Human Powered Vehicle

Concept Design Report

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Executive Summary

Every year the American Society of Mechanical Engineers (ASME) hosts a competition called the Human Powered Vehicle Challenge (HPVC). The goal of the competition is to design and build a vehicle that runs completely on human power. The competition is comprised of four sections. Winners are chosen for each event individually, and for the overall competition. These sections are: (i) speed/drag race event, (ii) endurance race event, (iii) a design challenge, (iv) innovation challenge.

The speed/drag race event will determine each team's top speed in a rolling start style race. There will also be a head-to-head drag race style tournament to see who crosses the finish line first. The endurance race will be a closed course track with several obstacles like cones, turns, and speed bumps. The race will be a 2.5 hour long relay race and the winning team will be determined by completed lap count. The design challenge will score teams based on their engineering skills. Teams with well built machines will be rewarded for their attention to detail. The innovation challenge calls upon leading advances in technology. Teams will choose one aspect of their vehicle to submit as their innovative component. Scores will be rewarded for teams who truly created something innovative, as well as how well the innovation works.

Our team chose to create a tadpole trike; referring to a vehicle with two wheels in the front and one wheel in the rear. Our vehicle will be set up for speed. The rider will be in a recumbent position, meaning the rider will be laid back and pedal with their feet in front of them. With the

rider in a low seating position, the frontal cross section of the vehicle is much smaller, thus allowing a streamlined aerodynamic shell to be built and attached around the frame. This shell will completely encase the rider, with windows for visibility and air ducts for ventilation.

Based on our design, the vehicle will be very competitive in the race portions of the competition. With help of Catrike, a local manufacturer of recumbent trikes, our team aims to implement sound engineering and be competitive in the design portion as well. For the innovation challenge, the team intends on building an automatic braking system. Our goal is to introduce a system that will safely avoid collisions with objects in the trike's path. We intend on using a combination of sensors to detect objects in the trike's path and their distances from the vehicle in real time. A computer will compile the information from the sensors and send information to a motor, which will be mechanically attached to a brake.

Currently, the team has finalized the design of the frame and chosen most of the major components for the build. The frame tubes are on track to be bent, cut and welded together by the beginning of the spring semester. Assembly of the frame, wheels, and drivetrain components will begin simultaneously with the design for the aerodynamic shell.

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Terms and Abbreviations

1. **Trike** - A three-wheeled vehicle
2. **HPV** - Human Powered Vehicle
3. **HPVC** - Human Powered Vehicle Challenge
4. **OSS** - Over Seat Steering
5. **USS** - Under Seat Steering
6. **DKS** - Direct Knuckle Steering
7. **RPS** - Rollover Protection System
8. **ASME** – American Society of Mechanical Engineers

1. Introduction

Every year, the American Society of Mechanical Engineers (ASME) hosts a competition known as the Human Powered Vehicle Challenge (HPVC). This competition is hosted in four locations: two in the United States and two internationally. The University of Central Florida is one of many schools to participate. The objective of this event is aimed to advance and increase the use and relevance of Human Powered Vehicles (HPVs) by providing unique guidelines, obstacles and challenges that show the full potential of engineering students.

HPVs vary widely in their design, shape and size. However, they all retain the same fundamental idea - to efficiently apply human power and create a viable form of transportation. A widely known form of human powered transportation is the bicycle, and HPVs seek to deliver a positive alternative to bikes and standard automobiles for commuting. The HPV is mechanically designed to be a recumbent vehicle. In a recumbent position, the rider is laid back with his or her feet out in front. For the competition, teams are required to create a two- or three-wheeled vehicle design that agrees with the team decisions. Based on our team's frame design and other important decision-making factors, we went with a tadpole recumbent trike design. Trikes are machines that are capable of reaching speeds up to 40 mph with the driving power through the legs only. They provide more stability than bicycles due to their third wheels. Tadpole designs have two

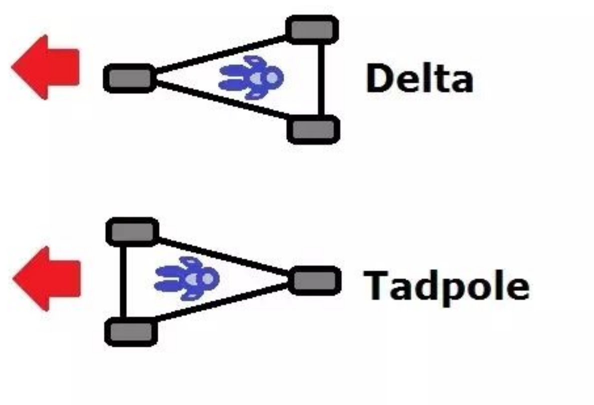

Figure 1: Tadpole vs. Delta

wheels in the front and one wheel in the back. This is opposed to a delta trike design, where the two wheels are in the back instead. Due to the recumbent position, trikes also deliver a more comfortable experience than bicycles over long periods of time. For students to achieve an effective design, intricate engineering skills and sophisticated concepts are used, along with a background knowledge of aerodynamics to construct a fairing for the trike. The fairing is designed around aerodynamic principles to ensure that the vehicle is as aerodynamic as possible with the constraints set by the structural frame.

The purpose of the frame is to support the rider and certain vehicle components. A Rollover Protection System (RPS) is implemented and acts as the "outer skeleton" of the design. This is a safety mechanism needed in the case of a turnover. The fairing and the frame are considered the two most important pieces to a trike design. Some concept designs include combining these two into one. But for our particular project, they will be made separately and then fit together in the building process. Our team's fairing will be removable for the different events in the competition.

