachment in the middle. It also suggests using wood or PVC pipe. Finally, it shows a spiked design for the third blade

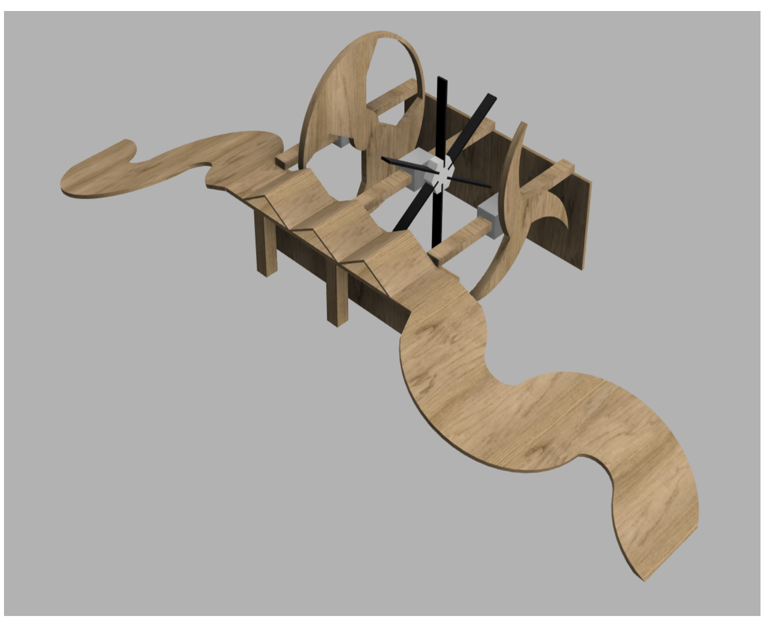

Figure 16. Final CAD model of the combined dynamic and static structure

The stability of the structure was a weak point, so walls were added to the sides. This would not only ensure cars were forced to drive through the turbines but would make sure they could flip the cars without the whole structure falling over. With this wall addition, the structure would be harder to transport, therefore the design was changed to fit like a puzzle. The walls would have little slits cut into them that allow the base of the turbines to slide right in. This would make it easy to assemble and disassemble the various parts.

When it came to the motors for the turbines, there were some troubles. None of the motors had enough torque by themselves, so a few new ideas were brought up. The first one being two 70 kg.cm (5 ft.lbs) motors with a gear system to transfer more torque. There would be three gears in total. A gear attaching to each motor and a third gear connecting both to the scoop wheel. The design for this can be seen in Figure 17. The other idea involved using a drill and gearing the output to 10 rpm. This idea seemed more cost efficient for a higher torque output but could be complicated. Some testing is needed, but the gear system seems to be a very plausible option.

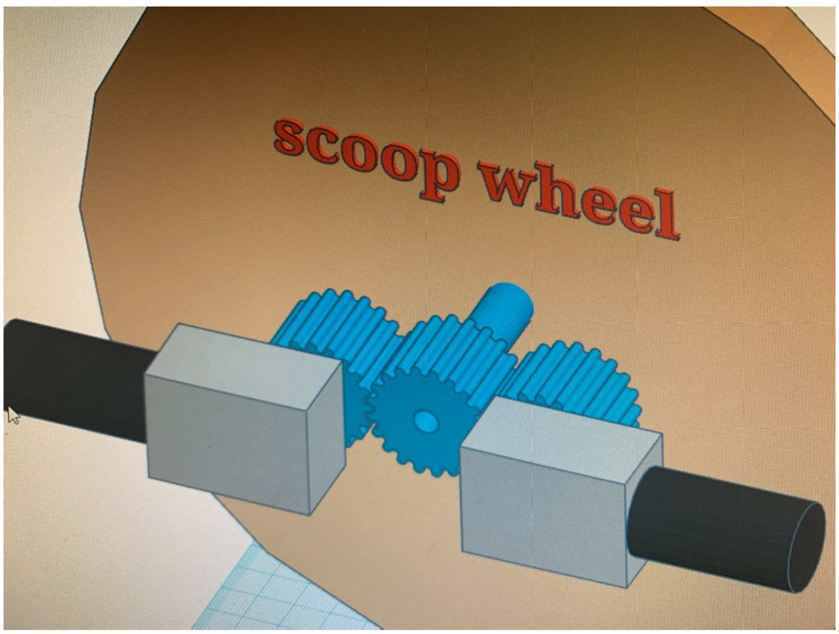

Figure 17. The potential gear system for transferring torque. It includes a series of gears attached to two motors to double the torque generated by the blade

Finally, an emergency stop system was needed in case cars got stuck in between the blades and the walls. It would essentially require a switch that could turn off the motors if the sensor stopped detecting movement. Figure 18 shows the potential outline for the system. The system would essentially work as follows:

The stop switch will be connected to the turbines that are intended to pick up cars (the first and last). The turbines will be connected to the AC to DC converter to power them. A relay will be connected to two switches in this circuit and will be closed by default. Connected to the relay is the Arduino. This will be connected to the two switches in the relay circuit. It will then be connected to two separate ultrasonic sensors mounted on the turbines. If a car gets stuck in the turbine or the blade stops moving for some reason, the ultrasonic sensor will detect this. The Arduino will recognize this halt in movement and send a signal to open the relay switch. This will open the circuit, stop the turbine and prevent the motor from taking any damage.

