ASME
Human Powered Vehicle

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Mid-Point Review
Document

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Introduction

There is a need for engineering efficient, reliable human powered vehicles in order for people to commute and transport goods. The goal of this project is to eliminate vehicles by designing a safe, efficient, and reliable vehicle that can be powered solely by the rider. The objective is to design this vehicle so that it meets the ASME Human Powered Vehicle competition rules, and is as light, strong, and fast as possible to win every competition entered. The constraints include not being able to use any vehicles from previous years, and it must be able to compete in both the speed and endurance events at the competition. Vehicles are typically made of metal alloys, composites, or a mixture of both, with a recumbent riding position and have a streamline design to minimize aerodynamic effects. The main criteria taken into account for the vehicle include the frame design, steering geometry, the material of construction, power input, fairing design, and seating position.

The competition will take place April 22nd-24th in San Jose, California at unique locations specific for the different competitions. There, the judges will test all of the vehicles for safety, structure, design, innovation, etc. and each team will compete in the men's and women's sprint and 2.5 hour endurance races.

Current Project Status

As seen in **Figure 1** below, the main frame is complete with the three wheels attached and the seat in predicted position. The next steps are to install the drive train, and the rest of the steering components before construction on the fairing begins.

Figure 1 - Current Construction

Description	Cost
Steel Plate, Aluminum Plate, Steel rod, Bearing, Adapter	$289.00
Derailer Hanger	$17.00
Heim Joints	$83.00
Lights	$68.00
Chromoly Steel	$300.00
Cranks, sprockets, caset, shifters, brake, chain	$1,010.00
Total	$1,767.00

Figure 2- Money Spent

Figure 2 above shows all of the parts that have been purchased to build the bike to where it is currently. The team is still on track to stay within the original budget for the entire project.

Solidworks Models

Figure 3 shows the Solidworks model that was created at the very beginning of the design process. The original design was a lot shorter and the roll cage was very simple compared to the final design shown in **Figure 4**. The current design has an angled roll cage and is more detailed with the position of each component. This model is the built version shown in **Figure 1**.

