# Human Powered Vehicle
# Team 24

## Background Report

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# 1. BACKGROUND

## 1.1 Introduction

The Human Powered Vehicle Competition (HPVC) is a project sanctioned annually by the American Society of Mechanical Engineers (ASME).The team is faced with a design problem and tasked with building a vehicle which could suffice as an alternative transportation method for people around the world. The competition consists of multiple aspects of design and testing, including an evaluation of a design report, innovation, endurance, speed, and braking capabilities of the vehicle.

## 1.2 Project Description

ASME's international HPVC provides an opportunity for students to demonstrate the application of sound engineering design principles in the development of sustainable and practical transportation alternatives. In the HPVC, students work in teams to design and build efficient, highly engineered vehicles for everyday use—from commuting to work to carrying goods to the market.

# 2. REQUIREMENTS

## 2.1 Customer Requirements

Customer requirements were given to the team as described by our client, Perry Wood. The client specified his three primary goals for the team: placing in the top three of each category in the competition, involving the Northern Arizona University's (NAU) ASME chapter in the project to allow them to take part in the building and design process to better gain an understanding for future projects, and upon completion of the vehicle, that it be used for community outreach.

The customer then stated that the team was to make separate criteria which would be necessary to meet these general requirements. These requirements can be found in Table 1, below. Weightings corresponding to these requirements can be found in Appendix A within the House of Quality (HoQ) diagram.

*Table 1: Team Specified Requirements*

| Team Requirements | |
|---|---|
| **Frame** | Overall length < 65 in. |
| | Width ≤ 36 in. |
| | Fit all team member heights (65 - 75 in.) |
| **Components** | 10 ft. turning radius |
| | Top speed of 40 MPH |
| | Overall weight < 90 lbs |
| **Cost** | Cost ≤ $7,500 |

As seen above, there are six main requirements that the team deemed necessary to the project. These requirements were decided upon after discussing the team's knowledge of past vehicles except for the requirement that the vehicle fits rider heights. The minimum value was taken from the shortest team member as the maximum was taken from the tallest.

## 2.2 Engineering Requirements

Engineering requirements were created by the team to see what design aspects would be needed to create the vehicle. This also allowed the team to split up the bike into various subsections which were then allocated to certain individuals responsible for its success.

*Table 2: Engineering Requirements*

| Engineering Requirement | Desired Outcome |
|---|---|
| **Minimize Weight** | Higher speed |
| **Decrease Deflection in Frame** | Optimal power efficiency |
| **Low Cyclic Loading** | Durability |
| **Simple Design** | Ease of manufacturing |
| **Rider Comfort** | Rider reaches full potential |
| | Smooth vehicle operation |
| **Minimum Expense** | Low cost quality parts |
| | Ease of manufacturing processes |
| **Safety** | Rider is unharmed in every way |
| | Able to compete in competition |

As seen in Table 2, each engineering requirement corresponds to a desired outcome. These requirements are included alongside the customer requirements within the HoQ where they are compared to one another. A more detailed explanation of how the HoQ functions can be found in Section 2.5, below.

## 2.3 Testing Procedures

### Frame

Frame testing was one of the first test procedures performed for the project along with ergonomic testing. To ensure the manufacturability of multiple curved components on the frame, multiple tubing sizes with different diameters and wall thicknesses were bought to test. The test procedure included bending the tubes with the tube bender provided by the machine shop to ensure that the tubes did not buckle or crinkle. Stress and strain tests were implemented on sections of the frame to verify the ANSYS calculations. The strain test consisted of applying loads along the frame and using strain gauges to evaluate the deformation on the frame. These tests are necessary to ensure that the frame is stable and rigid.

### Ergonomics

Testing in ergonomics consisted of testing different rider angles at the same power to see which positions required a lower cadence in rotations per minute. The data was recorded using a power tap in the hub of a wheel on a bike-trainer. Additional testing will use an asymmetric ring for the drive ring compared to the standard ring which was used in the original testing. Like the original test, the cadence of different powers produced by both rings was compared to determine which is most efficient.

### Fairing

In order to test the fairing, the team printed a scaled model. Adequate calculations were performed to scale the necessary values of wind and surface roughness in order to analyze it within a wind tunnel.

### Steering

Steering testing involved measuring different wheel’s tire angles and computing turn radii to ensure an agile vehicle. Along with this, input motion was compared to output motion in all linkages and a minimum difference in tire angle should be achieved to ensure feasibility of the design. Using SolidWorks Motion Simulation, data can be gathered to determine wheel angle, input and output displacement and wheel angle difference.

Since there may be multiple link attachment points, all of these combinations were tested and evaluated by the team. The most important aspects of the steering system was to minimize straight-line toe-in leading to excessive tire wear, combined with the ability to obtain both a large turn radius and small turn radius by switching attachment points.

### Drivetrain

Testing for the drivetrain was focused on optimizing the gearing. The rider was positioned in the seat at the most efficient angle determined during ergonomic testing and pedaled at a constant power. This produced data such as cadence, muscle fatigue, and overall comfortability. The chain rings were switched out varying on number of teeth. Once the specific ring and tooth size was determined, it was possible to calculate the amount of torque the rider will produce to select the correct crank length. This will allow the team to increase or decrease the amount of torque the chain will endure.

## 2.4 Design Links

### Frame

The main priority of the vehicle’s design is safety. The roll cage that is implemented into the frame ensures that the rider will not experience any harm if the vehicle were to slide or rollover. In addition, the wall thickness of the material will determine the amount of deflection and failure that the frame will experience. Choosing a thicker wall thickness will ensure that the frame does not experience failure while riding. Furthermore, a light material was used to decrease the amount of power the rider must input and the weight of the vehicle.

### Steering

By incorporating a highly adjustable steering system, the team can ensure safety for all involved with the vehicle by limiting the steering input for high speed situations.

### Fairing

The material used in the fairing is strongly related to the weight and safety engineering requirements of the vehicle. Weight of the vehicle was specified to be under 90 lbs and safety is to meet all competition requirements. Amongst the multiple possible composites to be used in the fairing, all of them had different material properties and resin contents along with material strengths and abrasion resistance. Analysis was conducted to find which would be the lightest solution of material while still taking into account the safety factors as well.

The shape of the vehicle is related to the top speed of the vehicle obtainable by the rider. A very heavy, stout design would protect the rider but not allow for enough drag reduction to achieve the top speed of 40 MPH. Therefore, an aerodynamic design and analysis is necessary to meet these requirements. Minimized surface area can also reduce skin drag as well as the necessary amount of material minimizing weight.

### Drivetrain

By implementing an asymmetric chain-ring onto the vehicle, the team was able to achieve an efficient pedal stroke, as well as decrease muscle fatigue within the system. Combining this with the correct cassette to power the rear wheel, the goal of 40 miles per hour is easily obtainable. A comfortable, efficient ride is produced when this is paired with the team's ergonomic data.

## 2.5 House of Quality

As stated before, the HoQ covers both the customer and engineering requirements. Correlations from strong, moderate, to weak are used to compare the requirements. Ranks are then assigned to see the importance of the customer requirement to the number of engineering requirements. A relative weight is then calculated, which shows a percentage out of 100, showing the importance of each customer requirement. This shows which areas of the vehicle will be focused on heavily compared to which are going to be looked at and completed but not a great length. The three highest percentages are weight, competition, and strength which are needed for the vehicle to be operable and safe for use as placing well in the competition is important. Appendix A has a full overview of the house of quality with tolerances and weightings.

# 3. Existing Designs

Past years' vehicles which found success in competition were analyzed as background research. This was done through analysis of each team's design reports as well as visual inspection of their vehicles. Online research pertaining to rules of the competition as well as cost limitations were also performed.

## 3.1 Design Research

To ensure the success of this project, research was conducted in the following manner: the team was broken up into six separate aspects of research including frame, fairing, steering, ergonomics, drivetrain, and innovation. This research was then conducted through observation at last year's HPVC, online searches of informative rules, and speculation of past team’s design reports.

Each section of the vehicle was analyzed on multiple other vehicles which are described in more sufficient detail within Section 3.2. Vehicles such as The University of Akron, Rose-Hulman, Utah State, University of Southern California, and NAU’s “Pulaski” were read over by the team and broken down. The team met with the “Pulaski” team members multiple times allowing the team a better understanding of the project and timeline to be set.

## 3.2 System Level

Throughout the research phase, human powered vehicles from different schools were researched to differentiate the benefits of each vehicle. They were then categorized based on speed, weight, and how well they placed during competitions. Therefore, the vehicles that were thoroughly analyzed came from NAU in 2014, Rose - Hulman, and California State University Northridge.

The human powered vehicle from NAU in 2014, Pulaski, is a standard that the team is following due to its success. The vehicle was successful throughout multiple sections of the competition and finished in the top three competitors. Their vehicle consisted of a tricycle and was able to reach a maximum speed of 45 MPH due to the ergonomics, fairing, and drivetrain design. The ergonomics and drivetrain design of the vehicle allowed the rider to provide maximum power output, while the fairing decreased the drag force against the vehicle. Furthermore, the Pulaski’s frame was built with 6061 Aluminum due to its high strength to weight ratio and utilized gusset plates to increase stiffness at high stressed areas. As a whole, the Pulaski was very successful and will be used as a reference guideline for the project [1].

Rose - Hulman is a consistent leader in the competition every year. Their vehicle weighed 60 pounds and reached a maximum speed of 36 MPH. The frame was constructed with 4130 steel, but the vehicle still contained a small weight because the ergonomics consisted of a slightly angled sitting position. Therefore, the frame was shorter than others. Also, their fairing was made with carbon fiber and Kevlar because the use of composites allowed for a lightweight structure that could still withstand high loads. The design of this vehicle was based on decreasing the weight as much as possible by selecting proper materials and decreasing total dimensions of the bike to reduce the amount of material used to build the vehicle. Since the total weight of the bike was decreased, the rider was able to use less power to achieve high speeds [2].

California State University Northridge placed at the top of the competition and their vehicle highly involved innovation. For instance, they created an autonomous braking system (ABS). The ABS assisted with braking on turns and increased the efficiency of braking. Furthermore, the fairing was constructed with carbon fiber and included a fairing dampening system. This reduced the drag force acting on the vehicle and decreased the weight. The team also included carbon fiber tie rods into their steering. With all of the innovative components combined with their frame, the vehicle placed at the top three for every section of the competition [3].

## 3.3 Subsystem Level

### Fairing

The team researched many universities that implemented carbon fairings for their vehicle. The advantage of using carbon specifically is the added strength and decreased weight that it provides. Alternatively, some universities chose to implement clear thermoplastic fairings and even partial fairings.

Since the team plans on using a carbon-based fairing, Rose-Hulman has been the main focus for background fairing research due to their performance throughout many competitions in the past. Their design, seen in Figure 1, featured a carbon fiber and Kevlar fairing that was completely sealed off to the environment. They achieved this by making a six-part mold with a two-part bag. To attach the many pieces together they used aluminum dowel pins to guide the pieces together.

In addition, the inside of the fairing had safety structures to protect the rider's shoulders in the event of a roll-over. In total, their costs for the entire fairing was over $10,000 for molds, safety and fairing materials. While the team does not plan on spending this much on the fairing, they offer great ideas that can be implemented into fairing designs [2].

*Figure 1: Rose – Hulman's Fairing*

The University of Akron implemented a thermoplastic fairing concept. This was a clear, mostly cylindrical fairing that allowed an almost 360-degree view for the driver. The added benefits of this idea are driver safety by having increased visibility and virtually no blind spots. Since thermoplastics are relatively weak and light, they added carbon fiber ribs to help add strength and rigidity to their fairing while still keeping the fairing as light as possible. Like most high performing teams, the University of Akron used computational fluid dynamics (CFD) to analyze their fairing. Since this shows a high aptitude to complete encompassing testing, the team performed CFD as well [4].

An interesting concept to the fairing subsection is a partial fairing. This was implemented by Colorado State University [5] and is basically a windscreen that is built to divert air over the top of the vehicle only. While a fully enclosed fairing is far superior to a partial fairing, the ease to manufacture it and the costs associated with it are also far lower than a fully enclosed fairing. In addition to its lackluster aerodynamic performance, water, dirt, and debris are able to travel into the cockpit. This can obstruct the driver's view or even harm the driver at certain speeds. Safety is also a large issue with this design since there is nothing physically keeping the driver’s appendages inside the vehicle. In the event of a roll-over, the driver's arms naturally want to extend out. With no enclosure, this could lead to injury. Therefore, it is best to utilize an enclosed fairing.

## Steering

Since there are a number of different ways to choose driver position and vehicle layout, there are many different concepts for steering. The NAU ASME club Human Powered Vehicle utilized push-pull steering, as seen in Figure 2, that activated an adjustable triangular shaped bell crank. This then rotated and activated adjustable tie rods. Following the tie-rods, the steering knuckles were attached and adjustable. Since all aspects of the steering were fully adjustable, they were able to find near perfect Ackermann angles after the design had been analyzed. Since computer models are not directly transferrable to real world applications, this would be a great idea to implement into the steering design.

*Figure 2: NAU ASME's Steering Design*

Unlike the NAU ASME team, the team would like to have slightly less adjustability to rely less on adjustments post construction. Making steering members adjustable also generally means having multiple places to join the members. In doing this, many holes are made in the members creating stress risers and a higher likelihood for failure. Having less adjustment will allow our steering members to be stronger and easier to analyze the University of Southern California introduced a joystick design for their steering. Since the joystick would activate various linkages down to the tie-rods and steering knuckles, this design would be relatively simple. Another benefit to this design is that it is entirely intuitive. Some push-pull lever action steering concepts could possibly lead to confusion across team members whereas a joystick allows a driver to push left for a left turn [6].

Other teams, like Utah State University’s team [7], attempted to assist their steering design by using a chassis tilt. Their steering method was a push-pull style, similar to the NAU Pulaski team’s design but allowed greater speed to be carried through a tight turn by leaning the chassis and driver into the inside of a turn. Since the tilt did not render acceptable results at high speeds and could be influenced by heavy pedaling, they decided to lock the tilt out at the discretion of the driver.

## Innovation

The innovation subsection of this vehicle is a place where teams can show their creativity, technical skills, and optimizations of a design. In the past, the NAU Pulaski team implemented the use of a reverse gear for their drivetrain which is shown in Figure 3. They created a way to engage the reverse gear while stopped, and use 'forward' motion of the crank to produce backwards motion of the vehicle. Until this team, this idea had never been encountered as in the past there was no way for a rider to move backwards unless they got out of the vehicle [1].

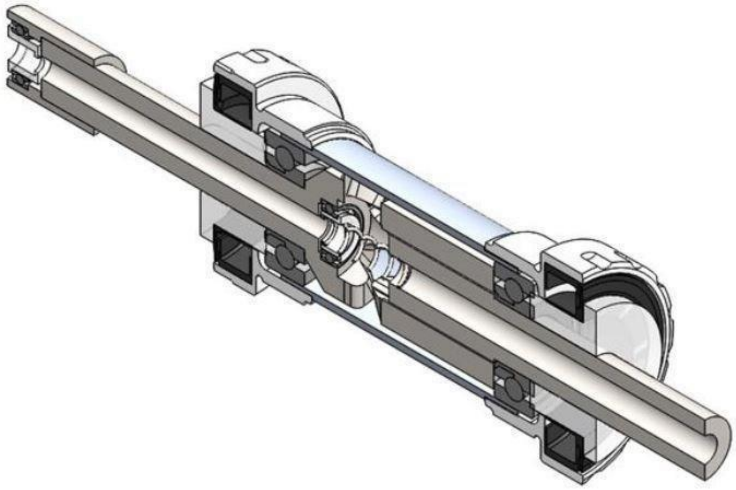


*Figure 3: NAU Pulaski's Reverse Gear Mechanism*

Another existing design from the innovation subsystem has been the use of Heads-Up-Displays. This is a projected image of information that is relevant to the driver. Examples of this are: lap times, speed, power, date and time. The projected surface would be on the visor section of the fairing so that the driver does not need to look away to see the information. Some teams have tried to implement this but have found issues with brightness of the display and speed of the microcontroller on which it depends. The concepts that affect the display's performance are the window clarity, speed of the microcontroller, and the quality of the accessories to accompany the microcontroller.