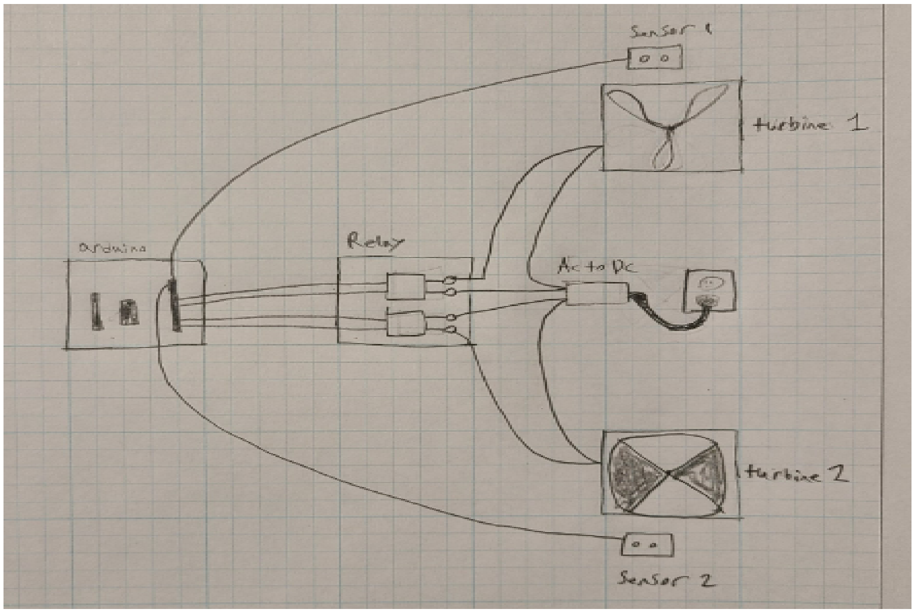

Figure 18. Emergency stop system circuit showing the connection between the arduino, relay, power converter and sensors. It shows the placement in respect to the first and third turbine

The decision matrix used to determine the best design idea can be seen in the figure below. The first two columns outline the criteria for a successful design as well as the weight each one holds on the overall function. The higher the score means the specific idea fit the required criteria the best. The final decisions were then implemented in the manufacturing phase.

		Base				Materials for Turbines										Materials for Base			
		Round		Square		Scoop		Rubber		Clear Vinyl		Open Wheel		Sledgehammer		Wood		PVC Pipe	
Criteria	Weight Factor	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Cost Effective	0.15	7	1.05	8	1.2	8	1.2	7	1.05	9	1.35	9	1.35	6	0.9	8	1.2	7	1.05
Durability (inflict damage/withstand cars)	0.15	4	0.6	8	1.2	7	1.05	10	1.5	8	1.2	7	1.05	9	1.35	9	1.35	5	0.75
Reliability (capable design)	0.15	7	1.05	8	1.2	8.5	1.275	7.5	1.125	8	1.2	9	1.35	3	0.45	9	1.35	8	1.2
Functionality (as an obstacle)	0.15	8	1.2	7	1.05	8	1.2	3	0.45	8	1.2	8	1.2	5	0.75	8	1.2	7.5	1.125
Size (modularity)	0.1	5.5	0.55	8.5	0.85	8	0.8	7.5	0.75	8	0.8	8	0.8	2	0.2	8.5	0.85	6.5	0.65
Look	0.1	4	0.4	7.5	0.75	9	0.9	9.5	0.95	10	1	8.6	0.86	10	1	9	0.9	5.5	0.55
Stability	0.2	6	1.2	9	1.8	8	1.6	9	1.8	10	2	9	1.8	2	0.4	9	1.8	6	1.2
TOTALS	1		6.05		8.05		8.025		7.625		8.75		8.41		5.05		8.65		6.525

Figure 19. Turbine Decision Matrix

3.2.2 Bridge

The bridge design was less complicated than the turbines. The designs initially started with the bridge going up over the top of the turbines, as shown in Waldenmaier's original design and Figure 20. However, the bridge had to clear the 2' blade diameter making the length and height too big. This would require more material and would make the design more expensive. To fix this, the bridge was set alongside the turbines as shown eaerlier in Figure 16. This would not only make it easier to build but would cause cars to fall into the turbines if they were unable to cross it successfully.

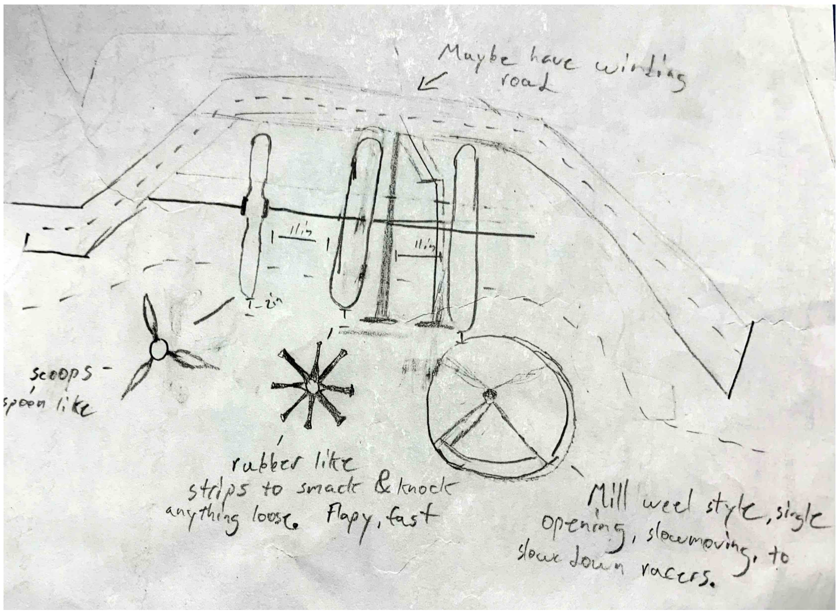

Figure 20. Design including a winding bridge traveling over the top of the three turbines

Curves were implemented into the bridge so that cars would have to take sharp turns while driving up the ramp. This would make it harder for cars with less maneuverability. While the design started with only curves on the way up and down, it was decided that dips would be added along the top to make the obstacle harder, as shown in Figure 21.

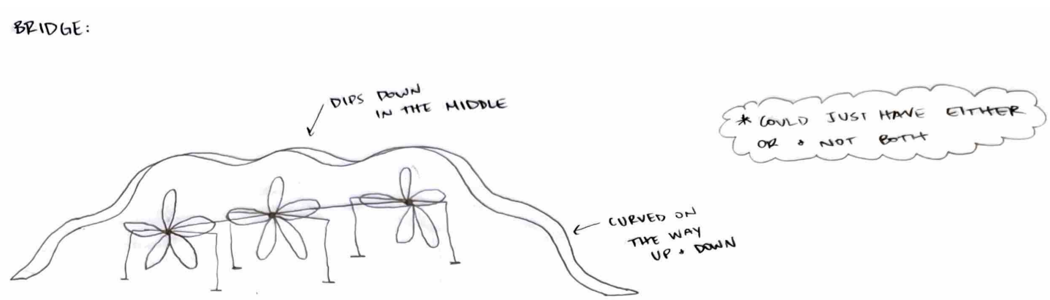

Figure 21. Bridge design emphasizing curves. The picture shows up and down curves on the ramp and dips down the middle of the bridge

This would hopefully influence more cars to risk the turbines. At first, the design involved making curved dips at the top. This would make it a smoother design, however after some discussion it was found that triangles might be easier. A potential design is shown in Figure 22. With the triangles, the wood wouldn't need to be shaped, but rather simply cut into rectangular pieces. The point at the top of the triangles would even make it harder to traverse. Cars with less clearance might struggle more to get over them, thus making the obstacle harder.

