http://go.asme.org/HPVC	**Critical Design Review Report Cover Page & Vehicle Description Form** **Human Powered Vehicle Challenge** **Competition Location: Liberty University** **Competition Date: April 12th to April 13th**
This required document for all teams is to be incorporated in to your Critical Design Review Report. Please Observe Your Due Dates; see the ASME HPVC website and rules for due dates.	

Vehicle Description

University name: University of Puerto Rico - Mayagüez Campus
Vehicle name: GuacaMaya
Vehicle number: 12
Vehicle configuration: Tadpole

Upright Semi-recumbent
Prone Other (specify): Recumbent

Frame material: AISI 4130 Steel
Fairing material(s): Fiberglass
Number of wheels: 3
Vehicle Dimensions (m)
Length: 2.95
Width: 0.8128
Height: 1.27
Wheelbase: 1.24
Weight Distribution (kg)
Front: 20.4
Rear: 11.3
Total Weight (kg): 21.7
Wheel Size (m)
Front: 0.508
Rear: 0.737
Frontal area (m^2): 0.9
Steering: Front ✓ Rear
Braking: Front Rear Both ✓
Estimated Coefficient of Drag: 0.122

Vehicle history: This Vehicle has not competed before. This is a new design.

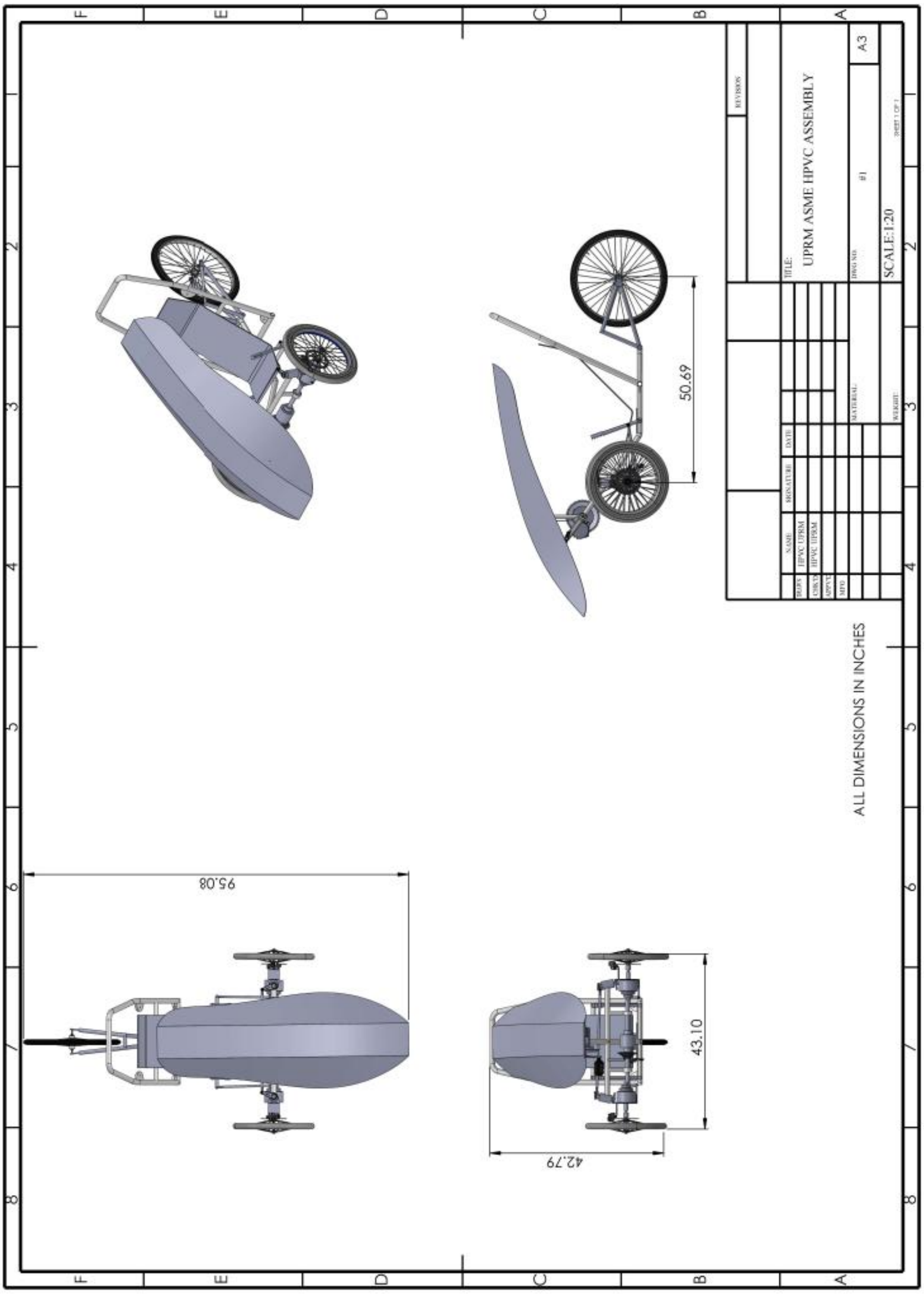
University of Puerto Rico- Mayagüez Campus HPVC Team
2024 ASME HPVC E-FEST Critical Design Review Report

Vehicle Name: Guacamaya
Vehicle 12:

Team Captains: Dariel Rivera & Sergio Ortiz
Advisor: Professor Rubén Díaz

Team Members

Hector Rivera	Claudia Velez	Orlando Marrero
Javier Garcia	Julio Ramos	David Candelario
Jose Lopez	Yulaiza Llerandi	



50.69
95.08
43.10
42.79
ALL DIMENSIONS IN INCHES
REVISION
TITLE:
UPRM ASME HPVC ASSEMBLY
NAME
SIGNATURE
DATE
DRAWN
HPVC UPRM
CHK'D
HPVC UPRM
APPV'D
MFG
MATERIAL:
DWG NO.
#1
A3
WEIGHT:
SCALE:1:20
SHEET 1 OF 1

Abstract

This abstract introduces the integrated approach of the Human-Powered Vehicle Challenge (HPVC) Team in the pursuit of engineering excellence and innovation. Our team operates across six specialized departments: Frame, Steering, Transmission, Brakes and Wheels, Aerodynamics, and Innovation. The Frame department meticulously designs and constructs the skeletal structure of our vehicles, focusing on lightweight materials and optimal rigidity to enhance performance and safety. Steering refines control mechanisms, ensuring precision and responsiveness for the vehicle's maneuverability. Transmission fine-tunes the power delivery system, maximizing efficiency and torque transfer from the human input to the wheels.

Brakes and Wheels department reliable braking systems and lightweight, aerodynamic wheel configurations to optimize stopping power and minimize rolling resistance. Aerodynamics delves into the intricacies of airflow dynamics, employing advanced computational simulations and wind tunnel testing to shape the vehicle's form for minimal drag and enhanced speed. The Innovation department serves as the creative nucleus of our team, pushing boundaries with novel concepts and technologies, from novel materials to groundbreaking design methodologies, driving the evolution of human-powered vehicle engineering. Together, these departments synergize to create a holistic approach to vehicle design, blending intricate design and manufacturing processes with human ingenuity to craft human-powered vehicles that redefine speed, efficiency, and sustainability.

Table of Contents

1. Design

1.1 Objective

The team has from the beginning been created to participate in ASME’s Electric Human Powered Vehicle Competition (e-HPVC) and take on its challenges. It has since then adopted the competition's objectives of creating and promoting alternative transportation from the regular combustion engine and promoting a more environmentally friendly way of commuting. The competition also allows participating students to have a more hands-on, real-life experience with the engineering process. This year, participants were challenged to add electrical components similar to an e-bike to the vehicle, making it more efficient while maintaining an environmentally friendly system.

Aside from the objective of meeting the competition’s requirements and winning said competition, the team has also internalized the objective of promoting such vehicles beyond the competition’s scope. This year the team has also made it a personal objective to donate the vehicle to a needed community for public and communal once the competition is over. Therefore, during the designing process, the team kept in mind to keep the vehicle user friendly, durable, and simple to maintain.

1.2 Background Research

ASME’s Human Powered Vehicle Challenge in UPRM has brought a desire amongst students to acquire and develop analysis and manufacturing skills, where they’re ultimately put to the test through this challenge. This year’s objective focused more on developing new and more efficient ways in which the recumbent trike’s design can be carried out. When it came to the initial design, previous projects were used as reference as the team figured out ways in which they could be improved, not only by restructuring, but also by adding features that could improve its mechanics. Changes such as the inclusion of a front wheel drive all the way to the inclusion of a battery assisted drive were some of the most notable ones.

When considering these new features, it was important for the rest of the departments to work around these ideas for the benefit of the design, such as the decision to make the steering mechanism under the seat for the linear path of the drive shaft, or the separation of a singular frame component to include a rear suspension. Compared to previous designs, none had included all these features, therefore it was up to this year’s team to try to produce a vehicle that can withstand the obstacles of the competition. Even though various changes were introduced to this year’s vehicle, a lot of similarities can be found between the previous ones and the one being worked on, such as the decision to choose a tadpole configuration over a delta configuration. This was because by evaluating past work, we noticed a trend in certain decisions, mostly due to practicality, as well as for various other decisions made; like how the aerodynamics department opted for a half fearing instead of a full fearing due to its manufacturing latency and complexity with the available resources.

In the end, knowledge and things considered, we can say that the work for our design was carried out successfully, where the skills of research and analyzing were put to the test, expanding our knowledge, and broadening our scope when making a design such as the Electric Human Powered Vehicle.

1.3 Prior Work

The design of the vehicle had some similar base design features from previous HPVs. However major changes were made to the vehicle's transmission systems and frame tube configurations due to incorporating the electrical systems (storage, and transmission), an electrical assist motor, and the change to front wheel drive. The frame design of the previous vehicles used the tadpole configuration (two wheels front, one aft) for its stability during performance and the platform it provided for placing a robust rollover protection system (RPS). This design retained the tadpole configuration, as it allowed to accomplish the safety requirements of the competition and added familiarity to the working style. This simplified the design efforts of the team designing the systems of the vehicle. The relative wheel sizes were retained to a lower size on the front of the vehicle than on the back.

