Report Cover Page & Vehicle Description Form e-Human Powered Vehicle Challenge
Competition Location: Boise State University
Competition Date: April 27-28

This required document for all teams is to be incorporated in to your Design Report.
Please Observe Your Due Dates; see the ASME e-HPVC website and rules for due dates.

Vehicle Description

University name: University of California, Irvine
Vehicle name: HPVC at UCI's Trike GPT
Vehicle number: 6
Vehicle configuration:

Upright ______ Semi-recumbent ✓
Prone ______ Other (specify) ______

Frame material: 4130 Steel
Fairing material(s): N/A
Number of wheels: 3
Vehicle Dimensions (m)

Length: 2.12
Width: 0.84
Height: 1.35
Wheelbase: 1.33

Weight Distribution (kg)

Front: 74.6 %
Rear: 25.4 %

Total Weight (kg): 38.6
Wheel Size (m)

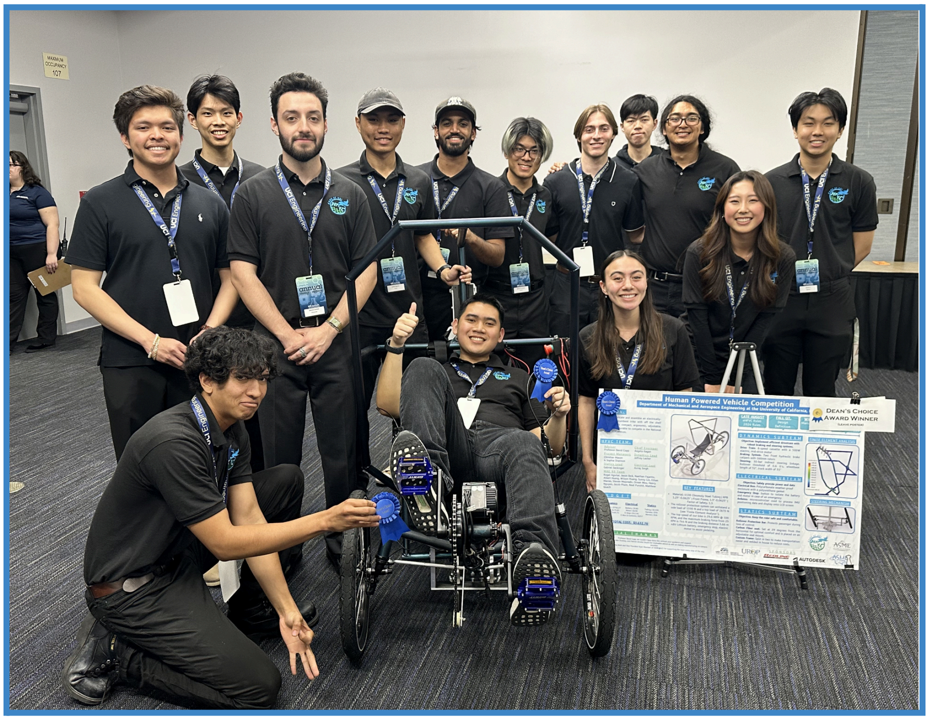
Front: 0.51
Rear: 0.66

Frontal area (m^2): 1.13
Steering (Front or Rear)
Braking (Front, Rear, or Both)
Estimated Coefficient of Drag: N/A

Vehicle history (e.g., has it competed before? where? when?):

This vehicle has never competed in any competition.

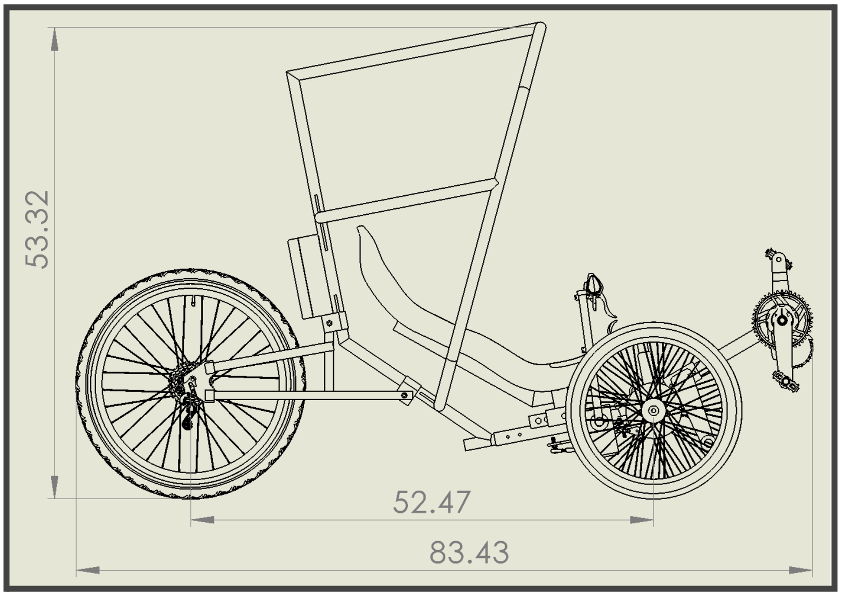
II. University of California, Irvine Human Powered Vehicle Project's Trike GPT