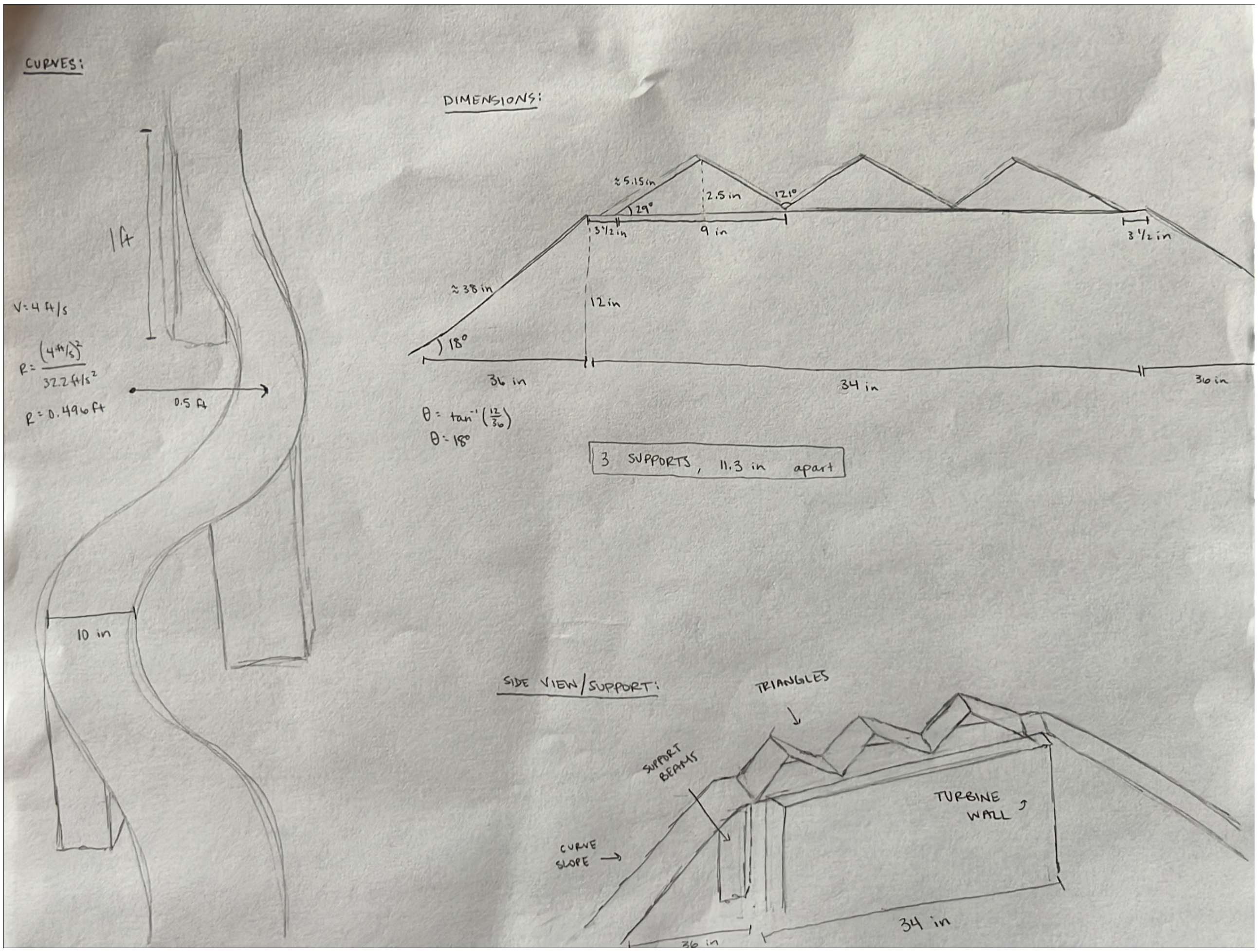

Figure 22. The drawing depicts the dimensions and design of the bridge. It shows the calculations for possible radius of curvature (6 in) for the ramps. It focuses on the angle and dimensions of the dips. The angle of incline is 29° and they are 9 in in length It also shows the supports along the ramp and the top of the bridge

Stability was also a very important factor in the bridge design. At first, triangular supports were thought to be best for supporting the ramp, however with a curve design they wouldn't work efficiently. This means beams would be needed to support the structure. Three supports would be placed at even intervals along the 34-inch bridge as seen in Figure 23.

Not only would supports be needed along the bridge, but also underneath the curves. The initial design for these can be seen in Figure 22. In addition to the beam supports, the bridge would be placed on top of the supporting walls of the turbines. This adds stability on one side, while the beam supports would hold up the other side.

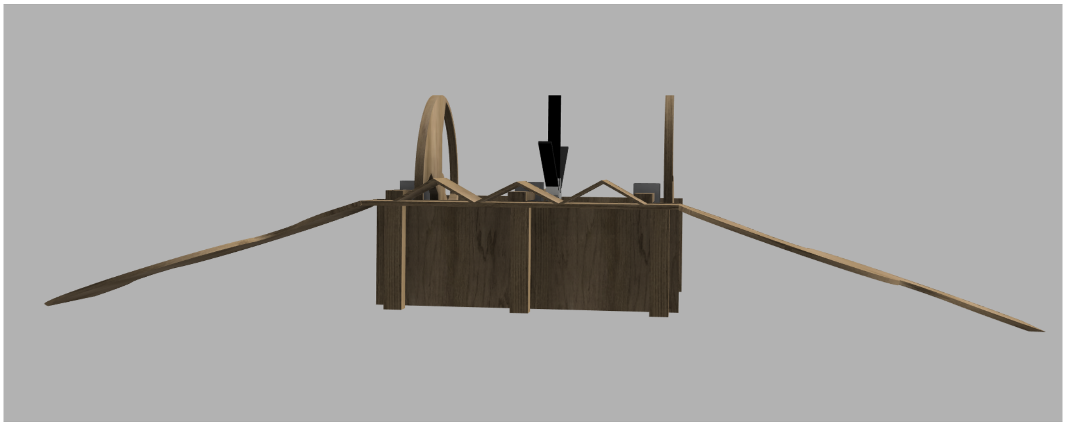

Figure 23. The CAD model shows the potential supports for the bridge. It would include three evenly spaced beams underneath the top

The decision matrix for the bridge can be seen in the figure below. This outlines the different criteria used to narrow down design ideas as well as their weight on the decision as a whole. The higher the score means the specific design fit the criteria the best and would produce the most successful structure.

