ASME HPVC

Final Proposal

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DISCLAIMER

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EXECUTIVE SUMMARY

Human Powered transport is often the most common or the only type of transportation available in underdeveloped or inaccessible parts of the world. The HPVC project is based on an intercollegiate competition hosted by the American Society of Mechanical Engineers (ASME). The competition includes events such as the endurance race, design event and women/men speed event. This competition provides an opportunity for students to implement sound engineering design principles learned throughout their college career to build an innovative, sustainable and safe vehicle that can provide inexpensive transportation alternatives.

The primary rules and regulations provided by ASME include: performance and safety requirements where the vehicle should demonstrate that it could come to a stop when travelling at a speed of 25 km/hr in a distance of 6m, can turn within an radius of 8m and have stability when travelling a distance of 30m at 5 to 8 km/hr. The vehicle must have a braking system incorporated in the front most wheel, all vehicles must include a rollover protection system that could protect the driver in the event of an accident, the interior and the exterior must be free from any sharp edges, open tube ends, screws protruding and other hazards, and finally all participants are required to wear clothing and protective equipment.

The first step in the design process was to identify the most important aspects of vehicle design. To achieve this, the team used a Hierarchical Task Analysis chart and Black Box Model to decompose the main function of the vehicle in to subfunctions. The subfunction are namely: frame, fairing, ergonomics, drive train, braking system, energy storage and steering. The subsections were further analyzed by conducting literature review. The comparison of older vehicle designs helped the team to identify different configuration combinations and emphasize on design aspects that can be enhanced to increase the efficiency of the vehicle. Decision matrices were used to analyze aspects such as recumbent, upright, two-wheel, three-wheel designs and then two-wheel upright, two-wheel recumbent, three-wheel recumbent designs. Literature review and Computational Fluid Dynamic (CFD) analysis was carried out on seven different fairing designs to decide on fairing type. After taking decision matrices, previous designs, rules and regulations set forth by ASME into account, the team decided on a two-wheel, recumbent bicycle with a fully enclosed fairing and a lighting system. Testing procedures were also developed to ensure that the vehicle is able to give out the desired results. A wind tunnel testing will be carried out on a smaller scale fairing to compare and verify the accuracy of the computational results obtained and frame testing will be conducted by applying different loads at different frequencies to determine the frame’s ability to achieve certain design parameters.

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1 BACKGROUND

1.1 Introduction

The HPVC project is an intercollegiate competition that requires all teams to design a completely human-powered vehicle. The purpose of the vehicle is to provide alternative transportation options for people in third world or developing countries. To be a viable option for these conditions, the vehicle must be inexpensive, easily manufacturable, and easy to use. When an effective design is completed, it could solve transportation issues in rural areas as well as reduce the use and reliance on fossil fuels. An effective design could be an important step in the future of humankind to reduce environmental impacts and improve access to important resources such as water, groceries, and medicine that are necessary to promote the development and growth of communities worldwide.

1.2 Project Description

The following is the original project description provided by American Society of Mechanical Engineers (ASME).

“Human powered transport is often the only type available in underdeveloped or inaccessible parts of the world, and if well designed, can be an increasingly viable form of sustainable transportation. ASME’s international Human Powered Vehicle Challenge (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 market.”

2 REQUIREMENTS

Detailed below are the criteria that will determine what features are most important in the design of an HPV. These include the customer requirements, engineering requirements, and a functional decomposition of the necessary features that must be included.

2.1 Customer Requirements (CRs)

The following is a list of customer requirements for the HPVC:

1. Cost within budget
2. Durable and Robust design
3. Reliable design
4. Safe to operate/rider protected in case of collision
5. Vehicle can reach high speeds
6. Vehicle must be light weight
7. Highly maneuverable
8. Contains cargo space
9. Unobstructed field of view
10. Aerodynamic
11. Fits different riders of varying heights and weights

The overarching customer need is for a human-powered vehicle capable of scoring top 10 of any of the events specified at the E-Fest competition. The secondary goal is that the vehicle is useable and accessible to any rider so that it may be used for community outreach and demonstrations. The eleven requirements that precede this are the means by which these goals shall be met.

2.2 Engineering Requirements (ERs)

The following is a list of engineering requirements along with the targeted value for each. After testing different fairing designs, the target value for drag coefficient has been changed from the value mentioned in the preliminary report.

Table 2.1: Engineering requirement list and target values.

Engineering Requirement	**Target Value**
Weight	< 50 pounds
Frame Strength	Yield FOS > 1.5
Turning Radius	≤ 15 feet
Top Speed	45 MPH
Drag Coefficient	CD < 0.1
Innovation	Points
Cost	< $5000
Mount/Dismount Time	< 30 sec
Frontal Area	≤ 5 square feet
Ergonomic	Comfort for 2 hours