A great way to include innovation ideas is to use a two-wheeled vehicle and find unique ways to control the stability of it and make it react like a three-wheeled vehicle when necessary. Rose-Hulman developed a concept that allowed two legs to be extended from the bottom of the frame and be retracted to be parallel to the frame. They used spring loaded rods that would be retracted as the vehicle moved away and gradually relieved weight on the rods [2]. In addition to this, teams have used pneumatics and magnetism to achieve the same result. This 'landing gear' concept allows teams to spend less time configuring kingpin angles, Ackerman angles, and camber angles. It also requires less components and material to join it all together. Finally, this allows the fairing to be much slimmer and allow it to more resemble an airfoil. The largest defect of the two-wheeled concept gets effectively eliminated at low speeds.

## Frame

Since materials are not specified for the Human Powered Vehicle, and rider position is left open, there is a wide array of frame types seen from competing teams. The cheapest and heaviest material used is steel. While ordinary stainless steel would be heavy compared to aluminum or titanium, there are variations of steel that can be advantageous. As previously mentioned, California State University, Northridge used a 4130 Steel which allowed it to be extraordinarily light and still maintain strength. They also used a semi-recumbent style for the rider position. This allowed their center of gravity to be low and framing to be relatively simple. To attach members, they used welds and then analyzed them since they offer a large stress raiser throughout the frame. In addition to this, they also evaluated members and the whole frame with Finite Element Analysis (FEA) [3].

The University of Akron utilized a different shape to their members as opposed to making their frame out of unique materials. They composed their frame out of curved beams rather than conventional straight tubing as seen in Figure 4. This greatly impacted the frame's torsional stiffness and led to less deflection from point loads. A curved member for the backbone of the frame led to a lower center of gravity that benefits cornering ability and aerodynamics as well [4].

*Figure 4: University of Akron's Frame*

The NAU Pulaski team implemented an aluminum frame material with a semi-recumbent rider position similar to California State University, Northridge. Since the material they used is much lighter than steel, the vehicle could accelerate and turn easier than an equivalent steel frame. Unfortunately, since aluminum is also significantly weaker than steel, the members had to be heat treated to increase their overall strength. This proved to be quite costly but was avoided using a sponsorship deal through Phoenix Heat Treating [1].

In addition to the potential for added costs, there is also a time delay that would be present. With steel members that are not heat treated, members can be welded and the frame can be constructed in a fairly small amount of time. With heat treated aluminum, on the other hand, the team will have to wait until the frame is together to send it to be heat treated and this process may take weeks. While other tasks may be performed in parallel to this, some subsections, like the fairing, depend on the frame to be present for calculations and physical testing.

# 4. Designs Considered

Before creating the designs to be considered for the HPVC, concept generation was split up into sections to cover the subsystems of from, steering, drivetrain, fairing, and innovation. To ensure that all the subsystems would be met, a functional decomposition was created. Each section consists of at least three different designs considered for the vehicle.

## 4.1 Functional Decomposition

The functional decomposition it offers a broad visual of what functions need to be completed by certain subsystems of the vehicle. This also ensures that designs meet all needed functions. Although the team has an in-depth understanding of the vehicle, a functional model ensures that the engineering requirements are met. Using the functional decomposition, as seen in Appendix B, each team member is able to see the overall goal that their subsystem accomplishes as well as determine which concepts have influence on other systems. This is necessary because the HPV's design must be molded around its interaction with other designs so there is no conflict when the subsystems are assembled alongside each other.

## 4.2 Frame Design

### Design #1: Straight Frame

The first design considered for a frame was a straight frame made of Aluminum 6061 - T6 as seen in Figure 5. A straight frame allows for the proper rigidity and stability to be able to compete in the competition. The main advantage of a straight frame is the ease of manufacturability. The frame would be fully manufactured at the machine shop on campus due to its simple geometry. To manufacture the frame, the team would need to notch every tube at the correct angle and then weld all the components together. A disadvantage of this design is that it requires more material than the curved frames and there is a possibility of the support beam bowing due to its length. This is a known disadvantage as last year's HPV consisted of a straight frame and chromoly steel and the support beam was so long that the weight of the rider caused instant deflection.

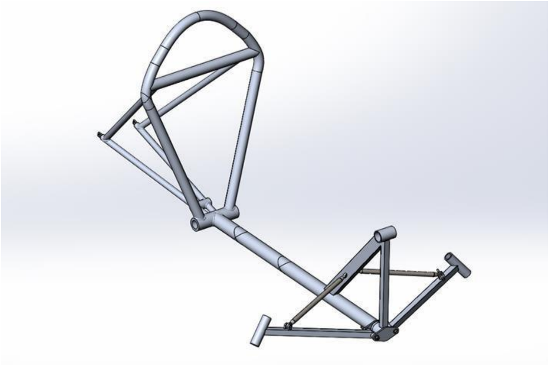


*Figure 5: Straight Frame Concept*

## Design #2: Completely Curved

The second design that the team considered was a completely curved frame as seen in Figure 6. The curved frame could consist of either a constant radius or three different radii. A curved beam with three radii would be more beneficial than a beam with a constant radius because it would allow for a lower center of gravity without touching the ground and adjustability of the location of the pedals. It would also reduce the number of welded joints and the length of the support beam therefore reducing the risk of deflection.

Strain hardening would occur when the tubes are bent increasing the internal stresses thus the frame design would be able to withstand higher stresses. Also, the roll bar system could be implemented along the frame and not on a vertical plane as seen in previous vehicles. This would allow for a shorter vehicle overall. The frame would be very difficult to manufacture on campus and therefore requiring to be bent with a Computer Numerical Controlled (CNC) tube bender due to the constant rolling that would have to occur to produce the different radii. Also, internal stresses is a difficult variable to manage through the heat-treating process as they cause warping upon cooldown.

*Figure 6: Completely Curved Frame Concept*

## Design #3: Partially Curved

The third design of the frame consisted of being partially curved as shown in Figure 7. This design was curved at three specific points and correctly angled throughout the frame. The benefit of this design was that the team could still develop a shorter frame that could be manufactured in the machine shop on campus. To manufacture the frame, the team would be able to use the tube bender provided and purchase the necessary dies. The frame maintains many positive attributes like the completely curved design above without the difficulty of manufacturing as well as less difficulty with the post heat treatment process.

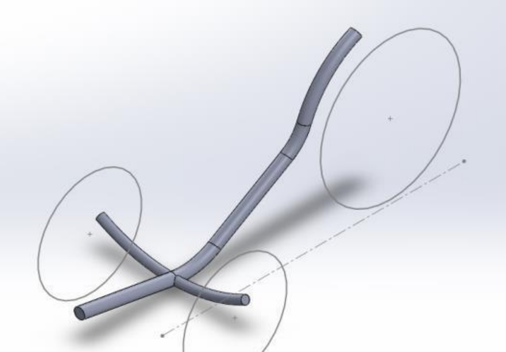


*Figure 7: Partially Curved Frame Concept*

## 4.3 Steering Design

### Design #1: Joystick (Single Linkage)

Design one, seen in Figure 8, allows the driver of the vehicle to push left or right on a joystick to activate the linkages down to the steering knuckle which then rotates the wheels. One disadvantage with this design is the amount of user force required for activation as this is caused by the need for a high mounting position in the vehicle. Another issue with this design is that the pivot point for the linkages need to be offset. This means that there will need to be a bracket attached to the frame to allow the steering linkages to be mounted off the frame. However, an advantage to this design is that it would be very cost effective and manufactured in house. The steering knuckle dropouts could be made with multiple mounting points as well, allowing greater variability to the effect of the output of the system.

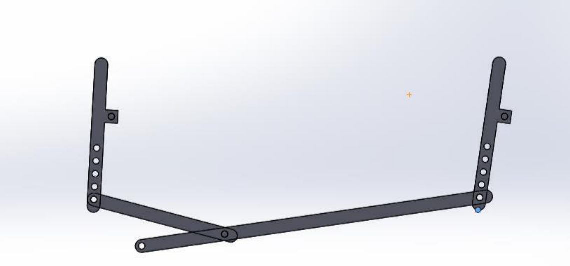


*Figure 8: Joystick Steering Concept*

### Design #2: Single Arm (Bell Crank)

As Figure 9 shows, design two incorporates an L-shaped crank that is rotated due to the position of the tie rod linkages being outside its “center.” The steering input will come from one arm that is pushed or pulled to turn left or right. A disadvantage to this design is that the input to the system will be done with one arm rather than two making the wheels harder to turn by the driver. Advantages to this design are that it is possible to make many attachment points to allow variation of the input force required and that the steering knuckle would be adjustable as well.

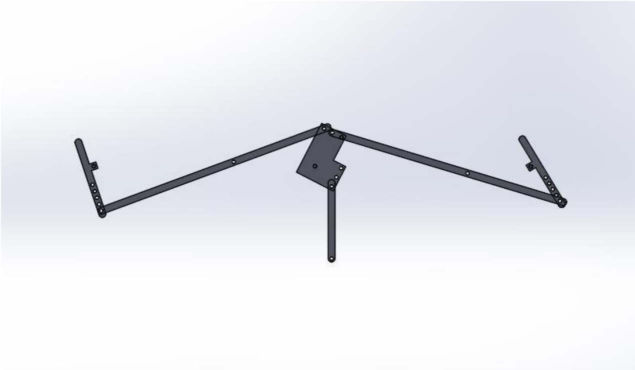


Figure 9: Single Arm Steering Concept

## Design #3: Double Arm (Bell Crank)

Design three, seen in Figure 10, employs the use of a bell crank to rotate and send output to the steering knuckle dropouts. A disadvantage to this design is that the mounting points may end up deforming at the top of the bell crank. Also, mounting must be on the frame and the lowest point to the ground leaving it susceptible to damage. Similar to design two, the bell crank and steering knuckle can be machined to accept many different attachment locations allowing the system to be adjustable and the input of a moment-couple will make actuation easier for the driver.

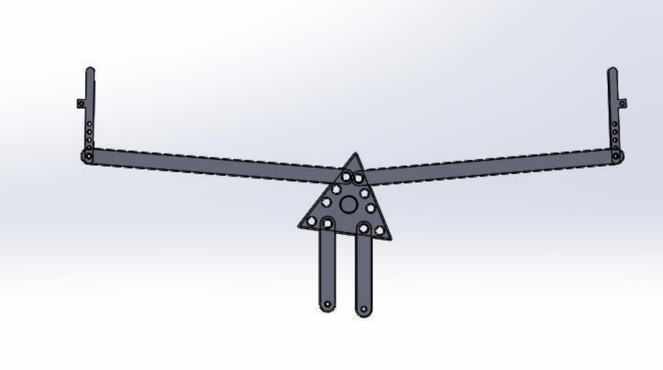


Figure 10: Double Arm Steering Concept

## Design #4: Rack and Pinion (Wheel)

This design utilizes a steering shaft as well as a rack and pinion system that will be operated through a steering wheel and can be seen in Figure 11. The rack is attached to the steering knuckle dropouts allowing the wheels to turn. The disadvantages to this system is the necessity of a gear reducer to make the turning force smaller for the driver. The driver would be making multiple rotations of the steering wheel for a small rotation of the wheels. While this would be good for the sprint event, it would not be advantageous for the endurance event. This system would also require a separate bracing system to control the deflection in the steering shaft. Benefits to this design include the access to pre-made parts and simplicity of the system.

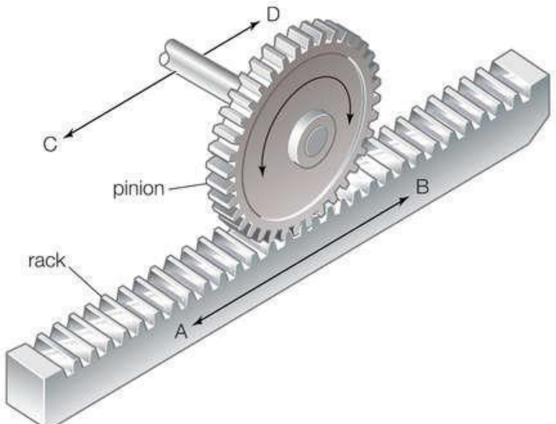


*Figure 11: Rack and Pinion Steering Concept*

## 4.4 Drivetrain Design

### Design #1: Belt

The first design out of the three that were chosen is the belt driven system. An example of this system can be seen in Figure 12. The major setback that this system is that all the components that are incorporated must be manufactured either in house or through another company. A unique belt tensioning system must be designed in order to improve functionality within the bike. The belt used in place of the longer chain of the chain driven system that spans the length of the bike would reduce the major issue of chain drop.

*Figure 12: Gear Driven Bike [8]*

### Design #2: Chain

The second design considered for the drivetrain was a chain driven system which can be seen in Figure 13. Due to the commonality of a chain driven drivetrain, this system is highly considerable for the final design due to the ease of manufacturability. All the components could be purchased from bike component distributors and additional components could be purchased to replace any necessary components on site. An issue with this system is the concept of chain drop. During chain drop, the chain is not aligned with any of the gears and there is no movement due to the chain not engaging with the teeth of the gears.

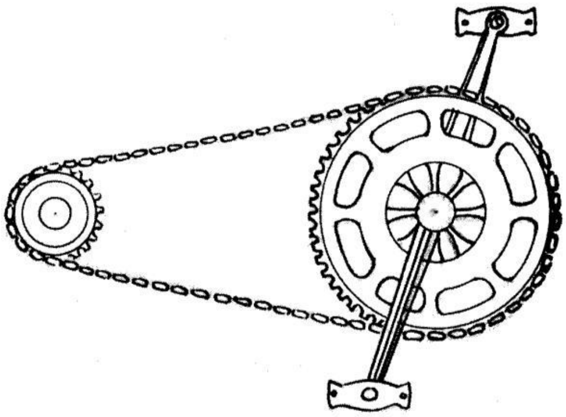


Figure 13: Chain Gear Drive [9]

### Design #3: Front Drive

The third design considered was the front driven drive system and an example is shown below in Figure 14. When breaking this design down into some categories, it can easily be seen that the front driven system is the most complex design as it primarily consists of numerous components which must work flawlessly together. This design requires a high level of amount of manufacturing and design work that would need to be done. However, the front driven system still has the advantage of using less chain to eliminate the issue of chain drop while taking in the benefits of having a compact drivetrain.

Figure 14: Front Driven [10]

### Design #4: Internal Transmission

The internal transmission design would incorporate a more traditional geared transmission. This design would be housed inside of a bottom bracket or portion of the vehicle and capable of multiple gearing ratios. The design would be innovative, however, difficult to manufacture. The design has the most moving parts which require more analysis and testing compared to the other drive systems.