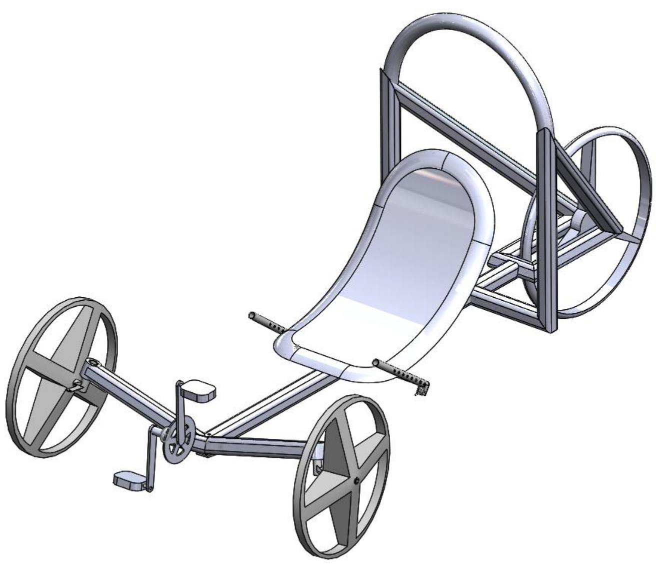

Figure 3- Original Proposed Design

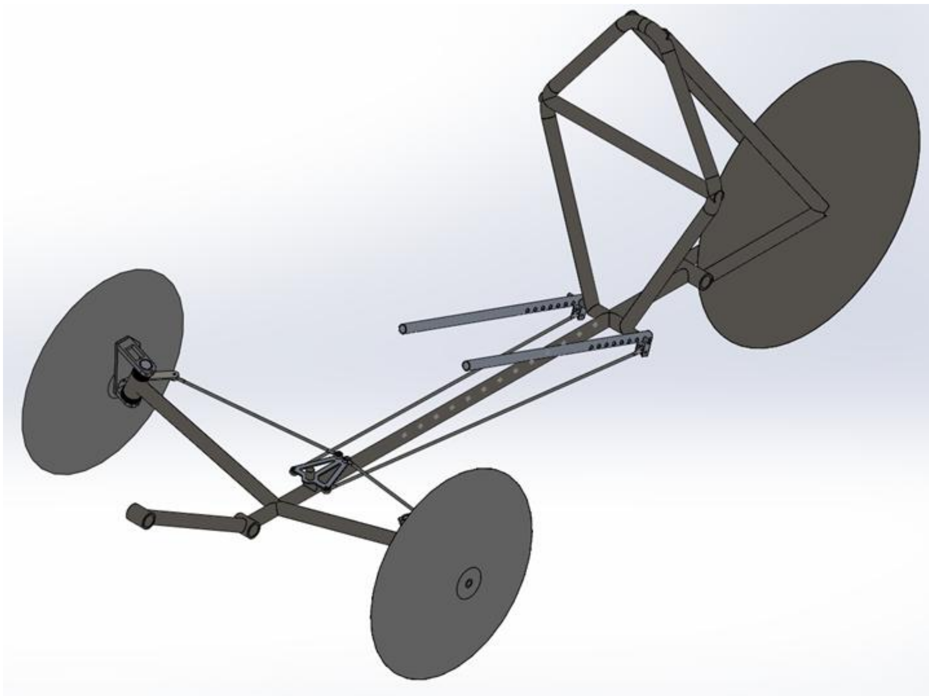

Figure 4- Current Design

Frame

The first step was to design the frame using SolidWorks so that all the dimensions and angles were finalized. Simulation of the cranks and steering were implemented to ensure there would be no interference issues with any of the tube members. **Figure 4** displays the finalized assembly model of the frame with the implemented steering. The overall dimensions of the frame are 95 inches in length, 35 inches high, 40 inches in width, and assumed to weigh 35 pounds.

Once the assembly model for the frame was completed, Finite Element Analysis (FEA) was conducted to analyze the stress in the members and ensure the frame was structurally sound. The simulation was tested in ANSYS under the assumption of a 400 pound load placed in the rider's position with the wheel supports acting as fixed displacements. The result gave a maximum deflection of 0.323 inches at the center of the frame; which is well with an acceptable range giving it an approximate factor of safety of 2. The ANSYS simulation can be seen below in **Figure 5**.

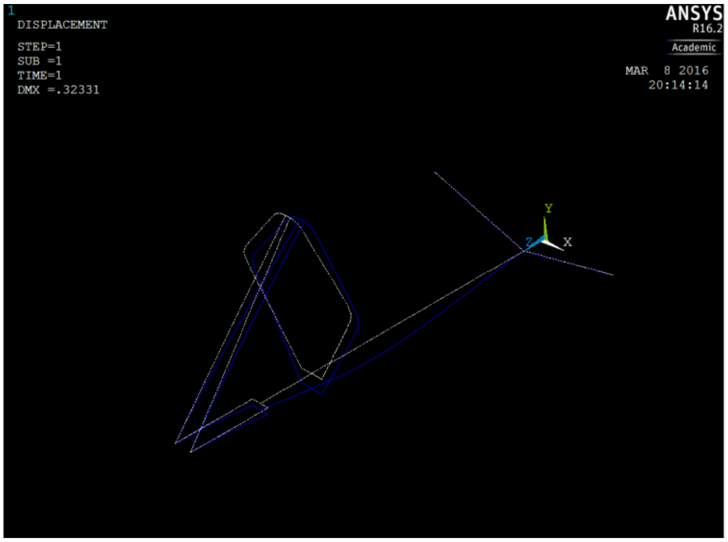

Figure 5- FEA Analysis

The frame was constructed using hollow tubing of Chromoly steel. The steel tubes were cut to length, notched, and finally welded together using a Tungsten Inert Gas (TIG) welder. Each weld required accurate angle precision for the support arms and the role cage to ensure proper alignment. Using steel for the frame proved beneficial because steel is easy to weld and does not require heat treatment. **Table 1** shows how Chromoly compares to other steels that were considered for the frame in yielding strength and tensile strength.