1. Weight (<50 pounds)
   The weight of the vehicle will affect the handling, top speeds, and operator fatigue significantly. For the vehicle to be competitive it is imperative that weight be kept down to a minimum.
2. Frame Strength (Yield FOS > 1.5)
   Structural integrity is crucial. If at any point there is a structural failure, the vehicle will no longer be viable for competition or for general use. For this purpose, a structurally sound design is required. Given the operating conditions and the lack of severe terrain and harsh environments, there is no need for overly conservative safety factors.
3. Turning radius (<=15 feet)
   The slalom event requires the vehicle to make an 8-meter (32 foot) U-turn. By aiming for a tighter turn radius, this increases the maneuverability of the vehicle during high speed maneuvers where sliding could occur.
4. Top speed (45 miles per hour)
   An important part of the competition is speed. In order to place top 10 in sprint or endurance, the vehicle must be faster than most of the competing teams.
5. Drag Coefficient (CD < 0.1)
   Another crucial part of preventing operator fatigue and ensuring highest possible efficiency and speeds is to have the lowest coefficient of drag possible.
6. Innovation (Points)
   Innovation is a key factor in the design report as well as a high priority customer requirement. In order to develop and push existing technology further, the team will need to create unique solutions to problems that will score high marks for innovation/.
7. Cost (< $5000)
   The purpose of the project is to create a relatively inexpensive vehicle for use in developing countries. As such, cost is an important factor. While the prototype is always more expensive than full production, it is wise to stay well within the allotted budget to account for travel, room and board, as well as competition fees.
8. Time to mount/dismount (<30 seconds)
   Some events in the race demand that the operator get into and exit the vehicle to complete certain tasks. Therefore, to maintain a competitive edge, it must be easy to mount and dismount.
9. Frontal area (<= 5 square feet)
   A lower frontal area will reduce aerodynamic drag forces and reduce the amount of material necessary to construct an effective fairing.
10. Ergonomic (minimum time in vehicle > 2 hours)
    The endurance race requires long time periods of vehicle operation. Performance must not come at the expense of the operator's comfort, especially in the case that the discomfort becomes chronic and reduces the desire to use the vehicle.

2.3 Functional Decomposition

The main function of the HPV is to effectively use human energy to power a recumbent bicycle through several different competition obstacles and events. The functional decomposition process is the defined functional parts of a product and how they can be differentiated into their functional composition. The following two sections will explain the black-box model and the hierarchical task analysis that the team created. The black box model will show the inputs and outputs from the user of the product. The hierarchical task analysis provides the team's objective tasks to complete the final goal of the project.

2.3.1 Black Box Model

Black-box modeling introduces the functionality of the product through materials (thick black line), energies (thin black line) and signals (dotted line). The left side of the model shows the input functions while the right side enhances the output of the product. This model creates an analysis of the general design and has no technical work of the design involved.

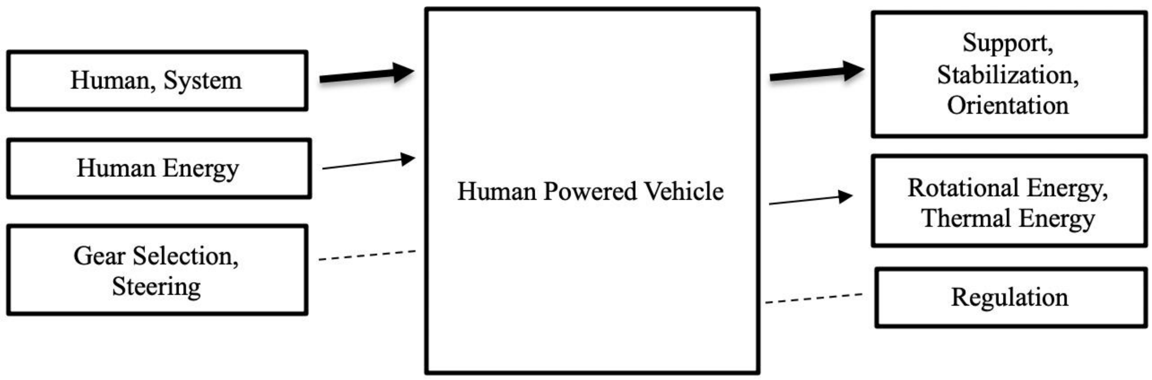

Figure 2.1: Human Powered Vehicle Black Box Model

Modeling the inputs and outputs of the human-powered vehicle has allowed the team to understand the general concept of the bicycle. Human interaction provides the vehicle with all functions resulting in braking, determined speed and rotation of wheels, and the final orientation of the vehicle. The team analyzed separate parts of the vehicle based on the model to create rough technical designs for the decision matrices and to explore the functional model as seen in the following section.

From the black box model, the team can construct a PVC version of the human powered vehicle. This allows them to understand the true size of the vehicle and where certain components will go when concerned with rider height and length. With a rough draft of the vehicle created in Solidworks and the trial version the team can appropriately collect the correct materials and manufacture the parts according to size when ready to build the final product.

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The Hierarchical model was used to build a structured and objective approach to determine the order that should be followed to achieve the goal of producing a final design

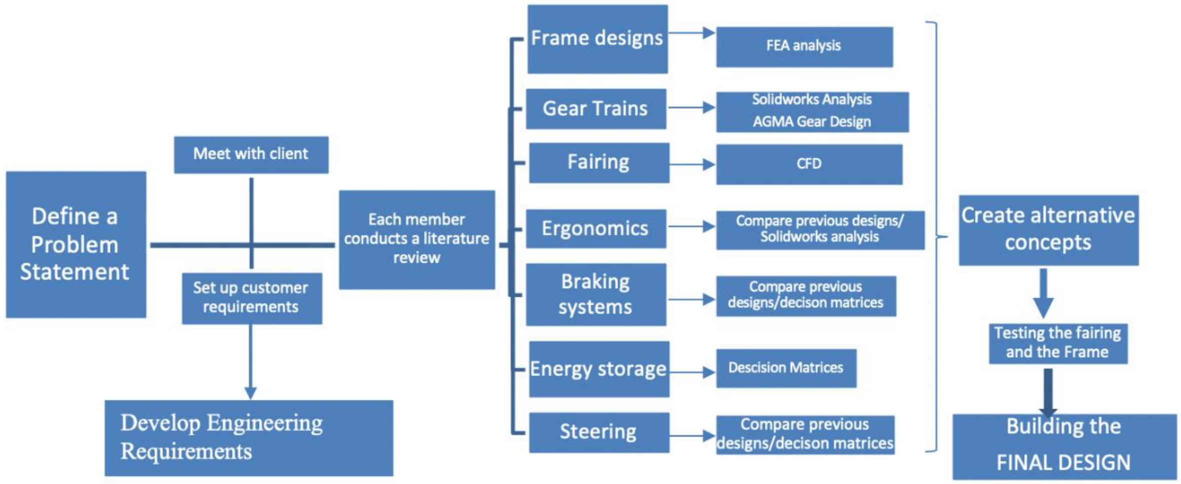

Figure 2.2: Hierarchical Task Analysis

The Hierarchical chart was used by the team to determine the order in which tasks should be completed. After meeting with the client and setting up customer and engineering requirements, the team was able to divide the overall function of the HPV into sub-functions. Then each member was assigned a sub function to research and carry out respective analysis. The results obtained from the analysis were used to build alternate concept designs. The alternative designs were further analyzed using decision matrices and a Pugh chart to conclude the final design. Protypes of the final designs will be created to confirm that the design is able to achieve desired outcomes.

