Human Powered Vehicle Challenge

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Team 9

Concept Generation and Selection

Document

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INTRODUCTION

Over the course of the 2013-2014 academic year, Team 9 will design, build, and compete in the Human Powered Vehicle Challenge (HPVC) through the American Society of Mechanical Engineers (ASME). The design of the vehicle consists of concept generation, analysis, and testing to ensure the best possible designs. To simplify the design process the vehicle was broken into six subsections with a single team member in charge of each section. These sections include: frame, fairing, steering, drivetrain, ergonomics, and innovation. For each subsection, three design concepts were generated and evaluated to make the best selection. Each of these design concepts will be discussed in detail as will the method used for selection of a final design. This paper will also briefly give an overview of the project and discuss the overall progress.

PROJECT DESCRIPTION

Team 9 will design and build a human powered vehicle to compete in the HPVC, held by ASME. The competition consists of a design event, a sprint or drag event, an endurance race, and an innovation presentation. The sponsors for this project are Perry Wood, the NAU ASME advisor, and ASME. A goal statement was generated that states the team will “Design a human powered vehicle that can function as an alternative form of transportation.” This provides the team a large scope while brainstorming ideas within their sections. A few objectives the team has for the vehicle are: speed, aerodynamics, and maneuverability.

GENERAL VEHICLE CONFIGURATION

Team 9 began the concept generation stage by exploring options for a general vehicle type that would perform best during the rigors of competition and for our client, Perry Wood. After initial research, the team came to the conclusion that a successful vehicle would convert the majority of the limited power source into forward propulsion, while remaining easy to control during a variety of operating scenarios.

With a large number of factors contributing to the speed and handling of any one vehicle, team members had a challenging time identifying a clear winner from a list of potential configurations. Criteria are weighted with the use of a comparison chart, seen in Table 1.

Table 1-Derivation of Score Factors

	Low Speed Stability	Stop & Go Traffic	Top Speed	Cargo Capability	(Vehicle Weight)/Rider	Efficiency	Maintenance	Durability	
Low Speed Stability		1	1	1	0	1	0	0	
Stop & Go Traffic	0		1	0	0	1	0	0	
Top Speed	0	1		0	0	1	1	1	
Cargo Capability	0	1	1		1	1	0	1	
(Vehicle Weight)/Rider	1	1	1	0		1	0	0	
Efficiency	0	0	0	0	0		0	0	
Maintenance	1	1	0	1	1	1		0	
Durability	1	1	0	0	1	1	0		
Sub Total	3	6	4	2	3	7	1	2	28

% Of Total (Score Factor)	0.107	0.214	0.143	0.071	0.107	0.250	0.036	0.071

The comparison chart allows the teams to specify an attribute's relative importance among the other attributes. Each "1" in a given column illustrates that the attribute defined in that column is of greater importance than the attribute defined in the corresponding row. Score factors are derived from a sum of each column divided by the total number of points earned from the relative importance assessment. See Table 2 for the decision matrix that provided aid in selecting the vehicle configuration.

Table 2-Vehicle Configuration Decision Matrix

	Score Factor	Recumbent Bicycle	4 Wheeled	Delta Trike	Tadpole Trike	Airplane	Multiple Rider Land Vehicle
Low Speed stability	0.107	2	6	4	5	1	3
Stop & Go Traffic	0.214	2	6	4	5	1	3
Top Speed	0.143	6	3	4	5	1	2
Cargo Capability	0.071	3	6	4	5	1	2
Vehicle Weight/Rider	0.107	6	2	5	5	3	4
Efficiency	0.250	6	2	4	5	1	3
Maintenance	0.036	6	3	5	5	1	4
Durability	0.071	2	6	5	5	1	4
Scores	1.00	4.21	4.04	4.21	5.00	1.21	3.00

Design concepts are ranked from 1 to 6, with 6 representing a vehicle that would perform the best in the specified scenario, and 1 representing the vehicle that would perform the worst.

The information contained within the decision matrix indicates that a tadpole trike should be the vehicle configuration used for this project. Team members felt the decision matrix was accurate and truly indicated a vehicle that would perform best under our tests. The team subsequently chose to pursue the decision matrix suggestion.

The configuration described as a tadpole trike is shown in Figure 1. This arrangement consists of two front wheels mounted coaxially with roughly 1 meter in between them and 0.5 meters in front of the rider’s hips. A third wheel is located along the vehicle centerline, directly behind the operator. The rider operates the vehicle from a recumbent position with propulsion power originating in the legs of the driver. Power input is usually located in the front of the vehicle, with the recumbent position being defined as a reclined, seated orientation.

Figure 1-Tadpole Trike

The team found that the tadpole trike was not the best performer in any of the design criteria. Instead, it was consistently second ranked in every category. The team discovered that the chosen configuration of a tadpole trike would not be the ideal choice if only intended for top speed attempts, or endurance competitions. However, the vehicle designers found this configuration provides the best all-around performance required to finish well in both the speed and endurance competitions at the ASME HPVC.

FRAME DESIGN

The frame design involves the main structure of the vehicle, as well as the roll protection system. The frame needs to be strong and stiff to maximize power transfer and to protect the rider. Weight is also a key component of the frame design. Since the frame consists of a large portion of the vehicle, any methods to reduce weight will have a significant impact on the overall weight of the vehicle. The frame should also allow for the seat to be easily integrated. For rider safety, the roll protection system must keep the rider within the vehicle from coming into contact with the ground in the event of a rollover. For the competition, the roll bar is also required to support a 600lb top load and a 300lb side load, with minimal deflections in either case.

Three major designs were considered for the frame, each of which will be discussed in detail below. All of the designs share a few common points. Each frame incorporates a three wheel design, with two wheels in the front and a drive wheel in the back. Each design includes a single hoop roll bar that will extend to the top of the tallest rider’s head, and will extend no further than to the edges of the widest shoulders. This will provide roll protection for the rider, while minimizing the cross sectional area of the vehicle to reduce drag.

The first frame design concept utilizes a single circular center tube as the main body of the frame, seen in Figure 2. Circular tubing has a high strength to weight ratio, but allows for some bending and torsional deflections [1]. Circular tubing is also very common. Therefore, it would be easy to obtain tubing in the exact dimensions needed. However, seat integration and overall fabrication will be difficult because most components will have to be attached to a round surface.

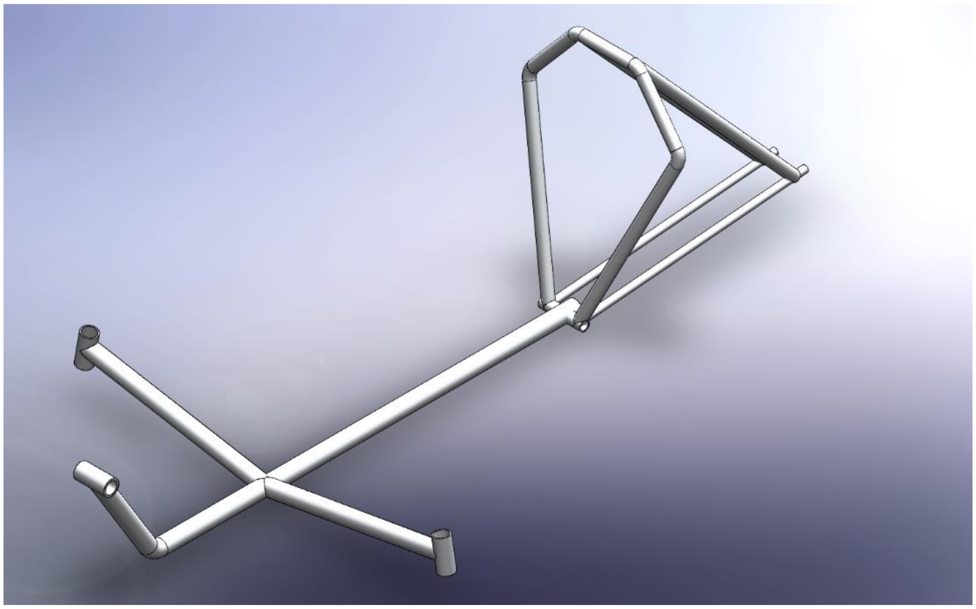


Figure 2-Single Center Tube Design

A second design considered, illustrated in Figure 3, uses a rectangular center tube. With a rectangular cross section, it is possible to obtain a much higher moment of inertia and polar moment of inertia in a specific plane [2]. This will result in a greater resistance to both torsional and bending deflections. With the square flat surfaces, this design will allow for simplified seat integration and manufacturing. However, this design will have a slightly lower strength to weight ratio, and rectangular tubing is less common. Therefore, finding the correct sizing may prove difficult.