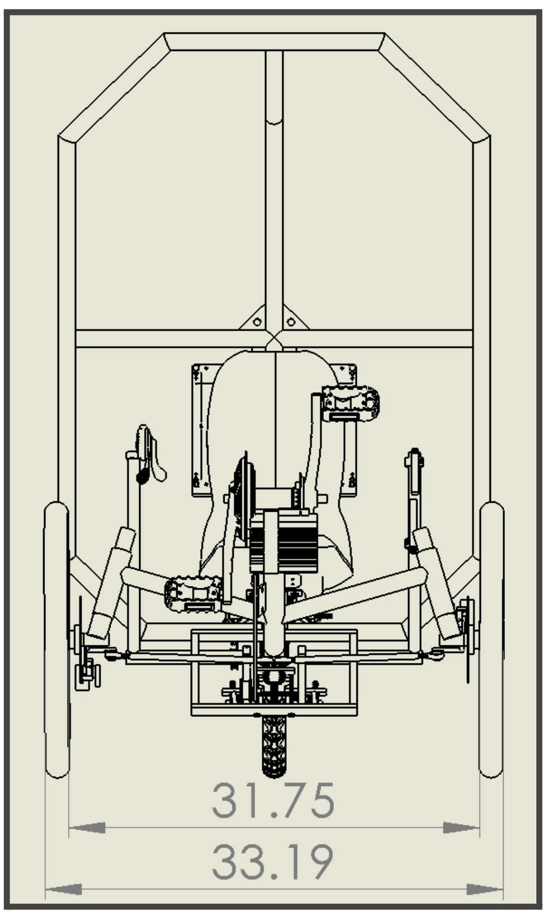
Vehicle #6

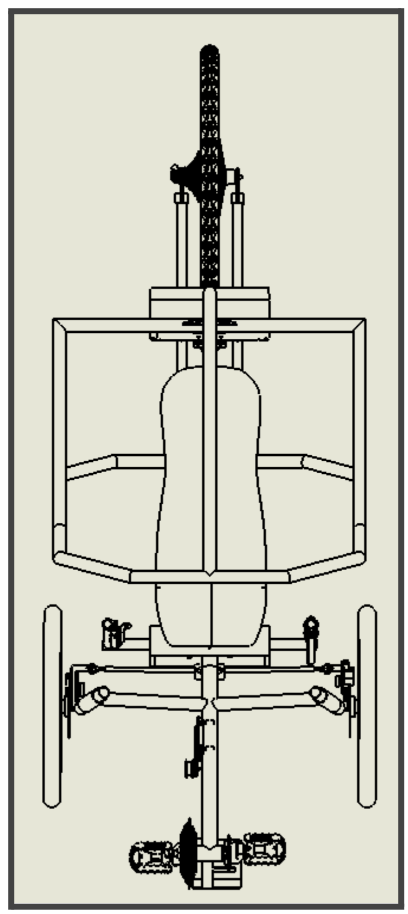
Team Members	Faculty Advisor	Designated Team Contacts
Sophia G. Shannon, Avi Singh, Christian Mason, Angelo Ilagan, Gabriel Sackinger, Jeffery Lasher, Rogel Aguilar, Jason DIck, Naethan Fajarito, Albert Huang, Wilson Huang, Sunny Lin, Ethan Macias, Henry Nguyen, Jacob Pham, Neal Purohit, Matthew Quach, Ocean Mou	Professor David Copp Email: dcopp@uci.edu	Angelo Ilagan Email: ilaganak@uci.edu Phone: 7076563673 Christian Mason Email: masonca@uci.edu Phone: 9499106641

III. 3-View Drawings of Vehicle



Side View of Vehicle with Wheelbase and Overall Length and Height Dimensions





Front and Top Views with Track and Overall Width Dimensions

IV. Abstract

The team name, e-Human Powered Vehicle Competition (HPVC), comes from the event hosted by the national organization American Society of Mechanical Engineers (ASME). This competition is one that the team ultimately aims to complete a build for and participate in. Another important mission is to establish this UCI senior design project as a recurring project that second/third year engineering students can join. In addition, this project is partnered with the ASME group at UCI.

The challenge consists of an endurance race that runs for 2.5 hours with many obstacles such as hairpin turns, uneven terrain, and inclines as well as a drag race, and a design event. The HPVC team at UCI will design and manufacture a recumbent, tadpole bike with a sufficient rollover protection system to keep the driver safe in case of an accident during any of these challenges. The bike consists of 5 major systems: a braking system, a drive train system, a steering system, a rollover protection system, and an electrical system.

The team has been split into three sub teams in order to complete this task. The statics which consists of the bike frame, rollover protection system, and seat. Dynamics which consists of steering, braking, and driving. Finally, there is the electrical team which focuses on the battery, electrical box, electric motor, tail/head lights, and other auxiliary devices. Overall, this year, the team aims to produce a bike that is ergonomic, safe, easy to transport, and compliant to the ruleset established by the aforementioned ASME competition.

V. Table of Contents

VI. Design

a. Design Objectives

Design, fabricate and assemble an electrically-assisted, recumbent trike with off-the-shelf parts that is safe and durable enough to compete in the National ASME competition in a two-quarter timespan. The trike should be compact, ergonomic, modular, and strong. It must also allow adjustability for multiple rider heights.

b. Background

The American Society of Mechanical Engineers (ASME) hosts the e-Human Powered Vehicle Challenge (e-HPVC), a design competition that gives students the opportunity to apply their engineering knowledge through the design and fabrication of human powered vehicles. While the term Human Powered Vehicle (HPV) refers to any means of transportation that is powered by human muscles, ASME is actually referring to a subclass of performance vehicles that include semi-recumbent bicycles or tricycles. These vehicles are designed to be fast, safe and ergonomic. They are equipped with performance drivetrains, aerodynamic fairings and rollover-protection systems to meet these certain attributes.

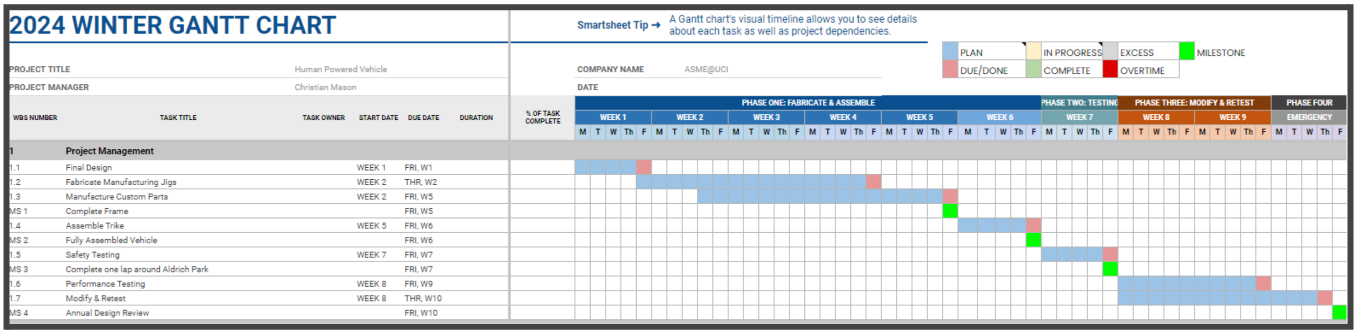
Steintrikes Wild One

c. Prior Work

With the documentation and CAD from last year's project, we are able to reference and improve their design of a recumbent, reverse trike. Their model utilized a 4-bar direct steering system, dual mechanical disc brakes, and an intermediate drivetrain with the motor acting as the center gear.