## 4.5 Fairing design

### Design #1: Full Fairing

The full fairing design, seen in Figure 15, uses a four-piece mold to create an entity that encases the vehicle completely. The fairing will be made from carbon fiber to make it lightweight. The advantage of a full fairing design is that it has the lowest drag coefficient of all the fairing designs. The disadvantage of this design is that it is costlier, adds weight, and has a longer manufacturing time.

*Figure 15: Full Fairing Concept*

## Design #2: Front Fairing

The front fairing design uses a fairing that covers only the front of the vehicle as seen in Figure 16. This has some drag reduction but much lower than a full fairing making it at a disadvantage. The advantage of this fairing type is that it costs less to manufacture. Due to requiring less material to manufacture it adds less weight to the vehicle.

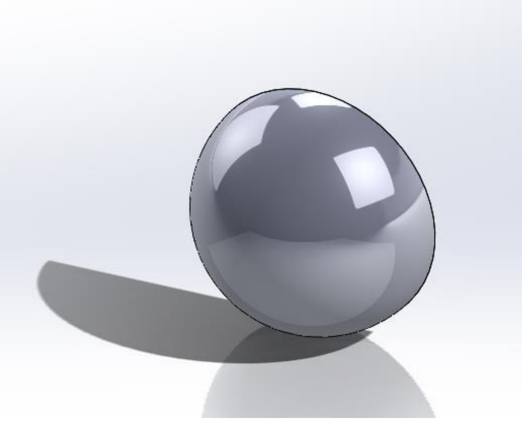


*Figure 16: Front Fairing Concept*

### Design #3: Rear Fairing

A rear fairing design incorporates a fairing over only the back section of the vehicle like the example shows in Figure 17. Advantages for this design is that it is cost effective as it costs less than a full fairing. Similar to the front faring, the time to manufacture is also less. The disadvantages are that is has little drag reduction and adds weight with no help to improve the vehicle.

*Figure 17: Rear Fairing [11]*

### Design #4: Soft Fairing

A soft fairing is a sleeve made from a lightweight, stretchable, malleable fabric. This could include many cotton-based fabrics or polyester materials. The ability to be malleable makes it simple for application while still providing some drag reduction. The abrasive properties of a soft fairing would not be nearly as safe as a full fairing but would offer the same amount as a front or rear fairing.

## 4.6 Innovation

The innovation portion of the competition is used to improve the vehicle with added functions that have not been attempted at competition in years prior. The designs specified below have added benefits for the vehicle and rider safety as it is a greatly weighted requirement.

### Design #1: On Board CPU

This design consists of an on-board computer system that would incorporate a heads-up display to allow the rider to see vitals, speed, distance traveled, and control turn signals. This design has an added safety benefit for the vehicle operator due to the information that would always be displayed to them.

### Design #2: Drag Reduction

The drag reduction system allows for zero pressure drop from the front to back of the fairing which eliminates drag. This is done by using a pump to take flow from the back of the fairing, where the pressure is high, and equate it to the stagnation pressure at the front of the fairing to create zero pressure drop. The benefit of this design allows for the fairing to be completely efficient as well as the vehicle.

### Design #3: Hydraulic System

The hydraulic braking system is a splitter design to split from one master cylinder to two different systems to equally brake both sides of the vehicle. The benefit of this part is increased braking safety. Complications for this splitter is manufacturing and calculating the correct and equal pressure for the pistons on the braking system.

### Design #4: Honeycomb Diffuser

The honeycomb diffuser is used in the back end of the fairing to take the flow on the back end and force it to become a laminar flow. The laminar flow will increase stability on the back end to help vehicle efficiency and improve safety for the rider. The honeycomb mesh would be bought and encased in a composite material that matches the fairing material.

### Design #5: Composite Capacitor

This design would incorporate Dr. Constantin Ciocanel’s research on a composite capacitor. This would work by laying a composite strip on parts of the vehicle that would see the most vibration. The vibration then causes the composite to work as a capacitor and provide power to a battery which can be used to power the LEDs in the safety system of the vehicle.

### Design #6: MSMA Power Harvester

This design uses Professor Perry Wood’s research. Magnetic Shape Memory Alloys (MSMA) are capable of generating power when exposed to a magnetic field and deformed or experience vibration. The generation of power could possibly be harvested and incorporated in the vehicle's lighting system or various other electrified components. This would be something that could be applied to many different sections of the vehicle such as wheels and hubs.

The concept generation phase of the project was successful in that at least three designs were created for each subsystem of the vehicle. As discussed, each design concept has its respective advantages and disadvantages. To select the best design, a decision matrix/Pugh chart hybrid was created to compare the designs while deciding how well they complied with the engineering requirements.

## 5. Design Selected

Selecting a design was done by using a decision matrix/Pugh chart hybrid which can be found in Appendix C. This allowed to see which designs are more feasible than the others and which designs are closely related in score. The ranking system was from 0-5 with zero being not at all useful and five being the most useful. Each design was given a score in relation to the different technical requirements set by the team: cost, functionality, simplicity, manufacturability, safety, resilience, and reparability. With the different technical requirements for each section an average was taken for each design and allowed for the top 2 designs in every subsection to be determined.

## 5.1 Rationale for Design Selection

For the final frame design, the team chose to have a 3-point bent frame made out of 6061-T6 Aluminum. This frame design will allow ease of manufacturing the entirety of it in the machine shop on campus due to only having three different radiuses at three different locations. The frame will also consist of less material and welded joints. Also, the frame can be shortened with this design and increase stability.

For steering, the team chose a double arm bell crank driven steering system. The reasoning behind this is that all the components are fully adjustable. This will allow us to alter the vehicle to specific events quickly and efficiently with a set of sockets. Along with adjustability, this design allows a large amount of leverage due to the moment couple applied to the bell crank. Having achieved both steering related engineering requirements, the team feels confident that this decision will help meet the customer needs.

The team also decided to have a traditional rotary chain drivetrain. This was chosen for its simplicity, manufacturability, and reparability. Chain driven drivetrains allow for common bike parts to be used and allow for ease of installation on the vehicle. Chains can easily be repaired if broken by removing a broken link and either adding a new link or simply re-pinning the chain with a missing link. In comparison to a belt design, chains can easily change length to accommodate designs while belts are specifically sized and difficult to adjust.

The fairing design will be a full fairing. Although the cost is greater than a front or rear fairing, it gives the most drag reduction to the vehicle. The manufacturing time will be longer but the aerodynamic benefits it gives the vehicle outweighs the time necessary to build it. The full fairing increases the safety, protecting the rider in the event of a roll over and weather conditions. The full fairing is also more resilient which makes it more durable.

In the innovation subsection, the team will attempt to incorporate an on-board computer system as well as a honeycomb diffuser. Both designs have added safety to the vehicle. The honeycomb diffuser adds stability on the back end and with further analysis possibly help make the vehicle more aerodynamic. This will add rigidity to the vehicle while possibly limiting the turbulent wake of the vehicle. The on-board computer system will allow the user to see up to date data and control signals in the car. This data would include rider and vehicle diagnostics for power output, speed, and various other safety information. Further analysis will be a deciding factor on which designs will be feasible and improve the vehicle.

The designs selected above can now be finalized and are summarized below in Table 3. These design selections will lead into analytical analysis for each part to further understand if they can be pushed forward into the prototype phase or revisited with other designs if the analysis fails.

*Table 3: Design Selections*

| Section | Design 1 Name | Design 2 Name |
|---|---|---|
| **Frame** | Straight | 3-Point curve |
| **Steering** | Double Arm | Single Arm |
| **Drivetrain** | Chain driven | Belt driven |
| **Fairing** | Full | Front |
| **Innovation** | On Board CPU | Hydro-system |
| | Honeycomb diffuser | |

## 5.2 Design Description

### Frame

The main design of the frame consists of a two point, bent support beam with a bent roll cage. An important aspect of the frame is being able to manufacture the entirety of it in the machine shop located on campus. The support beam and roll cage will be bent with the tube bender in the machine shop with the appropriate dies. Due to the number of dies provided by the machine shop, the outer diameter of the tubing was limited to the following sizes: 1, 1-¼, and 1-¾ inches. The support beam and roll cage will include a tubing size with an outside diameter of 1-¾ and 1-¼ inches, respectively. To ensure the stability of the frame, the support beam and roll cage will consist of a wall thickness of 0.125 inches. Furthermore, the frame will be made of 6061 Aluminum - T6 due to its strength-to-weight ratio. The rear triangle of the frame will be implemented with a tubing size of a 0.875-inch outer diameter and a wall thickness of 0.0625 inches. Figure 18 displays the geometry of the rear triangle.

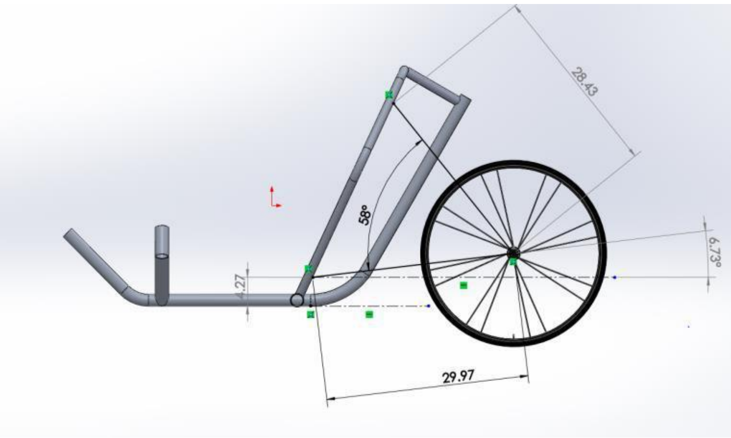


*Figure 18: Rear Triangle Geometry*

The design of the frame also impacts the steering design. The arms that lead to the kingpin are at a 35-degree angle and consist of the same cross - section of tubing as the support beam. Figure 19 demonstrates the design of the frame.

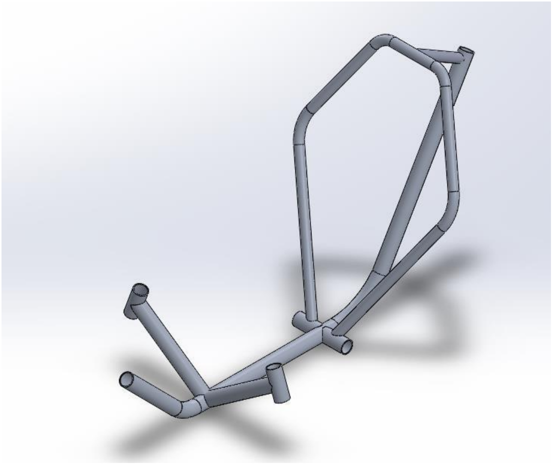


*Figure 19: Frame Design*

Preliminary analysis was done on the final design to ensure that the specifications set by the team and ASME. To perform the analysis, the software ANSYS was used where different loads were applied to the frame to evaluate the stress distribution and the locations with maximum deflection. The loads that were applied include the weight of the rider (200 lbf), force applied to pedals (24.183 lbf), side load on the Rollover Protection System (RPS) (299 lbf), and top load on the RPS (601 lbf). Figure 20 contains the deformation and stress caused by the rider. The maximum deformation that the frame experiences is 0.0067 inches and is located by where the pedals will be placed. The frame will be subjected to a maximum stress of 944.85 psi due to the weight of the rider. Figure 21 displays the deformation and stress due to the side load and top load applied to the RPS. The loads applied to the RPS induce a maximum deformation of 0.0123 inches and a maximum stress of 11,400 psi. Through this analysis, the team confirmed that the design would be stable.

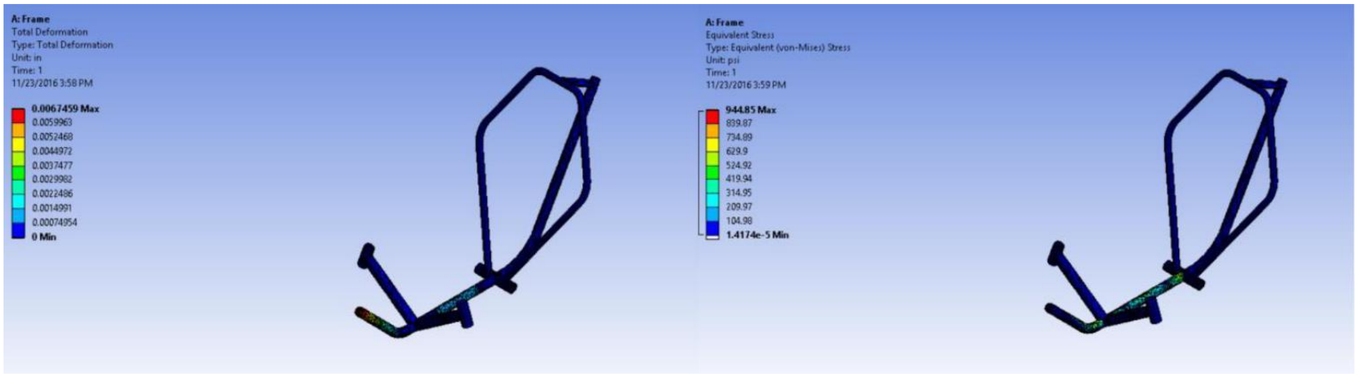


*Figure 20: Deformation and Stress Distribution Caused by Rider*

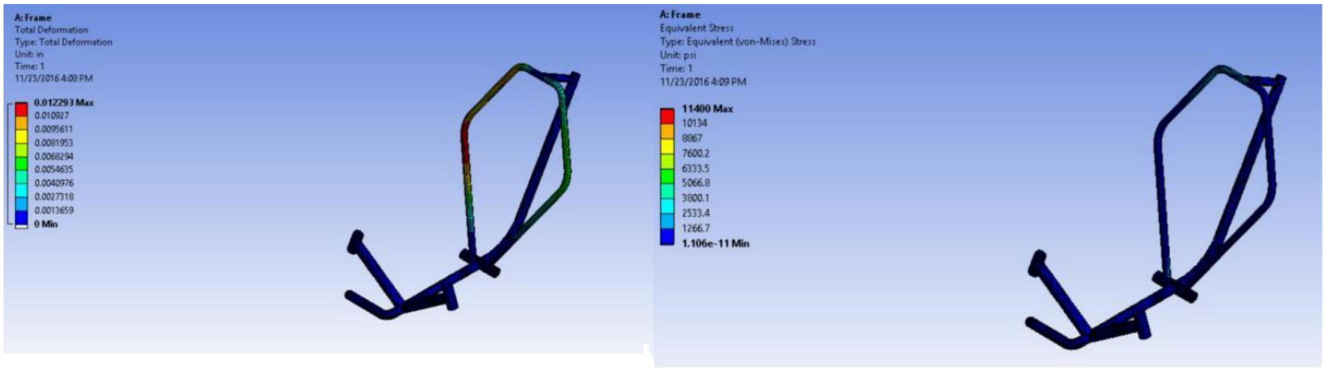


*Figure 21: Deformation and Stress Distribution Caused by Loads Applied to RPS*

## Steering

The vehicle's steering system will be a bell crank that is activated by a push and pull linkage (steering joysticks) by the driver. The joysticks will be made from the same material as the frame, 6061 heat treated aluminum, and have a cross sectional diameter of one inch with a wall thickness of one-eighth of an inch. Similarly, the steering knuckles will be made of 6061 aluminum and will be heat treated with the frame.