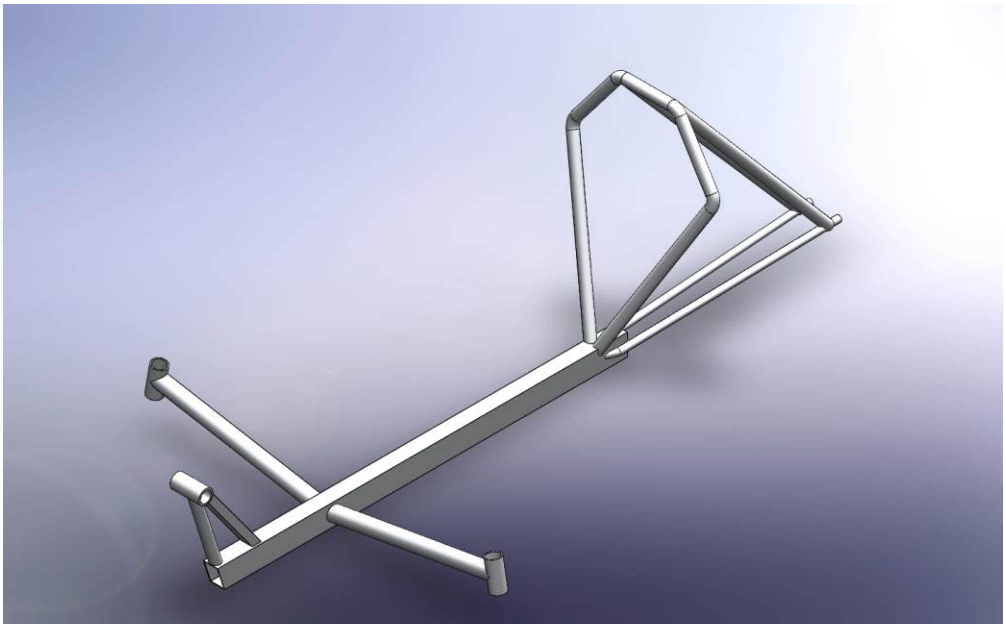


Figure 3- Rectangular Center Tube Design

The final design, seen in Figure 4, uses two circular center tubes that run the length of the entire structure. This design will provide higher resistance to deflections since it will be distributed over two bodies. With two separate attachment points, seat integration will be simplified. Also, finding the correct sizes should not be a problem. However, this system will have a lower strength to weight ratio than the single circular tube design. Lastly, the fabrication time and complexity will be higher than the two previous designs.

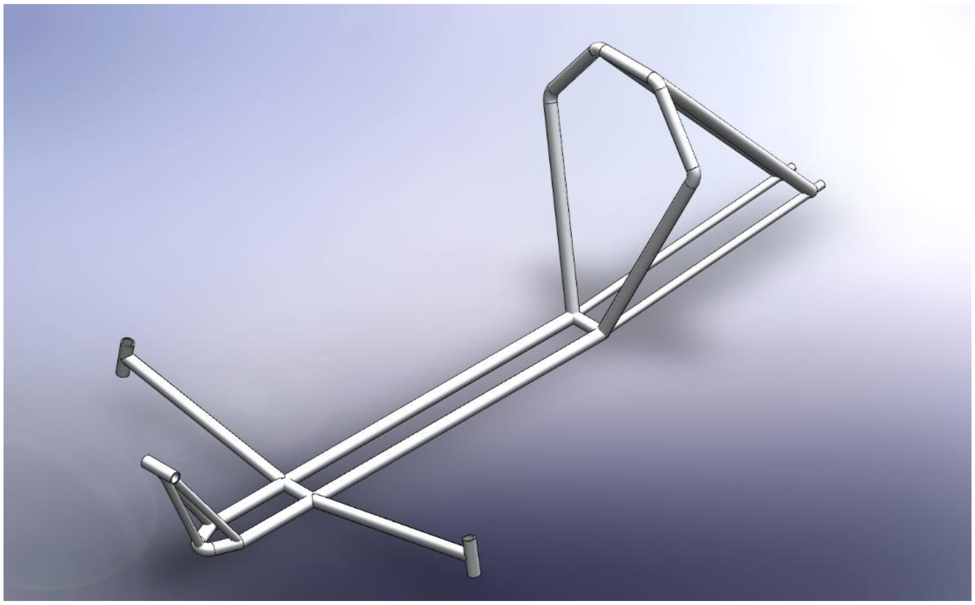


Figure 4- Double Circular Center Tube Design

To compare these three designs, a criteria matrix was created, as seen in Table 3. The four criteria that were compared include weight, ease of seat integration, resistance to deflection, and fabrication time. From this matrix, the resistance to deflection appears to be the most important of the four criteria, receiving a weighting factor of 2/5. Using these factors and criteria, a decision matrix was created; it is displayed in Table 4. The design that satisfied a specific criterion the best received the highest rank, of three. These ranks were then multiplied by the weighting factors from the criteria matrix, and then the sum of the scores for each design was taken.

Table 3- Frame Criteria

	Weight	Ease Of Seat Integration	Resistance To Deflection	Fabrication Time
Weight		1	1	0
Ease Of Seat Integration	0		1	1
Resistance To Deflection	0	0		0
Fabrication Time	1	0	0	
Weighting Factor	**1/5**	**1/5**	**2/5**	**1/5**

Table 4- Frame Decision Matrix

	Weight	Ease Of Seat Integration	Resistance To Deflection	Fabrication Time	
Weight	1/5	1/5	2/5	1/5	
Circular	3	1	1	2	Score
Weighted Score	3/5	1/5	2/5	2/5	1.6
Rectangular	2	3	3	3	
Weighted Score	2/5	3/5	1 1/5	3/5	2.8
Double Circular	1	2	2	1	
Weighted Score	1/5	2/5	4/5	1/5	1.6

The rectangular center tube design received the highest score in the decision matrix. Therefore, this will be the design the team will pursue. This design has the highest resistance to deflection, simplified seat integration, and the shortest fabrication time.

FAIRING DESIGN

Within the competition rules, it states “Each Vehicle shall include components, devices, or systems engineered specifically to reduce aerodynamic drag [3].” To complete these requirements, the team will be designing and creating a composite based fairing. A composite is a mixture of at least two materials, where one must be strong and stiff while the other, in ratio, is less strong but surrounds the strong material with an intimate bond [4]. Some examples of a composite include fiber reinforced polymers, concrete, and wood. While material has not been selected at this stage of the project, the overall design will be discussed and compared. Basic designs include: a front fairing, a tail fairing, and a full fairing. All three designs will be evaluated and matched to one another to see the differences. From this, the results will lead to a final decision and the beginning of the analysis.

The front fairing is a simple design that is used to help organize the fluid at the front of the vehicle to allow laminar flow to begin. Once the flow is smooth, the goal is to then have the flow pass over the operator and the tail of the vehicle. For this to happen, the nose would have to have a large cross sectional area to insure the rider and vehicle components were within that area. From Equation 1, if you were to increase the cross sectional area normal to the flow, the force would increase linearly, assuming the coefficient of drag, density of the fluid, and velocity stay constant. With a larger force, it would take more energy for the rider to reach top speeds or maintain cruising speeds. For a simple example, the fairing would have a coefficient of drag equal to that of a half sphere. Another issue with this design, is that once the flow passes over the edge of the fairing, turbulence would then be produced, leading to more drag forces against the rider. As seen in Figure 5, the nose would be a smooth surface with no sharp angles, while only covering a small section of the vehicle. The benefits include low weight, ease of manufacturing, wide range of view, and ease of access.