This kept the sloped frame design seen in other vehicles, which lowered the center of mass for better performance. The triangulation of the rear chain stays and its direct attachment to the RPS was also incorporated from previous vehicles due to providing the rigid support for the rear wheel, although in the new design, it was attached via a suspension system instead of directly welded into the RPS. The frame materials also included the consideration of the Nickel-Chrome alloy (AISI 4130 steel) for material selection present in the previous two vehicle designs. The aerodynamic fairing of previous designs had gone through the form of a full fairing (2020-2021) but the use of a windshield fairing was used in in the team's 2019 vehicle. Due to the reduced manufacturing complexity of the windshield design, it was revisited. The design also retained the hydraulic braking system for both front wheels due to their high strength and the reusability of the components. Additionally, the steering mechanism has been iterated from an under-seat steering system used also in 2019.

1.4 Organizational Timeline

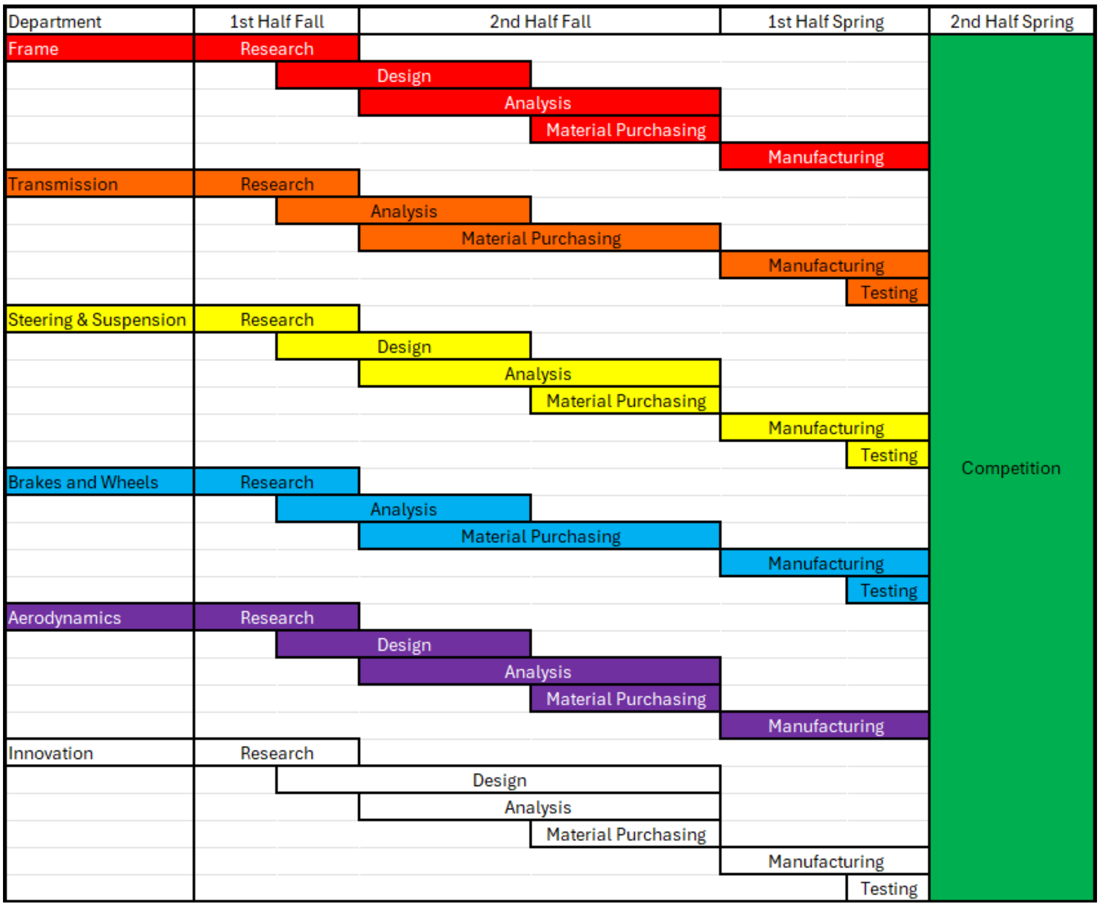


Figure 1: Organizational Timeline of HPVC UPRM

1.5 Design Specifications

Table 1: UPRM HPVC Design Specifications

Criteria Evaluated	UPRM HPVC Specification
Brake System	Stop in a range of 5 m at 15 mph
Minimum Turning Radius	Less than 5 m
Top Speed	Higher than 25 mph
Steering Mechanism	Show stability traveling 15 mph in a straight line
Top Load Deflection	A non- elastic deformation less than 0.70 cm
Top Load Safety factor	A minimum safety factor 1.2
Side Load Deflection	A non- elastic deformation less than 0.50 cm
Side Load Safety Factor	A minimum safety factor 1.2
Speed Bump Safety factor	A minimum safety factor 1.2
Production Cost	Less than $4000 per unit
Fairing Impact	Drag Coefficient less than 0.44
Vehicle Weight	Less than 36.3 kg

1.6 Structured Design Methods

1.6.1 Frame Design Selection

The frame department's objective was to design the structural skeleton of the HPV that provides optimum performance features. To have an HPV that contains the best features possible, the frame department researched and considered aspects like the trike configuration, the materials to be used to build the structure, and the role of the frame for each of the other vehicle systems. Once the team selected the trike configuration and completed the material selection, they commenced the frame designs and system considerations. This was initially done as separate designs by each of the frame department team members, which were later combined into a preliminary frame. This frame was then subject to various iterations to incorporate any changes based on structural analysis results and the support needs of the other vehicle systems (electrical, transmission, steering, aerodynamic).

Table 2: *HPV Configuration Decision Matrix*

Concept	Options
1	2 – wheel upright
2	Tadpole
3	Delta

Criteria	Relevance	Concepts		
		1	2	3
Performance	13	10	9	9
Handling	17	10	9	8
Design Complexity	21	8	10	9
Rider Ergonomics	15	7	9	10
Safety	21	6	10	9
Cost	13	10	7	7
Total		829	916	872

Table 3: *HPV Configuration Criteria*

Criteria	Description	Range Definition
Performance	How good is the performance?	1 = Poor Perfomance, 10 = Best Performance
Handling	How easy is it to ride?	1 = Very Complex, 10 = Less Complex
Design Complexity	How complex is the design?	1 = Very Complex, 10 = Less Complex
Rider ergonomics	How comfortable is it?	1 = Uncomfortable. 10 = Very Comfortable
Safety	How safe is the design?	1 = Unsafe, 10 = Safe
Cost	How much cost in materials?	1 = Very Complex, 10 = Less Complex

For the HPV configuration the options were: 2 – wheel upright, tadpole, and delta. Design complexity and safety were the factors that were given the most importance and weight. If the design is too complex, the HPV is at risk of failure, putting the rider at risk. The 2-wheel upright provided the most cost-effective and lightweight design but at the cost of safety and rider ergonomics. HPVs that have three wheels are the most stable, making them a safer and more relaxing experience due to it allowing the rider to ride in the recumbent position. A delta configuration provided a simpler and more cost-effective design path for the steering system due to the single front wheel. The tadpole allowed for greater stability during turns at high speeds, a more compact design, and a more favorable breaking scheme due to the force distributed along two front tires. Tadpole obtained the most points in design complexity since the UPRM HPVC team has experience manufacturing this configuration. Since the tadpole configuration was the one that obtained the most points in safety and design complexity, it was the design that was finally chosen.

Table 4: Chain Stay Decision Matrix

Concept	Options
1	Cantilevered
2	Fully Triangulated

Criteria	Relevance	Concepts	
		1	2
Structural Stability	36	2	5
Design Complexity	26	5	3
Weight	17	4	4
Cost	21	4	3
Total		354	389

Table 5: Chain Stay Criteria

Criteria	Description	Range Definition
Structural Stability	How stable is the vehicle?	1 = Unstable, 5 = Very Stable
Design Complexity	How complex is the design?	1 = Most Complex, 5 = Least Complex
Weight	How heavy is it?	1 = Lightest, 5 = Heaviest
Cost	How much cost in materials?	1 = Cheapest, 5 = Most Expensive

The fully triangulated chain stay was chosen for its structural stability, a criterion that has been considered crucial from the start. Even though it is a bit more complex in its design, it can ensure the rider's safety and ergonomics.

Table 6: Material Decision Matrix

Concept	Options		Criteria	Relevance	Concepts		
					1	2	3
1	Chromoly 4130		Yield Strength	21	4	2	5
2	Aluminum 6061 T6		Manufacturability	21	5	4	1
3	Carbon Fiber		Fatigue Resistance	18	4	3	5
			Weight	17	2	4	5
			Cost	23	5	3	2
			Ductility	10	5	4	1
			Total		410	327	337

Table 7: Material Criteria

Criteria	Description	Range Definition
Yield Strength	How elastic is it?	1 = Least elastic, 5 = Most elastic
Manufacturability	How complex is it to manufacture?	1 = Most Complex, 5 = Least Complex
Fatigue Resistance	How many loading cycles can be applied?	1 = Least cycles, 5 = Most cycles
Weight	How comfortable is it?	1 = Least Comfortable, 5 = Most Comfortable
Cost	How much cost in materials?	1 = Cheapest, 5 = Most Expensive
Ductility	How ductile is the material?	1 = Lowest, 5 = Highest

Material selection was driven by various properties of the candidates. These are density, yield strength, fatigue strength, elongation at break, ultimate tensile strength, and other factors such as price and manufacturability. After analyzing these properties to meet our requirements, the decision matrix was carried out. Although carbon fiber would be the ideal material because of its high yield, high fatigue strength and low weight, it is very expensive and challenging to manufacture. Aluminum was also not chosen for its low elongation at break, yield, tensile and fatigue strength. On the other hand, chromoly is a bit heavier but it is easier to manufacture, cheaper and more accessible in the market making it more convenient. It also has a high elongation at break, yield, tensile, and fatigue strength. Having selected the vehicle configuration, initial efforts by the team were made to produce independent frame designs from each member. These frames would be compared and combined into an initial frame.