		Over the top, straight bridge, curves on the way up (wood)		Around the side, curvy bridge on the way up, dips along the top (wood)		PVC skeleton bridge, over the top	
Criteria	Weight Factor	Rating	Score	Rating	Score	Rating	Score
Cost Effective	0.2	5	1	7	1.4	8	1.6
Durability (withstand cars)	0.25	8	2	8	2	6	1.5
Reliability (structural integrity)	0.15	9	1.35	9	1.35	5	0.75
Functionality (as an obstacle)	0.2	5	1	7	1.4	7	1.4
Difficulty	0.15	4	0.6	6	0.9	8	1.2
Look	0.05	3	0.15	7	0.35	9	0.45
TOTALS	1		6.1		7.4		6.9

Figure 24. Bridge Decision Matrix

3.2.3 Car

The first car design was meant to be moderately fast, with mobility making up for the lack of speed. This came in the form of a tank or modular vehicle that was unflippable and had a multi-traction system utilizing two different forms of tires: rough in the back and smooth but slick tires in the front. Figures 25 and 26 show the initial tank-like design. Figure 25 highlights the use of only treads; however, these would greatly decrease the maneuverability. Another idea was to use both wheels and tread, as shown in Figure 26. That way if the tread fell off or was damaged the car would still be able to run.

Figure 25. Preliminary car design emphasizing a tank-like structure and utilizing treads instead of wheels

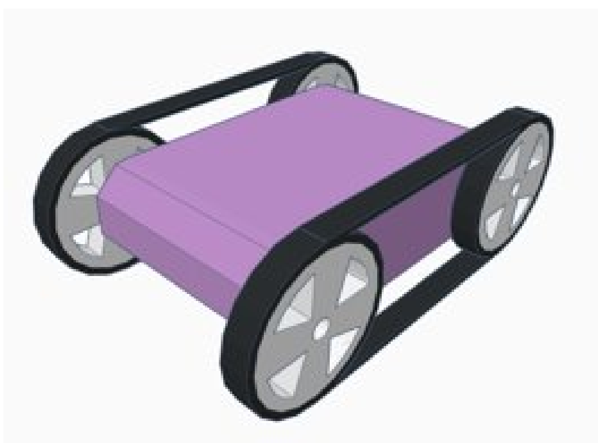

Figure 26. Car design with an alternative tread design. This design has both wheels and tread to create more versatility. It also provides a failsafe in case the treads fall off

This, however, still did not allow the car the desired maneuverability, so four wheels was the best decision. They would need to be bigger than the car in order to create an unflippable design. This meant finding wheels that were 4-5 inches in diameter. They would have either V-shape or spike tread to gain the best traction. It was also an idea to include cones on the wheels to prevent the car from getting stuck on its side as shown in Figure 27.

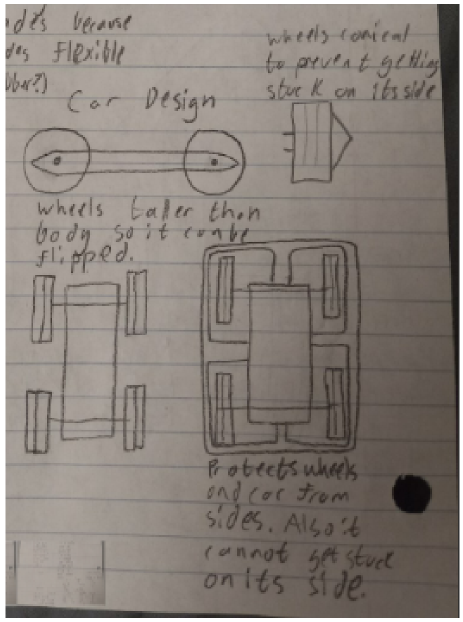

Figure 27. Car design emphasizing conical wheels to prevent the car from being tipped over

As for the car's body, a peanut-shaped design was found to be the best (Figures 28, 29, and 30) to compensate for a lack of shocks or elevated tires. The peanut shape would allow the car to drive over any sharp points without getting stuck. Having a thinner middle would allow a higher clearance to pass through obstacles with high centers, such as the dips in the bridge design.

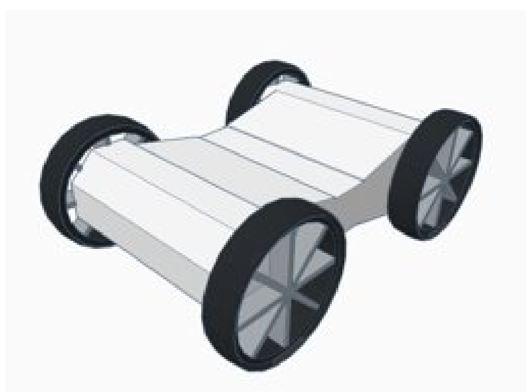

Figure 28. Car design emphasizing the peanut-shaped body and the wheels bigger than the chasis