2.4 House of Quality (HoQ)

This house of quality translates the customer requirements into engineering requirements. The customer and engineering requirements are defined in Section 2.1 and 2.2.

The house of quality has helped the team prioritize the engineering requirements. For instance, the decision of the rider position was determined by the turning radius and ergonomics. If the rider sits closer to the ground, then a longer wheelbase design equivalates to a larger turning radius. If the rider operates the vehicle sitting upright, then the rider fatigues more. Similarly, the decision to include a fairing comes from the top speed, drag coefficient, and frontal area requirements since a fairing usually decreases drag and increases speed. The frontal area assists in keeping the vehicle narrow and more aerodynamic. Next, the material and component choices are heavily defined by the cost requirement as this project is on a budget. As a result, the vehicle design is composed of machinable and cost-effective parts. Lastly, the innovation requirement has allowed the design to take on new aspects than a regular bicycle would have such as an adjustable seat to allow for height differences and a reclining angle to accommodate for rider comfort. *Figure 2.3* below shows the house of quality chart for the human powered vehicle design.

Weak Correlation		1									
Moderate Correlation		3		NAU HPVC Summer 2020							
Strong Correlation		9									
	Engineering Requirements	Frame strength (Yield FOS)	Weight (lbs)	Turning radius (feet)	Top speed (mph)	Drag Coefficient (CD)	Innovation (Points)	Cost (dollars)	Time to mount/dismount (	Frontal area (sq. feet)	Ergenomics (hrs)
Customer Requirements											
Low cost	2						3	9			
Durable and robust	5	9					1	3			
Reliable	5			3			9	3	3		
Safe to operate	5	9	3	9							3
High speed	4		9	1	9	9	3			9	
Maneuverability	4		3	9	3		3		3		
weight	4	3	9		9			3			3
Cargo space	3		3							1	
Field of View	4										9
Aerodynamic	4				9	9	3			9	
Fits multiple riders	5										9
High design report score	5	3	3	3	3	3	9	1	1	3	3
Absolute Importance		117	123	115	135	87	137	65	32	90	123
Relative Importance		11	12	11	13	8	13	6	3	9	12

Figure 2.3: The customer and engineering requirements in a house of quality

2.5 Standards, Codes, and Regulations

The standards given in the 2021 HPVC Rules Section verify that our design is valid and safe for competition. The ASME Y14.24/Y14.3/Y14.5 standard ensure that the HPVC committee will understand our team's design. If the drawings aren't within standard, then the team's vehicle may be disqualified from the competition. However, this class requires the use of ASTM Dimensioning and Tolerancing Standards for the drawing and CAD models. Next, the 16 CFR Part 1203 standard verifies that the team is using the correct safety helmet. This standard ensures the basic level of safety for the rider as the helmet does not count as an extra safety feature. Following, the AGMA Gear Design assists the team in picking and analyzing the correct gears. This standard defines which gear and gear material is best suited for vehicle design. Lastly, the 2021 HPVC Rules Section V (Safety) details the required safety measurements for building a human powered vehicle. These rules ensure that our design is qualified for the competition.

Table 2.2: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ASME Y14.24/Y14.3/Y14.5	Types and Applications of Engineering Drawings	Helps define the drawing standards of the vehicle.
16 CFR Part 1203	CPSC Safety for Bicycle helmets	This standard ensures the safety of the rider's head in case of a situation.
2021 HPVC Rules Section V (Safety)	ASME HPVC Rules for the 2021 Human Powered Vehicle Challenge	This ensures that the design of the vehicle is safe for the rider and other competitors.
ASTM	ASTM Dimensioning and Tolerancing Standards	This ensures that standard procedures are used for CAD drawings.
AGMA	AGMA Gear Design	These standards were used to ensure high factors of safety were met for the design of the drive train.

3 Testing Procedures (TPs)

The testing procedures that will be used in this project are the wind tunnel, frame strength, and speed and maneuverability tests. The wind tunnel test relates to the drag coefficient and frontal area while the frame strength test relates to the frame strength and weight requirements. Lastly, the speed and maneuverability test relate to the time to mount/dismount, ergonomics, top speed, and turning radius.

3.1 Testing Procedure 1: Wind Tunnel Test

The wind tunnel uses a chamber that allows air flow around an object and used to determine the aerodynamic efficiency of vehicles or airplanes. A scaled down model of the vehicle/ airplane will be placed in the middle of the chamber and air is provided by a fan system. This method can be used to simulate the air flow over vehicle under different wind conditions to match the real-world conditions. The wind tunnel test can be used to determine the wind forces, air pressure and other wind characteristics.