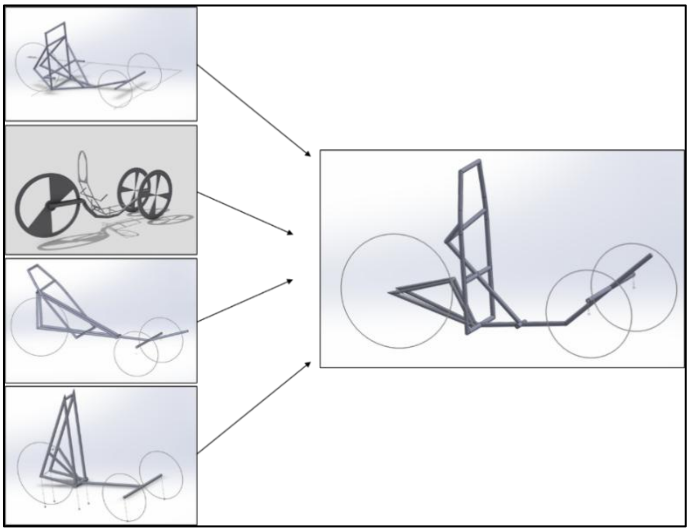


Figure 2: *Independent Preliminary Designs Combined into Initial Frame*

The initial frame was developed early in the design process, while other team departments determined their configurations for the vehicle. The main points of focus were a wide RPS, a low base frame height, and a high placement of the front wheels to allow clearance for front wheel drive. Later in the vehicle design process, the decision was made to incorporate a rear suspension, and the chain stay was structurally separated from the frame. Other initial design changes were done by feedback from the team members and focused more on reduction of material from the frame due to the decision of choosing chromoly steel as the design material.

From the second iteration onwards, the focus was the integration of the various vehicle systems with the frame structure and ensuring the RPS followed the structural requirements of the competition. Structural changes mainly consisted of reducing the number of tubes while increasing the thickness and external diameter to ensure rigidity and strength. Integration changes consisted of adding support structures for the steering, suspension, and aerodynamic components, while also ensuring that clearances were met for these systems. A point of focus was to allow for the steering knuckle of the vehicle to incorporate a constant velocity joint while allowing space for the steering arms to support the levers of the steering system.

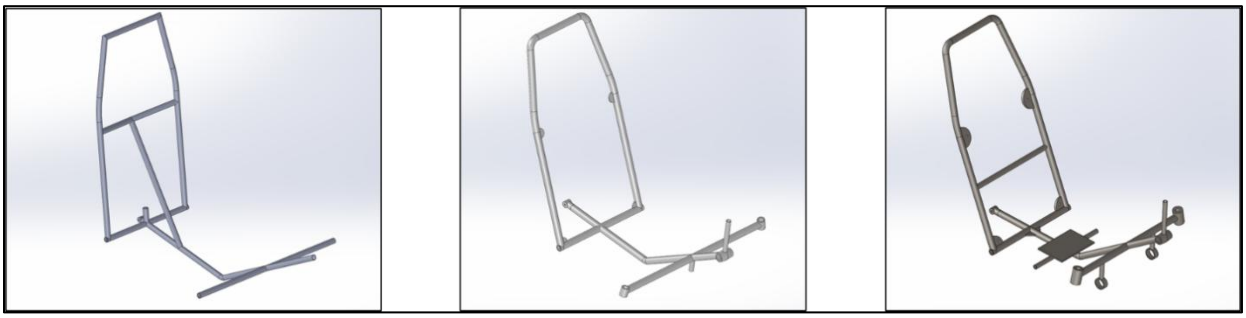


Figure 3: *Frame Iterations*

The final frame consisted of a chromoly (AISI 4130) structure with reinforcement plates on four points of attachment to the RPS to the base tubes. Two of the reinforcement plates also play the role of attachment for the harness to secure the rider. The RPS has an inclination of 25 degrees from the horizontal to reduce the frontal area taken by the structure. On the RPS also lies a lateral tube to support the attachment point for the vehicle suspension (not shown).As discussed, the frame has a low base and a high frontal tube, which allows the placement of the front drivetrain components and steering knuckles. Two frontal tubes hang down from the main lateral structure to allow the alignment of the driveshaft, constant velocity joint, and steering knuckle. Two lateral tubes extend from the sides of the seat fixture plate to allow pivoting of steering levers in the steering system. This alignment system adds complexity for the welding process but reduces the complexity of aligning the steering and transmission components.

The team strived for a relatively simple rear frame structure, only requiring the 4 bends of the RPS and no auxiliary support tubes. This would both reduce welding operations and allow space for the electrical generation and storage of components. The tradeoff was the thicker tubes, which would require more stringent bending, cutting, and welding processes.

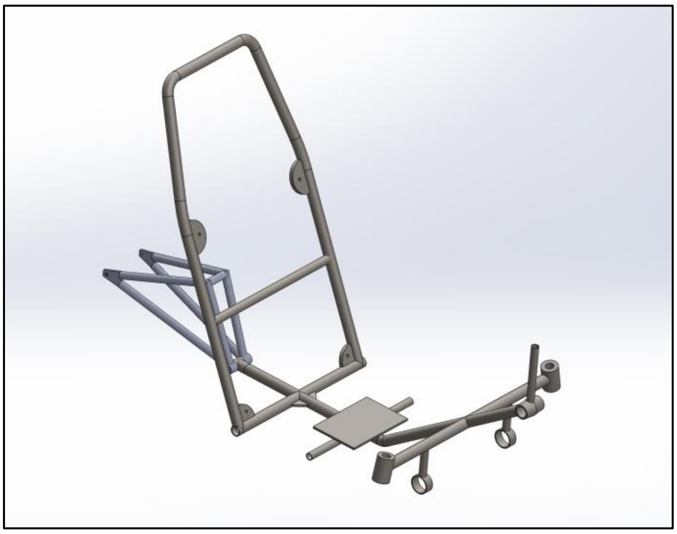


Figure 4:*Final Frame and Chain Stay Assembly*

1.6.2 Drivetrain Design Selection

In the selection process for an appropriate drivetrain, the vehicle had to be study and reliable, gives the driver mobility and be able to shift gears and speed for the competition. The biggest factor that contributed to the selection of the transmission system in the vehicle was the position of the components, which would make it more accessible and comfortable for the driver. The team had to decide between a rear-wheel drive and a forward-wheel drive configuration. As shown in the table below the rear wheel drive and forward wheel drive had advantages and disadvantages. The forward wheel drive was selected due to the complications with the chain, where the use of the extensive space between the chainring and the cassette made the chain vulnerable and there was less tension.

For the selection of the chainring, one chainring, two chainring and three chainring were considered. A 52 teeth single chainring was selected due to its simplicity, being able to transmit the most possible torque to the transmission and provided most comfort for the driver when applying force in the pedals. For the selection of the cassette, the range of speed which can be achieved by changing gears was taken into consideration when choosing the appropriate cassette. The cassette of the vehicle should be adaptive to different environments and having a range of different speeds is a major contributor.

Table 8: Type of Transmission System Evaluation

Forward Wheel Drive		Rear Wheel Drive	
Advantages	Disadvantages	Advantages	Disadvantages
1. Chain Management – Managing and maintaining the chain is easier due to its shorter size. 2. Pedal Responsiveness – A shorter chain makes pedaling feel more responsive. 3. Less Power Loss – Less power is lost due to the chain being shorter and closer to its standard use in bicycles.	1. Traction – It becomes more difficult to maintain traction on steep hills, due to the weight distribution. 2. Weight – A Forward Wheel Drive System generally requires more components.	1. Design Familiarity – Most recumbent trikes use a RWD system, therefore there is more information readily available. 2. Weight – This system generally has less components which means less weight.	1. Chain Management – The longer chain is harder to manage and maintain.

Table 9: Type of Motor Decision Matrix

Concept	Options
1	Mid-Drive
2	Hub-Drive

Criteria	Relevance	Concepts 1	Concepts 2
Weight	8	9	7
Maintenance	5	7	8
Power	9	9	7
Durability	7	7	6
Efficiency	7	8	7
Simple Design	5	6	8
Total		323	290

Table 10: Motor Design Criteria

Criteria	Description	Range Definition
Weight	How much will it weigh?	1 = Very Heavy, 10 = Less Heavy
Maintenance	How simple is the maintenance?	1 = Very Complex, 10 = Less Complex
Power	How much power does it provide?	1 = Less Power, 10 = More Power
Durability	How long does it last?	1 = Less Durable. 10 = Very Durable
Efficiency	How efficient is it?	1 = Less Efficient, 10 = More Efficient
Simple Design	How simple is the design?	1 = Very Complex, 10 = Less Complex

For the Drivetrain, an Electrical Mid-Drive Motor was selected due to numerous reasons. The simple design of a mid-drive motor allows the user to get in sync with the motor's behavior and pedal assistance making the motor highly effective and intuitive. The efficiency of this motor is a key element since the pedal assistance on these types of motor lets the user pedal faster and reach higher speeds. The durability of the motor is important since mid-drive motors have compact and long-lasting designs, wear and tear should not be a common issue with the motor.

Motor power is the most important aspect since it will help the user ride at faster speeds with less effort and handle obstacles and inclined roads more easily. Since the motor is designed to last, maintenance is not a big issue, and the motor will be inspected before and after use to ensure a safe ride. A differential system was implemented for the transmission of HPV. This transmission system allows both wheels of the HPV to turn independently without assistance. This allows the wheels on the front to turn at different speeds. This differential will reduce wheel slippage and provide a smoother transition when performing a turn.

1.6.3 Steering Design Selection

The steering design had two main categories: the steering mechanism and the linkage system to be used. For the steering mechanism, the department evaluated three types: over-seat, under-seat, and lean steering mechanisms. Initially, each type was evaluated as shown in Table__ by the criteria in table __.the chosen mechanism was over-seat, for its more user-friendly and aerodynamic features. The team has worked with OSS mechanisms in previous vehicles, so choosing this mechanism would have entailed working on improving previous designs. The linkage system to be used would depend greatly on its maneuverability as well as its compatibility with the steering mechanism. In table 13 a four-bar dual drag link mechanism was chosen for the vehicle based on the criteria in table 14.