In total, The HPV competition has four main events. The speed event provides teams with the opportunity to demonstrate the top speed of their vehicles. The fairing will be used to maximize speed and stability during this race. The endurance event allow teams to demonstrate the functionality, agility, and durability of their vehicles. The fairing will likely be detached for this event. However, our team may consider a partially detachable fairing instead. The design event is to allow teams to demonstrate the established principles of design engineering that went into the development of the vehicle. And finally, the innovation event gives teams the opportunity to implement a unique attachment or idea that allows their team's vehicle to stand out among the rest of the competition. Prior to the competition, our HPV team will be involved in the manufacturing and testing processes, with a heavy focus on the aerodynamic fairing. The Senior Design Foam Cutting will be helping our team form the shape of our fairing of choice.

For this project, our team must work to ensure that all requirements are met. This includes requirements set forth by the Senior Design coordinator, the faculty advisor, ASME, and sponsors. The HPV sponsor is Catrike, and they will supply the spindles, adjustable boom, and help with the bending and welding process of the frame design. The HPV team must collaborate in a timely manner with the Foam Cutting team to ensure a successful build of the aerodynamic shell. Also, team members must work effectively to perform adequate testing prior to the competition. The testing phase will commence at the beginning of the spring semester. Testing will include braking system tests, RPS testing, fairing testing, performance safety, and other non-mandated tests that help guarantee the overall success of the vehicle.

This report will outline system requirements that will be incorporated in the design stage. Decisions for certain aspects of the design, including wheel and steering configurations, will be discussed. Finally, assessment evaluations and future recommendations will be mentioned to carry over elements of this Senior Design project into works beyond graduation. The overall takeaway of the Human Powered Vehicle Challenge is to demonstrate the planning, analyzing and innovation phases of a unique engineering objective.

2. Needs Analysis

Transportation is always evolving in today's society. From bicycles to automobiles, people are always finding better ways to move around. Gas-powered vehicles have dominated in the past century, but alternatives exist that provide other advantages over mainstream vehicles. In general, trikes require no gas or other form of input power except human power (we are not concerned with motorized variants). Vehicles will typically require instruction manuals for their complex user controls and other features that exist. The simple controller layout that trikes provide allows new users to become familiar and accustomed to the controls with ease. Trikes are closely related to bicycles in how they function. The main requirements for performance include rider position, steering and gear shifting. Generally, consumers will be satisfied with products that are user friendly.

Bicycles are relatively close in comparison with trikes in how they function. However, trikes have qualitative characteristics that set them apart from bicycles. The recumbent position of the rider allows for longer trips without pain or ache. Bicycles typically put the user in an upright position and work different muscle groups than users in recumbent positions. However, there are exceptions for bicycles with similar recumbent designs. Generally, these designs are still less stable.

Recumbent trikes provide more stability for the user due to their three-wheeled design. Therefore, trikes become a suitable option for people who are less experienced with human powered vehicles that require a certain level of balance. Older individuals may tend to look away from vehicles that have a balancing requirement.

Cost also plays a key role in consumer choice. Mainstream vehicles usually run on gas or electricity, which becomes very costly over longer periods of time. Prices for trikes can range from hundreds to thousands of dollars, depending on the features and design structure. However, fuel is not an issue because it is not needed for operation. Overall, a trike can be an inexpensive in the long run, and they are a viable form of transportation for consumers who wish to find a feasible way to get around in short to medium distances. This assumes that the trike is properly taken care of and kept in an environment that prevents rust or other forms of deterioration.

Providing a best fit for transportation is not the only trait that trikes yield for their users. Other categories of consumers exist for the demand of these vehicles. The most popular reason for trike purchases include their ability to provide a healthy lifestyle. In modern society, people may find it unrealistic to have trikes as a viable source of transportation, but this is not the determining factor for all consumers. Because human power is the only driving force, trikes provide a great form of exercise for active individuals. Unlike bicycles, trikes work to enhance different muscle groups in the back and legs due to the recumbent position of the rider. Alternate forms of trikes exist that cater toward different exercising needs. One example includes trike scooters, where the hip muscles are the primary working muscles. Typically, bicyclists ride bikes for exercising purposes, and the same is true for trikes. Trikes offer movement and endurance in a unique fashion Their comfort provides a reliable form of exercise for active individuals that participate in healthy lifestyles.

Figure 2: Trike Scooter

Comprehensive, preliminary testing will be involved in the building process of our team's trike. Testing will ensure the ability of the trike to meet the requirements and expectations mentioned above and to maximize the consumer's satisfaction of the product. Different consumers look to purchasing a trike for different purposes, and the goal for our team, and other HPV companies, is to consider the wants and needs of these different individuals and to combine them into a single vehicle.

Table B: Pugh Matrix

Pugh Relationship Matrix							
	Stability	**Design**	**Innovation**	**Endurance**	**RPS**	**Baseline**	**Weighted Score**
Easy to Access	1	2	-1	-1	2	0	x1
Speed	1	0	-2	2	-1	0	x2
Safety	1	2	1	0	2	0	x3
Unique Design	-1	2	2	-1	-2	0	x1
Aesthetics	-2	1	0	-2	0	0	x1

Relationship		**Weighted score**	
2	Very strong	x1	No weight
1	Strong	x2	Weighted
0	Neutral	x3	Heavily weighted
-1	Weak		
-2	Very weak		

Part

The relationship matrix above describes consumer wants vs. needs and the relationship between the two. The column represents criteria for consumer wants and the row represents criteria for consumer needs. These two categories are compared, and the higher scores show producers which relationships are the most important. Weights are added to the score for criteria that are considered the significant.

3. Technology Assessment

Introduction

The purpose of the technology assessment is to evaluate information, technology, and devices that provide information about Human Powered Vehicles. This may also be used by consumers to determine assessment criteria for other types of equipment. This technology assessment is split into sections by the significant sub assemblies and/or components needed for use. Each item will be described and have information presented about them.