2022-'23 Isometric View of UCI HPV CAD

Organizational Timeline



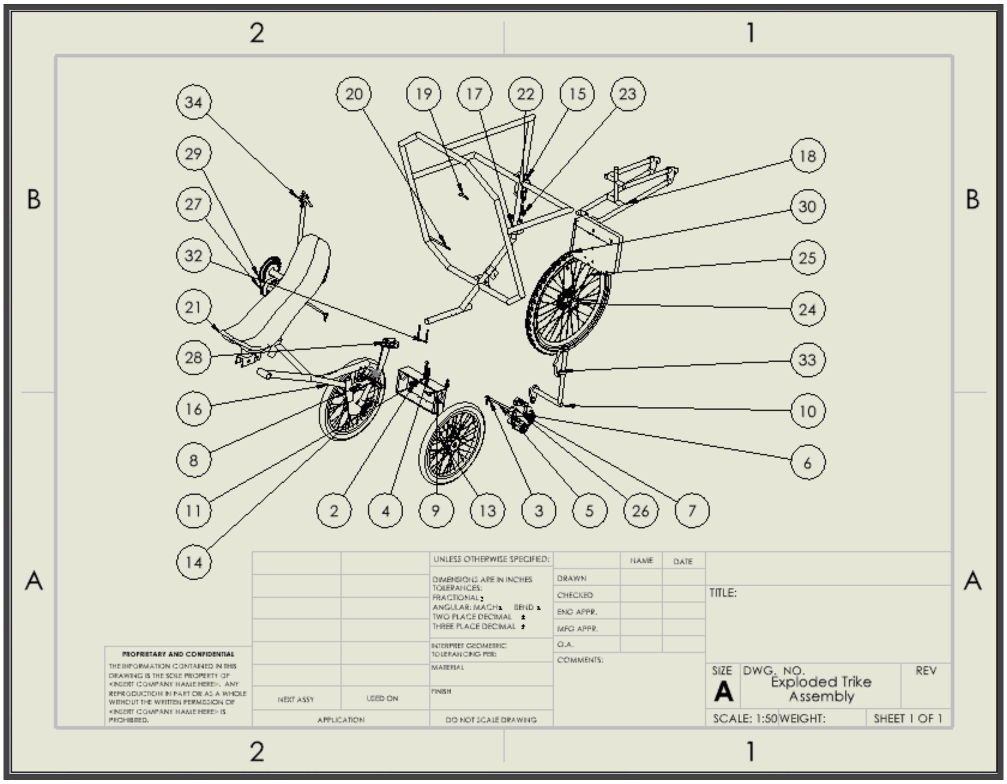
d. Design Specifications

We chose to design and build a recumbent, reverse trike that allows for comfort for the rider and stability from the front, two wheels. The vehicle weighs approximately 85 lbs with a wheelbase of approximately 53" and a track of 31.75." The frame was made out of 4130 steel tubes because it has a good strength-to-weight ratio and can be welded using the facilities at the University of California, Irvine. The tubes have an outer diameter of 1.25" with a 0.065" thickness. This frame was split into a front and rear section in order to make it easier to transport the vehicle to competition. These sections are attached through a pair of steel hex bolts and nuts. The carbon fiber seat is reclined to 29 degrees with four adjustable height settings.

Major Component List

- (1) 500W Bafang Mid-Drive Electric Motor w/ one chainring, 44T, and 170 mm crank arms
- (1) 8-Speed Shimano Cassette 11-32T w/ derailleur and shifter
- (1) 26" x 1.75" rear wheel
- Motor attached to (1) 68mm 4130 steel bottom brackets shell that is MIG welded to the frame
- (2) Shimano hydraulic brake calipers and levers with 160 mm rotors, one for each front wheel
- (2) 20" x 1.75" front wheels
- (2) Utah Trikes Spindles with EC34 Headsets
- (4) Aluminum Ball Joint Tie Rods
- (1) Custom Plasma Cut A36 Steel Bell Crank Plate
- (2) Custom Carbon Steel Handlebars
- (1) BTRPower 48 V 10 Ah Li-ion Battery

Isometric View of Exploded CAD



Labeled Components in Exploded CAD Drawing

ITEM NO.	DESCRIPTION	QTY.
1	Connecting Rod	2
2	Ball Joint Linkage	6
3	Ball Joint Linkage	6
4	Connecting Rod	2
5	3-8 in Ball Joint Rod End Assem	2
6	18-8 Stainless Steel Washer	4
7	Bell Crank V2.1	1
8	Handlebar Fixture	1
9	Handlebar Assembly	2
10	Button Head Hex Drive Screw	1
11	Low-Strength Steel Hex Nut	1
12	Left OTS Kingpin Assem V2.0	1
13	Right OTS Kingpin Assem V2.0	1
14	Frame_V2.1_Rear	1
15	Frame V2.1 Front	1

16	RF Frame Mount V2.0	2
17	Rear Forks V2.1	1
18	Zinc Yellow-Chromate Plated Hex Head Screw	1
19	Zinc Yellow-Chromate Plated Hex Head Screw	1
20	Front w Seat Mount Attached Subassembly	1
21	Derailleur Hanger	1
22	inch assembly description	1
23	26 in Tire	1
24	26 in Rear Wheel	1
25	Crank set	1
26	BAFANG BBS03 1000W Motor	1
27	Chain Pulleys Assem V2.0	1
28	Chainring	1
29	Battery Box (SG-20)	1
30	Battery	1
31	Medium-Strength Grade 5 Steel Hex Head Screw	2
32	Brake Lever	2
33	Shifter	1

Side View of In-Person Prototype

e. Concept Development and Selection Techniques

Decision matrices were used for each subsystem to determine the concepts used for each of the vehicle’s subsystems. Concepts with the highest percentage were utilized on the trike.

Drivetrain Parts Design Matrix Table

Rating 1-5		DRIVETRAIN PARTS					
		One-Speed Chain		Belt		Multi-Speed Chain	
Objectives	WEIGHT	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Safe	15.00%	4.00	12.00%	5.00	75.00%	3.00	45.00%
Durability	5.00%	3.00	3.00%	4.00	20.00%	3.00	15.00%
Cost	8.00%	3.00	4.80%	1.00	8.00%	3.00	24.00%
Ease of Assembly	10.00%	4.00	8.00%	2.00	20.00%	3.00	30.00%
Mechanical Advantage	35.00%	2.00	14.00%	1.00	35.00%	3.00	105.00%
Compatibility	19.00%	3.00	11.40%	3.00	57.00%	3.00	57.00%
Weight	8.00%	4.00	6.40%	5.00	40.00%	3.00	24.00%
SCORES	100.00%	3.29	59.60%	3.00	51.00%	3.00	60.00%

Brake Type Design Matrix Table

Rating 1-5		BRAKING MECHANISM							
		Mechanical Rim Brakes		Hydraulic Disc Brakes		Mechanical Disc Brakes		Mechanical Drum Brakes	
Objectives	WEIGHT	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Safe	15.00%	4.00	12.00%	4.00	12.00%	3.00	9.00%	1.00	3.00%
Cost	7.00%	4.00	5.60%	2.00	2.80%	3.00	4.20%	1.00	1.40%
Durable	10.00%	3.00	6.00%	5.00	10.00%	5.00	10.00%	5.00	10.00%
Ease of Use	10.00%	2.00	4.00%	4.00	8.00%	3.00	6.00%	3.00	6.00%
Ease of Assembly	10.00%	2.00	4.00%	2.00	4.00%	3.00	6.00%	1.00	2.00%
Braking Performance	25.00%	3.00	15.00%	5.00	25.00%	5.00	25.00%	5.00	25.00%
Compatibility	18.00%	3.00	10.80%	2.00	7.20%	2.00	7.20%	1.00	3.60%
Weight	5.00%	3.00	3.00%	4.00	4.00%	4.00	4.00%	1.00	1.00%
SCORES	100.00%	3.00	60.40%	3.50	73.00%	3.50	71.40%	2.25	52.00%