3.1.1 Testing Procedure 1: Objective

The main objective of this test is to ensure the accuracy of computational analysis conducted to calculate the Coefficient of drag of the full fairing that will be used in the HPV. A scaled down model of the final fairing design will be 3D printed and be placed in the wind tunnel to test the coefficient of drag (Cd) provided a scaled equivalent air speed of 45mph. The Coefficient of drag obtained will then be compared to the Cd obtained through the CFD analysis carried out. This test is important to ensure that the fairing used will be able to achieve its top speed and has the ability to withstand any wind condition. The wind tunnel will be used to confirm the ability of the fairing to satisfy engineering requirements such as achieving a top speed of 45mph, obtaining a drag Coefficient less than 0.1, frontal area less than 5 square feet (which relates to coefficient of drag calculations) and finally the safety of the driver (the fairing's ability to withstand different wind conditions that protects the driver).

3.1.2 Testing Procedure 1: Resources Required

The foremost resources needed for the test are the 3D printed model depending on the availability of the Makerlab at NAU and the availability of the lab where the wind tunnel is located. The team will also need material such as sanding paper to smooth out the surface of the fairing.

3.1.3 Testing Procedure 1: Schedule

The first step to carrying out a wind tunnel test is, finalizing the fairing design for the HPV. Once the design is finalized, it will be scaled down in Solidworks to ensure that the prototype would fit in the wind tunnel. The next step is to send the drawings in to the 3D printing lab to print the model and it would take a week or more (depending on the availability) to receive the model. The test itself would take only a few hours to run. The goal is to conclude the testing of the fairing within the first month of the semester.

3.2 Testing Procedure 2: Frame Strength Test

With granted permission from the mechanics of materials lab instructor, the frame for this vehicle can be set up on their test loading jig. This will allow the team to apply loads of different magnitude and frequency to determine if it performs within the design parameters.

3.2.1 Testing Procedure 2: Objective

The objective of this test will be to confirm the FEA analysis and ensure that the welded frame performs within the design parameters. It will also guarantee that the design is safe for testing and competition. This is a crucial step that will prove the quality of work done early on in the project while still allowing time to correct errors should a failure occur.

3.2.2 Testing Procedure 2: Resources Required

To complete this test, the frame material must be purchased, welded and assembled, and stress relieved or normalized. Additionally, any jigs or fixtures required to attach the frame to the testing jig must also be manufactured. The final step is to gain access to the mechanics of materials lab and get approval from the instructor to perform the test.

3.2.3 Testing Procedure 2: Schedule

The test itself should be relatively short and should only require a few hours. However, the time taken to assemble and manufacture frame components according to the design will be significant. If time allows, it would be preferable to complete this testing by the eighth week of the semester to allow for modifications should the worst-case-scenario of frame failure present itself.

3.3 Testing Procedure 3: Speed and Maneuverability Test

Upon completion of the vehicle, this test should be conducted by all team members, assuming no prior physical injuries.

3.3.1 Testing Procedure 3: Objective

The objective of this test is to confirm that any member of the team can ride the vehicle without problems. Given that problems might arise during this testing period, this test will show room for improvement. Along the same lines, this test will validate the completion of the vehicle and the possibility of competition.

3.3.2 Testing Procedure 3: Resources Required

The resources required are an empty parking lot, helmet, vehicle, timer, cones, a stopwatch, tape measure, and clear weather. The first step is to obtain the helmet, cones, and stopwatch assuming that the vehicle is built. The second step is planning a day with clear weather and an empty parking lot. The third step is transporting the vehicle from storage to the empty parking lot. The first setup will involve setting up two pairs of cones 50 meters apart. This 50-meter setup will test the speed of the vehicle. In addition to this 50-meter speed test, an extra 10 meters will be setup for stopping. The second setup will involve four cones set 7.5 meters apart from each other, except the first pair of cones will be set 8 meters apart. This will test the maneuverability and turning radius of the vehicle.

3.3.3 Testing Procedure 3: Schedule

This test is expected to occur after the two aforementioned testing and the completion of the vehicle. This test should occur between the 10^{th} and 14^{th} week of the fall semester at the latest to allow for improvements. The four-week time frame allows each team member to test out the vehicle for speed, comfort, and maneuverability. Each team member's testing should take 30 minutes making the testing 3 hours. To account for setup and clean up, the entire testing should take 3.5 hours. Only 2 team members need to be present during this testing, 1 to use the stopwatch and the other to ride the vehicle. During the testing time period, 10 minutes will be dedicated to testing the speed and the other 20 minutes will be dedicated to maneuverability. To note, a roll cage test will be done on the tallest team member without the fairing to ensure that the roll cage is large and strong enough. Lastly, before the first test is conducted, the brakes of the vehicle will be checked.

4 DESIGN SELECTED – First Semester

The design outlined in the preliminary report is similar to the design described in this report. The design selected is the two-wheel, recumbent vehicle. While the general layout has minor changes, the overall look and performance of the vehicle is the same.

4.1 Design Description

Initially, the team identified three different vehicle designs. These were:

- Two-wheel, upright
- Three-wheel, recumbent
- Two-wheel, recumbent

The final design chosen based on the analysis done is a two-wheeled vehicle with a recumbent riding position. Based on the customer requirements and engineering requirements, it was decided that this design was able to satisfy all the necessary conditions. This was done by creating several decision matrices which allowed a good comparison of typical performance characteristics. Through additional research on past HPVC vehicles created by NAU and students from other universities it was also noted that two-wheeled recumbent designs have fared well in competitions previously. Lastly, the newest change to the design is the addition of an Arduino controlled light system.

4.2 Implementation Plan

The first phase will consist of fabricating a prototype/Proof of Concept. This will begin with cutting inexpensive PVC pipe according to the roll cage and frame design. This prototype will validate the ergonomics of the design and test whether a human can safely and comfortably operate the vehicle. While the frame and roll cage are being prototyped out of PVC, the Arduino light system will be assembled and tested.