Vehicle Configuration

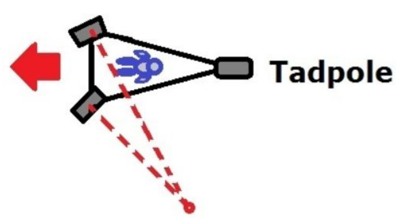

Figure 3: Tadpole Configuration

Our team decided against a two wheeled HPV very early in the design considerations. The most important criteria included stability at low speeds. The best way to satisfy this criteria was to add a third wheel. Having a third wheel reduces driver dependency to a minimum. Teams with a two wheeled HPVs require landing gear to hold the vehicle upright when it stops. Upon research, the team found that there are two types of trike configurations; tadpole trike with two wheels in the front, and delta trike with two wheels in the rear. Delta trikes are proven easier to build, but the tadpole trike is much more stable during braking and cornering maneuvers. Also, having one wheel in the rear allowed the use of high performance road bicycle drivetrain components.

Chassis

Most chassis are made out of either 6061-T6 aluminum, 7005 aluminum, or steel. Most trike builds found in our research included frames built with either round tubing or square tubing. Our chassis will be made out of 7005 aluminum round tubing. This material is being provided courtesy of Catrike, a local manufacturer of recumbent trikes. A combination of tubing sizes will be used, including 1", 1.25", 1.75", and 2" OD. The structural integrity of these tubes can be trusted because Catrike uses them on their production products. While designing the chassis, several measurements are going to be decided. These decisions will include wheel spacing, vehicle ride height, and rider positioning. These are just a few to be mentioned, but the most important considerations for early frame design are rider positioning and wheel spacing.

Figure 4: Recumbent trike with Square Tube Frame

The distance between the rear wheel and the front wheels is called the wheel base. The distance between the two front wheels is called the wheel track. On average, trikes have a wheel base ranging from 33” to 45”, and a wheel track ranging from 30” to 40”. Research has proven that trikes built for speed aim towards longer wheel bases, and shorter wheel tracks. Narrow, long trikes have the best characteristics for speed because the have small frontal areas, and long bodies, making them more streamlined. With a long wheelbase, the rider can be laid back into the recumbent position, meaning the rider is at a low seating angle with their legs pedaling in front of them. the more laid back the rider is, the lower the top of the vehicle can be to the ground. Some of the most laid back trikes are only 30”-36” tall including the roll frame. This is a height we would like to aim for.

Steering

The steering geometry involved on a tadpole trike is complicated. There are several geometry considerations that need to be calculated carefully for the trike to perform well. Below is a table with steering geometry terms and their descriptions.

Table C: Vehicle Steering Assessment

Geometry Consideration	Description	Effect on Performance
Kingpin Axis	The wheel’s axis of steering rotation; generally drawn through the steering joint or spindle.	N/A
Caster Angle	Angular displacement of the wheel’s vertical axis, measured in longitudinal direction. Thus, the kingpin axis touches the ground slightly ahead of the wheel’s contact patch.	Produces self centering action in the steering. Enhances straight line stability.
Camber Angle	Vertical angle of wheel in relation to vertical angle of	Negative camber enhances grip during cornering and

	vehicle, as viewed from the front or rear of the vehicle. Negative camber - top of wheel is closer to vehicle than bottom of wheel Positive camber - bottom of wheel is closer to vehicle than top of wheel	reduces chance of rollover. Not effective with round tires Zero camber enhances straight line acceleration due to maximum tire patch
Scrub Radius	The distance, in front view, from the kingpin axis to the contact patch of the tire. Negative scrub - kingpin touches the ground to the outside of the wheel Positive scrub - kingpin touches the ground inside the wheel	Changing the scrub radius changes the fulcrum point of the wheel. The wheel height in reference to the vehicle will now change as a result of turning the wheel, thus forcing the body of the vehicle to change in height. Negative scrub causes the wheel to be at its highest point to the vehicle in the center of the turning range. As a result, gravity acting on the vehicle will force the wheels into a straight orientation.
Toe In/Out	Toe in - The front wheels point inward toward each other Toe out - The front wheels point out, away from each other	Toe in is used to counter forces on the wheels at high speeds
Ackerman Compensation	The two front wheels rotate on different radius tracks when turning. This causes the inside wheel to scrub on the floor while the outside wheel rolls. The wheels are attached by a tie rod along a theoretical line from the center of esc front	By attaching the two front wheels along a theoretical line from the front wheels to the center of the rear axle, the turning radius of both wheels share a common center point for rotation. This compensation turns the inner wheel to a tighter radius than

	wheel to the center of the rear wheel.	the outside wheel, in either turning direction.

Keeping steering geometry in mind, the user input must also be decided. The handle bars on the vehicle can be set up on three main ways. Over Seat Steering (OSS) refers to a configuration of handlebars that are over the seat, and over the rider. Under Seat Steering (USS) keeps all steering hardware under the seat, and generally leaves the handle bars at the riders side by their hips. Direct Knuckle Steering (DKS) has the least steering hardware, because the handle bars are connected individually to each wheel's spindle and the handlebars end up at the riders side by their hips.

Figure 5: Over Seat Steering

Figure 6: Under Seat Steering

OSS and USS are very common because they are intuitive for the rider. OSS feels like a traditional bicycle, and USS has the rider pull backward and forward to translate turning. Both are comfortable for the rider and easy to use, but both require much more steering joints and hardware. DKS is the simplest and lightest configuration, avoiding extra hardware. DKS is less intuitive to use, requiring the rider to push and pull left and right rather than forward and backward. Research has shown that although the configuration may be confusing at first, the rider usually gets used to it after a few rides. In USS and DKS, the handlebars to the side of the rider offer much more lateral support that OSS, with reduces arm fatigue on long rides.