Steering User Control Design Matrix

Rating 1-5		STEERING USER CONTROL							
		Direct Knuckle		Over-Seat Joystick		U-bar		Side Stick	
Objectives	WEIGHT	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Safe	10.00%	3.00	6.00%	5.00	10.00%	4.00	8.00%	4.00	8.00%
Cost	10.00%	3.00	6.00%	1.00	2.00%	2.00	4.00%	2.00	4.00%
Ergonomic	20.00%	3.00	12.00%	4.00	16.00%	4.00	16.00%	5.00	20.00%
Ease of Manufacturing	15.00%	3.00	9.00%	4.00	12.00%	2.00	6.00%	1.00	3.00%
Ease of Assembly	7.00%	3.00	4.20%	2.00	2.80%	2.00	2.80%	2.00	2.80%
Handling Performance	20.00%	3.00	12.00%	3.00	12.00%	5.00	20.00%	5.00	20.00%
Compatibility	11.00%	3.00	6.60%	2.00	4.40%	2.00	4.40%	2.00	4.40%
Weight (Mass)	7.00%	3.00	4.20%	4.00	5.60%	2.00	2.80%	2.00	2.80%
SCORES	100.00%	3.00	60.00%	2.86	64.80%	2.71	64.00%	2.71	65.00%

Frame

The frame of the human powered vehicle is an assembly of tubing that serves as the primary structure which holds the vehicle together. This structure has a variety of demands placed upon it, several of which are due to constraints provided by the American Society of Mechanical Engineer's national Human Powered Vehicle Competition. These constraints were the primary control on the design of the vehicle, though the necessity of fabrication at UCI and the need for the vehicle to support itself also played roles in the frame design. The frame was made out of chromoly steel because it has a good strength to weight ratio and can be welded using the facilities at the University of California, Irvine. This frame was split into a front and rear section in order to make it easier to transport the vehicle to competition. These sections are attached through a pair of bolts. The frame was also designed to withstand a roll cage capable of withstanding a side load of 1330 Newtons at shoulder height and a 2670 Newton force acting 12 degrees off from the vertical.

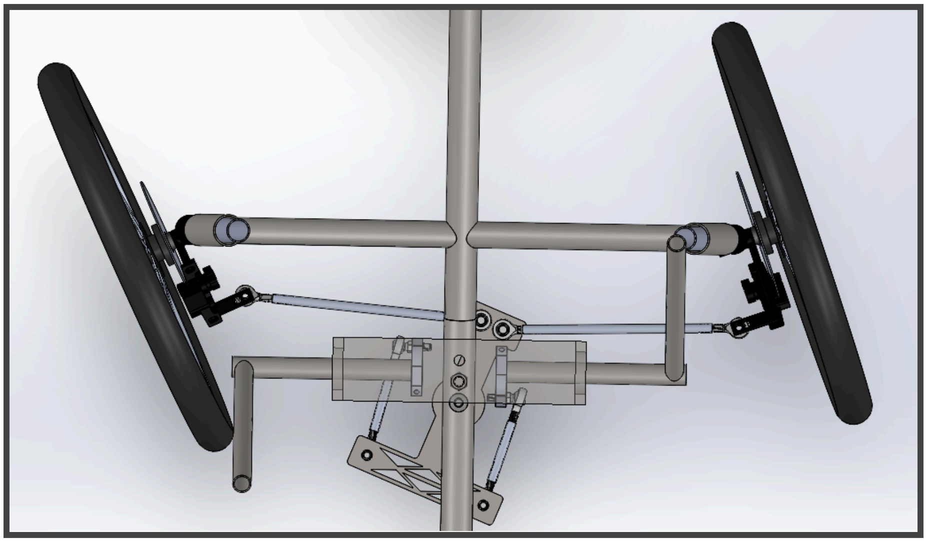
To meet these constraints, the frame of the vehicle was designed to be recumbent. This meant that the rider was set low to the ground, resting in a seat roughly at wheel height. Moreover, the rollover protection system arches over the rider, protecting against a rollover at all angles. To support the roll cage, a pair of L shaped crossbars bridge from the roll cage to the rest of the frame. The material was chosen to be 4130 chromoly since it has a strength to weight ratio equivalent to aluminum while being easier to weld together. Specifically, it could be worked with the equipment available at UCI.

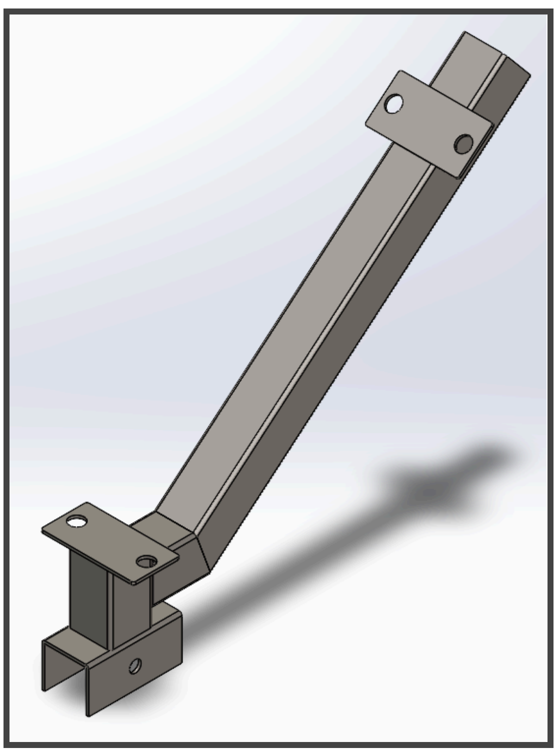
Since the frame is composed of hollowed out beams welded together, it is not possible for the attachment points for the harness to be drilled into the frame itself. Instead, two gussets were attached to the L shaped crossbar to mount the top of the harness. The bottom of the harness was mounted to the bar which connects the rear forks to the main frame.

f. Innovation

The steering system was a custom 10-bar, bell crank steering linkage with dual lever handlebars. The design was inspired from concepts seen in *The Recumbent Trike Design Primer.* The system optimizes ergonomics and handling performance for the rider as the push and pull method keeps the hands and arms range of motion as simple and intuitive as possible.

Top View of Steering System CAD





Isometric view of slider with back support.