Preliminary analysis can be seen in Figure 22 and shows that aluminum steering knuckles will be subjected to a maximum stress of 27 MPa through a corner. Specifically, this stress corresponds to a bending moment caused by taking a 10ft radius turn at 10 mph. Since our grade of aluminum will have a minimum tensile strength of 310 MPa, the team is confident in using this material for the knuckle.

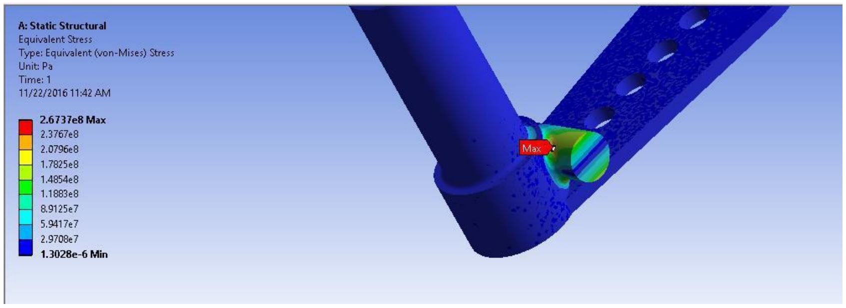


*Figure 22: Preliminary Analysis of Steering Knuckles*

The bell crank and all linkages are intended to be made out of the same 6061 aluminum, and are to be heat treated with the frame. However, finite element analysis will be performed to ensure absolute safety in using this material. If the analysis shows that aluminum is too weak for the stresses in the steering system, the affected components will be made from 4130 steel. To connect these linkages and allow flexibility in their movement, they will be attached with threaded ball joints. In this case, manufacturer specifications will be noted to ensure safety in using these parts. A full SolidWorks model can be seen in Figure 23 where they are displayed off the frame.

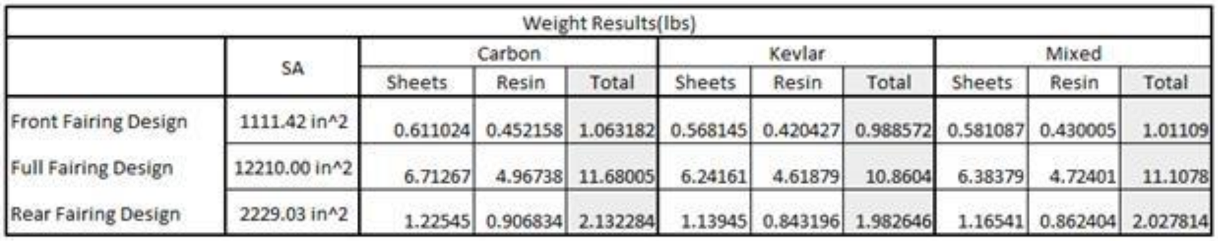
Figure 23: Full SolidWorks Model

## Fairing

The fairing will be a full fairing which will be generated by modeling an NACA Wing section or airfoil to meet the geometric properties specified upon completion of the frame. The airfoil will be modeled on a flat plate and have all sides ending in an orthogonal position to the plane in which the plate sets. This will improve the design simplicity in creating the geometry of the fairing as it will ensure symmetry as well as allow for air foil equations to be adapted for the geometry. In the design the team will be attempting to minimize pressure zones and drag on the top gradient of a foil while keeping the vehicle width and height as constraints. This foil shape will be the top down shape of the vehicle. The side shape will be less of a taper and represent more of a flat plate with filleted edges. The processes of development will be a continuing iterative process from now until late January post finalization of the frame design.

Table 4 below shows the results of weight analysis for a Front, Full, and Rear fairing design in its first iteration. From this weight analysis, the material for the fairing will be composed of primarily carbon fiber. Pre-impregnated 3k carbon fiber will be used in different layup patterns including twill and a plain weave. However, should cost need to be eliminated in the future the team will be using a wet layup instead. Based upon weight, carbon fiber will be the lightest of the three material options. One single layer of mixed carbon kevlar will be applied to the fairing. Further analysis of abrasive resistance will be necessary to decide on the exact placements of the hybrid material.

Table 4: Weight Results of Fairing



| Weight Results(lbs) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SA | Carbon | | | Kevlar | | | Mixed | | |
| | | Sheets | Resin | Total | Sheets | Resin | Total | Sheets | Resin | Total |
| Front Fairing Design | 1111.42 in^2 | 0.611024 | 0.452158 | 1.063182 | 0.568145 | 0.420427 | 0.988572 | 0.581087 | 0.430005 | 1.01109 |
| Full Fairing Design | 12210.00 in^2 | 6.71267 | 4.96738 | 11.68005 | 6.24161 | 4.61879 | 10.8604 | 6.38379 | 4.72401 | 11.1078 |
| Rear Fairing Design | 2229.03 in^2 | 1.22545 | 0.906834 | 2.132284 | 1.13945 | 0.843196 | 1.982646 | 1.16541 | 0.862404 | 2.027814 |

The first iteration seen in Figure 24 below, of full fairing was designed using lofts in SolidWorks in order to create a general geometry. Assumptions of max height and width were made in order to dimension other points of reference.

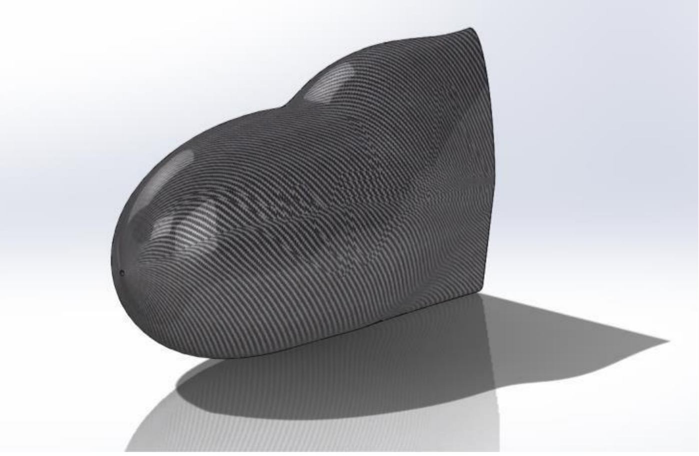


Figure 24: Fairing General Geometry

ANSYS Fluent was used to generate a coefficient of drag and visual representation of aerodynamics of the design. The velocity and pressure profiles as seen in Figure 25 below shows that abrupt change in geometry in the rear of the fairing causes a low-pressure area. Thus, the drag coefficient of .0178 will need to be re-evaluated as the value was substantially lower in comparison to predictions.

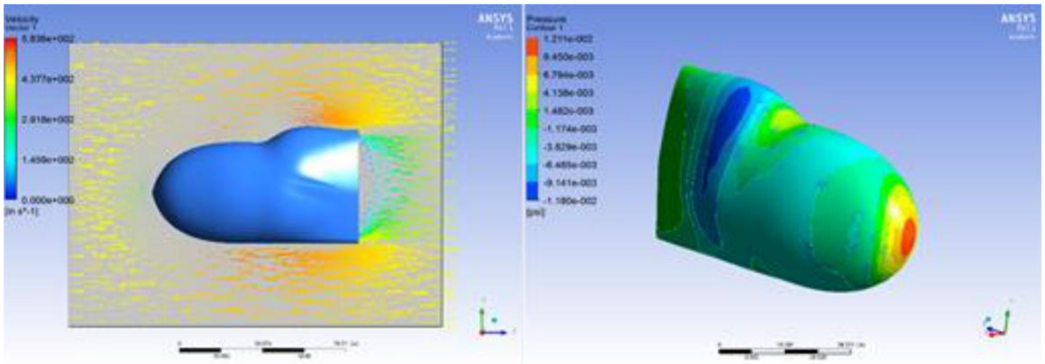


Figure 25: Change in Geometry of Fairing Causing Low Pressure Area

## Drivetrain

The drivetrain will utilize a 38-tooth asymmetric chain-ring. This chain-ring alone will improve power endurance by 10% at a cadence estimated around 90 RPMs. This can be seen in Figure 26 along with the overall percentage of power gained from using it. This 38-tooth asymmetric chain-ring also helps with muscle fatigue. In a normal pedal stroke, riders lose power on the upstroke due to the muscles not being able to produce the same amount of power as in the down stroke. In Figure 27 the muscle groups that are activated along a normal pedal stroke are shown. The asymmetric ring allows for these muscles to be used in the upstroke to effectively provide the same amount of power as the muscles in the down stroke.

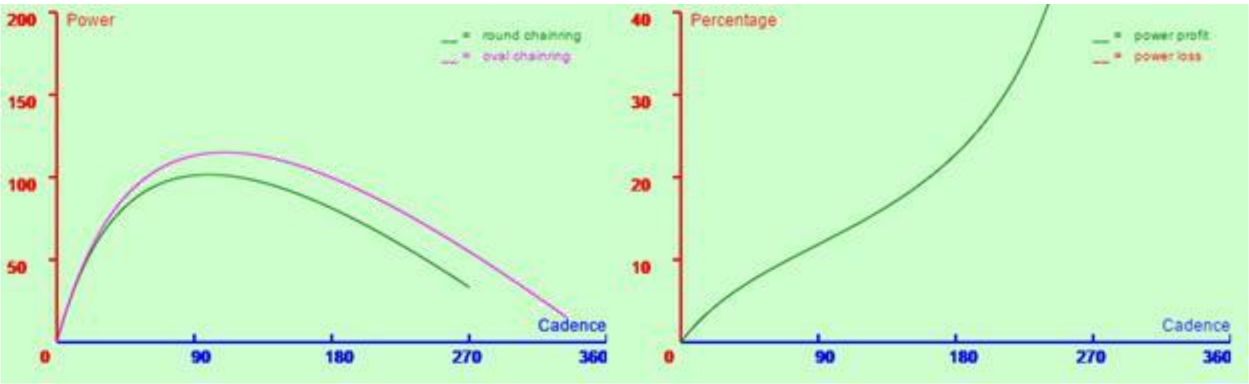


Figure 26: Improvement in Power Endurance and Percentage of Power Gained

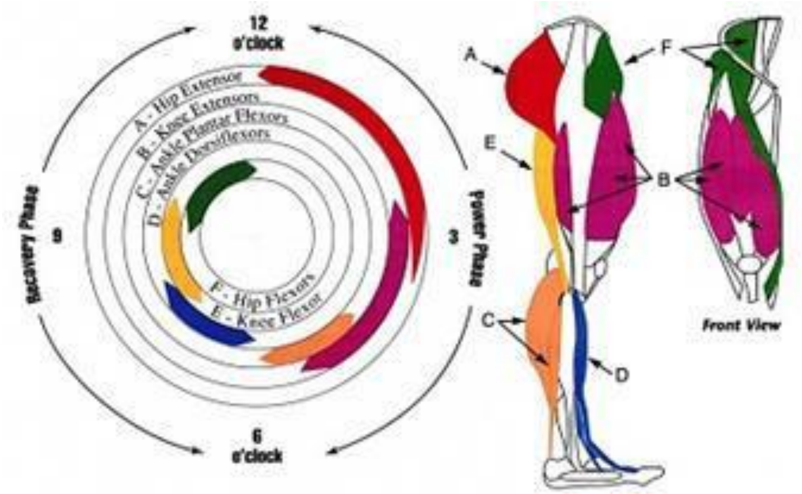


Figure 27: Muscle Groups Used

Along with the asymmetric chain-ring, the hubs that house the chain-ring will also be optimized. The hub itself will be housed within a larger hub, however, the smaller hub will be offset within the larger one and can be seen in Figure 28. The reason behind this is to enable a tensioning system within the hub that houses the chain-ring. The larger hub will sit inside the shell which is in turn welded to the frame. This larger hub will be free to rotate within this shell, and due to the offset of the small hub, when rotated, the chain-ring will either tighten the chain link system or loosen it.

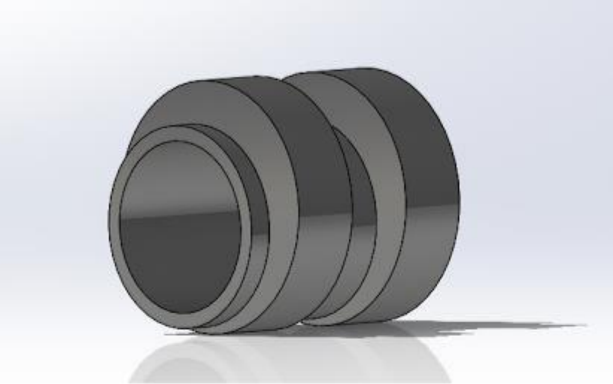


Figure 28: Hub

To incorporate the safety requirement further, the team will run the chain system through an exterior tube that runs parallel to the main frame. This guides the chain to where it needs to go, which reduces chain drop issues as well as acts as a protective measure from getting the rider's hands or feet caught in the moving chain system. Another added benefit to this is that the amount of noise the chain produces will be greatly reduced.

# 6. Proposed Design

## 6.1 Frame

The proposed design for the frame of the vehicle is a partially curved frame with a roll cage. To implement this design into the build of the vehicle, a prototype will be built to test and to which upon will be improved. The material for the prototype and final build will be purchased through Industrial Metal Supply (IMS). All the material will be notched at the appropriate angle using a notching stand or vertical mill with saw cutters. Tubes that need to be bent will be bent with the tube bender and the appropriate dies. After the tubes are fabricated to the correct dimensions, they will be welded together with a Tungsten Inert Gas (TIG) welder. Since the welding process will induce warping at the local welded areas, the frame will have to be heat treated to relieve the residual stresses and increase the strength of the aluminum. The heat treatment will be provided by Phoenix Heat Treatment. Also, a jig will have to be built to ensure that the frame will not warp during the heat treatment process. After heat treatment, alignment of the frame will be evaluated with a dial and flat surface. The cost of materials and processes can be found in Table 5.

*Table 5: Bill of Materials for Frame*

| ***Material Overview*** | | | | |
|---|---|---|---|---|
| **Product** | **Description** | **Vendor** | **Price** | **Quantity** |
| 1.75" OD x 0.125" x 8' L 6061 - T6 Aluminum | Support Beam | IMS | $50.66 | 1 |
| 1.75" OD x 0.125" x 4' L 6061 - T6 Aluminum | Steering Arms | IMS | $25.33 | 1 |
| 1.25" OD x 0.125" x 12' L 6061 - T6 Aluminum | Roll Cage | IMS | $64.96 | 1 |
| 0.875" OD x 0.065" x 6' L 6061 - T6 Aluminum | Rear Triangle | IMS | $30.00 | 1 |
| Dropouts | Dropouts | Nova-Cycles | $23.00 | 2 |
| Test Material and Prototype | Testing | IMS | $300.00 | N/A |
| Jig | Fixturing | IMS | $200.00 | N/A |
| Heat Treatment | Heat Treatment | Phoenix Heat Treating | $1,000.00 | N/A |
| Total | | | $1,693.95 | |

## 6.2 Ergonomics

The proposed design for ergonomics is a seat with an angle of 120 degrees. The seat will be adjustable for different rider lengths. Possible designs for this would be to buy a prefabricated seat. Another design would be to create one in the machine shop using fiberglass or carbon fiber. The adjustability will be done using clamps which can lock down once the seat is moved forward or backwards to the desired positions.

## 6.3 Steering

The proposed design for steering is a bell crank that is to be activated by joysticks in a push/pull motion. The way this system will be integrated into the overall design is by means of a headset typically used in bicycles with the addition of the steering knuckle to turn the wheels. To connect the steering to the frame, a press fit bearing will be installed in the bell crank and will then be bolted onto a protruding mount on the frame's primary member.