Drivetrain

The vehicle will use a bicycle drivetrain. There are many different kinds of drivetrain configurations for bicycles. In order from the front of the vehicle to the rear, the major components include the crankset, front derailleur, cog cassette, rear derailleur, and chain to tie everything together.

Cranksets come in different lengths depending on the height of the rider. The crankset assembly includes the cranks that the pedals attach to, and the chainrings. A chainring is the front sprocket that the chain wraps around. Crank sets can have anywhere from one to three chainrings in different sizes. More chainrings offer more gear ratios for the rider to choose from. The tooth count on the chainrings usually varies anywhere between 34 teeth to 53 teeth. The larger the chainring, the higher the gear ratios. Finding the right crankset depends on the application of the vehicle. Many mountain bikes prefer low gear ratios because of the rough terrain and grades they must ride through. Road bikes often prefer higher gear ratios for maximum speed. The front derailleur is responsible for pushing the chain onto the different chainrings. This means it must match the crankset in order to switch gears optimally.

The cog cassette is the set of gears on the rear wheel. Each gear is called a cog, and the set of cogs is called a cassette. Often times, there are eight to twelve cogs on the rear hub, all providing different gear ratio options for the rider. The smallest cog will produce the highest top speed, but it will be the most difficult for the rider to pedal. On the other hand, the largest cog will be the easiest, allowing the rider to produce great amounts of power, but the speed of the vehicle would be slow while the rider's feet are moving fast. Just like the front derailleur, the rear derailleur is responsible for pushing the chain onto each cog, but it also carries more responsibility. The rear derailleur has a cage that is spring loaded, which holds tension in the chain. These come in short cage, medium cage, and long cage options. The size differences refer to how much chain slack the derailleur can hold. Since the chain will be wrapping onto various sized gears, the derailleur must be able to hold the chain tight when the rider is on the smallest combination, and the largest, alike.

Wheels

Trikes can have a variety of different wheel sizes depending on their application. Trikes for comfort and agility usually use small 20 inch rims for all three wheels. this gives great turning ability and allows the trike to be short because the rider can be close to the rear axle. Trikes designed for speed use a large wheel in the rear and two small wheels in the front. The large rear wheel maximizes top speed because of its large circumference, while the two small front wheels allow the trike to have good turning ability.

Wheels come in all types of sizes; too many to list in one report. The team isolated two options for the rear, either a 700c or a 650b. and two options for the front, wither a 20 inch wheel or a 24 inch wheel. A 700c wheel is characterized by its size. 700 refers to the total diameter of the wheel with the tire installed. The letter c refers to a range of thicknesses of the rim, between 18mm and 28mm. These wheels are used for road bikes because they are large and very skinny. Prices for these can go upwards of $500 per wheel. Options for 700c rims include shallow, and deep section rims. This refers to the wall height of the rim. Deeper section rims are more expensive because they are more aerodynamic, and therefore more desirable. 650b rims are used for mountain bikes.

They are the same diameter as the 700c, but they are thicker. Their range of thickness is from 28mm to 38mm. The thicker rim allows for a wider tire which can sometimes be desirable if the terrain is rough, or if the rider wants more traction.

In the front, the smaller the wheel the better. Small wheels are stronger against lateral forces. Good sizes to use are between 20 inch or 24 inch wheels. The deciding factor when choosing front wheels size should be rider leg clearance. Larger wheels will generally touch the rider's legs in their turning position if they are not spaced properly.

Aero Shell

Aerodynamic shells, sometimes called fairings, come in many forms for HPVs. If an HPV has a fairing at all, it would either be a full fairing or a partial fairing. Partial fairings are useful when compared to unfaired vehicles, but full faired vehicles are proven to be the most effective in high speed application. Many shapes for fairings exist, all with their own characteristics.

4. System Requirements

4.1.1 Key Functions

I. Aero-Shell
   - A. Reduce drag acting on the vehicle
   - B. Provide safety for the rider from the outside environment
   - C. Will be judged during the design competition

II. Braking
   - A. Provides rider the ability to stop the moving vehicle
   - B. Minimum of one brake must be installed

C. Hydraulic brakes provide strength and durability during racing

III. Wheel System

A. Tadpole system wheel configuration.

B. Provides stability for the vehicle while riding.

C. Provides sufficient turning radius

IV. Drivetrain

A. Convey power from crankset to rear cog cassette

V. Chassis

A. Provide support for rider

B. Attach to the wheel base system

C. Support the aero-shell

VI. Automated Brake System

A. Provide braking power to the rear wheel when facing an obstacle

4.1.2 Device Interface

I. Steering Geometry

A. Front wheels are connected to assist in turn

II. Automated Braking System

A. Ultrasonic Sensor

B. Arduino

C. Servo

D. Brake

4.2.1 Theory of Operation

The design of this project is to make a human powered vehicle that will be able to compete nationally with other chapters of ASME. The entire foundation of this design is having a vehicle that is lightweight and fast, yet cost effective.

4.3.1 Benchmarking Analysis

Benchmarking analysis is the ability to be able to take the research of two parties and compare their existing design or performance against each other and adopt improvements that fit a current parties approach to continuous improvement. The benchmarking process usually consists of four steps: Planning, Analysis, Action, and Review.

1) **Planning**
   a) **Catrike**
      i) Design a chassis that meet minimum requirements for performance and safety, while being able to attach all other required aspects to ensure the vehicle is driving competitively.
2) **Analysis**
   a) **Catrike**
      i) Testing of previous models to note points of improvement for the current model were noted.
      ii) Chassis from previous model being improperly was noted.
      iii) Drivetrain system losing power due to friction was noted.

3) **Action**
   a) **Catrike**

i) The chassis was constructed with the proper spacing.

ii) The drivetrain system was constructed with the proper clearance to insure most efficiency.