$$F_d = \frac{1}{2} C_d \rho v^2 A \tag{1}$$

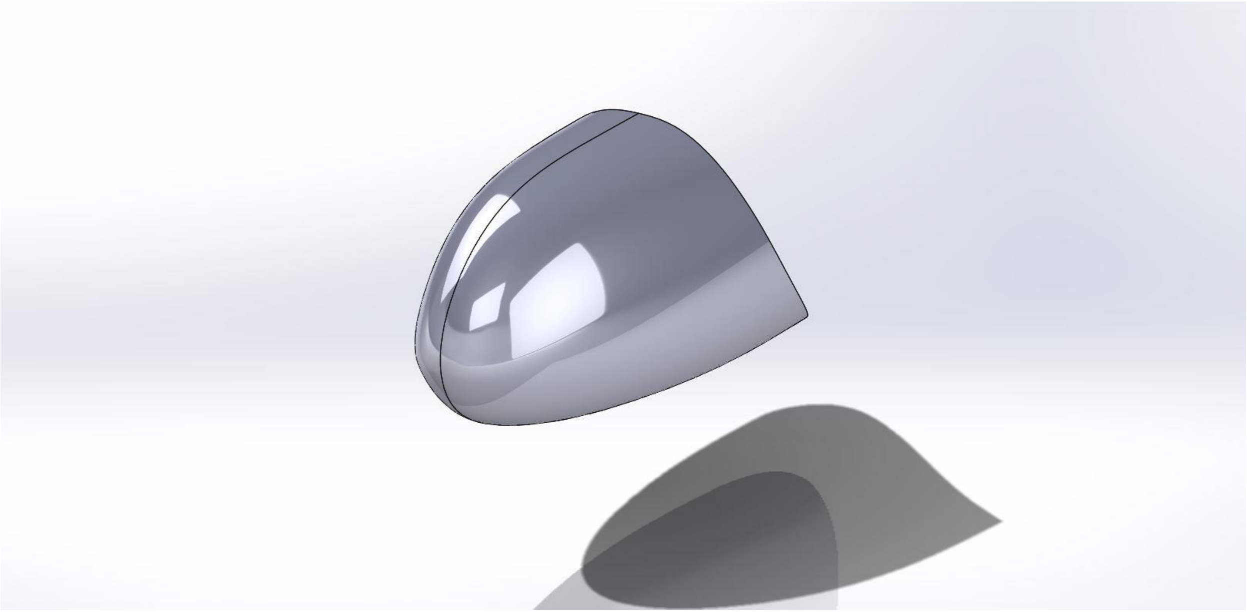


Figure 5- Front Fairing

Similar to the front faring, a tail faring would produce nearly the same results. While riding, assuming the riders body would fit in the hole seen in Figure 6, the air would hit the rider like that of a flat vertical plate. Upon diffusing around the rider, the air would follow the smooth curves of the fairing and stay in a streamline flow till the air left the tail. This would only happen at certain speeds, until turbulent flow would take effect from hitting the rider's body, thus causing more drag. With this design, there would be a similar coefficient of drag to that of a half sphere, where the flow is perpendicular to the flat surface. Its benefits, like the front fairing, are low weight, manufacturability, wide range of view, and accessibility to the bike.

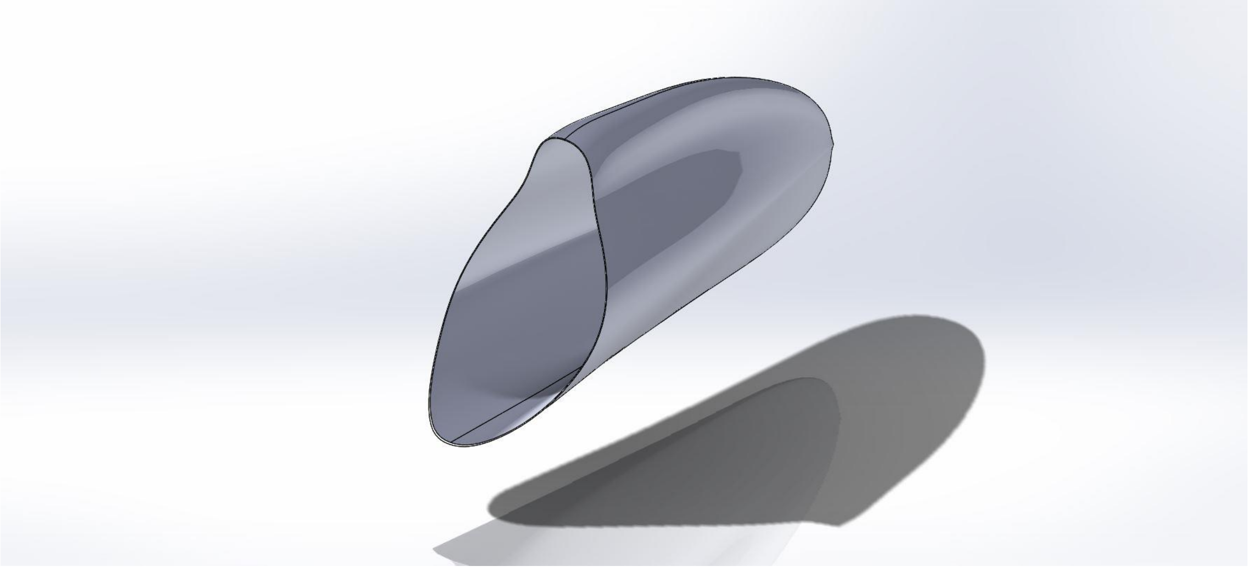


Figure 6- Rear Fairing

The final design concept, as seen in Figure 7, is a fully enclosed fairing. This would provide the benefits of being weather proof, rider protection, security, and decrease in drag forces. Although the weight of the piece will be higher than that of the partial faring, the coefficient of drag will decrease, helping the rider overcome the extra weight. For instance, once the air makes contact with the front of the fairing, it will follow the curves of the body until the air reaches the tail of the fairing. The coefficient of drag is similar to that of a streamlined body, which is around .04 [6]. Manufacturing the part will also be time extensive and complicated due to multiple layups for doors, window, removable nose cone, as well as a removable tail section.

Figure 7- Full Fairing

From the three designs above, the fairing section came to a conclusion that the full fairing, although heavier than the other two, will have a better coefficient of drag compared to the partial fairings. It will also keep the rider out of the elements and allow the rider to have a sense of security. The fairing shown in Figure 7 is a conceptual model and in no way dictates the final design shape. From this step forward, many changes will be made to the shape including: the length, height, and width. These variables will be changed either independently or dependently, thus creating numerous designs. These designs will be placed under computation fluid dynamics and their results, compared and evaluated. In conclusion, the team will be designing a full fairing to allow for better aerodynamics and weather proofing.

STEERING DESIGN

The steering for the human powered vehicle is a crucial component that will determine how well the vehicle will maneuver. The steering for the vehicle has constraints, given by the HPVC rule document. This document requires the vehicle to make a complete U-turn within an 8 meter radius [3]. The steering of the vehicle, however, cannot be too sensitive for the drag or speed trap portion of the competition. Therefore, the steering will likely have a sensitivity adjustment. The entire system must also be lightweight. Another requirement for the steering is to be responsive. This is defined as the lack of excess amount of play or movement in the input without response at the wheels. The steering also needs to be comfortable to use and not impede rider pedaling. Finally, the steering cannot require an excessive amount of force to operate, especially during tight maneuvering movements.

There are three different types of steering systems being considered for the vehicle; the first of which is a rack and pinion setup similar to that used in most cars. The next type is a Pittman arm, which is used in most solid front axle vehicle applications, such as trucks and jeeps. The final design being considered is a bell crank with a push-pull interface, similar to that found in a zero turn lawn mower.

The first design is the rack and pinion system with a typical steering wheel, as seen in Figure 8. This is the most common style for motorized cars. It uses a rack, which is generally a bar with gear teeth cut into it, and a meshing pinion gear that moves the rack left and right, which in turn moves the tie rods. The tie rods are adjustable linkages that transfer the linear motion to the knuckles, which are the parts that mount the wheels to the frame and allow them to pivot. A benefit of this design is that most parts to make this system are commercially available. However, one of the limitations of the rack and pinion system is that commercially available systems require about two full rotations of the pinion, which is directly connected to the steering wheel. This will be difficult to do within the confined space of the faring. The rack and pinion systems that do not require a full two rotations are excessively heavier and require roughly twice the force compared to the standard rack and pinion set. Lastly, rack and pinion systems interfere with the operator’s ability to exit the vehicle because the steering wheel is between the rider’s legs.