Table 1-Tensile vs Yielding Strength

Material	Tensile Strength (psi)	Yield Strength (psi)
Chromoly Steel	81200	52200
1018 Steel	63800	53700
A36 Steel	58000	36300

To ensure the frame would not fail test welds were conducted to prove welding capabilities. Welds were done using Chromoly steel as simulations of joints. The joints were inspected to ensure full penetration between the two surfaces and failure happened at the material before the weld. If the weld broke before the material, the weld failed. **Figure 6** shows a test weld conducted that broke at the material before the weld.

Figure 6- Test Weld

The main structure of the frame is consisted of a long main tube running down the center from front to back with two side arms at the front. The side arms were welded 15 degrees from horizontal and five inches from the second bottom bracket to ensure no interference with the sprocket. Holes were drilled two inches from each other along the main tube for adjustable seat positioning and end at the base of the roll cage. The roll cage is shaped like a coffin and has bends at the midpoint (70 degrees) and at the top (54 degrees). The roll cage is also angled eight degrees from vertical towards the rear wheel and supported with two rear beams to prevent any buckling. Dropouts were manufactured on CNC machines to hold the rear wheel. One dropout was manufactured with holes for a derailleur to be attached and is shown in **Figure 7**. Each dropout is welded on the inside of the rear support beams.

Figure 7 - Dropout

Steering and Steering Theory

Prior to any discussion of steering theory and design, it is first necessary to establish the terminology used to describe steering components. **Figure 8** illustrates the terms that will be used in this paper.

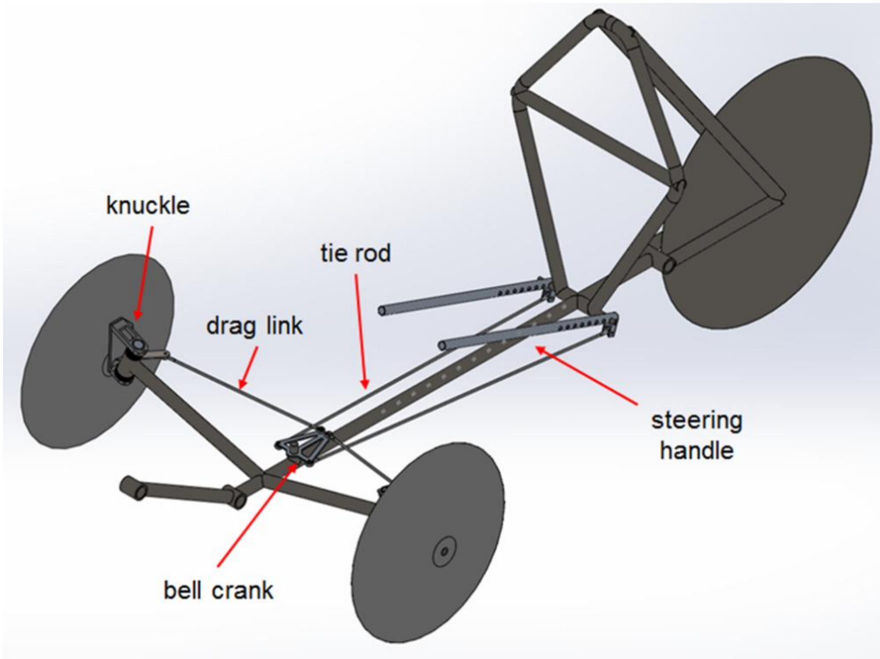

Figure 8 - Steering Component Names

The majority of the details of steering design are contained within the knuckles, which have their own terminology as well. **Figure 9** illustrates the language of that component.