4) Review

i) The chassis CAD will be critiqued by Catrike.

ii) The design for the aero shell will be peer reviewed.

4.4.1 Industry Standards - De Facto Standards

Table D: Engineering Requirements

Engineering Requirements	Preliminary Target Values & Acceptable Range of Values	Engineering Test Protocols & Engineering Test Standards
Mechanical Requirements	**Expected Frame Weight** Weight: 60 lbs **Expected Frame Volume** Length: 90 in Width: 36 in Height: 45 in	**CATRIKE BENDING REFERENCES** Basic requirements for the tube bending for the frame which influences the entire frame volume. **[2]**
Safety Requirements	**Rollover Protection System (RPS)** Top load : 2670 N @ 12° from the vertical Side Load: 1330 N @ the horizontal (0°)	**RULES FOR THE 2018 HUMAN POWERED VEHICLE CHALLENGE** Guidelines for Addressing Rollover Protection System functionality **[1]**

4.5.1 Key System Requirements

I. Mechanical System Requirements

II. Safety Requirements

I. **Mechanical System Requirements**

A. Vehicle must demonstrate sound engineering principles by being able to compete in all four events.

B. The chassis must be able to withstand specific loads from both the top and side.

C. The vehicle must have a working human powered drivetrain.

II. **Safety Requirements**

A. The vehicle's structural integrity must be sound to prevent any harm to the driver, participants, or the public.

B. The vehicle must be able to stop within 6.0 m from a speed of 25 km/hr. A turn radius of 8.0 m must be achieved. The vehicle should exhibit stability when traveling in a straight line for 30 m at a speed between 5 to 8 km/hr.

C. Hydraulic disc brakes will be applied to each front wheel as a minimum.

D. The rollover protection system must prevent the driver's head from hitting a surface should the vehicle flip. The RPS must handle a top load of 2670 N per driver/stoker at an angle 12° downward. In addition, a side load of 1330 N per driver/stoker will be applied horizontally at shoulder height.

E. A safety harness must be attached to a structural member.

F. All sharp edges will be filed, and any protrusions will be covered with appropriate guards.

G. The rider will be equipped with a helmet.

4.6.1 Performance Parameters

Table E: Performance Parameters

Performance	Parameters
Velocity	48 km/h
Brakes	Full stop within 6.0 m from a speed of 25 km/h
Turn Radius	8.0 m
Stability	Stable at speeds in a straight line between 5 - 8 km/h for a distance of 30 m
Expected Budget	$7500

5. Concept Generation and Selection

5.1.1 Concept Comprehension

The scope of this project involves designing a new and innovative recumbent trike as well as adding new innovative configurations and devices to make the vehicle practical with optimal performance.

5.1.2 Basic Functional Requirements For The Concept

A. The HPV must be able to stop from a speed of 25 km/hr within a 6 m distance, turn within a 8 m radius, maintain stability by traveling a distance of 30 m with a speed of 5 to 8 km/hr.

B. The vehicle must employ front wheel brakes, per front wheel, at the least.

C. Must have a rollover protection system (RPS) to adequately protect the rider in the case of an accident.

D. Designed structure must be able to sustain a top load of 2670 N at a 12° and a side load of 1330 N. The basic structure needs to guarantee that structure can withstand these specific loads.

E. There must be a harness equipped to ensure the driver is secure during all events.

F. The HPV that is designed must weigh no more than 60lbs.

G. Must be able to accommodate for different rider heights.

5.1.3 Different Human Powered Vehicle designs

Figure 7. University of Central Florida 2014 HPV, Knightrike with full fairing

Figure 8. University of Central Florida 2016 unfaired recumbent trike

Figure 9. University of Alabama's human powered vehicle with a partial fairing.

This shows the various styles or setups teams use to ride their HPV. The first figure shows a HPV with a full fairing. Fully faired trikes provide more performance with less input wattage as well as protect the rider from harm from the outside environment. This variation of HPV is excellent for speed type events such as drag races.

The second figure shows an unfaired recumbent trike or HPV. The unfaired recumbent trike relies on high output wattage for speed while the faired trike holds the same speed on less wattage. A difference can be seen in performance when the two are compared.

The third figure is an image of a partially faired HPV. This provides aerodynamic efficiency and reduces drag unlike an unfaired vehicle, but it is not as aerodynamically efficient as a fully faired vehicle would be.

<u>Observations Made About Different Past Teams HPV Design</u>

<u>2016 UCF ASME HPV Team:</u>

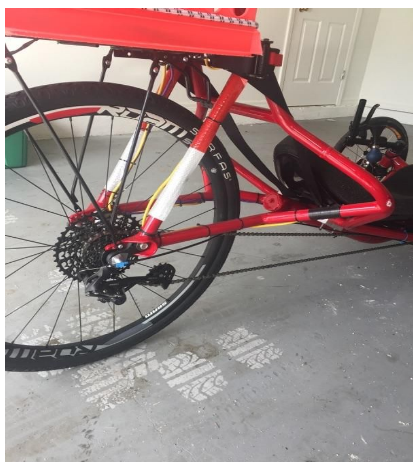

Figure 10: UCF 2016 ASME HPV Team Trike

Upon thorough observation of the last year's HPV, a few things were noted as being responsible for affecting its performance. The team designed their chassis with incorrect spacing and unnecessary spacing in the rear wheel section. The team also discovered problems with the chain management system. The placement and setting of the chains were set in a way where a large amount of friction develops. This factor could contribute to the loss of power when pedaling. The misalignment of the center of gravity causes uneven weight distribution. This in combination with potent brakes made it extremely easy for the trike to topple over when braking power is utilized.