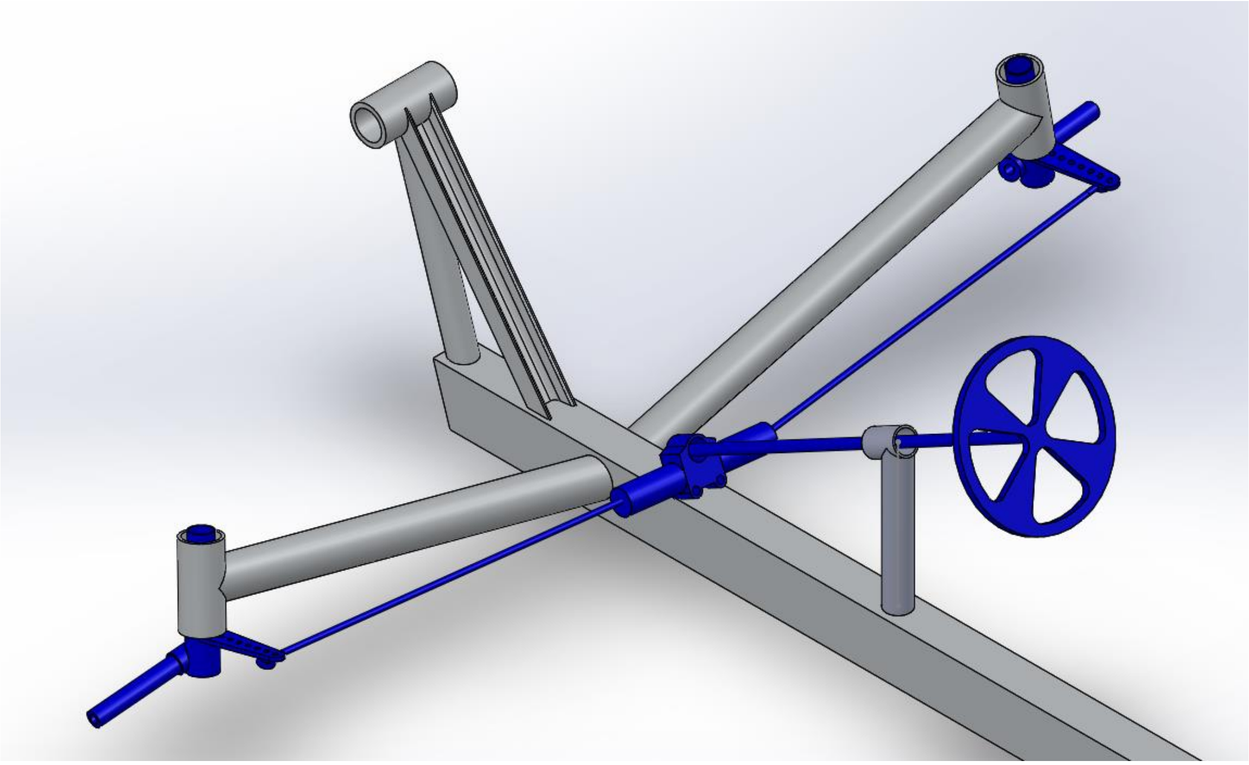


Figure 8- Rack and Pinion

The second design, shown in Figure 9, is a Pitman arm system that uses the same steering wheel as a rack and pinion system. Pitman arm steering systems are often used on go-carts, trucks, jeeps, and other heavy-duty applications. Pitman arm systems work by using the rotational motion of the steering wheel to turn a cantilever arm. At the end of the cantilever arm, two tie rods are attached that transfer motion to the wheels. The benefits of this of system are that it is lightweight. It will also require minimal fabrication and provide minimal play in the steering. One of the problems with this design is that it requires a large input force. Finally, the operator interface will be the same as with a rack and pinion and will have the same obstacles with exiting the vehicle.

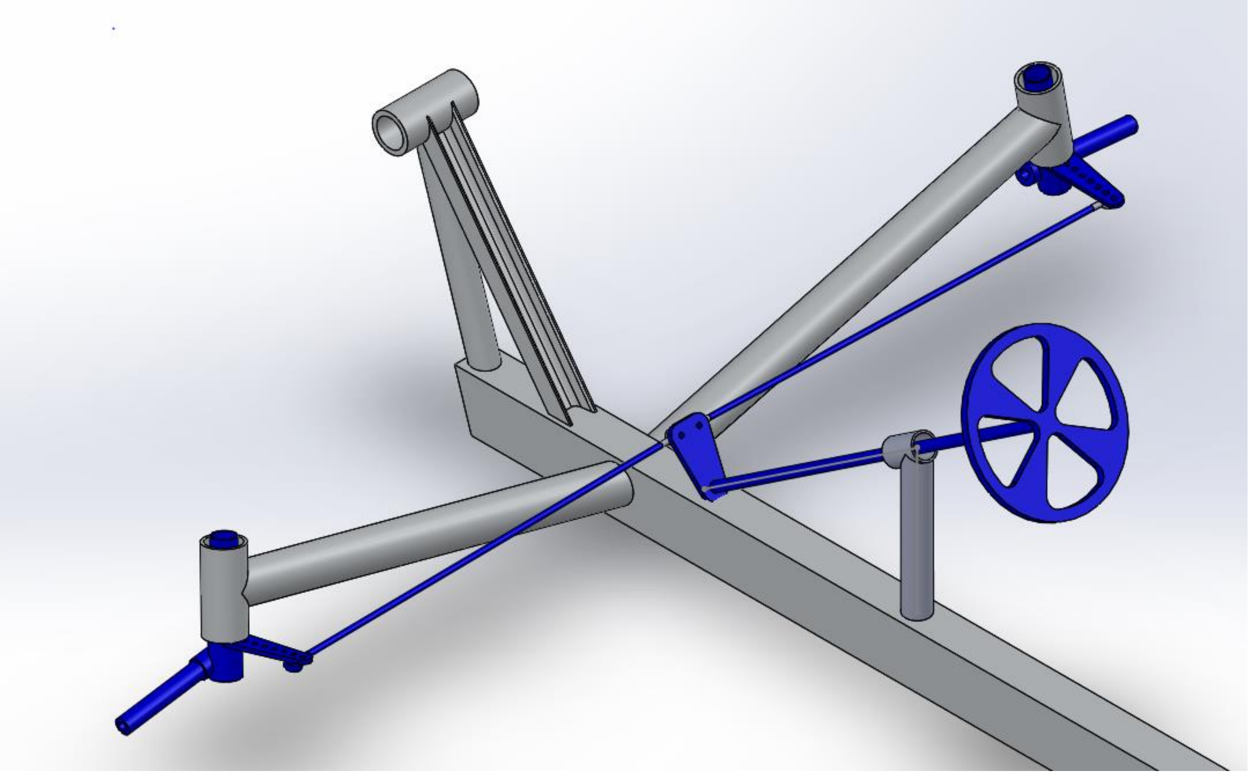


Figure 9- Pitman Arm

The final option is the bell crank push pull system, shown in Figure 10. This design is not directly used on any commercial vehicle the team is aware of. The input system is, however, very similar to that used in a zero turning radius lawn mowers. The operator would have two handles to interface with, where the user pulls right to turn right and pulls left to turn left. This system uses a set of adjustable linkages from the steering arms to turn a central bell crank. The bell crank is a part that is fixed to the frame, but allowed to rotate about a vertical axis. The purpose of this is to transfer the horizontal rotational motion of the steering arms to a vertical axis. The tie rods are then connected to the bell crank, which are in turn connected to the knuckles in the same manner as the previous two systems. The benefits of this system include a wide range of adjustability, as well as large amounts of leverage for easy maneuvering. This system also offers the possibility of folding out of the way for rider egress. The down sides of this system, however, include increased play with an extra set of linkages and extra fabrication time.