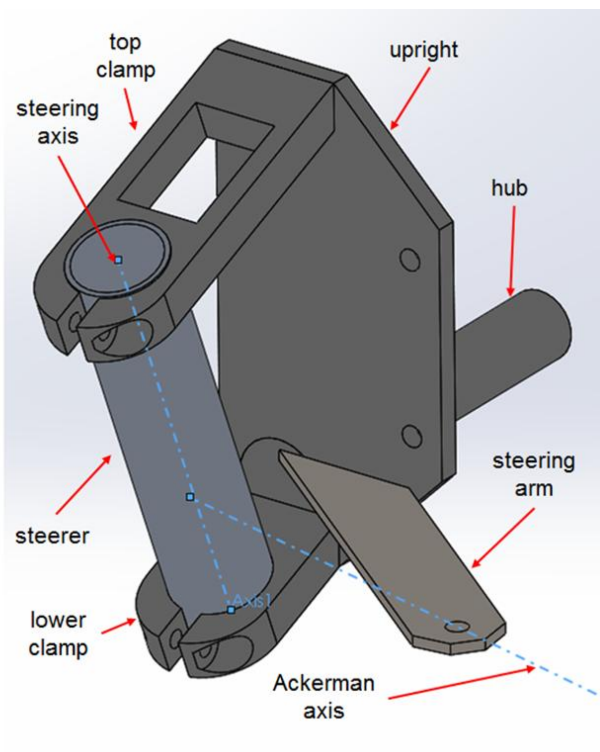

Figure 9 - Knuckle Component Names

The challenge of steering design is to guide the vehicle around a corner as accurately and efficiently as possible. Therefore, the steered wheels must be aligned in such a way as to minimize conflicting lateral friction forces throughout their entire motion. The basic approach to achieving this alignment is Ackerman geometry, in which a line normal to all wheels meets at the center of the arc the vehicle is following. Ackerman geometry is also known as the kinematic steering condition because it does not account for the dynamic forces encountered in a real-world turn, which tend to transfer weight from the front inner tire to the front outer tire as well as counter the centripetal force of the turned wheels (causing slippage). Those dynamic effects become more and more important as the speed of the turn and the mass of the vehicle increase. Because this vehicle is relatively light and slow in relation to its traction, we can assume the kinematic steering condition without significant error. However, another issue remains: Ackerman geometry cannot be achieved with simple mechanical linkages, it must be approximated. This is done by setting up the knuckles such that the "Ackerman axes," lines drawn through the steering axis and the connection of each steering arm to its drag link, intersect in the middle of the rear axle (**Figure 10**). While that sounds simple enough, the steering axis is inclined. This means that the vertical location from which the Ackerman axis has begun changes the design of the steering arm significantly. Most literature does not discuss the impact of steering axis inclination on Ackerman geometry, but this design assumes that the Ackerman axis lies completely within the plane of the steering arm for the reason that the arm is a lever, and levers can only act in one plane.