The resources needed for this design will be a vertical mill, lathe, a material supplier, heat treating supplier, and a hardware supplier. The team plans to source material from IMS, hardware from McMaster.com, heat treating through Phoenix Heat Treatment, and the vertical mill and lathe from the machine shop.

The tasks to implement this design with the frame are: constructed of machined components, take measurements based on frame components, cut tie rod linkages, and install ball joints. Next, the team must install the bearing and bell crank, install the star nut in the knuckle, and install the steering knuckle. Associated costs, sponsorship discounts, and remaining budget can be found in Appendix D.

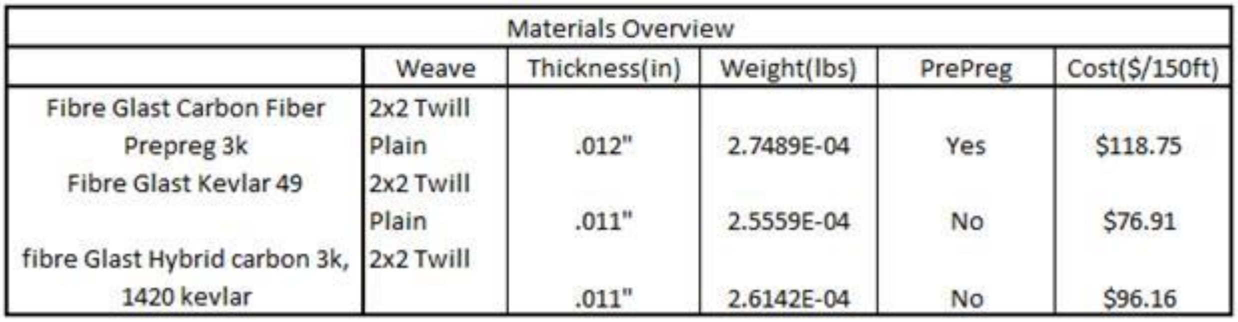
## 6.4 Fairing

In order to implement this design with its predecessors, including the frame and ergonomic aspects of the vehicle, final geometries will have to be identified. Once final geometries are approved, an airfoil equation will be used to maximize aerodynamic efficiency. Egress points will be inserted in the side of the vehicle and a door with an Abloy style lock will be used to ensure security. Mounting points to the vehicle and final installing actions will be planned. The current state of the mold type will distinguish how the fairing is assembled. The windscreens will be made of formed thermoplastic supplied from Prent located in Flagstaff, Arizona. Further development of the windshield will be necessary for the innovation portion of the vehicle as possible photochromic properties are currently in development.

Material will be obtained by MC Gill Corporation. The initial steps of construction will be to create a foam plug from printed sheets of the geometry. Then the team will have the plug finished and painted in order to create the proper mold. Creation of the mold will take place at Nova Kinetics. It is currently under discussion if using an oven for curing prepreg will be capable or cost effective.

Cost will be going mostly into foam, resin, body filler, and matrix material should the team be unable to get it donated. During the analysis of weight, cost was also considered. The unit cost of different materials can be seen in Table 6 below. Prepreg material cost already considers resin cost as heat is only applied to the material while the Kevlar and hybrid materials would require another purchase of resin.

*Table 6: Fairing Bill of Materials*



| Materials Overview | | | | | |
|---|---|---|---|---|---|
| | Weave | Thickness(in) | Weight(lbs) | PrePreg | Cost($/150ft) |
| Fibre Glast Carbon Fiber Prepreg 3k | 2x2 Twill<br>Plain | .012" | 2.7489E-04 | Yes | $118.75 |
| Fibre Glast Kevlar 49 | 2x2 Twill<br>Plain | .011" | 2.5559E-04 | No | $76.91 |
| fibre Glast Hybrid carbon 3k, 1420 kevlar | 2x2 Twill | .011" | 2.6142E-04 | No | $96.16 |

## 6.5 Drivetrain

The proposed design for the drivetrain is implementing an asymmetric chain-ring with a tooth count of 38-teeth. The rear cassette that drives the rear wheel will be a 11x28 cassette with 11 rings altogether. An idler gear was placed midway through the chain link system to properly tension the chain as well as reduce the amount of chain drop issues. Adjustable hubs combined with the idler system will aid in the correct amount of tension throughout the bike and will also reduce the amount of chain drop issues.

# 7. Implementation

## 7.1 DOE

Optimal Rider Seat Angle

Optimal rider position is needed for rider efficiency. This varies from the rider angle, position, comfortability, as well as visibility through the front windshield. With the entire team riding the vehicle a test was needed to see if there was an optimal angle for each individual rider or a single angle for the entire team. Each member participated in the test for this experiment.

To optimize the rider position each member was measured to find the optimal distance the seat was needed to be from the pedals. To determine which seat angle was to be used, each team member tested different seat angles ranging from 90 to 150 degrees at ten degree increments up to 130 and a twenty degree increment to 150. Keeping a constant cadence for every angle was used as a control variable to see power efficiency. Then a statistical analysis was done with the data in order to find the average power at each angle. The reason for this test was to see which angle provided the highest power while keeping a constant cadence. The angle or angles with the highest power are the optimal rider angles.

From the statistics found the both the 120 and 130 degree rider angle was found to be the most efficient in terms of power with the same cadence. When looking at the other factors such as comfortability and rider visibility. Both angles were comfortable for every member leaving visibility the final deciding factor. An angle of 120 degrees was chosen as it had the best visibility for every rider.  As for the rider position the distance for the seat differed for different operators with a change of distance of 4 inches.

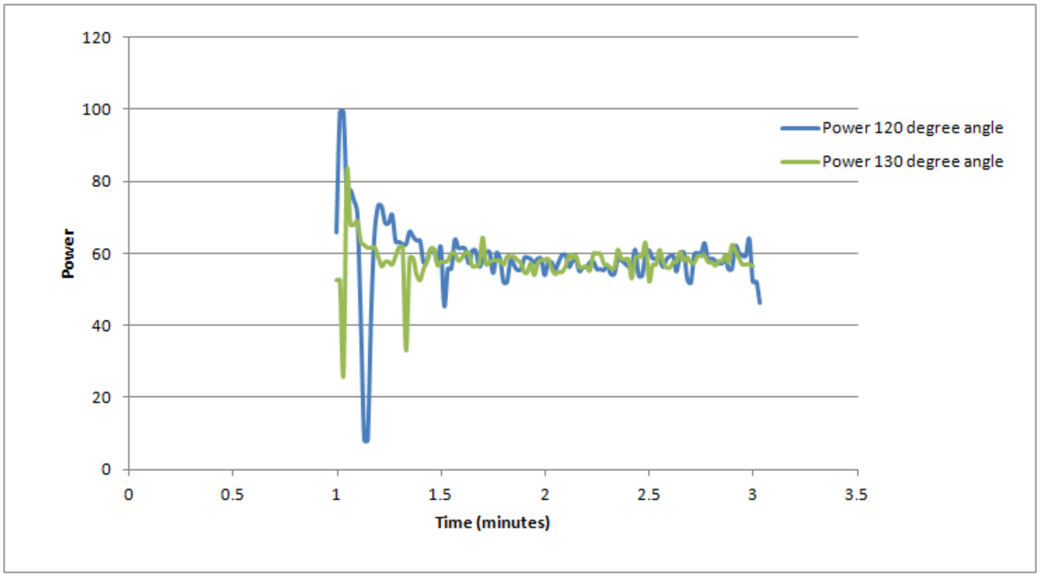


*Figure 29: Comparison of Produced Power for 120 and 130 degree Seat Angle*

From the results the seat was made with a 120 degree angle found. Implementing the different distances from the seat to the pedals meant an adjustable seat along the primary member. This meant the seat must be able to slide forward and back depending on the rider. With the seat movable, a stabilizing system was added in order to keep the seat from tilting from side to side and keep it in plane with the pedals.

## 7.2 Manufacturing

Manufacturing is part of the engineering process that implements raw materials, engineering design, and machining and/or treating to successfully complete a part. This process usually involves prototyping phases and should also allot time for multiple iterations. Looking at the manufacturing process that the HPVC underwent, these characteristics can be seen. Parts such as the bell crank, tie rods, steering levers and knuckles are all individual parts, however when combined, become part of a system; known as the steering system. Although the steering system is considered one aspect of the vehicle, it is important to note that this system is made entirely of parts which each underwent their own manufacturing process. Multiple systems live within the HPVC and below their manufacturing processes, along with specific machines used can be seen in detail. The bill of materials for each section of the vehicle can be found in Appendix E.

### Frame

One of the most important aspects of the HPV is the vehicle's frame. Providing structural support, safety through the RPS (Roll Protection System), and maintaining sound mounting points for all components, it was detrimental that the frame yielded little error. Using 6061 - T6 aluminum tubing, the frames main boom, which supports the RPS and rear triangle, was bent to specification using a manual tube bender. Utilizing the same tube bender the RPS cage was bent and mocked up to the main boom to ensure the correct fit. Following, the main supports, which attach the RPS to the main boom, were welded.

Once the main boom, and RPS system were successfully welded together, the rear triangle was manufactured. The rear triangle consists of two chain stays, two dropouts and two seat stays. These were all welded together to create the rear triangle. Lower bracket shells were machined on a lathe and then set screws were drilled and tapped within each shell. These were welded to the the front of the main boom to develop the housings for the lower brackets and primary and secondary cranks. A housing for the bellcrank was welded at the specific length, which was measured from the secondary lower bracket shell. Finally the arms where the steering knuckles and wheels would attach were cut and welded together. These arms housed the steering knuckles and were latter welded to the main boom. Gussets were added to increase strength in high stress concentrated areas.

To connect the aluminum tubing, as well as lower bracket shells and arms together, a method known as coping or notching was implemented. This process allows for circular tubing to sit flush against one another by cutting a concave cut from the piece of tube. All angles, lengths of tubing and diameter tubing specifications were gathered from the design portion of the project. Once the frame was completed it underwent a process known as heat treating. Heat treatment involves the use of heating or cooling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material. The frame is prone to warping due to being in the annealed state at high temperatures. Therefore, a steel jig was made to ensure the frame does not undergo high deformation.

The jig consisted of steel angle iron wrapped around the frame and steel beams that were welded to the angle iron to allow minimum deflection on the frame. Steel was used for this jig because it can withstand higher temperatures than the aluminum and would not warp during the heat-treating process. After the heat-treating jig was complete, the frame was taken to get heat treated. The frame went inside an oven that was heated at 948°F for 130 minutes to achieve an annealed state for the aluminum. After being in the annealed state, the frame was dumped into a quenching tank that contained a water solution within 7 seconds of being out of the oven. The quenching process hardened the aluminum and then the frame was put into a tempering oven at 400°F for 6 hours to reach a hardness specification of T6.

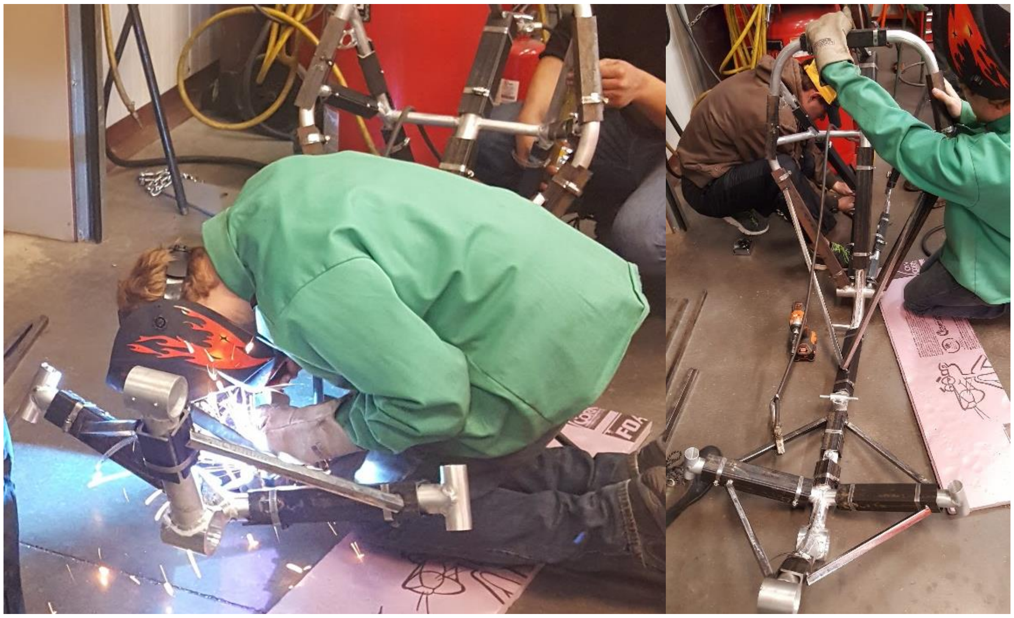


*Figure 30: Preparation of Frame for Heat Treatment*

## Steering

Stability and maneuverability both come from a well built and well-designed steering system. To implement what our team has designed, specific manufacturing processes were taken into consideration. The steering system, as mentioned before, is comprised of tie rods, a bell crank, steering levers and knuckles.

Starting from the top down, the steering levers were manufactured from square and cylindrical aluminum tubing. The tubing was cut using a horizontal band saw and then manually milled down to acquire the specific length. The square tubing was notched to accept the cylindrical tubing and then welded together, then bolted onto the frame with thrust bearings to allow for rotation. The bell crank was CNC milled out of a block of aluminum and mounted to the frame, and thrust bearings were added to allow for rotation of the bell crank. The steering knuckles underwent various processes to arrive at the final part. The steering knuckles themselves are comprised of multiple parts welded together. First the axials, which slide into the hub of the wheels, were machined on a lathe for precision. This was then joined with the lower portion of the steering knuckle, which both slides into the arms of the vehicle and has been machined to allow for adjustment within the steering. This section of the knuckle was CNC milled along with the brake mounts which slide over the axials and onto a sleeve which is where the brake mount is welded. To connect the system together tie rods were manufactured on a lathe at specific length to allow for adjustability and maneuverability within the vehicle's steering.

## Ergonomics

Providing a comfortable and efficient pedal stroke is the job of the seat. Without an adjustable seat position our team would not have been able to effectively fit a 65 inch individual up to a 75 inch individual. Manufacturing of the seat mounts took place on the manual mills. Two parts were created, the first being was the main boom mount. This was machined out of an aluminum block and was mounted by nuts and bolts. The second was the slide mount which attached directly to the main boom mount and the seat. Due to the adjustability within the slide mount our team was able to achieve the suitable range required.

## Drivetrain

Delivering power from the main cranks, through the idler gears, and to the rear cassette is the main problem solved by the drivetrain. Comprised of components purchased from SRAM, cranks, cassette, and rear derailleur, the focus was to deliver power efficiently with a simplistic design. To do this, multiple parts were manufactured in house to aid in this goal. Eccentric lower brackets were machined with the help of a lathe, which fit into the lower bracket shells previously mentioned in the frame section.

Following this, idler gear mounts were CNC milled to fit onto the idler gear shaft. Bearings were press-fit into the allotted space to allow for rotation of these mounts. Detrimental to the vehicle a chain guard was developed using a manual mill to eliminate chain drop issues. Set screws were implemented by drilling and tapping two holes to allow the part to mount to the shaft. At the rear of the vehicle custom dropout mounts were added to mount the derailleur. This was done by modifying the existing dropout mount by filling it down to the correct size and dimensions.