As the design phase progressed and more concepts regarding other departments were beginning to be considered for the vehicle, the department came across a big obstacle: how would a front-wheel drive system affect the steering mechanism? The integration of FWD led to a few changes in the design. Among those, switching to an under-seat steering mechanism with a simple four-bar linkage system with a single tie rod to reduce the number of components that would clutter the front of the vehicle and add weight or lower visibility for the rider. As it is, these options happened to be the next best decision in both categories

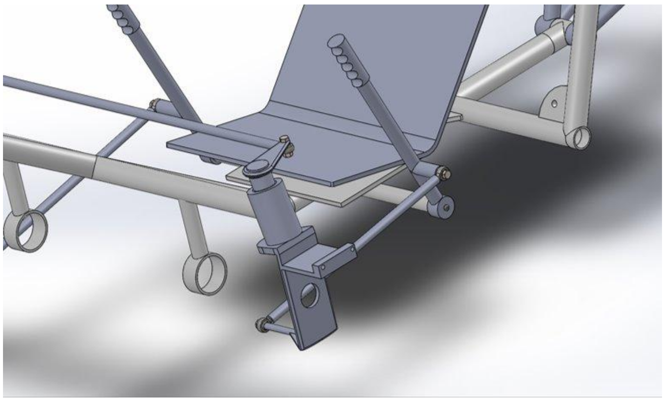


Figure 5: *Steering Mechanism*

Table 11: *Steering Mechanism Decision Matrix*

Concept	Options
1	OSS
2	USS
3	Lean

Criteria	Relevance	Concept 1	Concept 2	Concept 3
Weight	5	2	5	9
Complexity	20	6	5	2
Comfort	11	4	6	8
Ease-of-use	15	9	4	1
Aero	3	7	3	10
Stability	28	8	5	3
Strength of the system	18	6	5	2
Total:		662	490	338

Table 12: *Steering Mechanism Design Criteria*

Criteria	Description	Range Definition
Weight	How heavy is the system?	1 = Heavier, 10 = Lighter
Complexity	How complex is system, how many components, how difficult is it to manufacture or assemble	1 = Most Complex, 10 = Least Complex
Comfort	How comfortable is it for the driver to use, ergonomics	1 = Least Comfortable/Ergonomic, 10 = Most Comfortable/Ergonomic
Ease-of-use	How user-friendly is the system? Is it intuitive? Is it hard to adapt to?	1 = Least User-Friendly, 10 = Most User-Friendly

Aero	How does the frontal area of the system affect the vehicle's aerodynamics?	1 = Affects Frontal Area Most, 10 = Affects the Least
Stability	How stable will it be at different speeds, turning corners, etc.?	1 = Least Stable, 10 = Most Stable
Strength of the system	How resistant the system to shock, abrupt changes in steering, etc.?	1 = Weakest, 10 = Strongest

Deciding on over seat steering based on the Steering Mechanism Decision Matrix resulted in different ways in which the team could go about this mechanism, even designing steering wheel ideas for the vehicle; although due to decisions made further along the semester, an under-seat steering mechanism resulted in a more appropriate mechanism for our design, therefore switching to under seat steering as the definitive mechanism for the vehicle.

Table 13: *Linkage System Decision Matrix*

Concept	Options		Criteria	Relevance	Concept				
					1	2	3	4	5
1	Rack & Pinion		Complexity	18	2	10	6	9	7
2	4-bar		Maneuverability	9	10	7	8	7	5
3	4-bar, Dual Drag Link		Ease-of-use	5	10	9	9	4	7
4	4-bar, No tie-rod		Weight	3	3	9	8	9	8
5	4-bar, X-over		Compatibility with steering mechanism	15	9	10	10	3	1
			Total:		320	465	399	317	245

Table 14: *Linkage System Design Criteria*

Criteria	Description	Range Definition
Complexity	How complex is system? How many components? How difficult is it to manufacture or assemble?	1 = Most Complex, 10 = Least Complex
Ease-of-use	How user-friendly is the system? Is it intuitive? Is it hard to adapt to?	1 =Least User-Friendly, 10 = Most User-Friendly
Weight	How heavy would the system be?	1 = Heavier, 10 = Lighter
Maneuverability	How easy is it for the system to complete the turns	1 = Easier, 10 = More Difficult
Compatibility with the steering mechanism	How compatible is it with the chosen steering mechanism design?	1 = Less Compatible, 10 = More Compatible

1.6.4 Brakes and Wheels

During the decision process for the brakes, the braking power and the braking time are the most crucial aspects when choosing the types of brakes. Brakes with high braking power and low braking time provide the driver with the best responsiveness based on the driver's reaction time when applying the brakes. For the selection of the brakes, two different types of braking systems were considered, a hydraulic braking system and a mechanical braking system. The hydraulic braking system provided the best modulation, and braking power and wore out less overuse. In addition, four different brakes were considered as shown in Table 15. Using a relevance range from 1 to 10 and a rating, the range of 1 to 10 for each brake is created to decide the appropriate brake for the competition. Utilizing these criteria, the hydraulic braking disk was chosen due to its high potential for braking power. In addition, the hydraulic braking disk can be used for multiple different tires, is easy to obtain, simple, and is adaptable to different environments. They are better designed to handle higher temperatures and dissipate heat compared to the drum brakes; however, they are more difficult to maintain and provide more weight than the rim brakes.

Table 15: Brakes Decision Matrix

Concept	Options		Criteria	Relevance	Concepts			
					1	2	3	4
1	Disc		Weight	8	7	2	5	9
2	Drum		Maintenance	2	7	6	7	8
3	Coaster		Braking Force	9	10	5	5	6
4	Rim		Durability	7	7	3	3	7
			Availability	7	8	2	5	6
			Simple design	5	7	2	7	9
			Total		300	118	190	278

Table 16: Brakes Design Criteria

Criteria	Description	Range Definition
Weight	How much will it weigh?	1 = Very Heavy, 10 = Less Heavy
Maintenance	How simple is the maintenance?	1 = Very Complex, 10 = Less Complex
Braking Force	How much force do the brakes apply?	1 = Less Braking Force, 10 = More Braking Force
Durability	How long do the brakes last?	1 = Less Durable. 10 = Very Durable
Availability	How readily available are the brakes?	1 = Less Available, 10 = Readily Available
Simple Design	How simple is the design?	1 = Complex, 10 = Simple

In the selection of the wheels the most important aspect was the maintains, weight and the traction when driving. In Table 17, a criterion was made for the selection of the tires. Using a relevance range from 1 to 10 and a rating the range for 1 to 10 for each tire, the selected design are the clincher tires. The tire has an inner tube inside where it can be filled with air and can easily be removed or replaced. The clincher tires are useful in the occasion of a flat tire and the need to repair the wheel. In addition, clincher tires are much more available and cost effective than tubular and tubeless tires. However, clincher tires are much heavier than the tubular and tubeless tires. The chosen size of wheels for the eHPV were 20 inch for the front and 26 inch for the rear.

Table 17: Type of Wheel Decision Matrix

Concept	Options		Criteria	Relevance	Concepts		
					1	2	3
1	Clincher		Weight	6	3	9	5
2	Tubular		Maintenance	9	8	5	3
3	Tubeless		Traction	7	5	8	6
			Cost	5	7	4	5
			Availability	7	8	5	6
			Total		216	210	166

Table 18: Wheel Design Criteria

Criteria	Description	Range Definition
Weight	How much will it weigh?	1 = Very Heavy, 10 = Less Heavy
Maintenance	How simple is the maintenance?	1 = Very Complex, 10 = Less Complex
Traction	How good is the traction?	1 = Bad Traction, 10 = Great Traction
Cost	How much will it cost?	1 = Very Expensive, 10 = Less Expensive
Availability	How readily available is it?	1 = Less Available, 10 = Readily Available

1.6.5 Fairing

The fairing design is derived from the most aerodynamic shape in nature, a water drop. In order to properly fit the design of a vehicle, it was adapted by considering the most important sections to reduce weight and expenses. It has a frontal area of 1.081 m^2, 70 (in) long and 29.3 (in) wide. The initial design had a bigger frontal area and by adjusting slightly the design it was diminished along with the drag coefficient which was directly affected by it. As shown in Figure 6 the design provides full cover to the driver and vehicle, while reducing the overall vehicle drag coefficient.

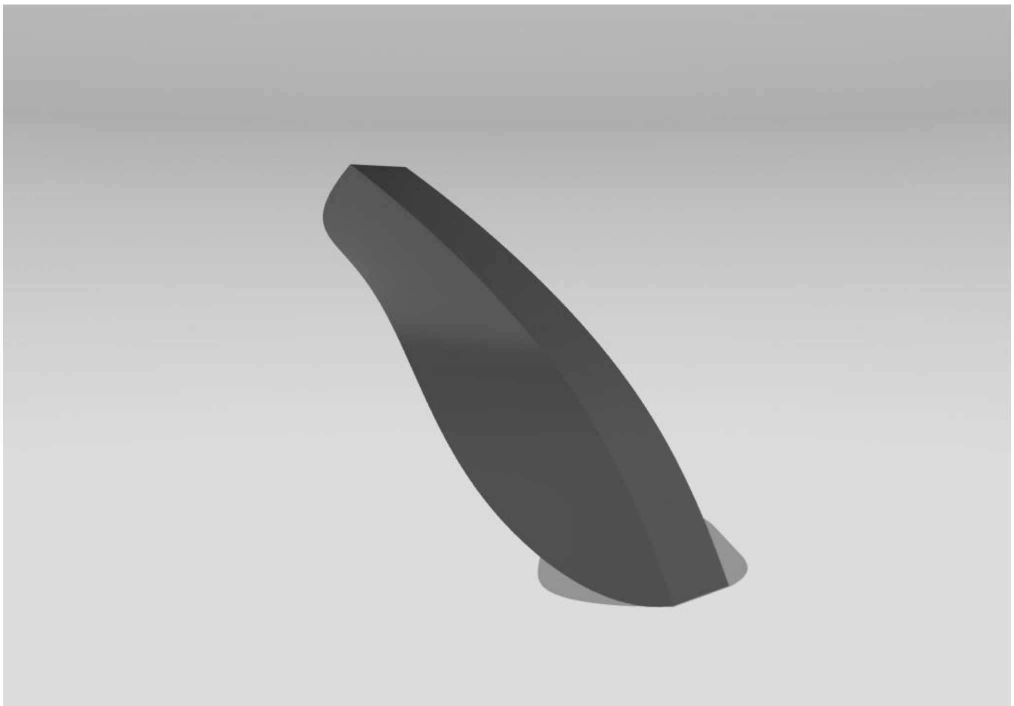


***Figure 6**: Fairing CAD Design*

Fiberglass is the material chosen for the fairing due to the low weight added, affordability, and availability of manufacturers. The use of only one material makes it a more efficient implementation since it has uniformity around the entire fairing lacking abrupt transitions that could affect aerodynamics performance.