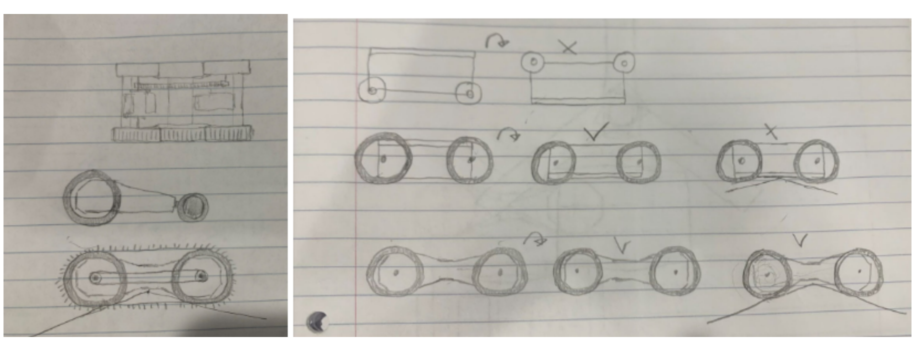

Figure 29. Car ddesign depicting the advantages of a peanut-shaped design. The car would be able to easily manuever over points dips

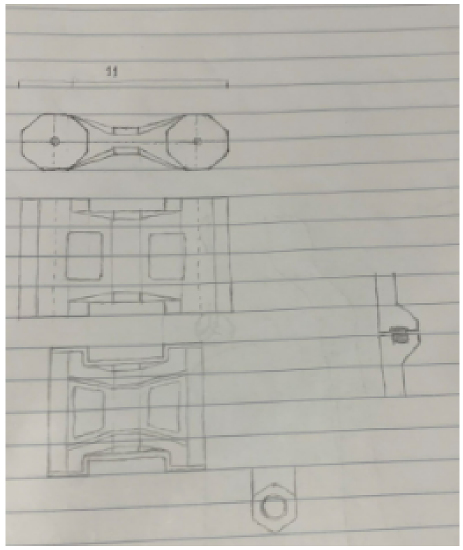

Figure 30. Detailed design of the car shape and potential structural design

The car needed to be designed to have zero turn capabilities and originally only needed two motors. One would control the wheels on the left and the other the wheels on the right. However, this wouldn't give the car enough power. To ensure it could crawl up any surface, each wheel would have a separate motor. The current model can be seen in Figure 31, with top, side and front views seen in Figure 32.

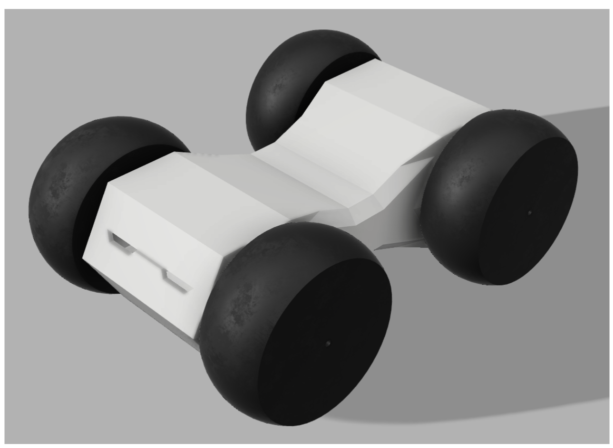

Figure 31. Isometric view of the CAD model for the final car design

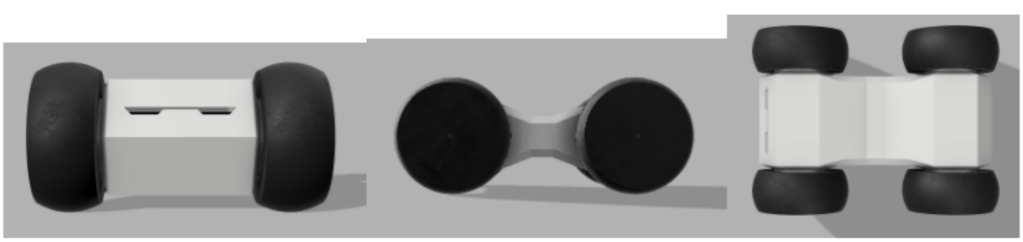

Figure 32. Front, side and top views of the CAD models for the final car design

Finally, the remote control would have two joysticks; one would control the left side and the other the right. If both were pushed forward the car would go in a straight line and if they were pushed in opposite directions, the car would rotate. This makes it easy to drive the car with straightforward commands.

The potential design for the remote control as seen in Figure 33 would be a trapezoidal-like shape printed in two parts, a top and a bottom. The inside of the controller would include separate compartments for the joysticks, the on-off switch, and a hole in the top for the antenna. The idea is a very simple design that can be printed and assembled very easily.

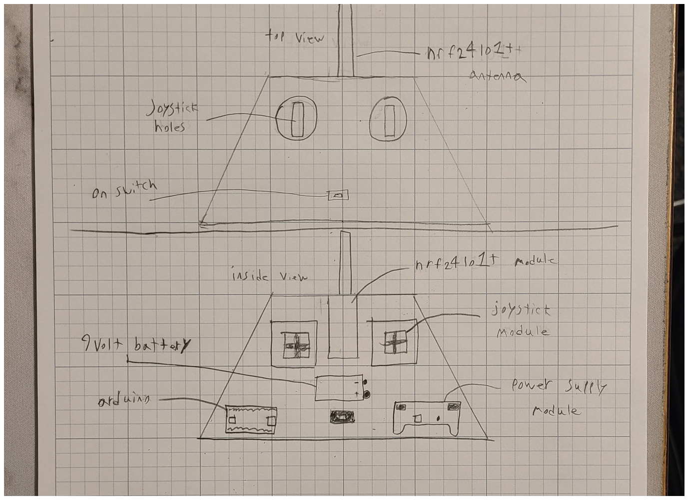

Figure 33. Controller design showing the organization of all the components. It emphasizes the holes for the joysticks and antennas, the compartments for the other electronics, and the trapezoidal shape.

The design matrix below shows the score given to each of the three car designs. These include the tread design, the combined tread and wheels design and the four wheels design. The criteria is outlined in the first column and the importance, or weight, of the criteria is in the second column. The four wheel design had the highest score and would best fit the team's specifications.