*Figure 31: Chain Guard*

## Fairing

Manufacturing of the fairing began with the solid modeling of the final shape. Once dimensions were finalized, large 72-inch-long cross sectional plots were printed showing each cross section at 2 inch intervals of the model. These plots were placed on a high density shaping foam that featured alignment rods down the center. Once each of the 20 cross sections were cut out they were adhered and stacked to form one large rough shape model.

Extensive shaping was done to this pattern using tools such as a cheese grater and sand paper. Once the final shape was achieved, fiberglass sheet was applied to the outermost surface. This allowed for a rigid surface to apply body filler for the more precise shaping process. Once the fiberglass cured it was sanded smooth and then body filler application began. Although lengthy, this process underwent much sanding and shaping until the first urethane primer coat was applied. Upon second preparation of the primer coat a final top coat paint was applied to give a smooth finish. This pattern was the basis for the construction of the mold.

Construction of the mold began by separating the pattern into two symmetrical sides. This was done by building what is known as a bridge in the composites tooling industry. The bridge serves as a boundary for the fiberglass to give a meshing surface to the second side. It is also a platform for means of alignment pins and pry bars may be used. Once the bridge was constructed, the pattern underwent extensive coats of release wax. Next in two separate stages, GELcoat and fiberglass were stacked to build a thick mold. This mold is what was used to construct the final parts.

The final carbon fiber parts began by prepping the mold. Wax tape was placed in all of the window and door seams go give door seats and trim lines. Two separate layups were done on each mold to obtain all needed pieces for the project. Lay up one included the main body of the vehicle. This was done in a wet layup procedure, followed by a compression vacuum bag to pull the excess air bubbles in the piece.

Once all of the pieces were cured, they were removed from the mold using separation wedges. Farther cleaning and post processing of the parts included trimming to size specifications as well as cleaning the exterior surface of wax residue.

Bonding of fairing was done by placing parts back into the mold and using a spreader to hold them in place. Strips of saturated carbon fiber were placed along the seam bonding it in place. Once cured the mold was removed giving one solid piece. The fairing was then fitted to the vehicle by deconstructing and reconstructing the vehicle within the fairing. The fairing was bonded to the frame permanently using saturated strip of carbon as well.

The door was fitted and equipped using commercial grade velcro. The windows were set using a clear tape. Electrical components were installed using a speed bond adhesive and fishing the wires through a small hole drilled in various locations.

*Figure 32: Fairing Removal from Mold*

## Innovation

Implementing an innovation aspect into the vehicle is weighed heavily in the design portion of the competition. After our choice to incorporate an electrochromic windscreen both for safety and anti-theft, the team found creating an inverter was truly challenging. The first iteration of developing an inverter was manufactured on-top of a copper coated plate. Connections between wiring components were milled out to create a slot for solder to sit in. Holes were drilled for fuses, capacitors, amps, transformer, and resistors to sit in, as well as a potentiometer. After this inverter failed the team went back to the drawing board to create a rough voltage step down inverter by hardwiring a potentiometer in conjunction with various resistors and capacitors. From this we learned that an in-house solution was not going to be feasible. A solution to this is where a store-bought inverted was modified with an inline fuse to allow for the correct voltage to power the electrochromic windscreen.

To add to aesthetic value to the vehicle a wiring harness was created. This allowed the vehicle to have overhead lighting, fans, front and rear lights as well as turning signals. A 3-D printed junction box was designed and printed with the use of ABS plastic. This junction box splices in all wiring connections to switches, which controls each aspect of the vehicle. An ignition switch and key was implemented to power the electrochromic windscreen. This is where the main power of the 12 V DC battery was plugged into. The inverter, in line with the 12 V DC power and ignition switch, converted the power to AC, once turned on, to allow the windscreen to function properly. To mount the windscreen velcro was placed around the inside of the front window. This allowed the windscreen to be removed if necessary.

*Figure 33: Manufactured Inverter*

*Figure 34: Modified Inverter*

## Final Vehicle

A comparison of the SolidWorks final vehicle and the manufactured final vehicle, both with and without the fairing, is shown below in Figures 35 and 36. The SolidWorks assembly of the vehicle experienced technical issues when inserting the wheels and so there is only one front wheel shown.

*Figure 35: SolidWorks Model of Vehicle (With and Without Fairing)*

*Figure 36: Actual Vehicle (With and Without Fairing)*

As it can be seen in these figures, there are few differences between the SolidWorks model and the manufactured vehicle. As with any manufacturing, every part has dimensional tolerances and so the sizes and positions of items are not exact like in the model.

# 8. Testing

Several types of testing were performed to ensure the chosen designs would suffice for the competition and also met or exceeded customer requirements. The testing included utilizing a wind tunnel to test aerodynamics, testing how much the frame deformed under certain loading conditions, as well as multiple performance testing of the final vehicle.

## 8.1 Aerodynamic

The fairing underwent wind tunnel testing to ensure the accuracy of the computer modeling. These tests were to ensure proper aerodynamic coefficient of drag. The test was conducted by printing a 1:12 scale model using a Fortus 250 3D printer. The material is ABS Plastic, printed with three internal contours. The surface was sanded to 600 grit sandpaper giving it a smooth surface. Upon construction of the model a test was developed for the wind tunnel.

Pressure and density were calculated based on the pressure of the test day. These values allowed us to fin similarities in Reynolds number thus scaling the needed velocity to mimic a full scale test at 15 MPH. This reynolds number corresponded to a wind speed of 120 MPH to achieve an accurate test.

The setup was attached to a sting balance which measured axial force. This axial force directly corresponded to the force which contributed to drag. The symmetrical shape of the foil allowed us to neglect lift in other directions.

As shown in Figure __ below a smoke stream was used to visualize the flow velocity over the model. It appeared to follow similar dynamics to the analysis results with a pressure drop and turbulent boundary developing near the rear of the vehicle.

*Figure 37: Wind Tunnel Testing*

Possible concerns and errors within this test included correlation of surface roughness in the model. It is believed that the model was too smooth thus the skin drag was inaccurately represented. Other sources of error may have included boundary walls and their effects on pressure within the control volume. Infinitely large space would yield optimal results however due to the constraints of the machine the test needed to maximize model size. Any smaller of a model and the tunnel speed would have surpassed the capabilities of the machine. Thus the boundary may have caused a different turbulence pattern in the vehicle with improper speed. This is suspected as the tunnel was ran to 96% speed with a model and without, yielding a variation in nearly .05 in of water measured from our pitot tube.

In conclusion to the test the 1:12 scale model yielded a coefficient of drag of .06. The analysis yielded 1.3. The errors described above are thought to have had effect on the results. Two iterations of the test were completed. The visual smoke stream showed a pressure drop in the top rear region of the vehicle with increased effects as velocity increased. The testing proved that the vehicle would perform within approximately 30% of analysis results. This provided sufficient for the team.

## 8.2 Rollover Protection System

Through the specifications given by the competition sponsor, ASME, the rollover protection system had to be physically tested. ASME provided the required loads and orientations that had to be applied to the RPS, which can be seen in Figure _. The testing consisted of applying a load of 2670 N (601 lbf) 12 degrees from vertical on the top of the RPS and a load of 1330 N (299 lbf) to the side of the RPS. The RPS was only allowed to deform 5.1 cm (2.008 in.) and 3.8 cm (1.496 in.) due to the top and side load, respectively.

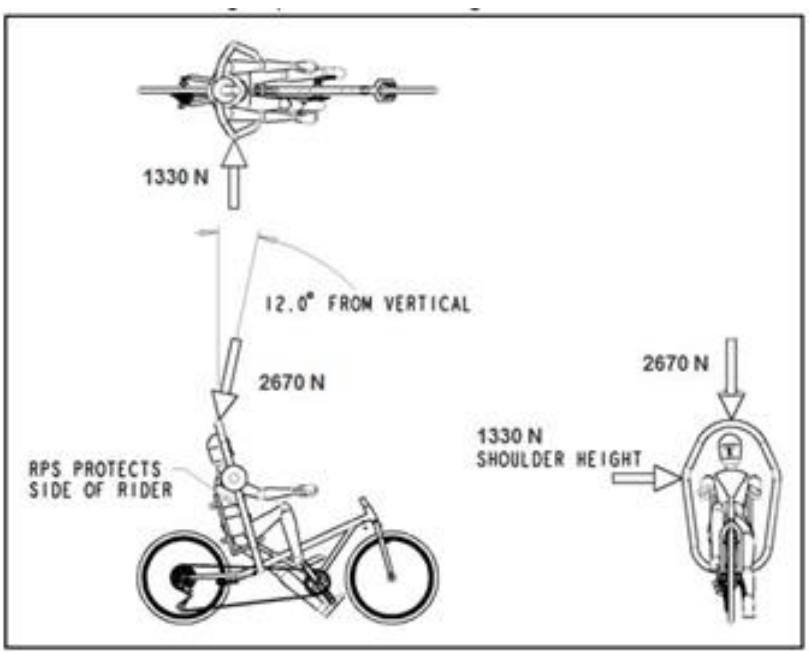


*Figure 38: Specified Loads and Orientations from ASME*

With the loads given to us, we created a testing jig that could provide the proper orientations. A base steel plate and angled steel jig were used by the 2013 HPVC team. The angled steel jig corresponded to the same angle that was needed for our testing phase, but the jig was built for 1.50 in. tubing. Therefore, the team used the manual mill to open up the steel jig to be able to fit 1.75 in tubing. This steel jig allowed for the frame to be angled to the correct orientation for the top load setup. A testing jig that would allow for a top load and side load was created from steel material. The jig consists of holes that allow for a load cell to be mounted with a threaded rod and slots that allow for the correct height needed to fit the necessary equipment to apply the loads. This jig is bolted onto two steel plates that ensure that it is level with the steel base plate. To allow for minimum movement of the jig, it was bolted to the steel base plate with a steel plate that has slots to allow for adjustability. After completing the testing jig, the frame was ready for testing.

The testing setup consisted of the testing jig, 5 kip load cell, 5 kip hydraulic ram, wooden block, and string. As shown in Figures _ and _, the wooden block uniformly distributes the load onto the frame at the correct locations and the load cell measures the loading applied by the hydraulic ram. The green steel structural frame shown in the figures was used as a reactant to the applied forces. For the side load setup, tie downs were wrapped around the structural frame and the testing jig to act as a reactant. The top load reactant consisted of an angle iron wedged in between the testing jig and steel frame. Applying the reactants ensures that the hydraulic ram is applying a load to the frame. To ensure the team was applying the proper loads, an LED display was connected to the load cell. To measure the deformation, string was tensely tied in the direction of the load. A sharpie mark was applied on the string where the wooden block was located without and with a load applied. The difference in length was measured with a measuring caliper, which had an accuracy of 0.0001 in. The results of the RPS test are shown in Table _.

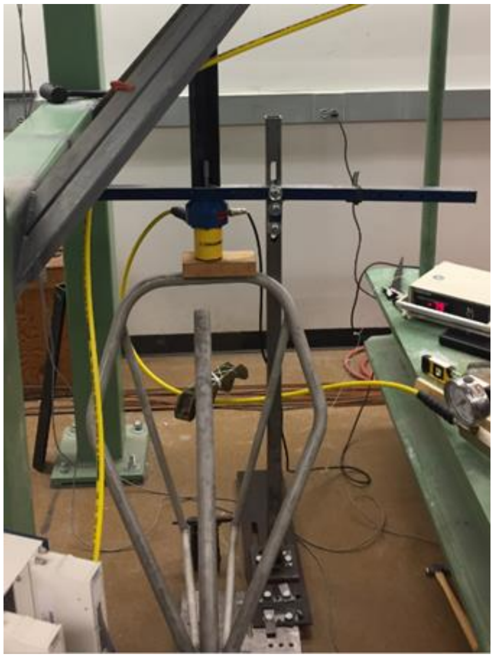


*Figure 39: RPS Top Load Setup*

*Figure 40: RPS Side Load Setup*

Table 7: Results of RPS Tests

| Test Setup | Load Applied (lbf) | Deformation (in.) |
|---|---|---|
| **Top Load** | 605 | 0.201 |
| **Side Load** | 324 | 0.321 |

## 8.3 Performance

Once the vehicle was able to be driven, its performance was tested to determine if objectives had been met. The criteria tested were of the steering, drivetrain, and braking system. The results of the testing can be seen if Table __.

Table 8: Performance Testing Outline

| Test Performed | Requirement | Outcome |
|---|---|---|
| **Turning Radius** | 10 ft. | 13 ft. |
| **Top Speed Achieved by Team** | 40 MPH | 30.1 MPH |
| **Stopping Distance** | 20 ft. | 3 ft. |
| **Stability** | Travel in a straight line at low speeds | Yes |
| **Protect Rider** | Yes | Yes |

While the steering system did not perform with a 10 foot turn radius all the time, the system is capable of achieving this with a sacrifice made to overall maneuverability and added stress that the team felt were unnecessary. To test the turn radius, a mark was made on the surface where the wheel began the turn. Another mark was made where the tire stopped turning after executing a 180 degree turn. The distance between marks determines the vehicle's turn radius.

The drivetrain system is also capable of producing the power to propel the vehicle at 40 MPH but is severely dependent on rider fitness and experience. This was analyzed by measuring the average cadence performed by a human. This cadence coupled with the gearing on our bike shows that it would be possible to reach 40 MPH with this vehicle.

Similar to the steering system, the braking system was tested once the vehicle was able to drive. Stopping distance was measured by the driver propelling the vehicle to 15 MPH and begin applying the brake at a designated area. The distance that the vehicle traveled after this area until it is stopped is the braking distance. Since the braking distance was 3 ft, the team felt it had excelled in this objective.

Testing stability was of ease to this vehicle since it is three wheeled and stable on its own. For this reason, the ASME designated objective was deemed as a pass.

Similarly, ASME required that the frame be tested for top and side loads to protect the driver in the case of a roll over. This was done by manufacturing a plate that acted as a ground support. This is where the frame was held at 12 degrees. Next, a hydraulic ram was wedged on top of the top beam of the roll protection system (RPS). This applies a vertical load and was found to greatly surpass ASME requirements. Likewise for testing the side load, a hydraulic ram was wedged between the outermost bend in the RPS and the testing frame to apply side loading. This was also found to greatly surpass ASME requirements.

Through testing, the team felt that the vehicle performed well and capable of being a reliable form of transportation in third world countries.

## 8.4 Remaining Requirements

Several of the customer requirements did not require formal testing as they simply passed or failed. These requirements are presented below in Table __ along with their outcomes.

Table 9: Remaining Customer Requirements Outcomes

| Requirement | Outcome | Pass or Fail |
|---|---|---|
| **Weight < 90 lbs** | 72 lbs | Pass |
| **Width** | 27.25 in. | Pass |
| **Frame Length < 65 in.** | 54.21 in. | Pass |
| **Fit Rider Heights (65 – 75 in.)** | Yes | Pass |

All of these requirements were met and/or exceed in most cases. This is due to the constant consideration of the requirements during the manufacturing stages and minimizing weight in certain componentry.

# 9. Conclusions

## 9.1 Contributing to Project Success

### Team Charter

As stated in the Team Charter, the team's purpose included placing in the top three at the competition and "to have fun and learn throughout the design and build process." Throughout the duration of the project, the team has maintained having some element of fun present during every process. As the team members have become closer through this project, there are no conversations that do not include some sort of joke. Multiple team members became more acquainted with the machinery in the machine shop while the others learned how to better collaborate.