Table 4.1: First Phase Detailed Breakdown

Part	Deadline	Information	People	Materials	Facilities
Frame	August 28th (tentative)	Lengths and Joints	At least 2 teammates	PVC, PVC joints, PVC cutters, heat gun	Machine Shop or Garage
Roll Cage	August 28th (tentative)	Lengths and Joints	At least 2 teammates	PVC, PVC joints, PVC cutters, heat gun	Machine Shop or Garage

The second phase will consist of building the design. The first sub-assembly for fabrication will be the frame since most systems are dependent on the structure. While the frame and roll cage are being welded, the steering system will be fabricated as well as the gear box and it's associated components manufactured in the machine shop. Once the frame and steering system are complete, then the seat can be attached to the frame. During this process, the drivetrain and wheels may also be attached to the frame.

Table 4.2: Second Phase Detailed Breakdown.

Part	Deadlines	Information	People	Materials	Facilities
Frame and Roll Cage assembly	September 20th (tentative)	Lengths and Joints and fabrication materials	At least 2 teammates	AISI 4130 steel tubing	Machine Shop or Garage
Gear Box	September 20th (tentative)	Dimensions and CAD drawings	At least 2 teammates	AISI 4140 steel	Machine Shop

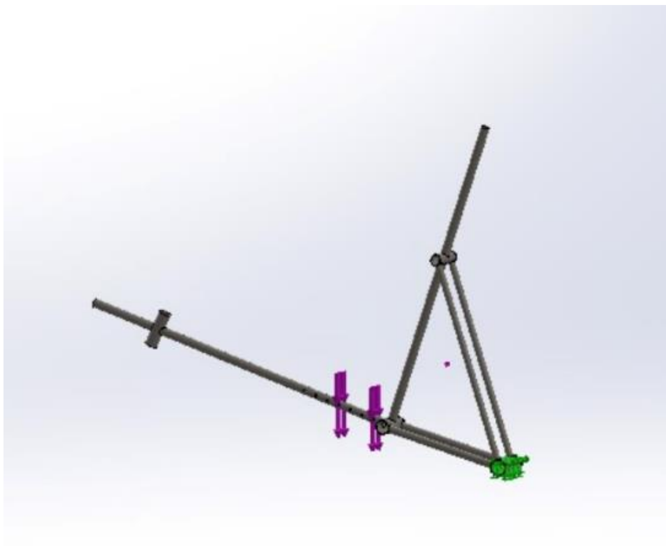

Figure 4.1: HPVC frame construction

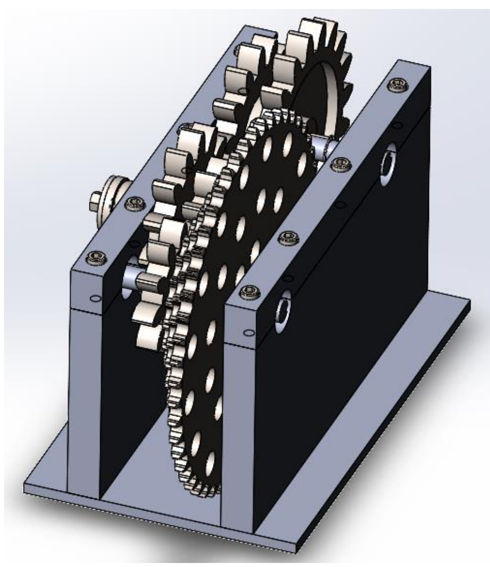

Figure 4.2: Gear Box

The third phase will take place in the same time frame as phase one and two. This phase will consist of finalizing the design and manufacturing of the fairing. First, a small-scale prototype will be subject to wind tunnel testing to validate the engineering requirements of the design. Once finalized, the team plans to work with a local company, Nova Kinetics, to manufacture the fairing as they have helped past HPVC teams with similar manufacturing needs.

Table 4.3: Third Phase Detailed Breakdown

Part	Deadlines	Information	People	Materials	Facilities
Fairing Model	August 28th (tentative)	Dimensions and CAD drawings	At least 2 teammates	3D printed plastics	Maker's Lab
Fairing	October 6th (tentative)	Dimensions and CAD drawings	At least 2 teammates	Carbon Fiber and Kevlar	Nova Kinetics

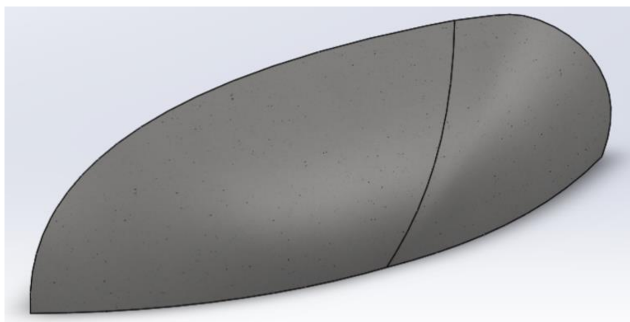

Figure 4.3: Fairing Design

The final phase of the team's implementation plan is to test the completed HPV and iterate sub-systems as necessary. Tests will include speed, maneuverability, and braking tests. This time will also allow the team to become familiar with the vehicle and become comfortable when riding it.

Table 4.4: Fourth Phase Detailed Breakdown

Part	Deadlines	Information	People	Materials	Facilities
Complete HPV	October 18th (tentative)	All teammates and completed HPV	Full Team	HPV, cones, stopwatch, measuring wheel, safety equipment	Empty parking lot

5 CONCLUSIONS

The human powered vehicle competition was created to help create affordable and sustainable modes of transportation to underdeveloped and inaccessible parts of the world. It allows students an opportunity to use their course material through engineering classes to develop a practical transportation device. Critical requirements of this project include a frame with roll over protection system, a braking system that allows the vehicle to stop within 6-meters traveling 25 km/hr and a stable turning radius of 8-meters. All approximations of cost come from the Bill of Materials found in Appendix A.