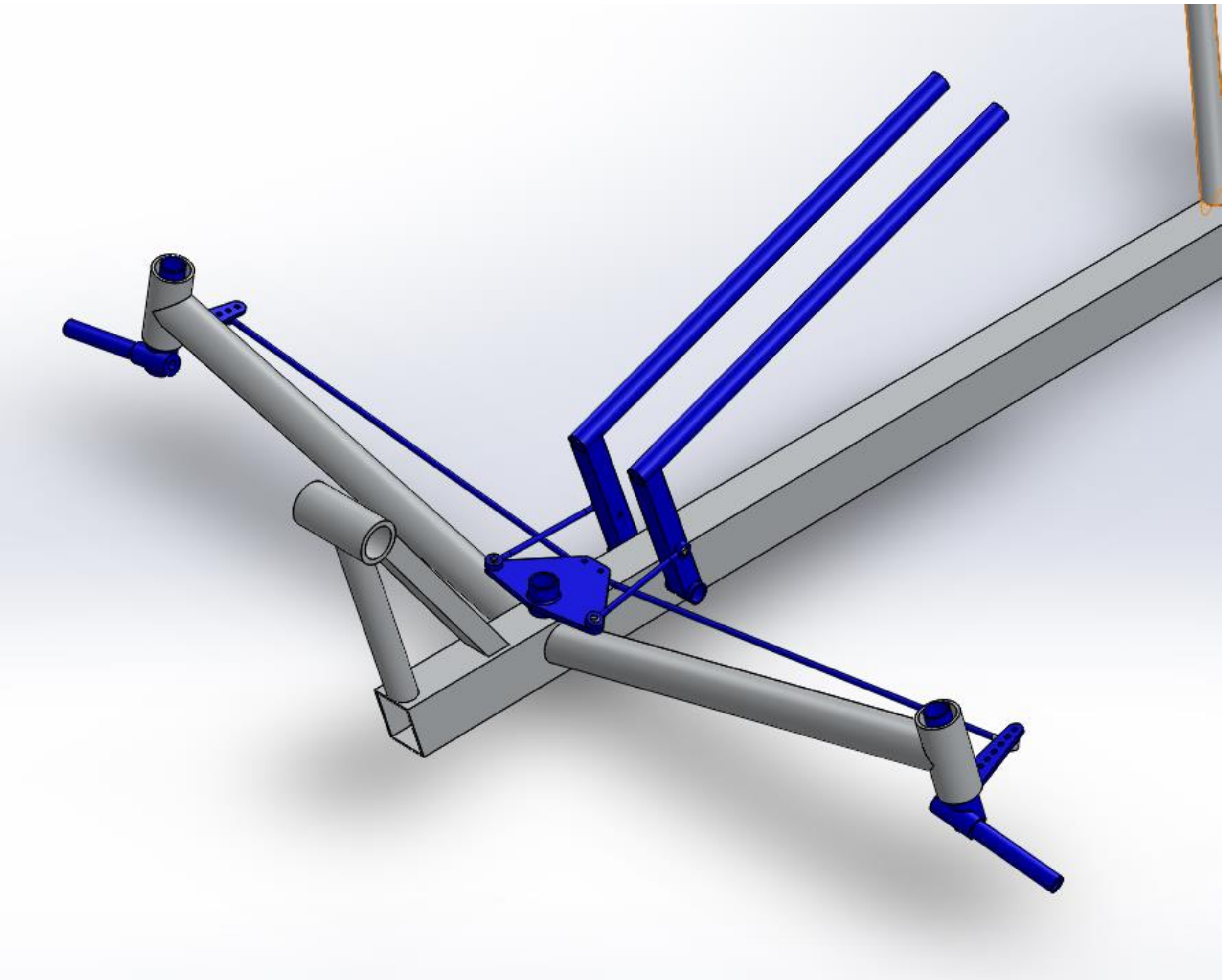


Figure 10- Bell Crank Push Pull

A criteria matrix was created to determine the importance of each section. This matrix is used to create a ranking system to weigh the different designs. The criteria used were: weight, cost, ease of use, ease of exiting the vehicle, fabrication, adjustability, and play. Each criterion was ranked against all of the other criteria on a scale of 0 to 1 with increments of 0.1. Table 5 shows ease of use was ranked highest with weight being of slightly less importance.

Table 5- Steering Criteria

Criteria	Weight	Cost	Ease Of Use	Ease Of Exiting Vehicle	Fabrication Time	Adjustability	Play
Weight		0.3	0.7	0.4	0.1	0.5	0.2
Cost	0.7		0.7	0.8	0.2	0.7	0.8
Ease Of Use	0.3	0.3		0.3	0.1	0.2	0.5
Ease Of Exiting Vehicle	0.6	0.2	0.7		0.1	0.2	0.3
Fabrication Time	0.9	0.8	0.9	0.9		0.8	0.9
Adjustability	0.5	0.3	0.8	0.8	0.2		0.2
Play	0.8	0.2	0.5	0.7	0.1	0.8	
Weight Of Criteria	3.8	2.1	4.3	3.9	0.8	3.2	2.9
Weight Factor	**2/11**	**1/10**	**17/83**	**13/70**	**3/79**	**9/59**	**4/29**

Table 6 compares each of the designs, where each design is given a rank from 1 to 10. The score for a given criteria is then multiplied by the corresponding weight each criterion received in Table 5. The weighted scores for each criterion are then summed to find the total score for each design.

Table 6- Steering Decision Matrix

	Weight	Cost	Ease Of Use	Ease Of Exiting Vehicle	Fabrication Time	Adjustability	Play	
RACK & PINION	2	2	4	2	9	3	4	SCORE
WEIGHTED SCORE	21/58	1/5	77/94	13/35	12/35	16/35	21/38	3.1048
PITMAN ARM	8	3	3	2	7	3	8	
WEIGHTED SCORE	1 17/38	3/10	43/70	13/35	4/15	16/35	1 2/19	4.5619
BELL CRANK PUSH PULL	6	8	7	8	3	6	3	
WEIGHTED SCORE	1 3/35	4/5	1 13/30	1 17/35	4/35	32/35	29/70	6.2476

Based on the scores calculated in the matrix above, rack and pinion was determined to be the worst choice, pitman arm was the second best and the bell crank push/pull system was determined to be the best. Despite its weight, it was the best in ease of use and ease of exiting the vehicle.

DRIVETRIAN DESIGN

The drivetrain subsection of the vehicle design encompasses the component selection and configuration of the vehicle's drive mechanisms. Due to the competition's requirement of the drive mechanism being powered solely by a human operator, the drivetrain will have a configuration similar to a bicycle. This involves the rider pedaling a crank system, as well as having the ability to shift gears to attain higher speeds.

Through the concept generation phase, three key drivetrain designs were researched and evaluated for application within the vehicle. These designs include an internally geared hub, step up gear, and a step up gear with the inclusion of a reverse gear. Figure 11 shows the general configuration of the drivetrain for the vehicle with the difference between each concept involving component selection. For each design considered, location 1 in the figure refers to the crank set and the dotted lines represent the chain line.

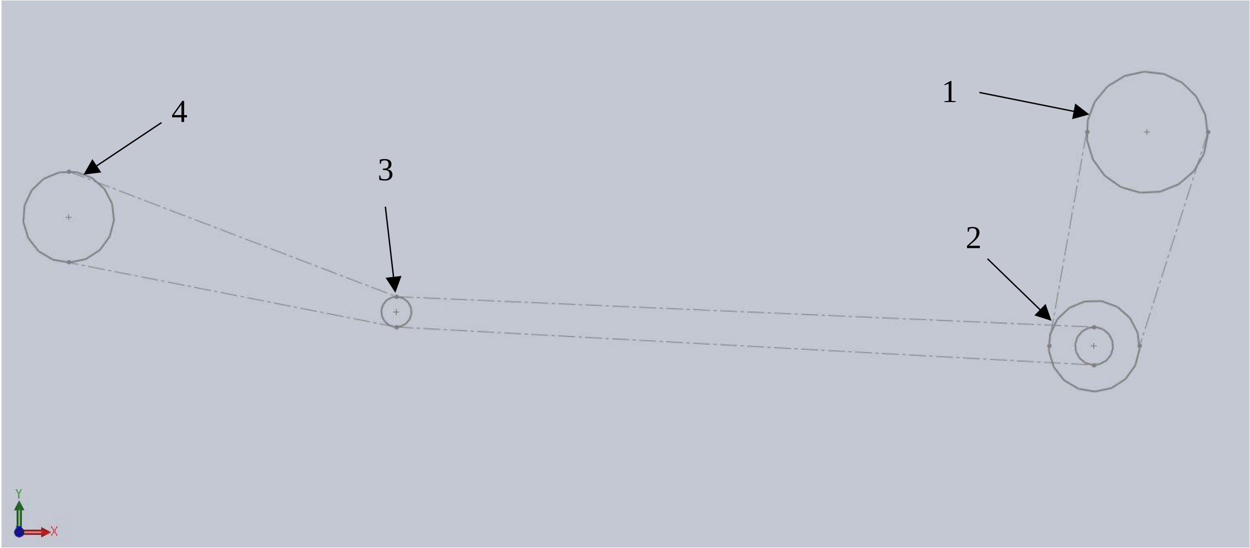


Figure 8- Drivetrain

The first design concept considered was an internally geared hub. This design uses the configuration seen in Figure 11, with location 4 designating the internal hub. This design has the advantages of a constant chain length and protection of gears from the elements. The disadvantages include increased weight, and a drop in efficiency when compared to a standard rear cassette. The efficiency of an internal hub at a given gear is 90.8% compared to 93.1% of a standard rear cassette and derailleur at the same gear [5].

The next design considered was a step up gear configuration, with a standard cassette in the rear. This design focuses on the use of different sized gears in location 2 for improved gear ratios. The advantages of this design include a lower weight, easy bike repair, and the ability to fine tune the gear ratio. The disadvantages include a varying length chain line, and exposure to the elements.

The last design generated was a step up gear configuration with the inclusion of a reverse gear. The layout of this setup would be identical to the step up gear configuration displayed above, except for at location 3, where a clutch system would engage a reverse gear. This design, as seen in Figure 12, allows the idler gear at location 3 to spin freely when not engaged. When engaged through the use of a cable, the shaft would lock and allow direct drive of the rear wheel. This design combines the benefits of the step up gear with the ability to go in reverse.