2013 Cal Poly Black Stallion Vehicle Design:

Figure 11: 2013 Cal Poly Black Stallion

Figure 12: 2013 Cal Poly Black Stallion with leaning mechanism

The 2013 Cal Poly Black Stallion implemented a leaning mechanism to assist in tighter turning radii and to handle similar to a streamliner which is of a two wheel configuration. Unfortunately, low speed and static stability were an issue as the leaning mechanism caused instability if not locked correctly. Riders experienced poor drivetrain efficiency due to the chain twist design coupled with a Rohloff internally geared hub. The Black Stallion experienced high weight concerns attributed to steel material being used for the construction of the frame. Also, it was discovered that having a steel frame was counterproductive when it came to the leaning mechanism because the full potential of the mechanism wasn't able to be utilized.

Result Of Observations for Past Designs

Upon reviewing issues from past HPV teams, it was decided against using the leaning mechanism as well as using steel for the frame. Aluminum will be the material used to construct the frame due to its lightweight and strength properties.

The chain management system will be different from the previous year's system. The chain will loop through the boom chain tensioner, then go through a low friction flange tube and chain idler. This trike will use the medium cage derailleur as the rear derailleur. The fastest gear ratio that currently will be achieved is 4.73, and by dimensioning the vehicle in such a way to incorporate this type of system reduces the amount of friction in the chain, therefore increasing overall performance.

The team will also be incorporating an automated braking system in the design. The team are considering a few options to accomplish this feature, such as using a passive infrared (PIR) sensor, ultrasonic sensor, or a camera in combination with a microcontroller and servo to achieve what is desired of the braking system. This feature is something that not many teams have done before and by accomplishing this it will not only fulfill our need for innovation but also aid in driving the HPV.

6. Preliminary Engineering Analysis

To begin, comparisons were made between a bicycle and the different configurations for a tricycle. With stability in consideration, a tricycle is superior because it is free-standing. A driver can easily get in and out of a tricycle with little to no help along with starting or stopping motion. The stability and balance of a bicycle are dependant on the driver. That is a factor we did not want. The tadpole and delta configurations were compared next after a tricycle was determined the best option. For speed and stability, tadpole beats delta due to the two wheels in front. Those front wheels provide better cornering at higher speeds, vital in a competitive environment. However, the steering geometry for a tadpole is more complicated than that of the delta. It is a factor of consideration. A tadpole trike has a lower center of gravity which allows for a low profile meaning less surface area for a more aerodynamic design. The delta configuration has greater maneuverability than the tadpole. The single front wheel can turn almost 90 degrees, allowing a tighter turn radius. The ingress and egress of a delta is superior due to the higher center of gravity. However, in a competition such as the ASME HPVC factors that affect speed and control are considered more important. A tadpole configuration was determined to be the best choice.

The frame of the trike must adhere to the parameters and specifications set by Catrike, as seen below.

CATRIKE BENDING REFERENCE

Tube Specifications

TUBE DIAMETER	WALL THICKNESS	BEND RADIUS	MAX TUBE LENGTH	MIN " TO END	MIN " BETWEEN BENDS
1"	0.065"	3"	57"	1.875"	1.9"
1.25"	0.083"	4.41"	17.875"	2.5"	3"
1.75"	0.083"	7.48"	24.375"	4.5"	5"
2"	0.083"	7"	49.21"	5"	5.5"
		Alt.1" Die Radius: ***CATRIKE USE ONLY***			
1"		*4.34"*	*57"*	*2.5"*	*2.525"*

*MIN " TO END - The bender has to have a minimum length of straight tube before a bend to hold on to.
*MIN " BETWEEN BENDS - bends may be able to be slightly closer together if they are in the same direction.

Figure 13: Catrike Reference

With the Catrike references in mind, the frame was modeled using Solidworks. The structural integrity of the frame was reassured by implementing triangles throughout the design in strategic areas. The wheelbase, the length between the front and rear wheels, will be between 30 and 41 inches in order to optimize turning radius, seat angle, and the weight of the frame. This was determined from observations made of the average trike. The wheeltrack, the width between the two front wheels, will be less than the average of 32 inches in order to have a slim profile and reduce weight.

A tadpole trike has a relatively complex steering system because of the two front wheels. Through research and comparisons, a Direct Knuckle Steering (DKS) system will be implemented. The control arms will give the rider lateral support similar to Under Seat Steering. DKS is relatively simple when considering a tadpole trike. Our trike will employ Ackerman steering geometry. This will insure that the inner wheel when turning will have a smaller radius than the outer wheel. This improves turning by reducing drag of the inner wheel.

The fairing has yet to be designed but it will be influenced by current models seen below.

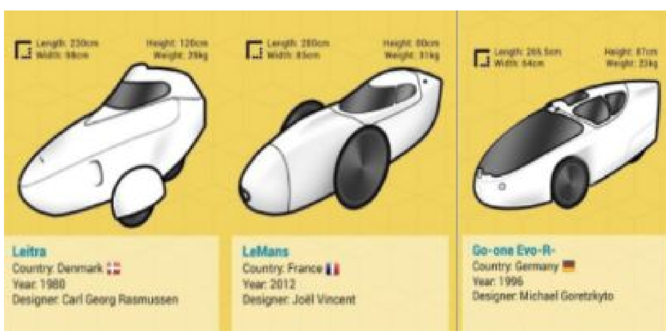

Figure 14: Aeroshell Examples

Our aero shell will be a hybrid of the 3 models depicted. From past accounts of drivers in a HPV with fairing, air ducts are a must in order to provide significant comfort to the driver. A duct system will be implemented into our design similar to the first model. A slim profile with a long nose is a design we are working towards. Our seat angle and wheelbase may require a larger cockpit than the one depicted in the second model. The third model showcases a large window which would enhance visibility minimizing chances of hitting obstacles. Our fairing will have proper visibility. Previous accounts of the competition highlight the importance of visibility both in the front and the rear. Our aero shell will have some improvement in rear visibility by having a window at the back or a portion of the fairing removable for certain events. Similarly to the third model, our fairing will have the front wheels flush with the shell to maximize aerodynamics.