Overall, the team was able to finalize most of the design through SolidWorks. They plan on using AISI 4130 alloy steel for the frame tubing. This will allow the team to be able to weld easily and have a vehicle weight close to or under the 50 lb projected weight. Through extensive FEA analysis, this material also proved a yield strength of 1.6 proving its ability to handle the necessary stresses that will be put onto the vehicle. Outer diameter of the tubing will range from 0.70 inches to 1 inch. All parts of the frame will be manufactured by the team and will be done in the machine shop with the proper tools available. A model of the frame will be crafted out of PVC and other cheap components to ensure the team has the wanted length, width, and features for the final design. Cost of the PVC and metal tubing have been approximated at $90.00.

Final design for the fairing will need to be outsourced as the team has decided to use carbon fiber and Kevlar. Approximated cost for this will be $1500.00. The proposed design will be a fully enclosed rider at about 2-meters long, 1-meter width and a height of 0.6-meters. CFD analysis has been done on the proposed design resulting in a coefficient of drag of 0.1629. This proves the fairing will be beneficial to the team as the rider will be able to resist drag more than a traditional cyclist. All analysis done on the fairing has been done using the Ansys program.

Drive train for the vehicle will include a two-speed transmission, allowing the rider to increase speed within distances. The full drive train has been designed in SolidWorks and the team has decided to manufacture their own gears and buy the necessary nuts, bolts, and bearings. With the crank shaft involved the approximated amount will be $1200.00. Proposed pedals for the vehicle are clip in to make sure the riders' feet do not slip throughout the course events. The vehicle will have a 26-inch diameter rear wheel and a 16-inch front wheel to allow stability and benefit the steering capabilities. This will add an approximated amount of $130.00.

The proposed steering column includes a stem and head tube manufactured by the team with the AISI 4130 alloy steel and a store-bought fork, handlebar, and headset. Approximated cost for the column is $140.00. This will allow the team to change the length of the stem once the model HPVC is built to accommodate for the arm length and comfortability of the rider. The difference of the 26-inch rear wheel to front wheel of 16-inches combined with the angle of 63.5 degrees at the head tube promotes more stability when turning at slower speed. Resulting in a trail of 5.3-inches will meet the competition requirement to turn the 8-meter radius.

Specific proposed ergonomics for the vehicle will be proposed during the Fall 2020 semester. The seat will need to be adjustable to the length of the rider's chest and leg length from the pedals to the base of the seat. Further research and decisions will be done in the Fall 202 semester as well as the manufacturing of the test model and final model. Testing procedures will result in changes of the final design.

6 REFERENCES

HPVC, A. (2020, January 30). *Human Powered Vehicle Challenge.* Retrieved July 19, 2020, from https://efests.asme.org/competitions/human-powered-vehicle-challenge-(hpvc)