		Rectangular base, treads		Rectangular base, combination of wheels and tread		Peanut-Shaped, Wheels bigger than the car, 4 motors, zero turn	
Criteria	Weight Factor	Rating	Score	Rating	Score	Rating	Score
Cost	0.15	8	1.2	8	1.2	7	1.05
Durability (damage)	0.2	5	1	6	1.2	8	1.6
Reliability (expected performance)	0.15	4	0.6	7	1.05	8.5	1.275
Functionality (perform against obstacles)	0.3	5.5	1.65	7	2.1	9	2.7
Look (style)	0.05	10	0.5	5	0.25	9.5	0.475
Space	0.1	8	0.8	8	0.8	7	0.7
Controllability (unexpected terrain)	0.05	6.5	0.325	6	0.3	8	0.4
TOTALS	1		6.075		6.9		8.2

Figure 34. Car Decision Matrix

4. Detailed Design

4.1 Turbines

4.1.1 Assumptions

The turbine, with all the moving parts, is expected to take up a very substantial chunk of time. The turbines will allow for vehicles within the specifications to traverse them, only needing good timing and a good operator. The structure will be stable and evenly weighted, able to perform properly. Vehicles will not be able drive around the blades unless they take the alternative route over the bridge. The turbines are not designed to destroy but rather to hinder the cars.

4.1.2 Functions and Meeting Specifications

The overall function of the turbines would be to damage cars going through it. To do this, three different blades with different challenges were designed. The first blade has a scoop like shape that will hopefully pick up and flip cars that are too slow. The second blade will be made of clear vinyl and will spin at high speeds. This will hopefully knock lose any unsecured material and cause damage to the cars passing through. Both wheels satisfy the team manager's specifications that it should harm the car. They meet the requirements of having one fast moving turbine and one slow moving turbine too. In addition, the third wheel, which had no specifications, will be an open wheel. The purpose of this wheel is not so much damage as difficulty. It will end up hurting the cars if they cannot traverse the opening fast enough, but it is more a strategic obstacle.

In addition, each of the turbines will have a different motor. The first and last wheel will have a speed of about 10 rpm, satisfying the specification to have a slow-moving wheel. The slow speed of the motor will create a higher torque and be able to spin the heavier wheel designs. It will also be better to assist in picking up the 8 Ib cars. The second turbine will have a speed of about 40 rpm, satisfying the specification of a fast-moving wheel.

Professor Waldenmaier wanted a boundary to prevent the cars from traversing around the blades. Since the design has rectangular bases for better stability, the wheels were designed to be placed in front of the supports. This allows the blades to reach the far corners without hitting anything and ensures the cars don't have room to squeeze by. Walls were also attached to the turbines to increase stability. These would ensure the turbines don't flip over and will force the cars to go through them by creating an outer barrier. Due to the static structure, or bridge, being attached to the turbines, the walls also act as a barrier keeping the cars within the obstacle if they fall off into the turbines. It forces them to finish going through blades rather than taking the bridge path again.

Finally, the function of the emergency stop system is to ensure the cars don't break the turbines. The team manager wanted the wheels to be able to pick up the cars, therefore if they drag them upward and get stuck against the walls it could burn out the motor. The emergency stop system would detect if the blades stopped moving at regular intervals and shut down the motor. This would release the cars from the blades and allow the normal rotational motion to resume.

4.1.3 Prototypes

Gear System

The motor purchased using the $75 budget did not have enough torque for the application, therefore a new motor had to be found. Even after finding a new motor with a torque rating of 70 Nm or 5 ft.lbs, there still wasn't enough torque to spin both the blades and the car's weight. To correct this, a gear system was implemented. By using gears, it would be possible to double the amount of torque exerted by the motor. To do so, a gear ratio of 2 would be needed and therefore, the first design was 8:16. The smaller gear would have 8 teeth, while the larger would have 16 teeth. This would effectively double the torque to be about 10 ft.lbs. However, the downside of this is the motor would only spin at 5 rpm, being much too slow for the application. To counteract this, the rpm of the motor was changed to 20. This faster rpm would allow the motor to increase torque and decrease in speed without any issues. The torque rating on the 20-rpm motor is about 4.34 ft.lbs, therefore the gear ratio would have to be larger than 2. After doing calculations again, the new gears would have 12 teeth (driver) and 28 teeth (driven) giving a ratio of about 2.333. This would increase the torque to about 10.126 ft.lbs and decrease the rpms to roughly 8.57. While this would be slower than the target speed of 10 rpm, it would still satisfy the requirements for this obstacle. To reference these calculations, they can be found in Appendix B. After calculating the speed and torque, a CAD model for the gears was created. This model can be seen below.

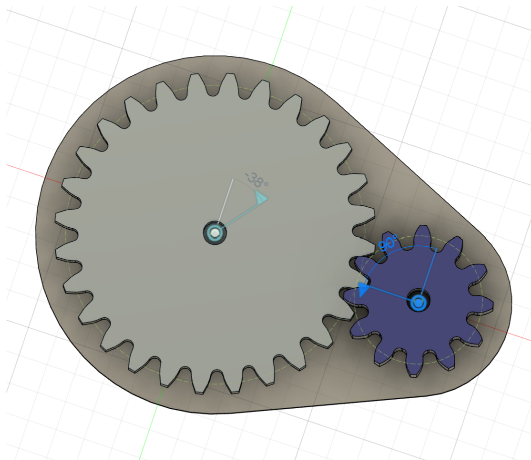

Figure 35. Gear CAD Model

The gears were designed to fit the motor with too little torque so that they could be tested before the real motor arrived. The idea was that the gears could be functional, and the kinks could be worked out before testing them on the actual motor. After ensuring the gears connected properly on the CAD model, they were 3D printed. The smaller gear had slight variances in the middle hole and had to be sanded down so that it would fit the motor. Below is a picture of the finished gears.

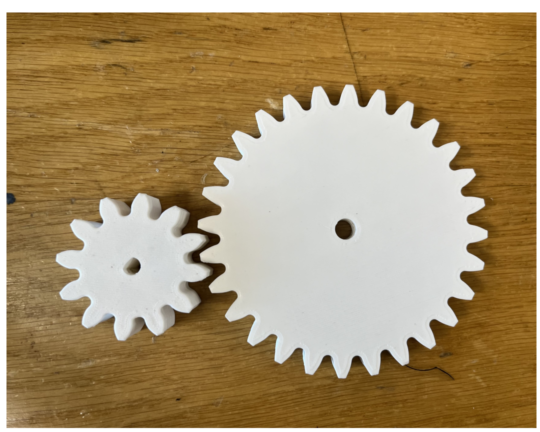

Figure 36. 3D Printed Gears

To test the gears, a spare wooden board, leftover from building the turbine frame, was used. A hole was drilled into the middle so that the bigger gear could be inserted into it. A previously printed shaft and bearing was used to connect the gear to the board and the weight. The end of the shaft was wrapped in duct tape so that it wouldn't fall out when the gears started spinning. The motor was hand held on the top of the board because there wasn't enough space to mount it properly. 12 volts were input into the motor and the teeth connected smoothly. The test was conducted without weight at first, then with a 3 oz crowbar, and finally a vice grip that weighed about 1 lb (15.4 oz). The motor was able to turn the vice grip, but started to lift under the weight. There was a lot of resistance, therefore a box or shield-like structure would be needed to counteract that and keep the motor from being ripped off the frame of the turbine. In addition, the gears would start to slip and disconnect because the motor wasn't mounted and the board was very thin. When the correct motor arrives and the blades are constructed, the system can be tested properly. The constructed blades will also allow more weight to be tested. Below is a picture of the testing set up with the 1 lb vice grip. The thin board and handheld motor can be seen, but the picture also shows a strong connection between the gears.