1.6.6 Suspension

For the suspension selection, the team evaluated the placement and type of suspension added to the vehicle. The options to be evaluated were front vs. rear suspension and coil vs. hydraulic. The selection chosen based on the decision matrix was a rear coil suspension. However, the coil suspension was later changed to hydraulic since the team believed that a coil suspension would not be appropriate considering the vehicle is to be designed for a more urban terrain as compared to an off-road terrain.

***Table 19:** Suspension Decision Matrix*

Concept	Options		Criteria	Relevance	Concept			
					1	2	3	4
1	Full		Complexity	21	3	7	4	6
2	Rear		Practicality	18.5	7	6.5	5	6
3	Hydraulic		Durability	10	6	4	5	8
4	Coil		Weight	24.5	5	8	7	4
			Strength	26	8	5	6	8
			Total:		583	633.25	554	623

Table 20: Criteria for Suspension

Criteria	Description	Range Definition
Complexity	How complex is the system? How many components? How difficult to manufacture or assemble?	1 = Most Complex, 10 = Least Complex
Practicality	How well does it function for team's purposes?	1 = Least Practical, 10 = Most Practical
Durability	Capacity to operate in similar conditions to its initial state resisting user induced fatigue	1 = Least Durable, 10 = Most Durable
Weight	How heavy is the mechanism?	1 = Heavier, 10 = Lighter
Strength	How resistant is it to irregularities in path and changes in terrain?	1 = Weakest, 10 = Strongest

In the thought process for designing the suspension component was to analyze where in the rear part of the vehicle would the suspension be attached to. For the first iteration, a basic rear suspension CAD was added., a basic rear suspension CAD was, a basic rear suspension CAD was added.

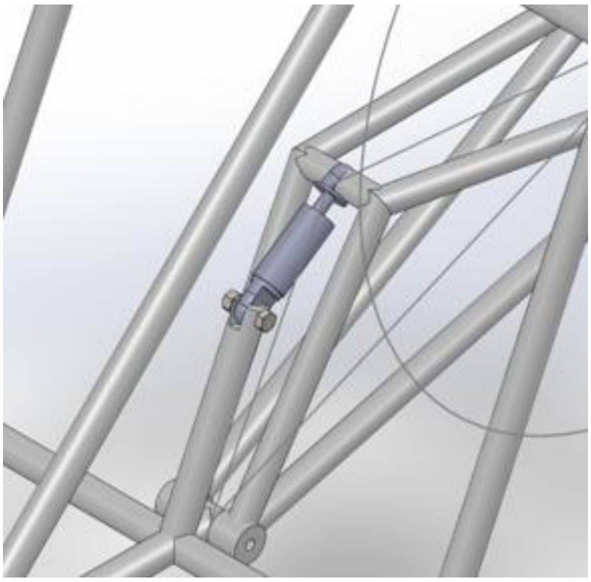


Figure 7: Rear Suspension Assembly 1st Iteration

Some of the problems encountered with the assembly design are the rod may create a cantilever that could lead to eventual deflection with the vibration forces acting on the frame material. This is to be solved using a simple geometric evaluation by positioning the bottom part of the eyelet of the suspension to be in a higher contact point than that of the superior eyelet.

2. Innovation

2.1 Purpose

The purpose of this division is to create something fresh and new that can be applied to the vehicle. The main objectives are to encourage innovation that advances the state of the art in human-powered vehicles and to provide the opportunity to demonstrate significant technological advances that meet the needs of one or more departments. It is essential to assume many important factors, such as whether an idea can be incorporated with the agreed specification. It must meet the following criteria: functional, lightweight, economical, and efficient while showing benefits such as performance, ergonomics, cost, environmental or social.

2.2 Concept Evaluation

The idea that the innovation department decided to pursue was a front wheel drivetrain. From past iterations and competing vehicles, a common trend was designing a tadpole configuration. This also meant that it would be rear wheel drive and would need to have a long chain to transmit the power from the front wheels to the rear one. The team wanted to make the length of the chain substantially shorter. Consequently, it was decided in the design phase of the project to pursue a front wheel drivetrain with a tadpole configuration.

2.3 Learnings

To be able to achieve a front wheel drivetrain on a tadpole configuration the team had to understand the mechanics of differential. Since most trike differentials are used on delta configurations where the differential is situated in the two rear wheels and just has to make the wheels turn at different angles simultaneously. Having it in the front two wheels of the tadpole configuration meant employing the same concept mentioned and also having it be able to transmit the power produced by the rider through the crankset to the differential to finally the front wheels. The team learned about the different types of connections needed to meet both requirements.

2.4 Execution

To begin working with the proposed innovation idea, a bicycle differential had to be researched. After finding such component, in the Hase Differential as seen in Figure 8. The team then had to design and manufacture the drive shafts that would connect the differential to two cv joints that would themselves be connected to the front wheels. The cv joints will help transmit the power from the differential to the wheels, while helping them maintain different turning angles at the same velocity.

Figure 8: *HASE Bikes differential component*

The results obtained from these connections meant that the team had to also design a locking mechanism through the axis of the wheels so that they could move forward while driving the car whilst being connected through the driveshafts. This prevented them from being unresponsive to that power transmitted and also gave the ability to coast when not pedaling.

3. Analysis

3.1 RPS Analysis

Ensuring rider's safety is the team's top priority. That is why these finite element analyses were done on the rollover protection system. These ensure that, given a situation where the vehicle rolls over, the rider is safe and receives no harm. To qualify these analyses as successful, HPVC rules state that there cannot be any sign of permanent deflection or fracture, and that all the elastic deformation experienced in the vehicle cannot exceed the competition limits for each load case. Additionally, to simulate the harness reaction forces to the rollover, the attachment points were set as fixed supports.

3.1.1 Top Load

The following simulations were conducted using Ansys Workbench 2022 static structural analysis. The RPS top load analysis, shown in Figures 11 and 12, follows HPVC guidelines that a 2670N force is applied to the topmost tube of the RPS at an angle of 12 degrees from the vertical axis. To simulate the harness straps supporting the rider while the vehicle is rolled over, four fixed supports were applied at the harness mount locations as shown in Figure 9.

3.1.1.1 Modeling

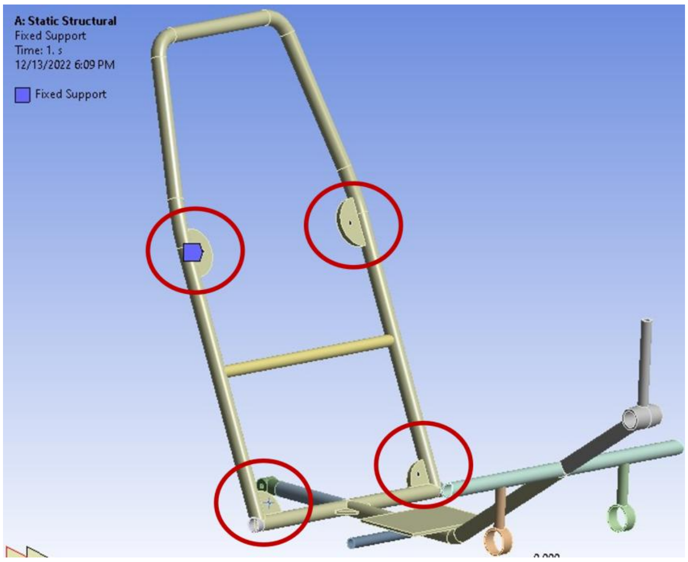


__Figure 9:__ Top load analysis fixed support's location

__Figure 10:__ Top load analysis force location

Figure # shows the fixed supports chosen to replicate the harness system attachment points for the top load and side load analysis Additionally, Figure 11 shows the location of the top load distributed through the top-most tube for the RPS.

3.1.1.2 Results

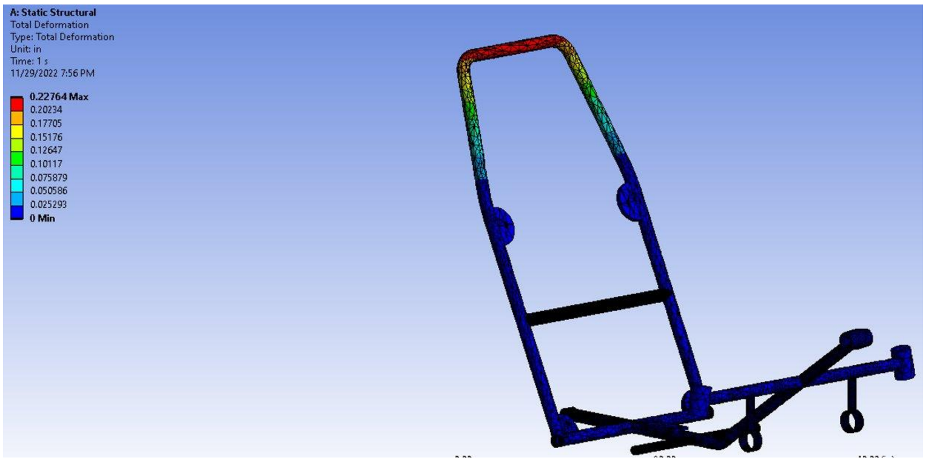


Figure 11: RPS Top Loading Deformation Results

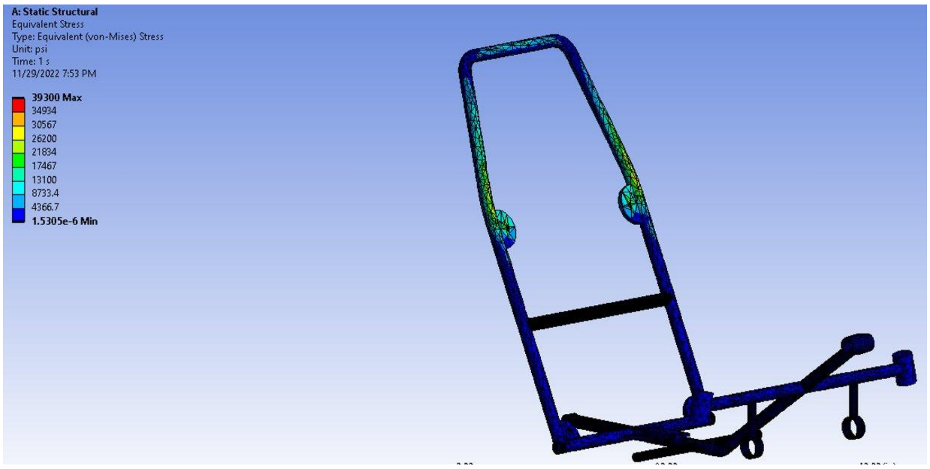


Figure 12: RPS Top Loading Equivalent Stress Results

The maximum total deformation that the RPS experiences in the top load analysis is 0.58cm. This deformation analysis is successful because it does not exceed the maximum deformation allowed for the top load analysis, which is 5.1cm. Additionally, the safety factor calculated with the maximum equivalent stress resulted in 1.7. This safety factor exceeds the team's own goal of achieving safety factors above 1.5.