The Team Charter also discusses the team goals which include the aforementioned purpose of winning the competition, which was not completely achieved as the team placed 6th overall. However, the team did place 3rrd in the design portion of the competition so the work done is still a success in this aspect.  The vehicle is capable of outperforming past NAU vehicles but this has not been verified as no testing was performed to determine this. The team also desired to have a reliable scheduling process and track its productivity efficiently. To achieve this goal, the team used the Gantt Chart program to schedule when tasks should be completed. Using the Gantt Chart was mostly successful as it kept the team organized but once the competition dates had been released, the team had to work much harder and more quickly to account for the loss of time.

Ground rules determined in the Team Charter were based on meeting procedures and the meeting location. Team meetings were to be held every Tuesday at six o'clock P.M. at the NAU machine shop as this time worked the best for all team member's schedules. There were few exceptions when this time did not work for some members and so another meeting was scheduled during the week in this case. Besides the few exceptions, this ground rule was followed successfully.

Each meeting was to begin with an update of the schedule and then the team would move onto the items included within the agenda. All decisions would be voted upon where a 75% majority was needed to be chosen. If there were dissenting views, the team would discuss and vote upon these as well. The use of peer evaluations is how team members were to be held accountable for their designated tasks. Most team decisions did not require a vote as usually every team member agreed with the proposed motion. As all team members were completed their tasks in a timely manner, no specific team member needed to have a discussion with the rest of the team about their performance.

The only barriers faced by the team were scheduling issues and team member's workloads. Team members notified the rest of the team if they had any specific scheduling conflict or workload issues prior to the scheduled team meetings so this was not a problem at any time.

## Positive Project Performance

The most positive project performance aspects for this team included time management, product quality, and presentation/report work. As already discussed, the team stayed on top of the schedule even after the competition dates affected the pace. The team's time management was positive aspect as if there was a task needing completion, team members would stay as long as possible during the weekly meetings until it was finished. Product quality was a positive aspect because the team performed preliminary testing within the machine shop to ensure the best materials and designs were used leading to the creation of a successful competition vehicle. Finally, all presentation/report work was discussed usually at least a week before their respective due dates. All reports and presentations received full marks showing how successful the system was.

Certain tools, methodologies and practices contributed to positive aspects of the team's performance. Google Docs and Slides was helpful in the creation of all the reports and presentations as the team did not have to meet in order to complete their assigned sections. The use of decision matrices to determine which designs to attempt was successful as it has led to the team creating a vehicle that beats past NAU vehicle specifications. By meeting up every week at the same time in the same location, the team stayed up to date on all assignments for the class as well as the actual competition.

## 9.2 Opportunities for Improvement

### Negative Project Performance

The most negative aspect of project performance was team communication. While the team communicated when they had scheduling conflicts or overwhelming workloads, other areas of communication fell short. For example, one team member would misinterpret what another had said leading to several cases of confusion as to what was expected of them. This did not affect the team's performance terribly, but it did consume valuable project time to mend the situation explaining the misinterpretation. The team did improve upon this by fully explaining any confusing matters during the remainder of the project.

The team encountered problems once the competition dates were released as the schedule had to be condensed. With the competition scheduled for March 17-19, the team essentially lost almost two months' worth of time. This loss of time meant all competition deadlines had been moved up leading to the team scrambling to complete construction of the vehicle. Five of the six team members were available to work over the school's winter break which greatly helped in completing the vehicle on time.

Another problem the team faced was issues with certain software use on the school computers. Creating the required capstone website was difficult to begin as the instruction guide was confusing. Other software issues include using ANSYS to perform simulations. The school computers would often crash when certain mesh sizes were attempted to be used. These large mesh sizes were needed for the most accurate simulation results otherwise the team would have used smaller meshes. All software issues were resolved after some time, but it did create stress for the team members.

### Specific Improvements to Make

A specific organizational action that can be taken to improve performance would be the use of a different messaging system. The team used a group text to convey general information to all members. As there are several types of phones and service providers within the group text, some members did not receive the information as quickly as others. Sometimes the information did not go through at all and created confusion at times.

All members gained some sort of specific technical knowledge. These skills included manufacturing knowledge, hardware assembly, the use of electrical diagrams, project management, composites knowledge, and material properties knowledge. This knowledge was gained through the constant involvement of all team members throughout the project. As a whole, the team learned how to better manage their time and how to efficiently use their free time to work on any aspect of the project.

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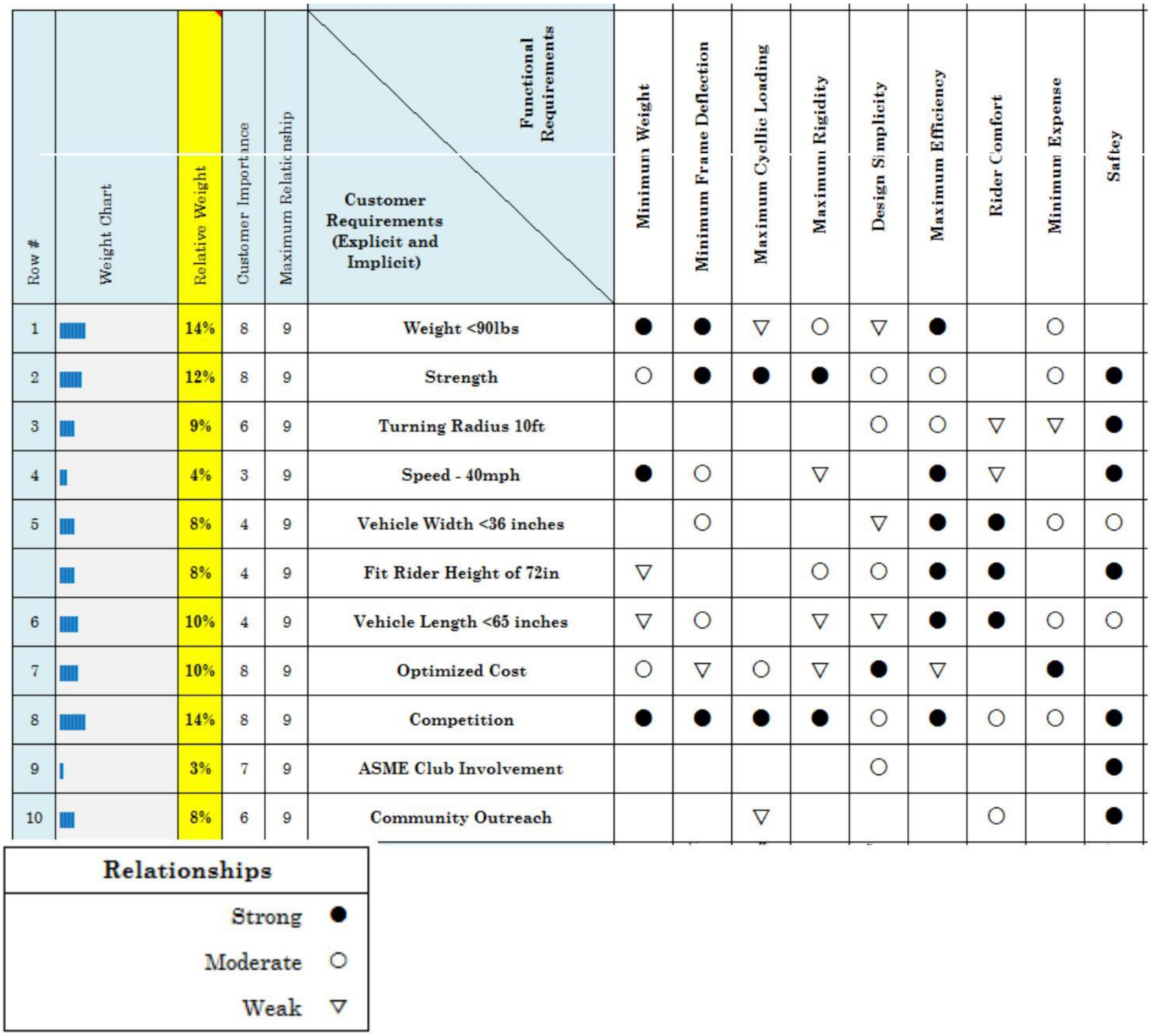
# APPENDICES

## Appendix A



| Row # | Weight Chart | Relative Weight | Customer Importance | Maximum Relationship | Functional Requirements<br>Customer Requirements (Explicit and Implicit) | Minimum Weight | Minimum Frame Deflection | Maximum Cyellic Loading | Maximum Rigidity | Design Simplicity | Maximum Efficiency | Rider Comfort | Minimum Expense | Saftey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ▮▮▮▮▮ | 14% | 8 | 9 | Weight <90lbs | ● | ● | ▽ | ○ | ▽ | ● |  | ○ |  |
| 2 | ▮▮▮▮ | 12% | 8 | 9 | Strength | ○ | ● | ● | ● | ○ | ○ |  | ○ | ● |
| 3 | ▮▮▮ | 9% | 6 | 9 | Turning Radius 10ft |  |  |  |  | ○ | ○ | ▽ | ▽ | ● |
| 4 | ▮ | 4% | 3 | 9 | Speed - 40mph | ● | ○ |  | ▽ |  | ● | ▽ |  | ● |
| 5 | ▮▮▮ | 8% | 4 | 9 | Vehicle Width <36 inches |  | ○ |  |  | ▽ | ● | ● | ○ | ○ |
|  | ▮▮▮ | 8% | 4 | 9 | Fit Rider Height of 72in | ▽ |  |  | ○ | ○ | ● | ● |  | ● |
| 6 | ▮▮▮ | 10% | 4 | 9 | Vehicle Length <65 inches | ▽ | ○ |  | ▽ | ▽ | ● | ● | ○ | ○ |
| 7 | ▮▮▮ | 10% | 8 | 9 | Optimized Cost | ○ | ▽ | ○ | ▽ | ● | ▽ |  | ● |  |
| 8 | ▮▮▮▮▮ | 14% | 8 | 9 | Competition | ● | ● | ● | ● | ○ | ● | ○ | ○ | ● |
| 9 | ▮ | 3% | 7 | 9 | ASME Club Involvement |  |  |  |  | ○ |  |  |  | ● |
| 10 | ▮▮▮ | 8% | 6 | 9 | Community Outreach |  |  | ▽ |  |  |  | ○ |  | ● |

| Relationships | |
|---|---|
| Strong | ● |
| Moderate | ○ |
| Weak | ▽ |

*Figure 41: House of Quality and Legend*

# Appendix B

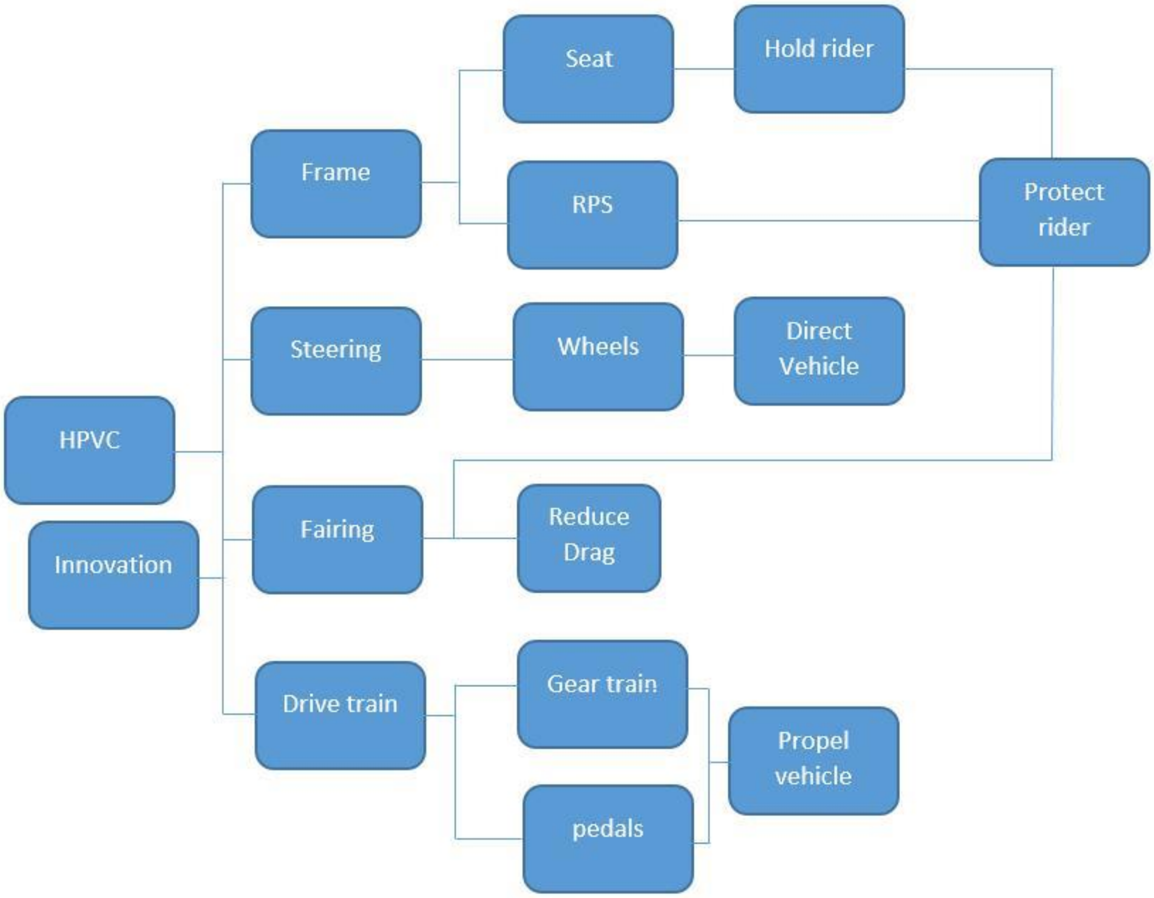
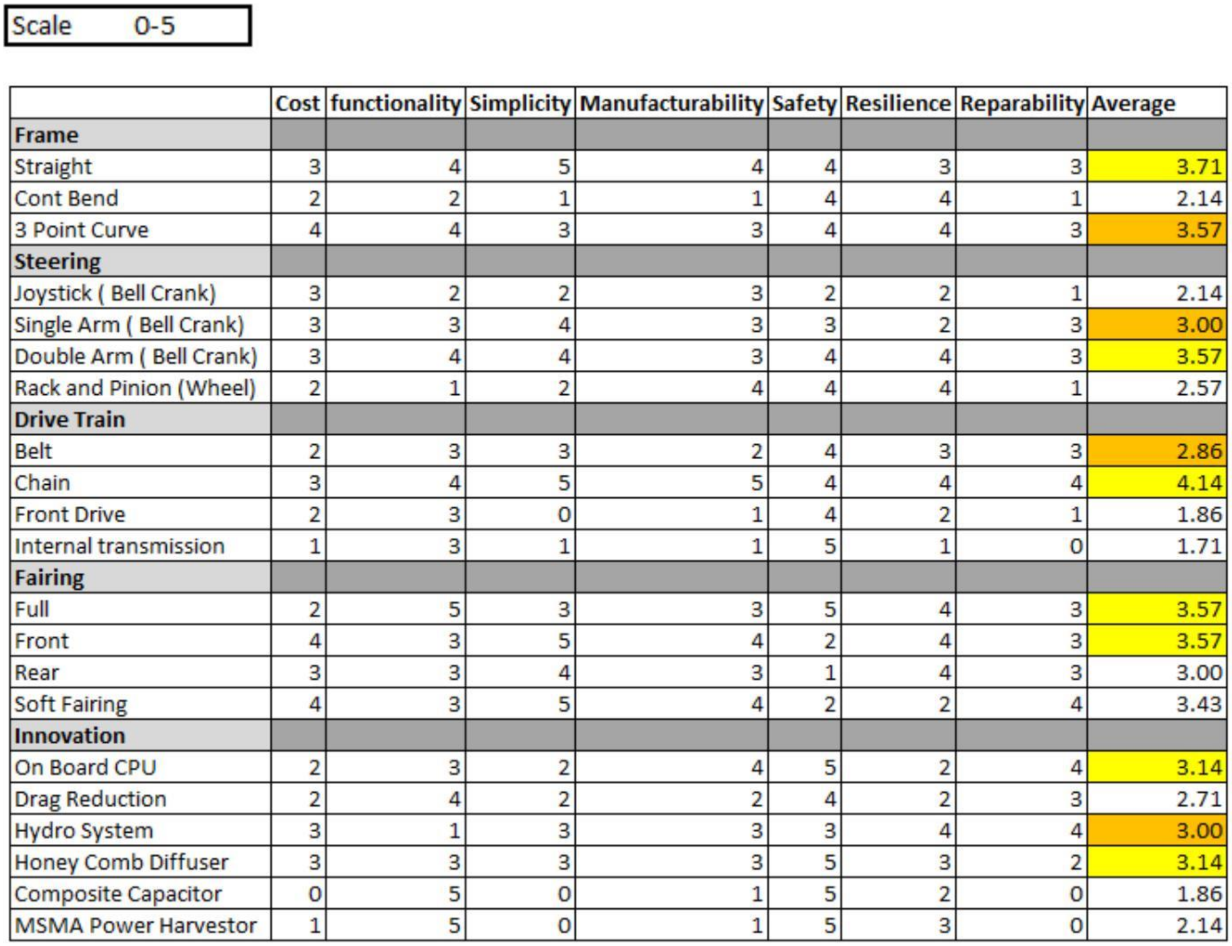