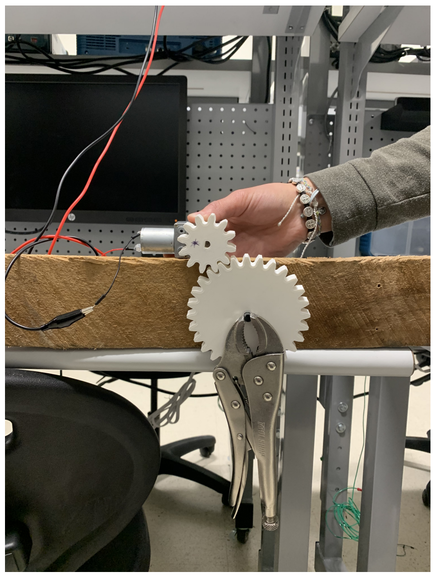

Figure 37. Testing with the 1 lb Vice Grip

After testing, the gear system could be constructed. Adjustments needed to be made in the CAD model to address the bigger dimensions of the motor and to create an insert for the bearing. Five holes for the screws were also added to this model after the gear for the first blade was printed without them. This made it more difficult to drill the gear into the blade without damaging it. By adding the holes for the screws, it eliminated this problem for the third gear. Below is the CAD model for the new gears.

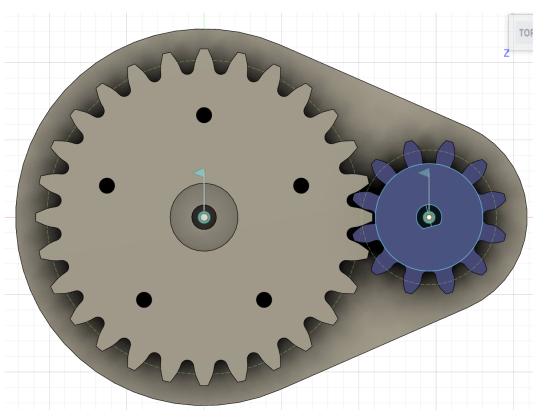

Figure 38. Cad model for revised set of gears emphasizing the five holes for screws and the bearing insert.

After redesigning the models, the gears were 3D printed. There was a little bit of trouble printing the small gear, so it had to be printed twice. With the second print, the diameter of the hole in the center was decreased slightly to fit tighter on the shaft of the motor. A dead axle system was chosen to connect the blades to the motor. This means the gear and blade would have bearings embedded in them to create movement rather than having the whole shaft move. This would ensure there was no rubbing against the wood as the blade spun and also made attaching the gear to the blade much easier. The larger gear was screwed into the scoop blade making it one big component. There were no issues with the blade hitting the small gear when testing. A picture of the blade and gears can be seen in Figure 39.

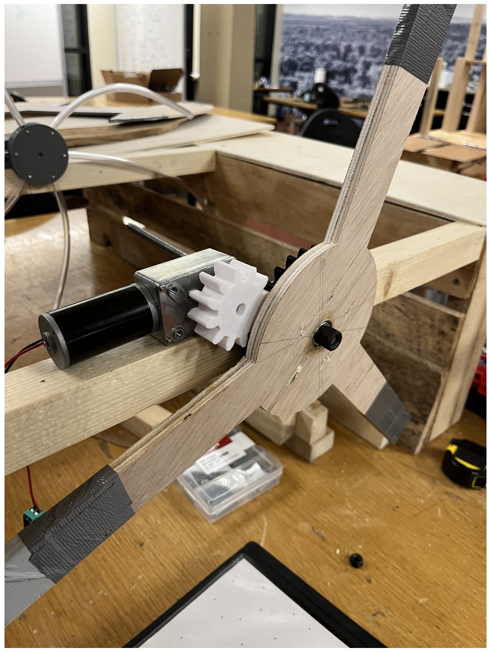

Figure 39. Prototype of the first blade with the large gear screwed on and the dead axle system constructed

Motor Box

To screw the motors to the turbine frame, a box-like structure would be needed to fit around the motor and hold it in place. The box would need to be able to withstand the resistance from the weight lifted. Using the materials provided, a prototype box was printed with PLA. The design consisted of a box with a slit in the front for the shaft to stick out of and a hole in the side for the wires to connect. Two platforms came out of the sides so that it could be screwed into the wood. The design for the box can be seen below.

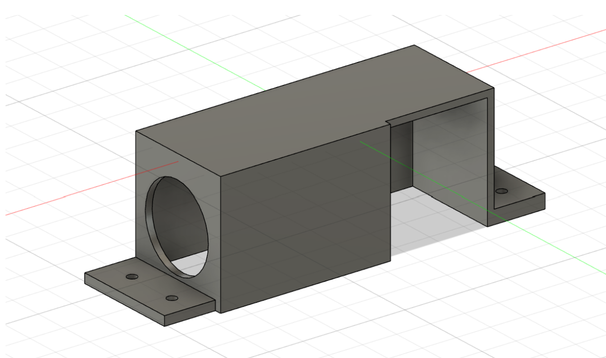

Figure 40. CAD Model for the Motor Box

After printing, the first box was found to be too small because it wasn't quite wide enough or tall enough. This caused the walls of the box to bend and caused issues with the motor sitting flush against the wood. Adjustments were made to the design to compensate for this, and a second box was 3D printed. This time, the box fit around the motor, but was not quite as snug allowing room for the motor to slide around. This prototype also didn't sit quite flush with the wood, so the position of the hole was lowered and the box was made thinner. A third design was then 3D printed. This box fits the motor the best, has no bending in the walls, sits almost flush with the frame and is the best option. Below is a picture of the final 3D printed box.