The seat was an adjustable carbon fiber seat mounted to a metal slider. This slider rests on a 1.5” x 1.5” with a 0.095” gauge u-channel welded to the frame. There is a 0.5 inch diameter hole in the slider and 4 0.5 inch diameter holes in the U channel which allow the seat to be attached to the frame of the vehicle. A removable pin attaches the seat to one location on the frame. All four holes are equally suitable for mounting the seat, so the seat can be mounted farther forwards or backwards on the vehicle. This allows for more riders to ride at maximum efficiency.

VII. Analysis

a. Rollover Protection Bar Analysis

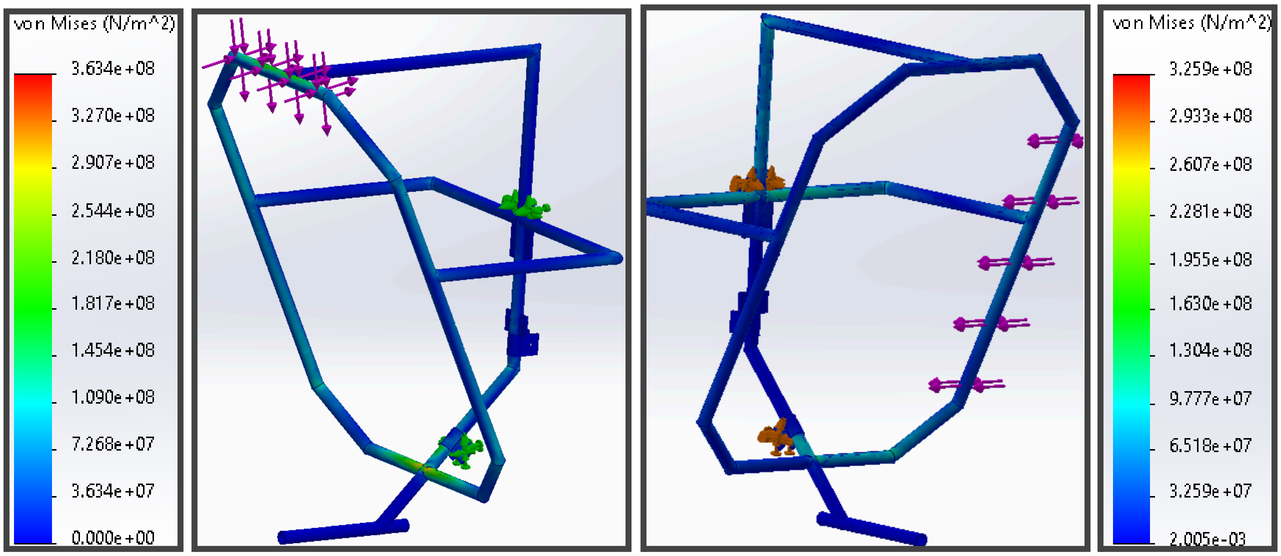


Figure: The frame experiencing a vertical load of 2660 Newtons (Left) The frame experiences a side load of 1330 N (Right)

The Rollover protection system endured both the vertical and horizontal force tests with a sufficient factor of safety. The load path is from the location of the applied load, through the rollover protection bar and the frame to two upper gussets and the lower attachment point of the rear forks to the frame. The upper part of the harness is attached to the upper gussets through a bolt. The lower part of the harness is attached to a rod which slides through the lower attachment point of the frame. The factor of safety achieved in the vertical force test is 1.3 and the factor of safety for the horizontal force test is 1.5. The total displacement caused by the application of force on the frame is less than 5.1 cm, with a vertical displacement of 1.59 cm and a horizontal displacement of 1.02 cm.

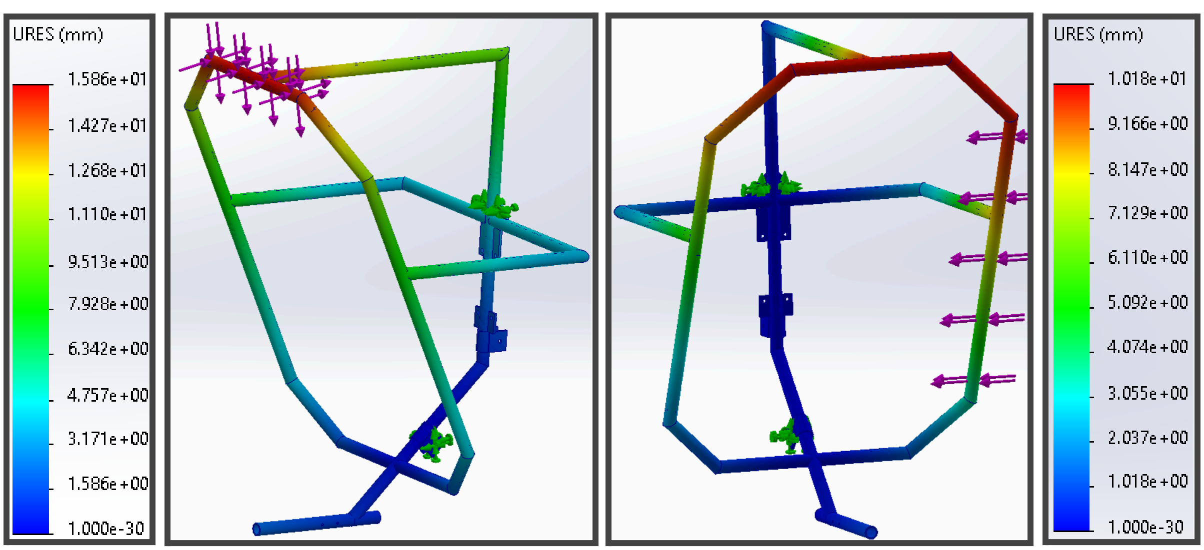


Figure: The displacement of the frame in mm. The left side illustrates the vertical load, the right the side load.

b. Structural Analyses

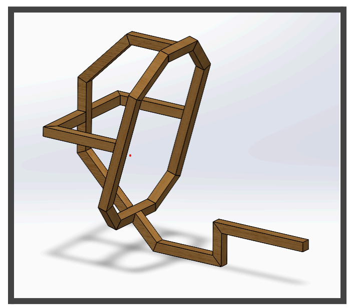
Prototype Risk Assessment

Although procuring the materials will be fairly simple, a potential risk to the development of the prototype would be the accuracy of angle cuts. If some angles are slightly off due to human error when measuring the angles and equipment inaccuracy, some parts of the frame, namely the hexagonal rollover protection bar will not connect. This is especially the case since some of the angles in the 3D-model are not standard and contain awkward decimal numbers.

Other considerations include the number of hours the workshop is open and the limited machines that are working and safe for students to use without extensive training. Much of the static subteam is untrained in woodworking machines, which may prevent us from using more efficient equipment when building our prototype.