7. Concept Evaluation Plans

The American Society of Mechanical Engineers defines risk assessment as the study of consequences, likely or unlikely, and their potential costs in compensation for errors and harm [4]. Risk is the likelihood a hazard will cause harm [5]. Risk = Likelihood x Severity.

A risk assessment matrix will be used as seen below.

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Figure 15: Risk Matrix

Likeliness terms:

1. Frequent – Continuously experienced.
2. Probable – Will occur frequently.
3. Occasional – Will occur several times.
4. Remote – Unlikely, but can reasonably be expected to occur.
5. Improbable – Unlikely to occur, but possible.
6. Eliminated – Incapable of occurrence.

The terms of severity are:

1. Catastrophic – Results include: death, permanent disability, or irreversible significant environmental impact.
2. Critical – Results include: permanent partial disability, injury or occupational illness that may result in hospitalization, or irreversible minor environmental impact.
3. Marginal – Results include: minor injury lost work day, or reversible moderate environmental impact.
4. Negligible - minor injury no time lost, minimal environmental impact, or monetary loss

Risk Factors:

1. Brake malfunction - System failure caused by a kink or leak in the hydraulic line. Danger to driver and others. Must make sure the brake lines have available space free from any moving parts that may pinch or puncture the lines.
2. Sensor malfunction - When automatic braking system is on, a failure of the system is a danger to the driver and others. A shortage in the wiring, water damage, broken wire may cause a sensor malfunction. Precautions must be taken to ensure the sensor is protected from the elements and that the wiring is free from any moving parts.

3. Structural failure - Weak spot in the frame may give due to an impact. The rollover frame may not be sturdy enough to safeguard the driver. Buckling of the frame would be detrimental to the vehicle. Load tests will be executed in order to prove the load bearing capabilities of the frame and rollover protection system. Catrike will perform all welds to insure quality.
4. Operating conditions - Weather can be unpredictable and will affect the usage of the vehicle. Heat can be uncomfortable and even deadly especially inside a fairing. A fairing with air ducts to let air flow through while in operation will keep the driver cool and comfortable. An implemented aero shell will be a barrier against the weather such as precipitation.
5. Chain line slippage - No power transferred to the rear wheel due to the chain line slipping from the teeth or coming loose completely. Vehicle would become an obstacle itself by not being able to move. Must make sure the chain has proper tension and will hold the tension through all sprockets.
6. Flat tire - Wheels can be punctured causing difficulties in moving the trike. Damage can occur to the rim of the flat tire. Flat tire will cause some loss of control. Must have spare inner tubes. Thicker treads can be used to help prevent punctures. Rear wheel can benefit from a thicker tire due to the inconvenience of servicing it.
7. Fairing integrity - Collapse of the fairing due to a failure in the supports or lack thereof. Danger to the driver as it would prohibit them from escaping the vehicle and broken parts of the shell could cause harm. The fairing itself must be strong along with the supports. The supports must be positioned in strategic points throughout the inside of the shell.

Table F: Risk Analysis

RISK ANALYSIS			
Risk	**Probability**	**Severity**	**Overall Risk Analysis**
Brake malfunction	Remote	Catastrophic	Serious
Sensor malfunction	Remote	Critical	Medium
Structural failure	Improbable	Critical	Medium
Operating conditions	Probable	Marginal	Serious
Chain line slippage	Remote	Marginal	Medium
Flat tire	Occasional	Marginal	Medium
Fairing integrity	Improbable	Critical	Medium

1. Significant Accomplishment and Future Works

The team has taken significant steps in designing the project. After meeting with our sponsors and grasping an understanding of what is needed to produce a Human Powered Vehicle, the HPV chassis was modeled and assembled with the majority of the necessary components to create the recumbent trike. The team was successful with incorporating the desired copy geometry into the design of the model. There is still a lot of progress that needs to made to actually complete the project and designing the fairing is among them.

There have been discussions as to what look and what shape the fairing should have. Multiple tests need to be taken to obtain data to validate the use of a fairing in competition. Among others tasks structural analysis of the frame must be done to find the weak points of the frame as well as to test whether or not it could theoretically withstand the test load required by the RULES FOR THE 2018 HUMAN POWERED VEHICLE CHALLENGE [2]. Besides the actual manufacture of the frame and its components, CFD analysis of the fairing must be performed as well to make sure its design is aerodynamically efficient. Once CFD of the fairing is completed, the fairing can be produced. Finally, the HPV can physically be assembled and ready for test runs before competition.

2. Conclusions and Recommendation

Based on the team's research and utilities provided from Catrike and ASME, the team is in a good position to construct a competitive human powered vehicle. The team's chassis is being overlooked by Catrike, providing redlines to ensure the chassis is both durable and effective. Looking forward, the team needs to ensure all the small components of the trike are installed properly. From the research on the previous versions of the trike, the team noted the smaller component installation is where the most improvements need to be made. The team is taking the right steps in their parts installation research to ensure the full assembly of the trike is done properly.

The team has proper work space to assemble the trike but might lack the all tools being in their work space. Some of the tools are being loaned by ASME, meaning they need to be returned. The team can not afford to be held still because of a lack of a tool. It would be in their best interest to order all the necessary tools as soon they realize its necessity. The reports that need to be submitted with the trike may also be a problem for the team in the future. It would be recommended to the team to organize and divide the work load properly to ensure their best work is submitted in time.