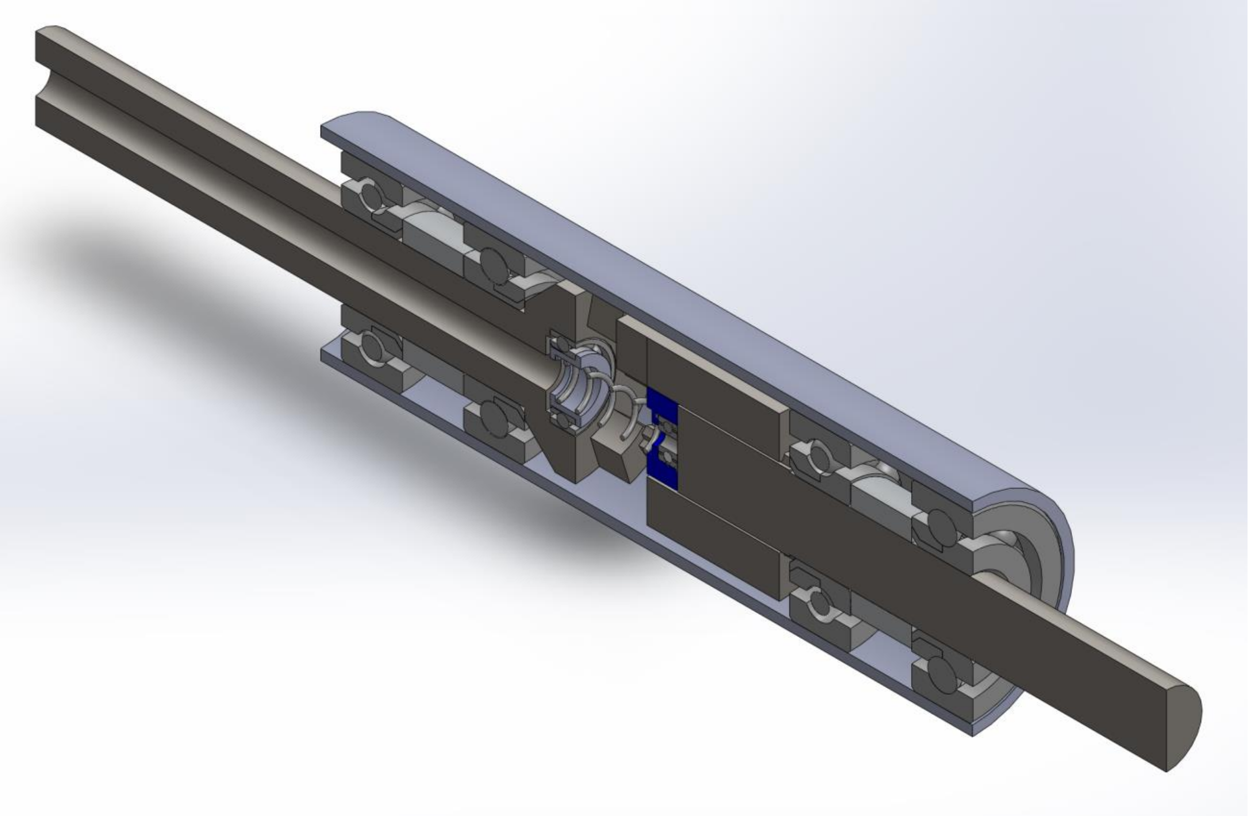


Figure 9- Reverse Clutch

After evaluation of the design concepts, the third design, a step up gear configuration with the inclusion of a reverse gear, was selected. This was chosen due to the added advantage provided by the reverse gear with the benefits of the step up gear. This design will allow a fine tuned gear ratio for maximum speed and maneuverability.

ERGONOMICS

Ergonomics for the human powered vehicle focuses on rider position and comfort. These design aspects are important because they allow the rider to get maximum efficiency with the vehicle while maintaining comfort. A key design aspect established by the team is seat adjustability. The team members vary in height from 5’4” to 6’3” and it is imperative that every member is able to operate the vehicle. With this in mind, the seat design must include a way to adjust the seat quickly to fit the appropriate operator. After brainstorming several designs, three concepts were chosen to be investigated more in depth. These concepts include the type of bracket needed to support the seat while sliding along the frame.

The first concept, as seen in Figure 13, includes rectangular lower brackets and one rectangular vertical tube connected to the mid back of the seat. The lower brackets will slide along the frame to adjust for rider height.

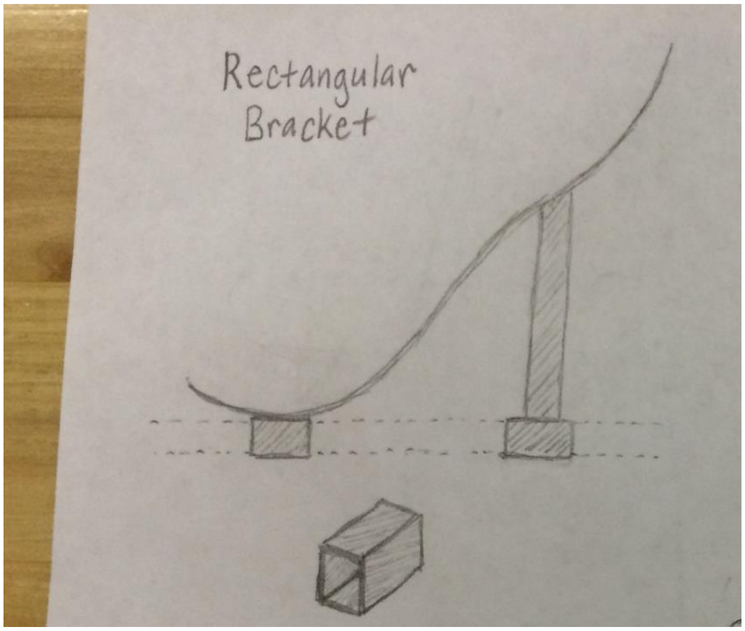


Figure 10- Rectangular Bracket

The second concept, as seen in Figure 14, includes cylindrical lower brackets and one round vertical tube connected to the mid back of the seat. The cylindrical lower bracket provides minimal torsion support for the seat.

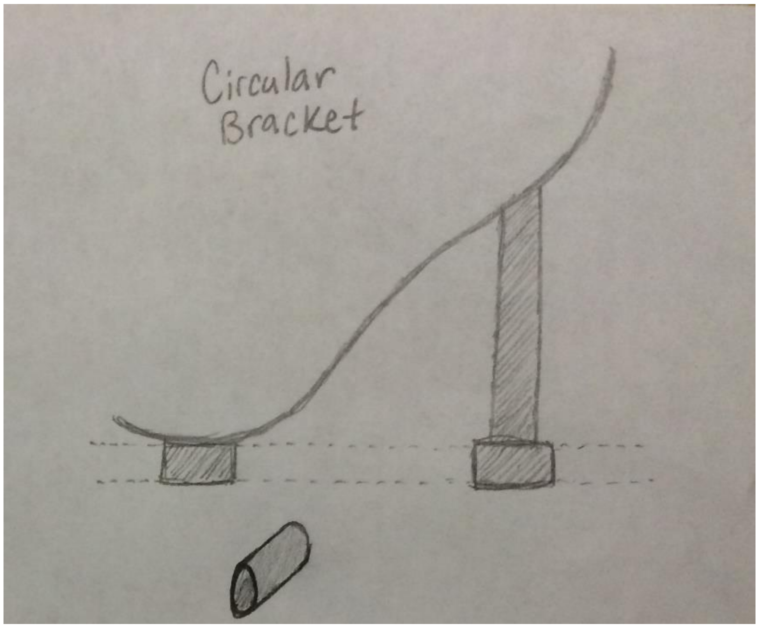


Figure 11-Circular Bracket

The third concept, as seen in Figure 15, includes two side-by-side cylindrical lower brackets and a back support bar. This bracket layout provides greater torsional support. However, this design weighs significantly more.

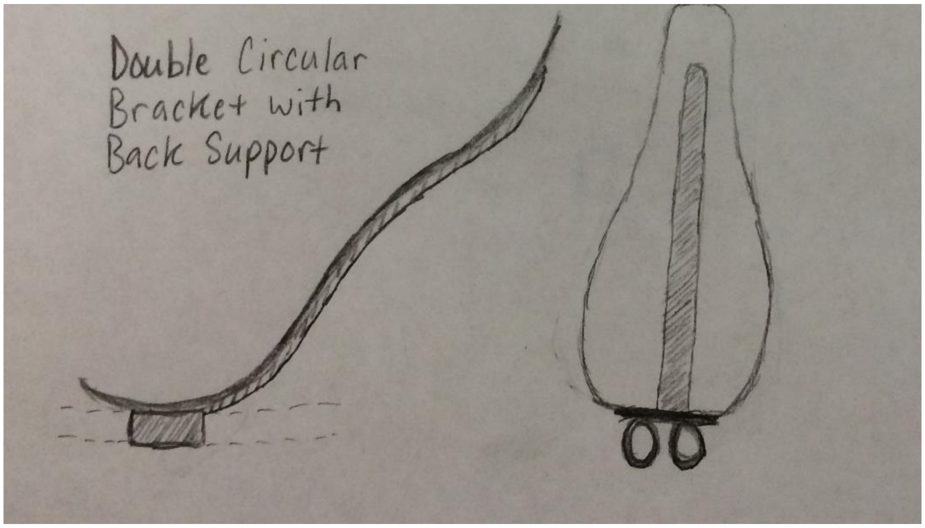


Figure 12- Double Circular Bracket

Due to the dependence of the design for the bottom bracket with the frame design, the rectangular bracket was selected.