Prototype Build Process

To begin the process of creating the prototype, a 3D-model of the frame was created in SolidWorks. However, instead of in the shape of circular, welded metal, the frame was built out of rectangular prisms with a square cross-section equal in length (1.5 inch) to the radius of the welded frame's circular cross-section. Moreover, using the CAD, a spreadsheet of the necessary lengths and angles the bars need to have was created.



A screenshot of the geometry prototype CAD in SolidWorks.

Quantity:	Length:	Angle 1:	Angle 2:		
1	9.5	67.5	67.5		
2	10.25	67.5	67.5		
2	24.82	67.5	67.5	**Hexagonal Frame**	
2	7.78	67.5	67.5		
1	13	67.5	67.5		
1	10	74.56	67.5		
2	15	67.5	67.5	**Backbone**	
1	15	67.5	60.44		
2	15.65	45	90	**Side**	* These two will l
2	11.06	45	74.56	**Bars**	
1	14.5	67.5	45		
1	7	60.44	45	**Front**	
1	7	45	45		
1	20	45	90		

An image of the spreadsheet detailing the lengths and angles of bars.

The process began with marking the lengths and angles on the wooden bars with a ruler, protractor, and pencil. Sharpie was later used to darken the markings and verify the angles to be cut. Hand saws were used to cut the angles. After all the wood pieces were cut, the gluing process began first with the rollover-protection bar. The next portion of the process was to glue together the spine and front of the frame prototype.

Prototype - Initial Tests and Expected Results:

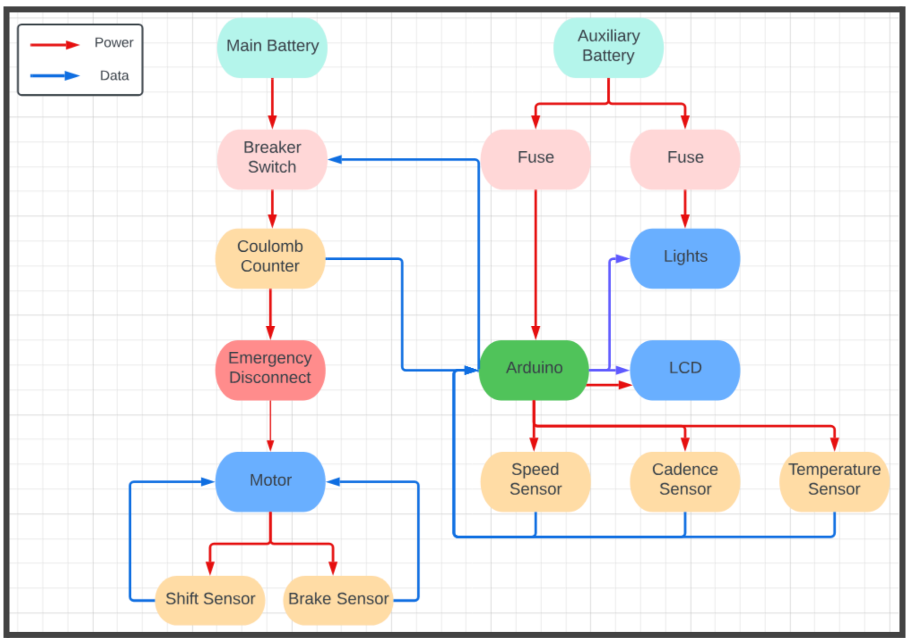
After the completion of the geometry prototype, our testing mostly revolves around how the placement of the seat, the harness, and frame all comes together to provide a comfortable and effective ergonomic design for the driver.

To accomplish this, two or three members will hold the seat roughly in place where it is aimed to be mounted and another member will sit in it. The seated member will push their legs forward to reach the front edge of the frame and we will note how far their legs extend, as well as their height in comparison to the frame. Additionally, the member will test how easy it is to get in and out of the seat without bumping their head against the top of the rollover protection bar.

c. Aerodynamic Analyses

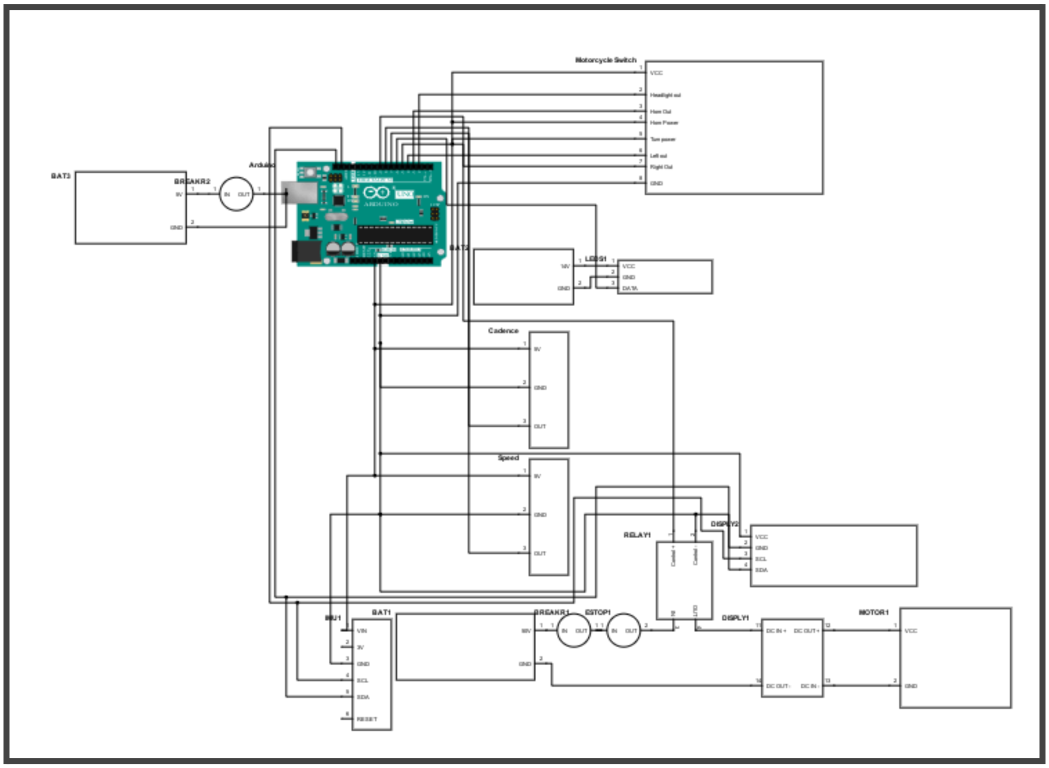
No aerodynamic analyses were performed.

d. Electrical Analyses



Electrical Systems flowchart showing the power and data pathways for our system

The above diagram shows the design of our electrical system. The main battery is a 10 Ah 48V battery, and is limited by software control and by the breaker switch to 10A max. The emergency disconnect will completely disconnect the battery from the motor mechanically. The Motor is then integrated with the brake and shift sensors to stop the motor from powering itself during braking and shifting. The Auxiliary battery powers an arduino that reads cadence and speed data from the wheels using hall effect sensors. We have a temperature sensor on the battery which triggers a relay to turn off the battery when it goes outside of normal operating range. Finally, the arduino also powers the brake lights and turn signals. On the next page is the circuit diagram created from the flowchart.