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Appendices

A. User Needs

<u>Client's Needs</u>
Competition legal
Stability
Roll Protection System (RPS)
Design
Innovation
Endurance

B. Relationship Matrix of User Needs to Engineering Requirements

Pugh Relationship Matrix							
	Stability	**Design**	**Innovation**	**Endurance**	**RPS**	**Baseline**	**Weighted Score**
Easy to Access	1	2	-1	-1	2	0	x1
Speed	1	0	-2	2	-1	0	x2
Safety	1	2	1	0	2	0	x3
Unique Design	-1	2	2	-1	-2	0	x1
Aesthetics	-2	1	0	-2	0	0	x1

Relationship		**Weighted score**	
2	Very strong	x1	No weight
1	Strong	x2	Weighted
0	Neutral	x3	Heavily weighted
-1	Weak		
-2	Very weak		

C. Vehicle Steering Assessment

Geometry Consideration	Description	Effect on Performance
Kingpin Axis	The wheel's axis of steering rotation; generally drawn through the steering joint or spindle.	N/A
Caster Angle	Angular displacement of the wheel's vertical axis, measured in longitudinal direction. Thus, the kingpin axis touches the ground slightly ahead of the wheel's contact patch.	Produces self centering action in the steering. Enhances straight line stability.
Camber Angle	Vertical angle of wheel in relation to vertical angle of vehicle, as viewed from the front or rear of the vehicle. Negative camber - top of wheel is closer to vehicle than bottom of wheel Positive camber - bottom of wheel is closer to vehicle than top of wheel	Negative camber enhances grip during cornering and reduces chance of rollover. Not effective with round tires Zero camber enhances straight line acceleration due to maximum tire patch
Scrub Radius	The distance, in front view, from the kingpin axis to the contact patch of the tire. Negative scrub - kingpin touches the ground to the outside of the wheel Positive scrub - kingpin touches the ground inside the wheel	Changing the scrub radius changes the fulcrum point of the wheel. The wheel height in reference to the vehicle will now change as a result of turning the wheel, thus forcing the body of the vehicle to change in height. Negative scrub causes the wheel to be at its highest point to the vehicle in the center of the turning range. As a result, gravity acting on the vehicle will force the wheels into a

		straight orientation.
Toe In/Out	Toe in - The front wheels point inward toward each other Toe out - The front wheels point out, away from each other	Toe in is used to counter forces on the wheels at high speeds
Ackerman Compensation	The two front wheels rotate on different radius tracks when turning. This causes the inside wheel to scrub on the floor while the outside wheel rolls. The wheels are attached by a tie rod along a theoretical line from the center of esc front wheel to the center of the rear wheel.	By attaching the two front wheels along a theoretical line from the front wheels to the center of the rear axle, the turning radius of both wheels share a common center point for rotation. This compensation turns the inner wheel to a tighter radius than the outside wheel, in either turning direction.

D. Relevant Engineering Standards

Engineering Requirements	Preliminary Target Values & Acceptable Range of Values	Engineering Test Protocols & Engineering Test Standards
Mechanical Requirements	**<u>Expected Frame Weight</u>** Weight: 60 lbs **<u>Expected Frame Volume</u>** Length: 90 in Width: 36 in Height: 45 in	**CATRIKE BENDING REFERENCES** Basic requirements for the tube bending for the frame which influences the entire frame volume. **[2]**
Safety Requirements	**<u>Rollover Protection System (RPS)</u>** Top load : 2670 N @ 12∘ from the vertical Side Load: 1330 N @ the horizontal (0∘)	**RULES FOR THE 2018 HUMAN POWERED VEHICLE CHALLENGE** Guidelines for Addressing Rollover Protection System functionality **[1]**

E. Performance Parameters

Performance	Parameters
Velocity	48 km/h
Brakes	Full stop within 6.0 m from a speed of 25 km/h
Turn Radius	8.0 m
Stability	Stable at speeds in a straight line between 5 - 8 km/h for a distance of 30 m
Expected Budget	$7500

F. Risk Analysis

RISK ANALYSIS			
Risk	**Probability**	**Severity**	**Overall Risk Analysis**
Brake malfunction	Remote	Catastrophic	Serious
Sensor malfunction	Remote	Critical	Medium
Structural failure	Improbable	Critical	Medium
Operating conditions	Probable	Marginal	Serious
Chain line slippage	Remote	Marginal	Medium
Flat tire	Occasional	Marginal	Medium
Fairing integrity	Improbable	Critical	Medium

G. ABET Matrix (Competence and criticality matrices)

MECHANICAL ENGINEERING DESIGN COMPETENCE EVALUATION

Rate this *design project* in illustrating effective integration of mechanical engineering topics:

Project Title: ASME HUMAN POWERED VEHICLE

Please rate the relative importance of the given topic in this design project

ME Design Areas	Critical/Main contributor	Strong contributor	Necessary but not a primary contributor	Necessary but only a minor contributor	Only a passing reference	Not Included in this Design Project
Thermal-Fluid Energy Systems				X		
Machines & Mechanical Systems	X					
Controls & Mechatronics				X		
Materials Selection		X				
Modeling & Measurement Systems	X					
Manufacturing		X				

Aeronautical and/or Mechanical Topics Utilized in this Senior Design Project

List the topic, criticality of that topic to the project, and the location of the topic work in the report.

Semester: FALL 2017

Project Title :ASME HUMAN POWERED VEHICLE CHALLENGE

Topic	Criticality to Project	Section and Page(s)	Comments
Aerodynamics	Necessary	IV.22;VI.36	
Controls and Mechatronics	Necessary but Minor	IV.23	
Fluid Mechanics	Neccesary	N/A	
Machines and Mechanical Systems	Necessary	III.16	
Modeling and Measurement Systems	Neccesary	N/A	
Materials Selection	Necessary but Minor	IV.25;VI.31	