One of the most important aspects of ergonomics is the rider position. This pertains to the angle between the rider's back and center tubing of the frame, the rider's chest and center of the cranks, and the center of the cranks and center tube of the frame. The maximum power output from the operator depends on these angles because different muscles are used at different angles. The angle between the rider's back and center tube of the frame will be determined first, as it relates to the rider's visibility. The rider's eye level should be slightly higher than the top of the rider's foot on the pedals. Currently, the team is conducting a test using a trainer bike in the recumbent position that can be adjusted in multiple ways to determine the position that allows for maximum power output. A sketch of this trainer can be seen in Figure 16.

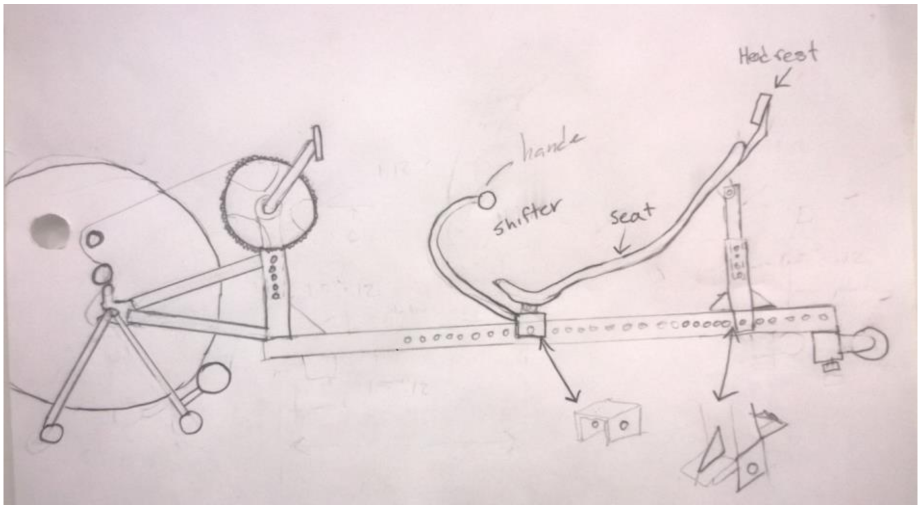


Figure 13- Power Testing Trainer

INNOVATION

Each year, ASME judges set three topics of interest for teams to focus on for the design of a Human Powered Vehicle Challenge (HPVC) entry. In 2014, ASME has placed emphasis on: weather proofing, rider safety, and sustainable manufacturing. The members of the 2014 design team have chosen to pursue each of these topics in the design and fabrication of their entry to the HPVC. Of the three options, a single topic of innovation will be selected for presentation to the judges at competition as our innovative solution to the problem they have identified.

While none of the designs conceived under the innovation subsection are critical to the basic operation of the vehicle, these concepts will work to further improve human powered vehicles as a viable, safe, and comfortable replacement for traditional automobiles. The team will be drawing much of its’ inspiration from the automotive industry, while still remaining loyal to the environmentally friendly, health conscious culture associated with human powered vehicles.

ASME has intentionally allowed teams to interpret the term weatherproofing openly, leaving no constraints on which direction teams may pursue. This year the team chose to focus their weather proofing solutions towards high temperature and rainy operation.

During research, the team identified how critical it is to adequately cool the operator if high power output is desired. A ducting system that allows external air to enter the fairing volume was devised. However, this concept alone would not prove beneficial in hot operating environments. Furthermore, open ducts could allow moderate amounts of precipitation to enter the fairing.

Subsequently a servo operated, closing duct design was developed. This will allow the vent to shut during cold or wet operating environments. The ability of the duct to close also gives the rider the option to close off the system when lower aerodynamic drag is of greater benefit than increased cooling.

For operation on days that are excessively warm, the team considered methods for cooling the incoming air to a temperature below that of the ambient, surrounding air. This temperature decrease would increase heat transfer between the operator’s skin and surrounding air. While the incoming wind velocity will improve the evaporation sweat, further cooling the operator.

A finned cold block and evaporative cooling solution will be explored as methods for cooling the incoming air. However, neither solution may be viable if further analysis determines that, for the system to be effective, either its size or mass is unreasonably large for the application. A preliminary model of the proposed duct and finned cold block can be seen in Figure 17.

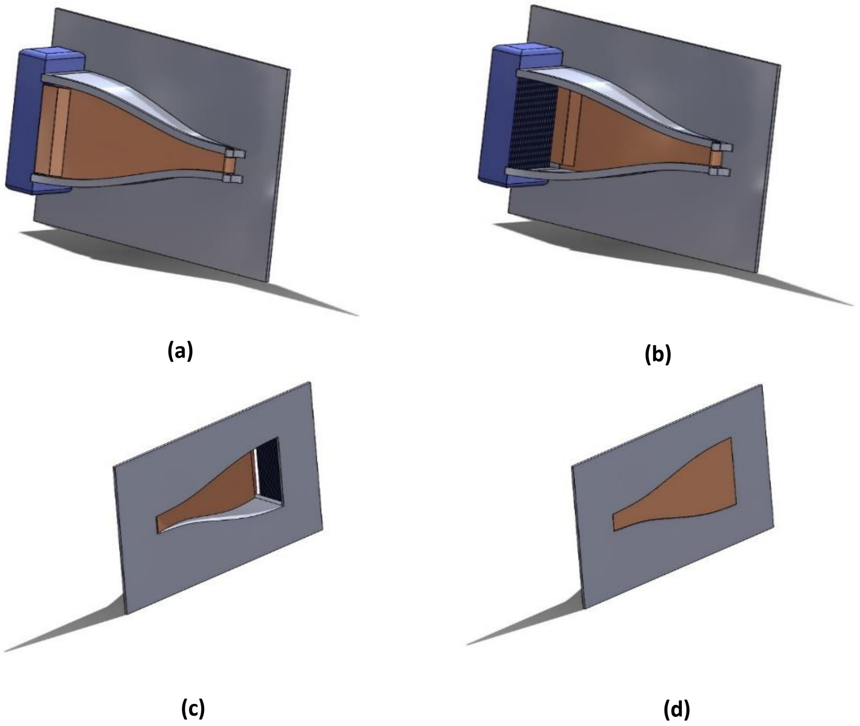


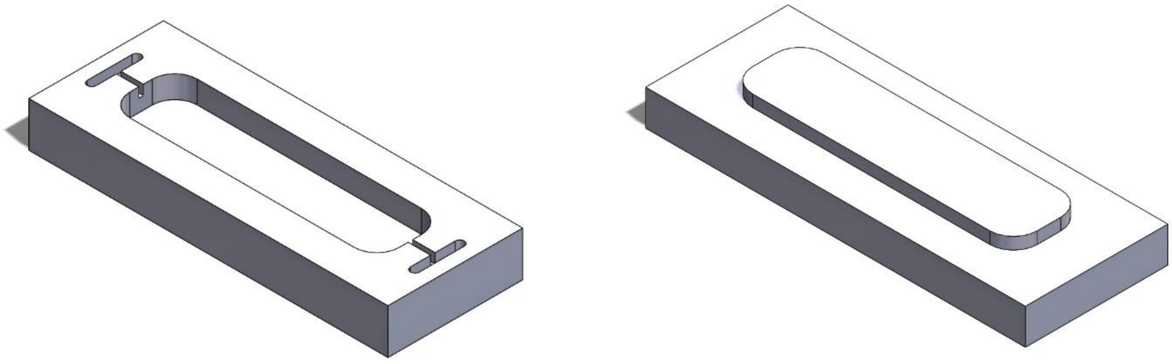
Figure 17- (a) Interior Vent Open, (b) Interior Vent Closed, (c) Exterior Vent Open, (d) Exterior Vent Closed

One of the most beneficial aspects of automobiles is their ability to keep their operators relatively comfortable under adverse conditions; meanwhile bicycles perform poorly in this area. Team members will attempt to design a vehicle that will be completely watertight while operating during rainy weather. This will require any openings to the outside to be closed and sealed during a rain storm.

Another feature seen in automobiles that the team wishes to incorporate is the ability to communicate driver intentions. For optimal safety, the team has chosen to outfit the vehicle with a fully functional light communication system, including: headlights, taillights, brake lights, and turning signals. Low drag side view mirrors will also be installed to further increase driver awareness.