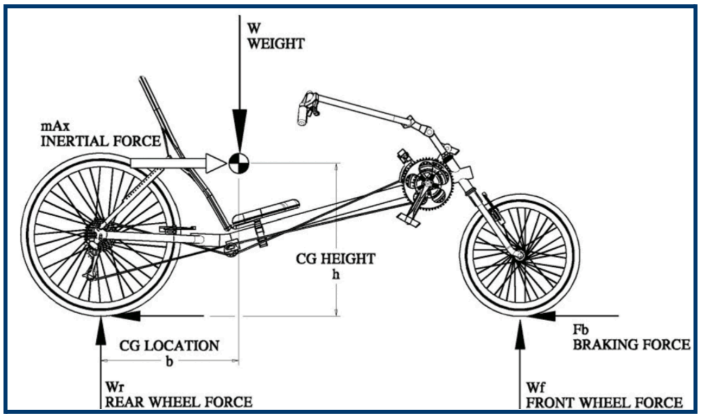
Electrical Circuit Diagram showing all components of our system

Operating the vehicle without the use of an electric motor is incredibly difficult. The sheer weight of the vehicle makes it very hard to get it up to a reasonable speed. With a normal person only really outputting around 250-300W pedaling, the electric motor has the potential to at least double the amount of power output through the pedals. When operating at the full 500W, our riders could easily accelerate to 25 mph, a speed difficult to maintain on even a normal bike which weighs much less. The consistency of the motor's power also allows the riders to maintain their speed for much longer. The benefits of hybrid human-powered vehicles are immense. The benefits of speed, power, and consistency far outweigh the mild increase in weight, and a slight increase in complexity. The weight increase becomes even more negligible on our vehicle, which is much heavier than commonly used bicycles.

e. Other Analyses

Braking

Free Body Diagram from Mark Archibald's Design of Human-Powered Vehicles



Equations for Pitchover Threshold and Braking Force from Mark Archibald's Design of Human-Powered Vehicles

$$F_x - F_{AERO} - F_{RR} - F_B - mgG = ma_x$$

$$x_{Braking} = \frac{1}{2A_x g} * V_o^2$$

$$A_{x,MAX} = -\left(\frac{L-b}{h}\right)$$

Calculated Pitchover Threshold, Braking Force, and Braking Distance

Measurements	
Track, **t** (m)	0.804
Wheelbase, **L** (m)	1.341
CoG from Rear Axle, **b** (m)	1.001
CoG from Ground, **h** (m)	0.501
Mass w/ 165 lb rider (kg)	113.2

Pitchover Threshold (G's)	Max Braking Force (N)	Minimum Braking Distance (m)
- 0.67	744	3.66

Drivetrain

Calculated Torque and Speed Values

Tin	
Tout [lb*ft]	44
11	23.51
13	27.78
15	32.06
18	38.47
21	44.88
24	51.29
28	59.84
32	68.39
Vout [mph]	
11	29.6
13	25
15	21.7
18	18.1
21	15.5
24	13.6
28	11.6
32	10.2
# of Cassette Teeth	

$$F_{avg} = 750N$$

$$\tau_{crank} = F_{avg} * L_{crank} = 750N \ * \ 0.17m = 65.13N * m = 48.15lb * ft$$

$$\tau_{wheel} = \left(\frac{N_{cassette}}{N_{crank}}\right)\tau_{crank}$$

$$RPM = 100\ RPM$$

$$\omega_{in} = \frac{100\ RPM}{60\ s} = 1.667\ rad/s$$

$$\omega_{out} = \left(\frac{N_{cassette}}{N_{crank}}\right)\omega_{in}$$

$$V_{out} = \omega_{out} * D_{wheel} * \pi$$

Torque and Speed Calculations

Steering

Equations for Outside/Inside Wheel Angles and Rollover Threshold from Mark Archibald's Design of Human-Powered Vehicles

$$\delta_o = \tan^{-1}\left(\frac{L}{R+\frac{T}{2}}\right) \qquad \delta_i = \tan^{-1}\left(\frac{L}{R-\frac{T}{2}}\right) \qquad RT_{\text{TADPOLE}} = \frac{b}{L}\left(\frac{t}{2h}\right)$$

Measurements	
Track, **t** (m)	0.804
Wheelbase, **L** (m)	1.341
CoG from Rear Axle, **b** (m)	1.001
CoG from Ground, **h** (m)	0.501

Calculated Rollover Threshold, Wheel Angles, and Maximum Speed at a Turn

Turning Radius, **R** (m)	Inside Wheel Angle (deg)	Outside Wheel Angle (deg)	Rollover Threshold (G's)	Max Speed at Turn (mph)
3.00	27.31	21.51	0.60	9.40
4.00	20.44	16.94		10.85
5.00	16.26	13.94		12.14
6.00	13.47	11.83		13.29
7.00	11.49	10.27		14.36
8.00	10.01	9.07		15.35

VIII. Testing

a. Developmental Testing

Electrical Safety System Testing

There are 4 sections in the electrical safety system: fuses, the circuit breaker, emergency stop, solid state relay. The fuses, circuit breaker, and emergency stop were first tested in a lab using a multimeter, power supply, and various components. They were also tested later when fully assembled and placed onto the vehicle.

To test the fuses, a variable resistor is connected in series with the desired fuse. Then, a 5V or 15V voltage is applied, depending on whether that fuse will be connected to the Arduino or small battery. By varying the resistance, can adjust the current flowing through the fuse and thus determine whether the fuses will break properly. To ensure the fuses operate properly under the maximum current, I used the multimeter to measure the impedance of the fuse and conducted a connectivity test. The resistances of the fuses were on the order of 0.01 ohms, which means they do not impact power delivery.

To test the circuit breaker, I first measured the resistance and connectivity of the circuit breaker using the multimeter. This resistance was on the order of 1-4 ohms, which means that the circuit breaker does not impact electrical performance. Then, I applied a 10A current through the circuit breaker by pairing it with a small resistor and applying a high voltage. Then, I conducted the resistance and connectivity measurements again. The resistance changed to a few mega ohms, indicating that the circuit breaker successfully stopped the current flow. Then, I enabled the circuit breaker reset button. The resistance and connectivity reset back to normal operational mode.