7 APPENDICES

7.1 Appendix A: Bill of Materials

Bill of Materials									
Team: Human Powered Vehicle Competition Team									
Part #	**Part Name**	**Qty**	**Description**	**Functions**	**Material**	**Dimensions**	**Cost Per Unit**	**Cost**	**Link to Cost estimate**
1	**Fairing**								
		20	Carbon 2x2 twill	To build the fairing	Carbon Fiber	50"W*0.009"T	$14.49	$ 289.80	https://www.sollercomposites.com/Carbon-3K-Fabrics.html
		10	Kevlar plain weave	To incorperate into the fairing	Kevlar	39"W*0.008"T	$13.99	$ 139.90	https://www.sollercomposites.com/Carbon-3K-Fabrics.html
		20	Different materials will be used for molding purposes (an average cost value will be used for cost approximation)	to mold sections together	Molding Material	depends on the material	$9.00	$ 180.00	https://www.sollercomposites.com/Carbon-3K-Fabrics.html
		1	E-Z Poxy 5 gal. kit EZ 10 resin, EZ 83 Hardner	To build the fairing	Epoxy/Resin	40 lbs. resin, 17.6 lbs. hardener	$986.00	$ 986.00	https://www.aircraftspruce.com/pages/cm/resin/ezpoxy.php
		2	POLYPROPYLENE COPOLY/COPOLYMER SHEET | NATURAL	To be used as a window/ window screen	Thermoplastic (winow/windscreen)	12"W*24"L	$41.12	$ 82.24	https://www.interstateplastics.com/Polypropylene-Copoly-copolymer-Natural-Sheet-PRONEQ%7ESH.php?sku=PRONEQ+SH&vid=20200803165824-5p&dim2=24&dim3=12&thickness=0.250&qty=2&recalculate.x=88&recalculate.y=13
2	**3D Printed Fairing**								
2.1	3D Printed Fairing	1	A scaled down model of the fairing will be 3D printed	for wind tunnel testing	ABS plastic	TBD	$10.00	$ 10.00	https://cf.nau.edu/library/makerbot/submit/
3	**Ergonomics**								
3.1	Seat								
3.2	Seat Cushion								
3.3	Harness	1	I five point racing harness	Safely holds the rider in position in the event of an accident	steel adjuster with nylon st	2" thick	$170.00	$ 170.00	https://www.simpsonraceproducts.com/products/simpson-platinum-plus-5-point-harnesses?gclid=EAIaIQobChMIjorDpNCA6wIVEhLnCh1IDQY0EAYYBiABEgLBdvD_BwE&gclsrc=aw.ds
4	**Frame**								
4.1		1	Frame tube	Provide structure and support to the vehicle	4130 Steel	1" x 0.065" x 70"	$40.52	$ 40.52	https://www.mcmaster.com/89955K639
4.2		1	Frame tube	Provide structure and support to the vehicle	4130 Steel	0.75" x 0.065" x 70"	$37.98	$ 37.98	https://www.mcmaster.com/89955K599
5	**Drive Train**								
5.10	Base Plate	1	Base Plate	Attachment point between frame and gear	4130 Steel	6.3" x 10.38" x 0.25"	$35.32	$ 35.32	https://www.mcmaster.com/4459T151
5.20	Bearing Housing	1	Bottom Inner Bearing Housing	Houses bearings that shafts ride in	6061 Aluminum	4.75" x 10.38" x 0.75"	$37.97	$ 37.97	https://www.mcmaster.com/9246K564
5.30	Bearing Housing	1	Bottom Outer Bearing Housing	Houses bearings that shafts ride in	6061 Aluminum	4.75" x 10.38" x 0.75"	$37.97	$ 37.97	https://www.mcmaster.com/9246K564
5.40	Drive gear	1	Drive Gear	Takes rider input and transfers throughout gear box	4140 Steel	1.125" x 2"r	$106.84	$ 106.84	https://www.mcmaster.com/4473T64
5.50	Drive Shaft	1	Drive Shaft	Drive gear rides on and shaft rides in bearings	4140 Steel	0.5"d x 4.275"	$10.51	$ 10.51	https://www.mcmaster.com/8935K38
5.60	Driven Gear	1	Driven Gear	Output gear that transfers power to chain and sprockets	4140 Steel	0.5" x 1.5"r	$106.84	$ 106.84	https://www.mcmaster.com/4473T64
5.70	Sprocket	1	Front Sprockets	Accepts gear box power and transfers to rear wheel	4140 Steel	1.5" x 9"d	$106.84	$ 106.84	https://www.mcmaster.com/4473T64
5.80	Bearing	1	Inner Bearing Top Cap	Houses bearings that shafts ride in	6061 Aluminum	1" x 10.38" x 0.75"	$37.97	$ 37.97	https://www.mcmaster.com/9246K564
5.90	Gear	1	Intermediate Gear	Transfers power between drive and driven gears	4140 Steel	1.075" x 3"d	$106.84	$ 106.84	https://www.mcmaster.com/4473T64
5.10	Shaft	1	Intermediate Shaft	Intermediate gear rides on shaft	4140 Steel	0.5"d x 2.65"	$10.51	$ 10.51	https://www.mcmaster.com/8935K38
5.11	Bearing	1	Outer Bearing Top Cap	Houses bearings that shafts ride in	6061 Aluminum	1" x 10.38" x 0.75"	$37.97	$ 37.97	https://www.mcmaster.com/9246K564
5.12	Shaft	1	Output Shaft	Output gear rides on shaft as well as Front Sprockets	4140 Steel	1"d x 4.3"	$10.51	$ 10.51	https://www.mcmaster.com/8935K38
5.13	Key	1	Key 0.125x0.125x2.125	Locks gear to shaft for power transmission	18-8 Stainless Steel	0.125" x 0.125" x 2.125"	$1.66	$ 1.66	https://www.mcmaster.com/92530A136
5.14	Key	1	Key 0.125x0.125x1.075	Locks gear to shaft for power transmission	18-8 Stainless Steel	0.125" x 0.125" x 1.075"	$1.66	$ 1.66	https://www.mcmaster.com/92530A136
5.15	Key	1	Key 0.125x0.125x0.5	Locks gear to shaft for power transmission	18-8 Stainless Steel	0.125" x 0.125" x 0.5"	$1.66	$ 1.66	https://www.mcmaster.com/92530A136
5.16	Key	1	Key 0.125x0.125x1.5	Locks gear to shaft for power transmission	18-8 Stainless Steel	0.125" x 0.125" x 1.5"	$1.66	$ 1.66	https://www.mcmaster.com/92530A136
5.17	Retainer Ring	6	External Retaining Ring	Locates components on shafts	15-7 PH Stainless Steel	0.039" x 0.468"d	$9.75	$ 58.50	https://www.mcmaster.com/91590A122
5.18	Ball Bearing	5	Ball Bearing AFBMA 12.2-0.5-1.125-0.25-10,SI,NC,10	Shafts ride in bearing to reduce friction	440C Stainless Steel	0.25" x 1.125"d	$23.94	$ 119.70	https://www.mcmaster.com/4668K6
5.19	Thrust Bearing	1	Thrust Bearing AFBMA 24.2.6-8TB031-6,SI,NC,6	Provides additional support to intermediate shaft	Steel	0.9375"d x 0.25"	$2.89	$ 2.89	https://www.mcmaster.com/6655K17
5.20	Washer	1	Plain Washer 8mm	Spreads load from bolt	18-8 Stainless Steel	1.5mm x 15mm	$7.14	$ 7.14	https://www.mcmaster.com/98689A116
5.21	Bolt	8	6x1.0x50mm SHCS Bolt	Attaches bearing housings and top caps	18-8 Stainless Steel	6mm x 50mm	$1.10	$ 8.76	https://www.mcmaster.com/91292A144
5.22	Bolt	8	6x1.0x40mm Hex Bolt	Attaches gear box to base plate	Zinc Plated Class 8.8 Steel	6mm x 40mm	$1.20	$ 9.58	https://www.mcmaster.com/94036A527
5.23	Bolt	1	8x1.25x25mm Hex Bolt	Attaches intermediate shaft to thrust bearing	Zinc Plated Class 8.8 Steel	8mm x 25mm	$10.75	$ 10.75	https://www.mcmaster.com/94036A425