Figure 41. 3D Printed Motor Box for the second blade

A motor box was also printed for the bigger motor. The design had to be very sturdy in order to withstand a significant amount of resistance from the blades as they pick up a heavy weight. This meant the dimensions were made bigger and the box's thickness was increased. It was printed with a 30% infill for extra strength. The box is a little small and doesn't sit flat on the frame, however the hole was sanded down and made wider allowing the motor to fit better. A picture of the motor box can be seen in Figure 42.

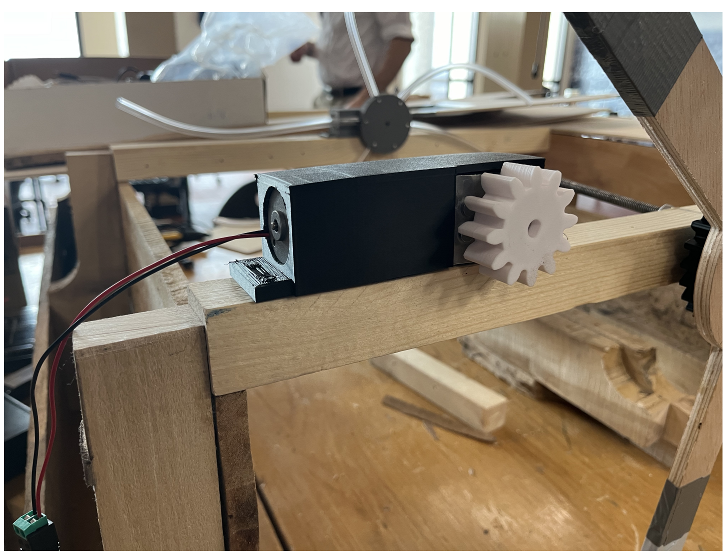

Figure 42. First prototype of the 3D printed motor box for the first and third blade

After testing the third blade, the resistance from lifting the weight was so great that the motor box needed to be redesigned. The initial design in Figure 42 was stable, however if more supports were added to better connect the screw platform to the rest of the box, the overall design would be stronger. Triangular supports connecting the platform to the box were added creating a more trapezoidal shape. This change can be seen in the CAD model in Figure 43. In addition to the supports, the hole was moved down a few millimeters so that the top of the motor was even with the top of the box. Finally, a little notch in the hole on the side was created so the wires attached to the motor would be able to stick out without interference. Finally, the box was printed at a 40% infill to provide more strength. Overall, the design is more reinforced and also fits the motor better. Below is a picture of the revised CAD model and the 3D printed prototype.

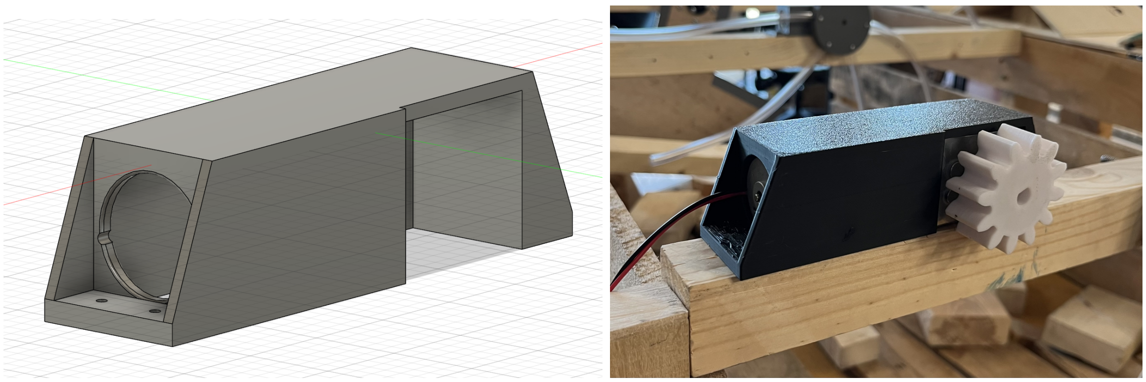

Figure 43. (Left) cad model for newly designed motor box (Right) 3D printed motor box

<u>**First Blade (Scoops)**</u>

The CAD model developed for the first turbine is shown in Figure 44. There were some calculations that were needed to properly design the model because the gaps between the blades had to be able to fit an 8x8in car, or the maximum dimensions allowed. Additionally, the gears used to give the turbines enough torque need to be protected by the turbine. The radius of the gears is slightly less than 5".

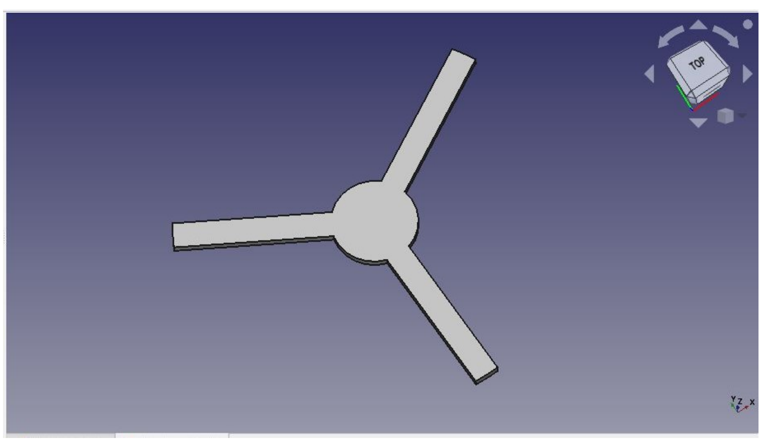

Figure 44. CAD model for the first blade. This was used to cut the shape out of the plywood

The first blade's thickness needed to be changed to 1/5in due to the lack of plywood options. Adjustments also had to be made to the model in order to compensate for this. The first turbine was made from two identical 1/5in pieces glued together. They were cut out using the CNC machine and were glued together. The blades could then be mounted on the frame and used to test the gear system as well as their own stability. The cut out piece of the first wheel is shown below.