3.1.1.3 Validation

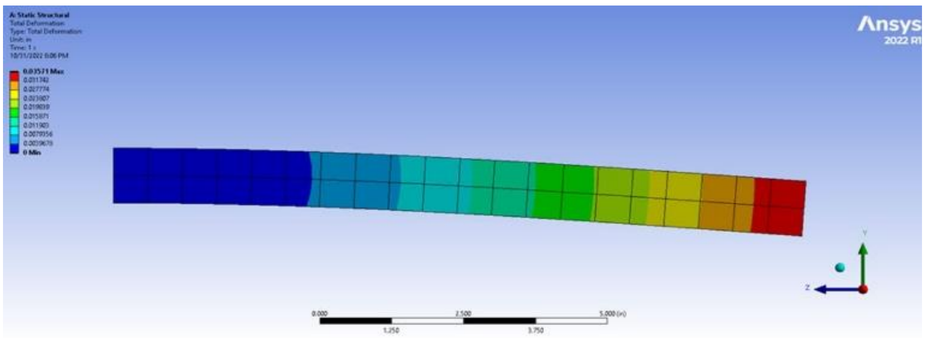


Figure 13: Validation Total Deformation Results

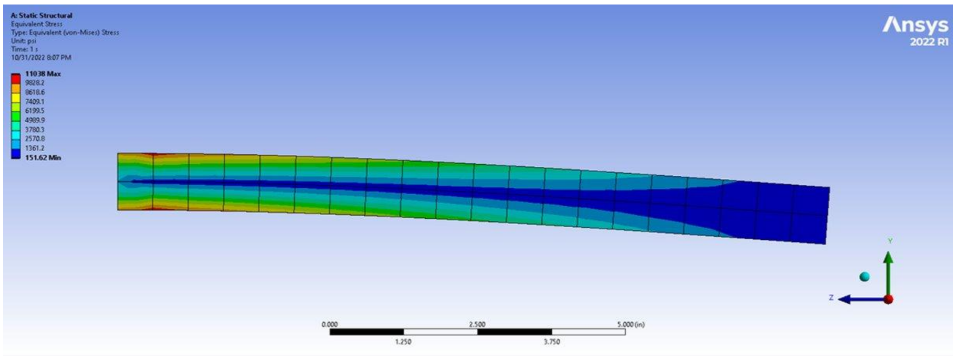


Figure 14: *Validation Equivalent Stress Results*

3.1.2 Side Load

The RPS side load analysis, shown in Figures 17 and 18, follows HPVC guidelines that which a 1330N force is applied at shoulder height to a tube on the side of the RPS. Like the top load analysis, to simulate the harness straps supporting the rider while the vehicle is rolled over, four fixed supports were applied at the harness mount locations as shown in Figure 15.

3.1.2.1 Modeling

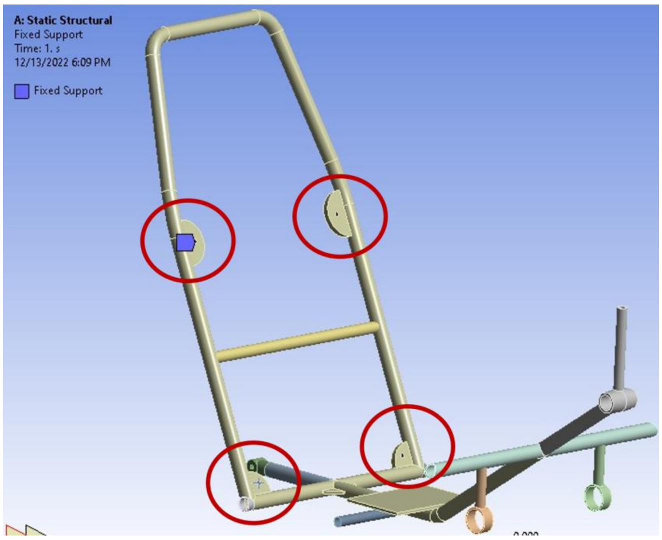


Figure 15: *Side load analysis fixed support's location*

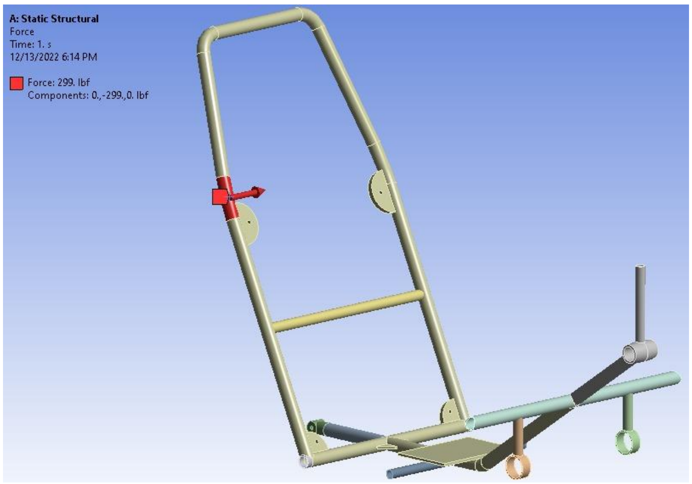


Figure 16: Side load analysis force location

Figure 15 shows the fixed supports chosen to replicate the harness system attachment points for the side load analysis Additionally, Figure 16 shows the location of the side load distributed, which was exerted throughout the tube at shoulder height of the rider.

3.1.2.2 Results

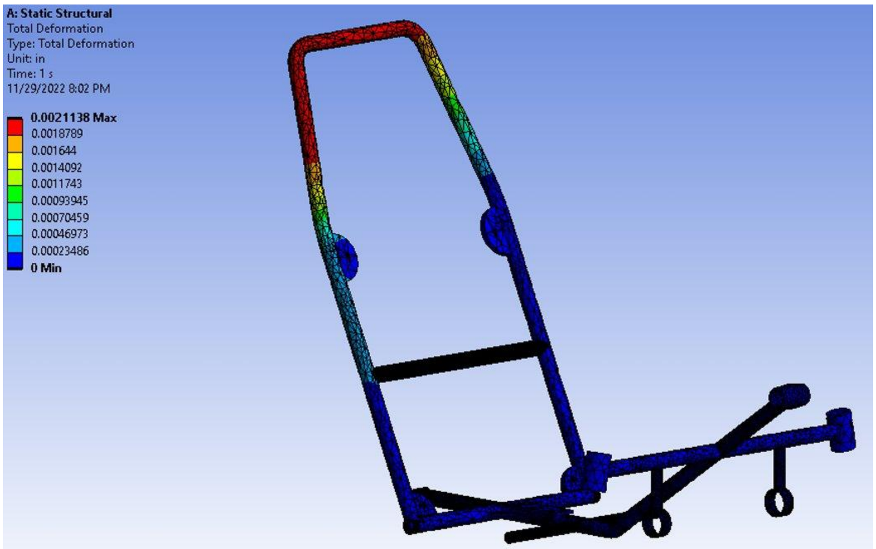


Figure 17: RPS Side Loading Deformation Results

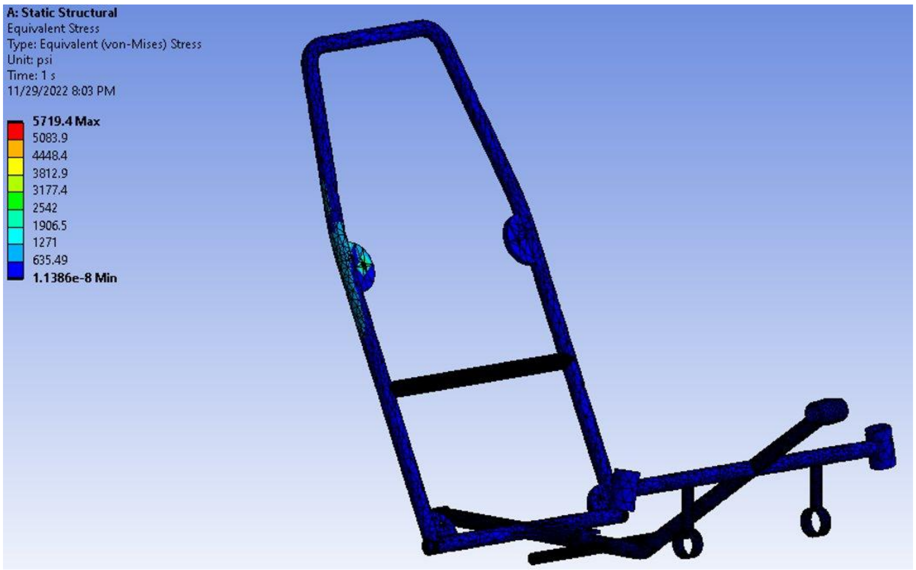


Figure 18: *RPS Side Loading Equivalent Stress Results*

The maximum total deformation that the RPS experiences in the side load analysis is 0.0054cm. This deformation analysis is successful because it does not exceed the maximum deformation allowed for the side load analysis, which is 3.8cm. Additionally, the safety factor calculated with the maximum equivalent stress resulted in 11.6. This safety factor exceeds the team's own goal of achieving safety factors above 1.5.