Sustainable manufacturing refers to the team's ability to construct the vehicle with a minimal impact on the environment. Because incorporating all contemporary methods of sustainable manufacturing is out of the scope of this project, the team chose to focus its efforts on one, popular aspect of this methodology, waste. Specifically, team members will focus on the minimization of waste and the recycling of materials previously deemed unusable. This methodology will extend through all aspects of the design and construction of the vehicle.

Team members have identified abundant sources of useful materials in not ideal states. These include: metal shavings, metal scraps, various plastics, carbon fiber, and fiberglass scraps. The team will explore the viability of combining these materials to form a new composite material that has improved properties relative to the raw forms of the source materials. In the event such a combination is identified, it will be utilized on the vehicle when appropriate. Figure 18, shows a mold that has been fabricated for testing of material combinations.



(a) **(b)**

Figure 18- (a) Test Mold Bottom, (b) Test Mold Top

Aluminum castings fabricated from scrap metal chips are also under consideration. Vehicle parts that require machining produce considerable amounts of waste that is generally discarded. The team is evaluating the possibility of collecting this machining waste and recasting this material into new parts.

PROJECT SCHEDULE

The team is currently on schedule to complete the design phase of the project by 2013 winter break; meanwhile some sections of the project are currently ahead of schedule. The team will try to stay on track through the completion of the project in May 2014. The Gantt chart can be found in the Appendix, which displays current progress on each task listed. It will be updated throughout the project to reflect the progress completed.

CONCLUSIONS

Team 9 has researched and identified the components required to produce a human powered vehicle capable of excelling at the ASME HPVC. The vehicle will have the ability to safely maneuver the dangers of heavy city traffic while providing a relatively low budget alternative to automobile based transport.

The team intends for the designed vehicle to be capable of traveling at 40mph on flat ground using nothing but human power. In order to attain such speeds, drag on the vehicle must be significantly lower than of a traditional bicyclist. The team’s decision to pursue a fully faired recumbent tricycle will make these goals attainable. When compared to a traditional cyclist the recumbent position provides a drastically decreased projected frontal area, combined with the streamlined shape of a fully enclosed fairing, the final vehicle should be capable of speeds well in excess of those of a traditional cyclist. The inclusion of a bell crank steering system will allow the rider precise control over the vehicle without requiring constant focus to stay on a desired path. A test proven, power optimized rider position, will ensure the rider expends a minimal amount of energy for maximum power output. Meanwhile, a high efficiency drivetrain should ensure that minimal power loss occurs during the transmission of power to the wheel. The investigation of a reverse gear could lead to additional safety in combination with the headlights and brake lights installed on the vehicle. Continued research into the fields of sustainable manufacturing and operator cooling systems could lead to features that further set the vehicle apart from its’ competition. With all of the innovative and efficient design concepts, the team is on track in creating a vehicle that can be used as a daily mode of transportation.

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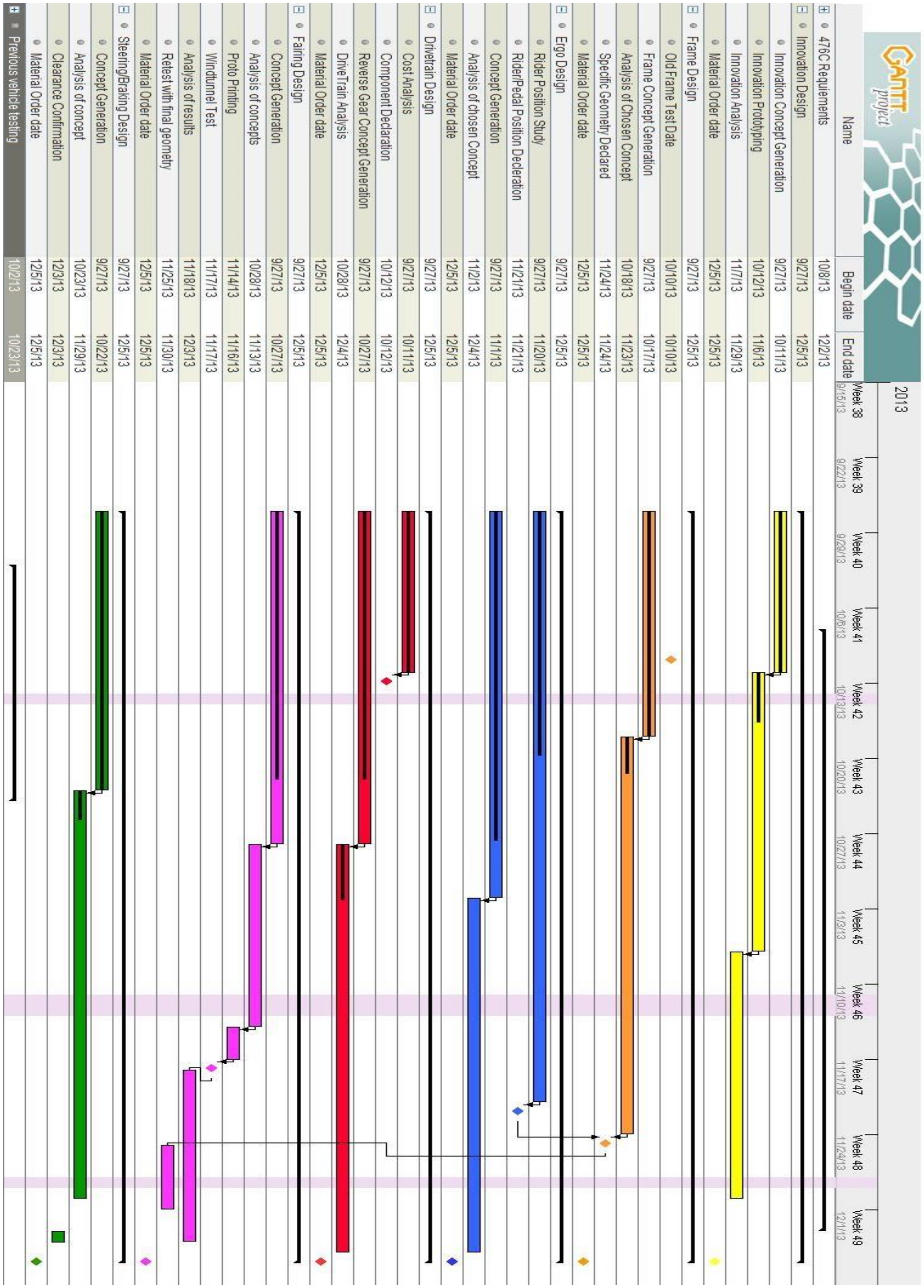
APPENDIX

Gantt Chart



Name	Begin date	End date
476C Requirements	10/8/13	12/2/13
Innovation Design	9/27/13	12/5/13
Innovation Concept Generation	9/27/13	10/11/13
Innovation Prototyping	10/12/13	11/6/13
Innovation Analysis	11/7/13	11/29/13
Material Order date	12/5/13	12/5/13
Frame Design	9/27/13	12/5/13
Old Frame Test Date	10/10/13	10/10/13
Frame Concept Generation	9/27/13	10/17/13
Analysis of Chosen Concept	10/18/13	11/23/13
Specific Geometry Declared	11/24/13	11/24/13
Material Order date	12/5/13	12/5/13
Ergo Design	9/27/13	12/5/13
Rider Position Study	9/27/13	11/20/13
Rider/Pedal Position Declaration	11/21/13	11/21/13
Concept Generation	9/27/13	11/1/13
Analysis of chosen Concept	11/2/13	12/4/13
Material Order date	12/5/13	12/5/13
Drivetrain Design	9/27/13	12/5/13
Cost Analysis	9/27/13	10/11/13
Component Declaration	10/12/13	10/12/13
Reverse Gear Concept Generation	9/27/13	10/27/13
DriveTrain Analysis	10/28/13	12/4/13
Material Order date	12/5/13	12/5/13
Fairing Design	9/27/13	12/5/13
Concept Generation	9/27/13	10/27/13
Analysis of concepts	10/28/13	11/13/13
Proto Printing	11/14/13	11/16/13
Windtunnel Test	11/17/13	11/17/13
Analysis of results	11/18/13	12/3/13
Retest with final geometry	11/25/13	11/30/13
Material Order date	12/5/13	12/5/13
Steering/Braking Design	9/27/13	12/5/13
Concept Generation	9/27/13	10/22/13
Analysis of concept	10/23/13	11/29/13
Clearance Confirmation	12/3/13	12/3/13
Material Order date	12/5/13	12/5/13
Previous vehicle testing	10/2/13	10/23/13