To test the e-stop, it was wired in series with the multimeter. A voltage is applied and current is measured. When the e-stop is disabled, the current will drop to zero. Actual testing showed that at 50V 1A that the e-stop successfully blocked current flow in less than 0.1 seconds.

The solid state relay, or SSR, allows a low voltage input to control the output of a high voltage device. In the HPVC vehicle, the 5V arduino input will control the 48V battery output. The SSR was tested by first setting the Arduino input to 0V. The current and voltage of the output were measured using a power meter, and readings were recorded to be approximately 0. Then, the arduino input is set to 5V. The power meter measured current flow and voltage, which indicated that the SSR works. The delay of the SSR was measured by turning the input to high then low, and vice versa. This delay is extremely small, on the order of a few milliseconds, which means the Arduino can successfully control the operation of the motor safely.

Geometry Prototype Verification:

During testing, it was discovered that the rollover protection bar was too small in width, as a person's shoulders can almost touch both bars on the side of the frame. Further, on average, the person sitting in the seat has a large gap between their head and the top of the frame and can also reach the pedaling area without needing to fully lock their knees.

Rollover Protection Bar Verification

Figure: The rider suspended by the vehicle while the vehicle rests upside down.

To determine if the rollover protection bar provides sufficient protection against a rollover, a rider was placed inside the vehicle. The vehicle was then flipped onto its side and upside down. It was observed that the vehicle kept the rider off the ground both for when the vehicle was flipped and when it was on its side. Furthermore, the vehicle did not significantly deform as it was rolled over. During testing, the rider combined with the bike weighed 115 kg, producing a gravitational force of 1127 newtons, 84.7% of the modeled side load. Thus, the rollover protection system's strength was partially verified.

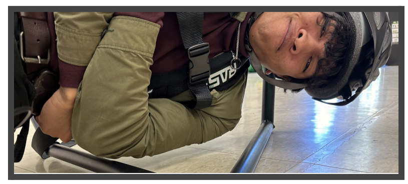


Figure: The rider clearly off the ground while the vehicle is on its side.

Road Testing

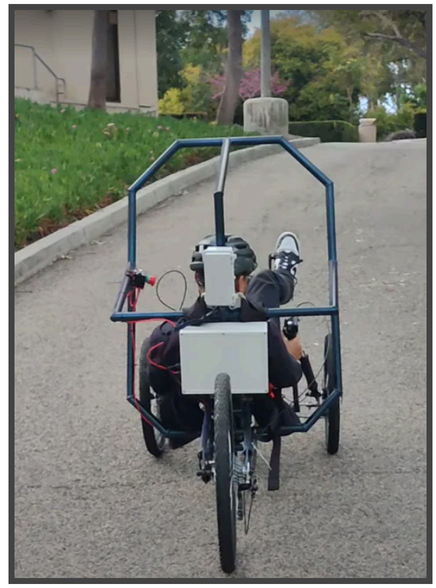
To fulfill performance requirements, we must fully assemble the trike and test its capabilities on an even, empty road. We set up cones to mark the correct distances stated in the compliance table and used cameras and timers to capture data. We were successful in complying with our requirements set by our stakeholders and produced a vehicle ready to race in the ASME competition.

Team Braking Test and Markings for Results

For the braking test, we set up two cones 6 m apart and allowed our rider to brake at the left cone with an initial speed of 25 kph. We were able to brake with a distance of 4.34 m (171 in) and 4.52 m (178 in).

Steering Test for Functionality

For the steering test, we set up two cones 8 m apart and allowed our rider to turn on the inside of one cone and the outside of the other cone at a consistent turning angle. We were able to successfully hit the 8 m turning radius.



Vehicle Incline Test Beside ICF

Straight Line Test

For our drivetrain test, we set up cones to mark a total of 30 m and allowed our rider to travel at 5-8 kph, which is a walking pace, in a straight line to fulfill requirement 1. Although not a requirement, we also tested the vehicle's capabilities going up an incline, since the endurance race will feature a 5% grade going uphill. The motor and rider's power was overall successful in propelling the vehicle up the incline.

b. Seat Mount Verification:

The testing procedure involved seating a rider on the mounted seat, with the seat securely fastened to the mount. Additionally, another individual provided support from the back to ensure the seat remained oriented as it would be on the human-powered vehicle. Through this process, the mount successfully underwent verification, demonstrating its capability to sustain the weight of both the person and the seat

IX. Conclusions

a. Comparison

Compliance Table

	Requirements	Comply/Not Comply	Verification
1	Shall travel 30 m in a straight line at a speed of 5-8 km/hr	C	Will be met when prototype is completed
2	Shall stop from 25 km/hr in 6 m	C	Safety testing with maximum braking force
3	Each front wheel shall have its own set of brakes	C	Steering proof of concept
4	Shall have a minimum turning radius of 8m	C	Testing with cones and tape measurer
5	Shall be able to withstand a top load of 2760 N and a side load of 1330 N	C	Upside-down and side load with rider
6	Maximum width of the vehicle shall fit through a 36” wide door	C	Will be met when prototype is completed
7	All fasteners shall be secured with a thread locking method	C	Will be met when prototype is completed
8	All drivers of all vehicles shall be secured to their vehicle by safety harnesses with lap and shoulder belts (also known as 4 or 5 point safety harnesses)	C	Safety testing with rider (check for slack)
9	Maximum power rating of electrical motor shall not exceed 500W	C	Electrical testing
10	Maximum system voltage is limited to 50V	C	Electrical testing
11	All vehicles shall have an external emergency shutdown switch that isolates the battery from the other electrical components when actuated	C	Electrical testing
12	Each vehicle is limited to one traction battery and shall have a maximum capacity of 500 Wh	C	Electrical testing
13	Shall use off-the-shelf parts	C	Various Shimano brakes and drivetrain parts acquired
14	All custom-made parts are made on campus	C	Frame is cut and welded in ET

b. Evaluation

To fulfill the vehicle requirements, we conducted the tests mentioned in the Testing section where we evaluated the RPS with a rider inside to test the top and side loads, performed road tests to test the drivetrain, brakes, and steering system, and verified the safety systems of the electrical system with the emergency stop button and fuses. We were overall successful in complying with the requirements.

c. Recommendations

In regards to the frame, tube bending should be explored as many errors were found with the tube angles and using such a tool could reduce the time and resources in creating the overall frame and speed up the production for assembly. Square tubing could also make the welding process easier as it is less difficult to create a straight weld bead than a curved weld bead on a circular tube.

For the steering system, its performance is adequate, but is not worth the overall complexity, weight, and cost in the end. Much time was concentrated on fabricating the steering system as there are various custom components needed for the handlebars to function properly. Future designs should reduce the number of components without sacrificing ergonomics.

X. Acknowledgements

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