3.2 Structural Analysis

In addition to the RPS analyses as competition requirements, the frame department conducted two additional analyses. These analyses are backload analysis and weight distribution analysis. In the backload analysis, the team is simulating a rollover situation, like that of the previous analyses, where the vehicle rolls over in an inclined hill and experiences the contact with the ground in the back side of the RPS. The load used to conduct this analysis is the same as the top load analysis, 2670N, but it is applied at 12 degrees in the opposite side of the RPS. In this case, the force is applied from back to front, not front to back. On the other hand, the weight distribution analysis consists of applying the individual weight of vital components of the vehicle in their specific locations to see if the vehicle can support all its components and the driver. This takes into consideration the transmission, braking, steering and aerodynamic components.

3.2.1 Back Load Analysis

In the backload analysis, the team is simulating a rollover situation, like that of the previous analyses, where the vehicle rolls over in an inclined hill and experiences the contact with the ground in the back side of the RPS. The load used to conduct this analysis is the same as the top load analysis, 2670N, but it is applied at 12 degrees in the opposite side of the RPS. In this case, the force is applied from back to front, not front to back. Fixed supports were in the four-attachment point of the harness.

3.2.1.1 Modeling

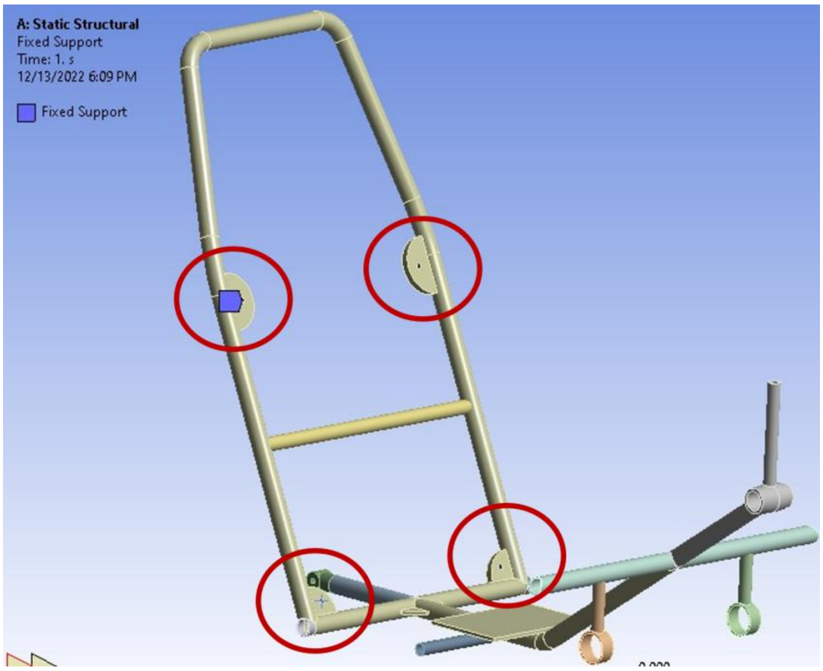


Figure 19: Back load analysis fixed supports location

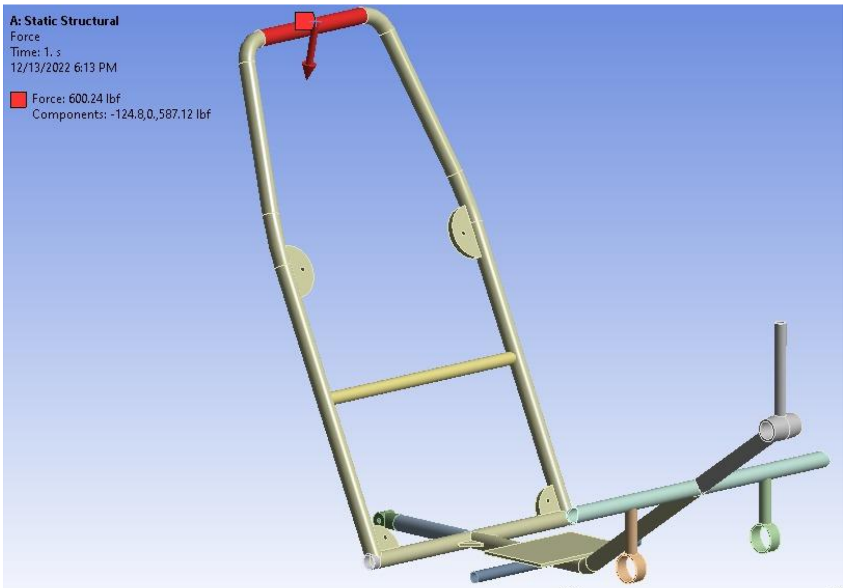


Figure 20: Back load force location

Figure 19 shows the fixed supports chosen to replicate the harness system attachment points for the structural analysis done applying a back load to the RPS. Additionally, Figure 20 shows the location of the back load distributed along the top tube of the RPS, from back to front.

3.2.1.2 Results

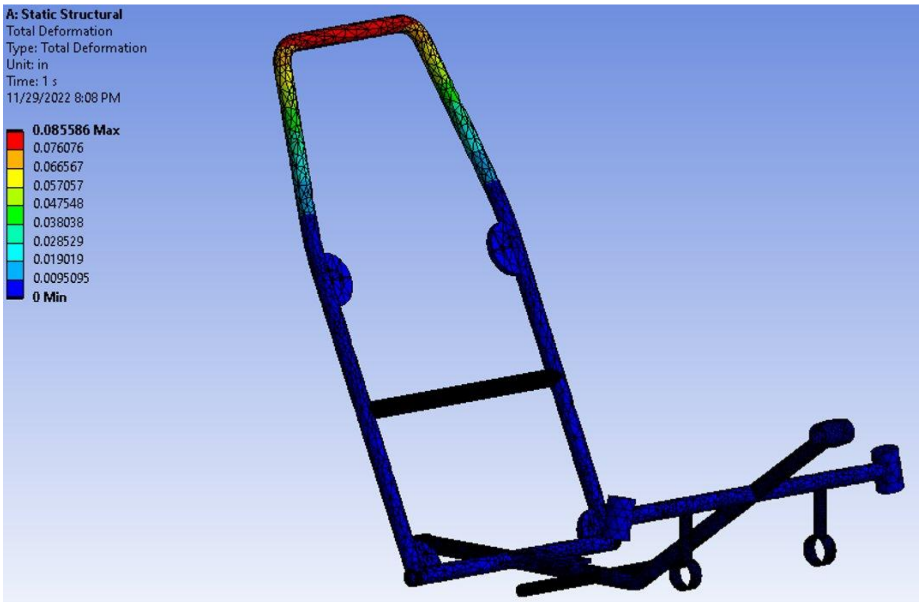


Figure 21: *RPS Back Loading Total Deformation Results*

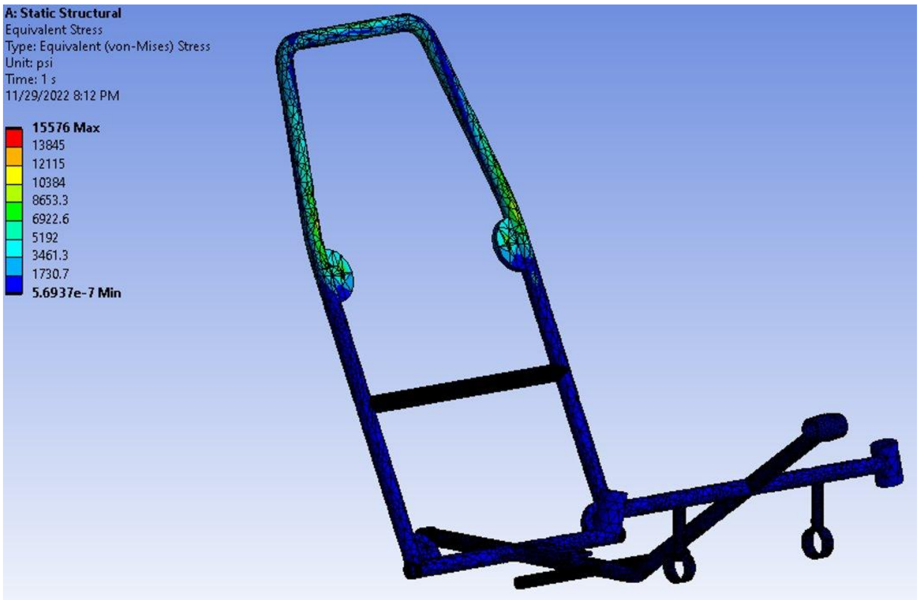


Figure 22: *RPS Back Loading Equivalent Stress Results*

The maximum total deformation that the RPS experiences in the backload analysis is 0.22cm. This deformation analysis is successful because it does not exceed the maximum deformation allowed for both top and side load analyses. Additionally, the safety factor calculated with the maximum equivalent stress resulted in 4.3. This safety factor exceeds the team's own goal of achieving safety factors above 1.5.

3.2.2 Weight distribution Analysis

The weight distribution analysis consists of applying the individual weight of vital components of the vehicle in their specific locations to see if the vehicle can support all its components and the driver. This takes into consideration the driver as well as transmission, braking, steering and aerodynamic components. The forces considered in the analysis were a 200 lbs. rider weight, 30 lbs. differential, 18 lbs. steering components on the kingpins, 10lbs. fairing, and a 50 lbs. battery. The analysis takes into consideration the heaviest components from every division. Additionally, the vehicles own weight, and the standard earth gravity were considered.