5.24	Sprocket	1	Rear Sprocket Cassette 11-32T	Allow multiple gear ratios between gear box and rear wheel	Nickel Plated Steel	7.9" x 7.9" x 7.9"	$109.98	$ 109.98	https://www.amazon.com/Shimano-CS-HG500-10-cassette-bicicleta-velocidades/dp/B00WLFTGQQ/ref=sr_1_2?crid=1MY8I6V4MZKJ8&dchild=1&keywords=10+speed+road+bike+cassette+11-32&qid=1596511549&sprefix=bike+cassette+11-32+10%2Caps%2C322&sr=8-2
5.25	Freehub	1	10 speed freehub	Allow one way clutch for pedalling and room for 10 speed cassette	Steel	2.2" x 1.5" x 1.5"	$22.94	$ 22.94	https://www.amazon.com/Shimano-RM33-10-Speed-Freehub-Body/dp/B0189NWHX2/ref=sr_1_1?dchild=1&keywords=10+speed+freehub&qid=1596512647&sr=8-1
5.26	Wheel	1	26" Rear wheel	Transfer power from drive train to the ground for propulsion	Steel	26"d x 7"	$51.98	$ 51.98	https://www.amazon.com/WheelMaster-Bicycle-Wheel-2-125-Steel/dp/B000AO7DC4/ref=sr_1_2?dchild=1&keywords=26+rear+bike+wheel&qid=1596512913&sr=8-2
5.27	Wheel	1	16" Front Wheel	Balance, steering, and stability	Steel	16"d x 6"	$28.99	$ 28.99	https://www.amazon.com/Wheel-Master-Front-Bicycle-Silver/dp/B000AO3GKC/ref=sr_1_2?dchild=1&keywords=16+front+bike+wheel&qid=1596513069&sr=8-2
5.28	Tube	1	Rear Tube	Hold air pressure between rim and tire	Rubber	1.9" x 4.5" x 2.7"	$4.96	$ 4.96	https://www.amazon.com/Bell-STANDARD-Tube-26-1-75-2-25/dp/B000AAYBHI/ref=sr_1_2?crid=36O7ZXOWOPZWA&dchild=1&keywords=26+inch+bike+tube&qid=1596513235&sprefix=26%22+%2Caps%2C271&sr=8-2
5.29	Tire	1	Rear Tire	Provide traction between HPV and riding surface	Rubber	26"d x 1.95"	$44.99	$ 44.99	https://www.amazon.com/Kenda-Commuter-Cruiser-Bicycle-26-Inch/dp/B00KXXH2QE/ref=sr_1_8?crid=1XJWIMB6G61ZZ&dchild=1&keywords=26+road+bike+tires&qid=1596513600&sprefix=26%22+roa%2Caps%2C260&sr=8-8
5.30	Tube	1	Front Tube	Hold air pressure between rim and tire	Rubber	1.8" x 2.6" x 4.5"	$4.96	$ 4.96	https://www.amazon.com/Bell-16-Inch-Universal-1-75-Inch-2-25-Inch/dp/B003CUDJ3U/ref=sr_1_4?crid=3SCRH25QKPM1T&dchild=1&keywords=16+inch+bike+tube&qid=1596513673&sprefix=16+%2Caps%2C274&sr=8-4
5.31	Tire	1	Front Tire	Provide traction between HPV and riding surface	Rubber	16"d x 1.75"	$22.46	$ 22.46	https://www.amazon.com/Continental-Ride-Trekking-Bicycle-16x1-75/dp/B01FTD9SPK/ref=sr_1_9?dchild=1&keywords=16%2Binch%2Bbike%2Btire&qid=1596513751&sr=8-9&th=1&psc=1
5.32	Chain	20	Chain	Transfer power from gear box to rear wheel	Steel	0.3125" x 20'	$4.54	$ 90.80	https://www.mcmaster.com/6261K173
5.33	Master Link	1	Chain Master Link	Connect chain ends together	Steel	03125" x 0.312	$0.87	$ 0.87	https://www.mcmaster.com/6261K193
5.34	Crank Set	1	Crank Set	Transfer Power from user to gear box	Aluminum	7" x 1.25" x 1"	$22.99	$ 22.99	https://www.amazon.com/BAFANG-Electric-Essential-Accessary-Accessories/dp/B07B7D6VFP/ref=sr_1_3?dchild=1&keywords=bike+crank+arms&qid=1596516482&sr=8-3
5.35	Pedals	1	Pedals	Provide platform for user to input power to gear box	Steel/ Aluminum	4" x 4" x 1"	$36.99	$ 36.99	https://www.amazon.com/HEPINGJIANGENBO-Mountain-Pedal-ZP-109S-Platform/dp/B083TGJ74V/ref=sr_1_6?dchild=1&keywords=bike+clip+pedals&qid=1596516665&sr=8-6
6	**Steering**								
6.10	Threaded Headset	1	Threaded Headset	Attaches the steering stem to the fork inside of the head tube	Steel	1" diameter	$12.00	$ 12.00	https://www.sqvbicycles.com/products/1-threaded-fixie-track-road-bike-headset-1-black-html?variant=32746310543&utm_medium=cpc&utm_source=google&utm_campaign=Google%20Shopping
6.20	Threaded Fork	1	Threaded Fork	Attaches the headset to the front bike wheel	High tensile steel	1" d, 35 mm rake, 165 mm steerer length	$23.99	$ 23.99	https://www.brandscycle.com/product/sunlite-threaded-mx-fork-16-inch-231941-1.htm?variations=923855
6.30	Stem	1	Stem	Attaches the handle bar to fork rake inside of head tube	4130 Steel	1" od x 6'	$40.60	$ 40.60	https://www.mcmaster.com/steel-tubing/od~1inches/
6.40	Handlebar	1	Handlebar	Attaches to the stem	6061 Aluminum	31.8 mm riser, 690 mm	$32.00	$ 32.00	
6.50	Head tube	1	Head tube	Attaches stem and fork rake	4130 Steel	1" id x 1.5" od x 1ft	$31.23	$ 31.23	https://www.mcmaster.com/steel-tubing/od~1inches/
				Total Cost Estimate:			$2,389.25	$ 3,249.41	