*Figure 42: Functional Decomposition*

# Appendix C

*Table 10: Decision Matrix/Pugh Chart*

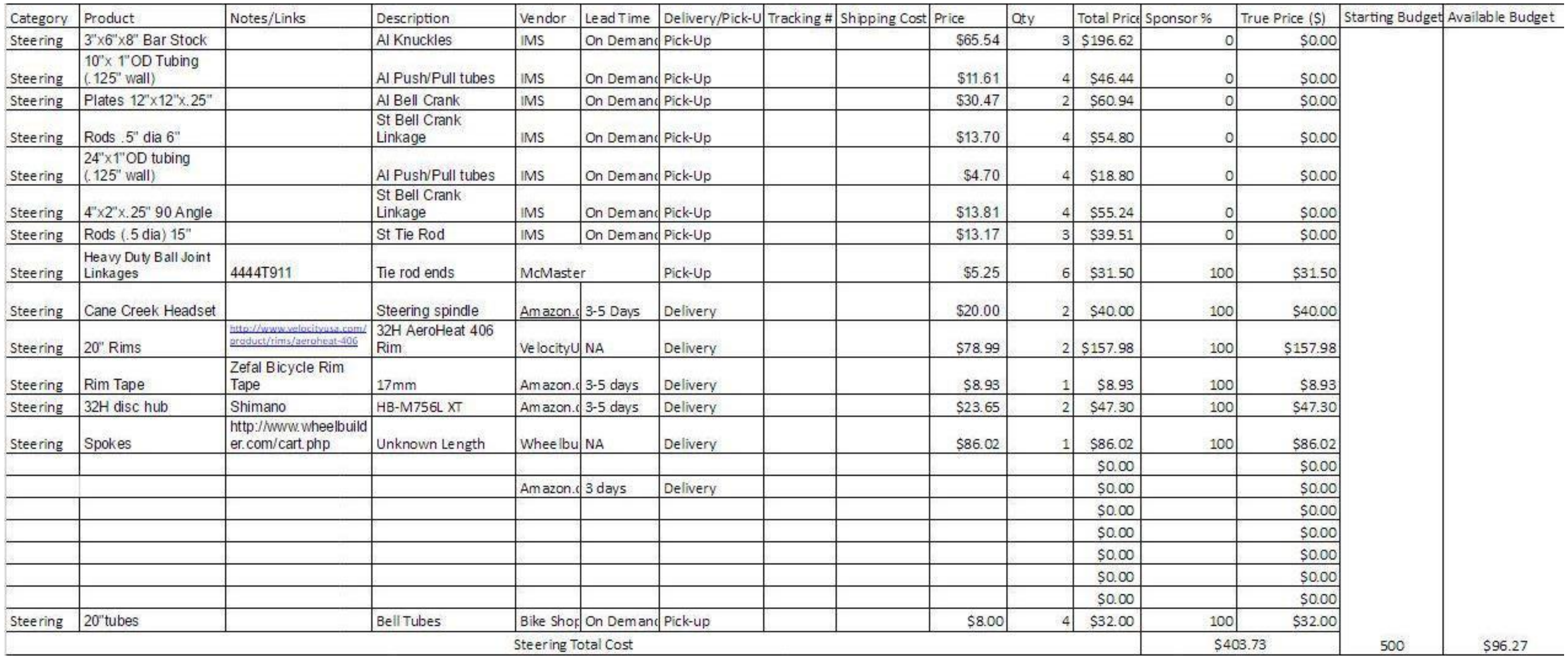


Scale 0-5

| | Cost | functionality | Simplicity | Manufacturability | Safety | Resilience | Reparability | Average |
|---|---|---|---|---|---|---|---|---|
| **Frame** | | | | | | | | |
| Straight | 3 | 4 | 5 | 4 | 4 | 3 | 3 | 3.71 |
| Cont Bend | 2 | 2 | 1 | 1 | 4 | 4 | 1 | 2.14 |
| 3 Point Curve | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 3.57 |
| **Steering** | | | | | | | | |
| Joystick ( Bell Crank) | 3 | 2 | 2 | 3 | 2 | 2 | 1 | 2.14 |
| Single Arm ( Bell Crank) | 3 | 3 | 4 | 3 | 3 | 2 | 3 | 3.00 |
| Double Arm ( Bell Crank) | 3 | 4 | 4 | 3 | 4 | 4 | 3 | 3.57 |
| Rack and Pinion (Wheel) | 2 | 1 | 2 | 4 | 4 | 4 | 1 | 2.57 |
| **Drive Train** | | | | | | | | |
| Belt | 2 | 3 | 3 | 2 | 4 | 3 | 3 | 2.86 |
| Chain | 3 | 4 | 5 | 5 | 4 | 4 | 4 | 4.14 |
| Front Drive | 2 | 3 | 0 | 1 | 4 | 2 | 1 | 1.86 |
| Internal transmission | 1 | 3 | 1 | 1 | 5 | 1 | 0 | 1.71 |
| **Fairing** | | | | | | | | |
| Full | 2 | 5 | 3 | 3 | 5 | 4 | 3 | 3.57 |
| Front | 4 | 3 | 5 | 4 | 2 | 4 | 3 | 3.57 |
| Rear | 3 | 3 | 4 | 3 | 1 | 4 | 3 | 3.00 |
| Soft Fairing | 4 | 3 | 5 | 4 | 2 | 2 | 4 | 3.43 |
| **Innovation** | | | | | | | | |
| On Board CPU | 2 | 3 | 2 | 4 | 5 | 2 | 4 | 3.14 |
| Drag Reduction | 2 | 4 | 2 | 2 | 4 | 2 | 3 | 2.71 |
| Hydro System | 3 | 1 | 3 | 3 | 3 | 4 | 4 | 3.00 |
| Honey Comb Diffuser | 3 | 3 | 3 | 3 | 5 | 3 | 2 | 3.14 |
| Composite Capacitor | 0 | 5 | 0 | 1 | 5 | 2 | 0 | 1.86 |
| MSMA Power Harvestor | 1 | 5 | 0 | 1 | 5 | 3 | 0 | 2.14 |

# Appendix D

*Table 11: Steering Overview*



| Category | Product | Notes/Links | Description | Vendor | Lead Time | Delivery/Pick-U | Tracking # | Shipping Cost | Price | Qty | Total Pric | Sponsor % | True Price ($) | Starting Budget | Available Budget |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Steering | 3"x6"x8" Bar Stock |  | Al Knuckles | IMS | On Deman | Pick-Up |  |  | $65.54 | 3 | $196.62 | 0 | $0.00 |  |  |
| Steering | 10"x 1"OD Tubing (.125" wall) |  | Al Push/Pull tubes | IMS | On Deman | Pick-Up |  |  | $11.61 | 4 | $46.44 | 0 | $0.00 |  |  |
| Steering | Plates 12"x12"x.25" |  | Al Bell Crank | IMS | On Deman | Pick-Up |  |  | $30.47 | 2 | $60.94 | 0 | $0.00 |  |  |
| Steering | Rods .5" dia 6" |  | St Bell Crank Linkage | IMS | On Deman | Pick-Up |  |  | $13.70 | 4 | $54.80 | 0 | $0.00 |  |  |
| Steering | 24"x1"OD tubing (.125" wall) |  | Al Push/Pull tubes | IMS | On Deman | Pick-Up |  |  | $4.70 | 4 | $18.80 | 0 | $0.00 |  |  |
| Steering | 4"x2"x.25" 90 Angle |  | St Bell Crank Linkage | IMS | On Deman | Pick-Up |  |  | $13.81 | 4 | $55.24 | 0 | $0.00 |  |  |
| Steering | Rods (.5 dia) 15" |  | St Tie Rod | IMS | On Deman | Pick-Up |  |  | $13.17 | 3 | $39.51 | 0 | $0.00 |  |  |
| Steering | Heavy Duty Ball Joint Linkages | 4444T911 | Tie rod ends | McMaster |  | Pick-Up |  |  | $5.25 | 6 | $31.50 | 100 | $31.50 |  |  |
| Steering | Cane Creek Headset |  | Steering spindle | Amazon. | 3-5 Days | Delivery |  |  | $20.00 | 2 | $40.00 | 100 | $40.00 |  |  |
| Steering | 20" Rims | http://www.velocityusa.com/product/rims/aeroheat-406 | 32H AeroHeat 406 Rim | VelocityU | NA | Delivery |  |  | $78.99 | 2 | $157.98 | 100 | $157.98 |  |  |
| Steering | Rim Tape | Zefal Bicycle Rim Tape | 17mm | Amazon. | 3-5 days | Delivery |  |  | $8.93 | 1 | $8.93 | 100 | $8.93 |  |  |
| Steering | 32H disc hub | Shimano | HB-M756L XT | Amazon. | 3-5 days | Delivery |  |  | $23.65 | 2 | $47.30 | 100 | $47.30 |  |  |
| Steering | Spokes | http://www.wheelbuilder.com/cart.php | Unknown Length | Wheelbu | NA | Delivery |  |  | $86.02 | 1 | $86.02 | 100 | $86.02 |  |  |
|  |  |  |  |  |  |  |  |  |  |  | $0.00 |  | $0.00 |  |  |
|  |  |  |  | Amazon. | 3 days | Delivery |  |  |  |  | $0.00 |  | $0.00 |  |  |
|  |  |  |  |  |  |  |  |  |  |  | $0.00 |  | $0.00 |  |  |
|  |  |  |  |  |  |  |  |  |  |  | $0.00 |  | $0.00 |  |  |
|  |  |  |  |  |  |  |  |  |  |  | $0.00 |  | $0.00 |  |  |
|  |  |  |  |  |  |  |  |  |  |  | $0.00 |  | $0.00 |  |  |
|  |  |  |  |  |  |  |  |  |  |  | $0.00 |  | $0.00 |  |  |
| Steering | 20"tubes |  | Bell Tubes | Bike Shop | On Deman | Pick-up |  |  | $8.00 | 4 | $32.00 | 100 | $32.00 |  |  |
| Steering Total Cost |  |  |  |  |  |  |  |  |  |  |  | $403.73 |  | 500 | $96.27 |

# Appendix E

*Table 12: Frame BOM*

| Part No. | Description | Qty. |
|---|---|---|
| 1 | 2” OD x 0.1258 wt Aluminum 6061 - T6 Tubing 1 | 1 |
| 2 | 1-¾” OD x 0.125 wt Aluminum 6061 - T6 Tubing | 5 |
| 3 | 1.5” OD x 0.08” wt Aluminum 6061 - T6 Tubing 2 | 2 |
| 4 | 1-¼” OD x 0.125 wt Aluminum 6061 - T6 Tubing | 1 |
| 5 | 1” OD x 0.125 wt Aluminum 6061 - T6 Tubing | 8 |
| 6 | 3” OD x 0.430” wt Aluminum 6061 - T6 Round Stock | 1 |
| 7 | 2.625” OD x 0.243” wt Aluminum 6061 - T6 Round Stock | 1 |
| 8 | Gusset Plates | 5 |
| 9 | Vertical Dropouts | 2 |

*Table 13: Steering BOM*

| Part No. | Description | Qty. |
|---|---|---|
| 1 | Steering Knuckles | 2 |
| 2 | Joysticks | 2 |
| 3 | Bell crank | 1 |
| 4 | Tie Rods | 4 |
| 5 | 5/16” Thrust Bearings | 2 |
| 6 | ½” Thrust Bearings | 4 |
| 7 | ⅜” Pan Head Bolt | 8 |
| 8 | 5/16” Pan Head Bolt | 1 |
| 9 | 5/16” Fender Washer | 2 |
| 10 | ½” Washer | 4 |
| 11 | ⅜” Nut | 8 |

*Table 14: Ergonomics BOM*

| Part No. | Description | Qty. |
|---|---|---|
| 1 | Seat | 1 |
| 2 | Seat Clamp | 2 |
| 3 | Cushion | 2 |

*Table 15: Drivetrain BOM*

| Part No. | Description | Qty. |
|---|---|---|
| 1 | SRAM (RED) 22 chain | 3 |
| 2 | SRAM XG-1190 Cassette | 1 |
| 3 | SRAM (RED) eTap Rear Derailleur | 1 |
| 4 | SRAM eTap BlipBox | 1 |
| 5 | SRAM eTap Blip Clamp | 2 |
| 6 | SRAM eTap BlipGrip | 2 |
| 7 | SRAM eTap BlipBox | 1 |
| 8 | SRAM eTap Battery | 1 |
| 9 | SRAM eTap Battery Charger | 1 |
| 10 | NX 1x X-SYNC™ Crankset | 1 |
| 11 | X5 Crankset | 1 |
| 12 | GXP® Bottom Bracket (Red) | 2 |
| 13 | TRP HY/RD Road disk (Silver) | 2 |
| 14 | Specialized Purple hand Grips | 2 |
| 15 | 32 T idler gears. | 2 |
| 16 | SPD clipless pedals | 2 |
| 17 | Eccentric bottom brackets | 2 |
| 18 | Flower bell | 1 |

*Table 16: Fairing BOM*

| Part No. | Description | Qty. |
|---|---|---|
| 1 | Left Side Piece | 1 |
| 2 | Right Side Piece | 1 |
| 3 | Left Side Skirt | 1 |
| 4 | Right Side Skirt | 1 |
| 5 | Thermoplastic Window | 5 |

*Table 17: Innovation BOM*

| Part No. | Description | Qty. |
|---|---|---|
| 1 | Smart Tint Adhesive Material | 1 |
| 2 | Thermoplastic Windscreen | 1 |
| 3 | DC/AC Voltage Inverter | 1 |
| 4 | Switch | 1 |
| 5 | Key | 1 |