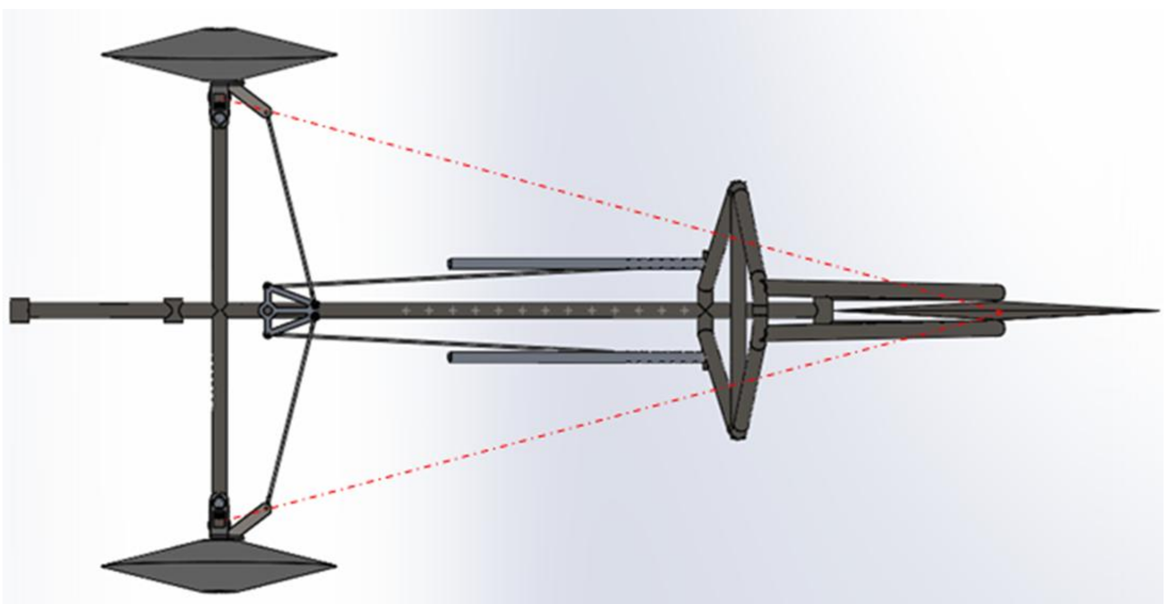

Figure 10- Ackerman Geometry

Although parenthetical, at this point it is pertinent to note that the number of rear wheels is not significant, as rear wheels do not pivot relative to each other and therefore share an axis.

The steering system is on schedule to be completed well prior to competition. The knuckles represent the vast majority of the manufacturing time and have both been completed. All that remains to be completed are the bell crank, steering handles, and drag links and tie rods. These components will all be made of aluminum because there are no welded components with tight geometric tolerances.

Fairing Plans

The fairing is used to make the vehicle more aerodynamic by reducing the drag force. Below, **Figure 11 and 12** show the two proposed ideas for designing the vehicle fairing. The design will be dependent entirely on time constraints before the competition and ease of construction. The fairing will completely encapsulate the bike and have front and side windows to help the driver see all their surroundings at all times. The budget for the fairing is approximately $2,000 but the goal is to construct it as cheap as possible

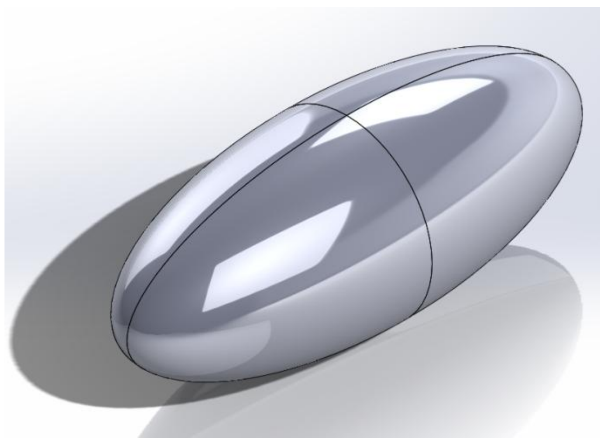

Figure 11 - Egg-Shaped Design

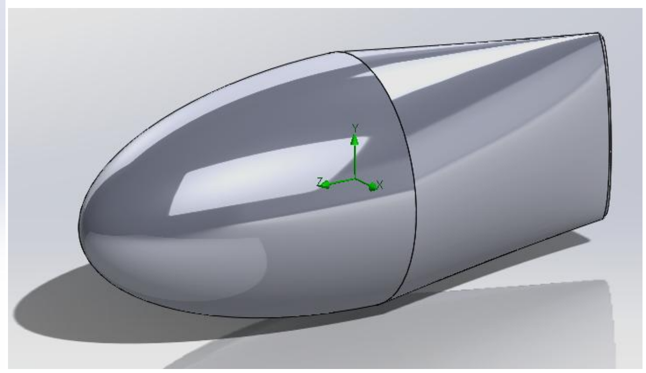

Figure 12 – Tail Fin Design

Conclusion

The Solidworks model has been thoroughly updated to match the exact design and construction that is done today. The project is on track for completion prior to competition, and is within budget set at the beginning of the design process. Chromaly steel was used for the frame because of its material properties and it was what was available for our time constraints. An ANSYS stress analysis shows that the frame should have a maximum deflection of 0.323 inches given a 400 pound stress exerted on the middle of the entire structure. The steering system has been redesigned for efficiency and stability, and will be completed next. The fairing will be built to protect the rider and help reduce drag to increase the aerodynamic efficiency and will begin being constructed after all the details with the frame and steering are finalized.

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