3.2.2.1 Modeling

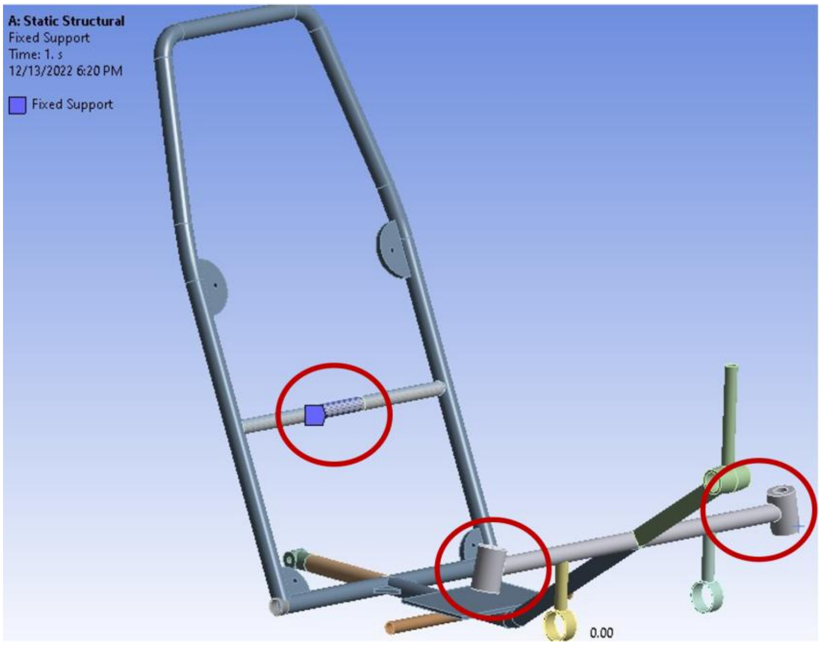


Figure 23: *Fixed supports for the weight distribution analysis*

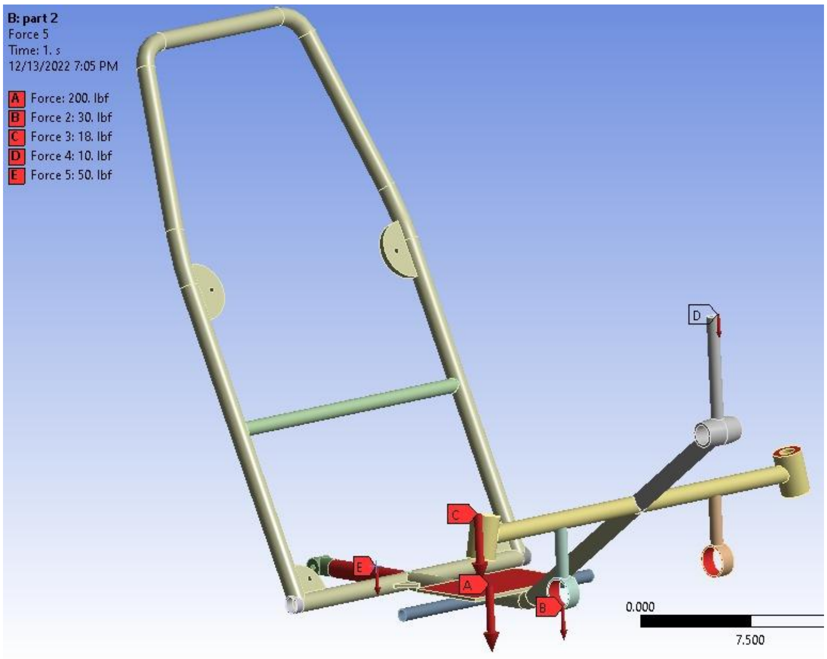


Figure 24: Weight distribution forces of each component found in the frame

Figure 23 shows the fixed supports chosen to conduct the weight distribution analysis. The supports were chosen in those areas because those are the contact point the whole frame will be having with the ground. The center tube of the RPS is where the suspension will rest, and the two kingpins is where the wheels will be placed. Additionally, Figure 24 shows the location of each load that was considered for the weight distribution analysis. Force 'A' is the driver weight, force 'B' is the differential, force 'C' are the steering components, force 'D' is the fairing weight, and force 'E' is the battery of the electronic systems.

3.2.2.2 Results

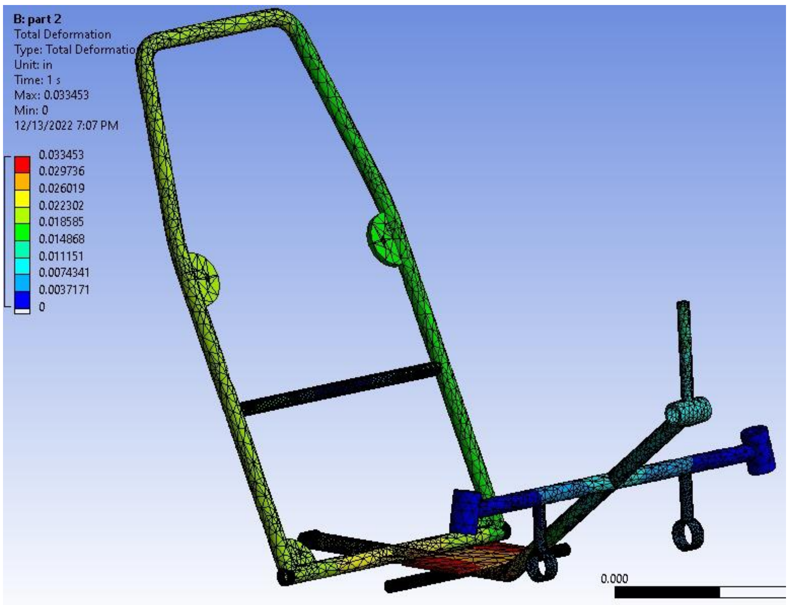


Figure 25: Weight distribution total deformation results

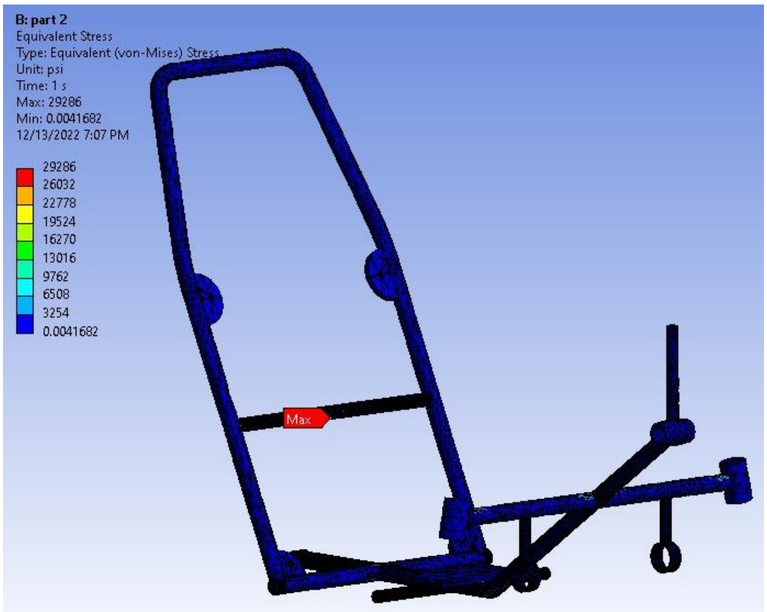


Figure 26: Weight distribution equivalent stress results

The maximum total deformation that the frame experiences in the weight distribution analysis is 0.083cm. This deformation analysis is successful because it does not exceed the maximum deformation allowed by the competition, which is 5.1cm, at it is within a safe acceptable range. Additionally, the safety factor calculated with the maximum equivalent stress resulted in 2.3. This safety factor exceeds the team's own goal of achieving safety factors above 1.5. This weight distribution analysis shows that the frame can withstand the weight of all the components from all the different departments in a static environment.

3.3 Aerodynamic Analysis

3.3.1 Objective

The department is focused on delivering quality aerodynamic analysis by focusing on the method utilized to calculate the drag and force variables that characterize an aerodynamic body. Objectively the goal is to compare each aerodynamic body design and obtain the lowest drag coefficient respectively. The analysis help visualize the flow of the designs in their early stages in order to potentially correct or re-design the aerodynamic body. Calculations of the drag and force variables are obtained through CFD Analysis utilizing Ansys Workbench.

3.3.2 Modeling Method & Assumptions

3.3.2.1 Assumptions:

CFD analysis for both sphere and windshields will consider the following conditions: k-epsilon flow, neglected lift force, no-slip condition on boundary layer and velocity of 11.18 m/s (25mph). Also, both analyses ignore the wheels, frame, and passenger weight.

3.3.2.2 Validation Procedure Analysis

Initially, the process of validating our methodology with the CFD software consisted in performing an analysis for a defined body. The defined body selected for analysis was a sphere whose Cd value ranges from 0.43-0.50. The same analysis that is developed for the sphere will be replicated for the upcoming aerodynamic design analysis. Furthermore, the performed analysis made use of the experimental values seen in Table 21.

***Table 21**: Input Variables for Experimental & Theoretical Calculations*

Velocity	Density	Dynamic Viscosity	Kinematic viscosity	Characteristic Length (L)	Area
11.18 [m/s] [25.00 mph]	1.225 [kg/m^3]	1.86E-4 [kg/m*s]	1.55E-4 [m^2/s]	0.0508 [2 in]	0.00810 [m^2]

3.3.2.3 Results:

Averaging range of drag values, our nominal cd value for the sphere would equal 0.465. Comparing this nominal Cd value to the experimental value, shown in Figure 27, results in percent error of 6.41 %. This value is accepted as it is within range.

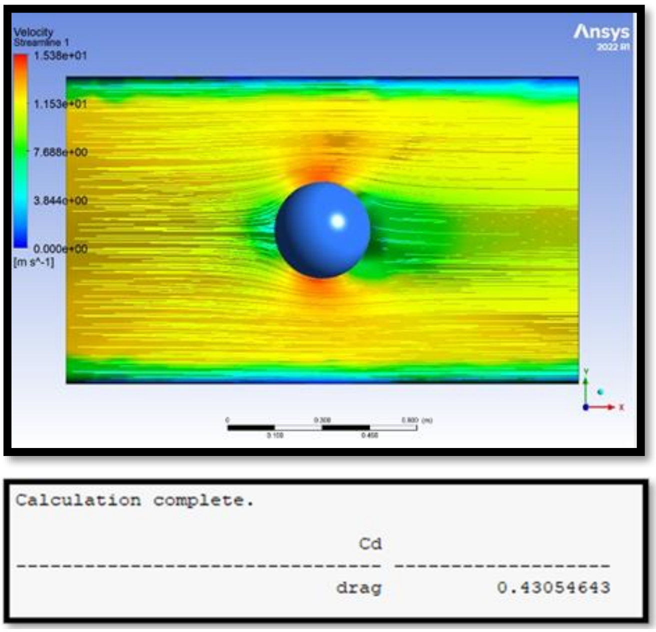


***Figure 27:** Velocity Profile and Drag Result for the Sphere*

Furthermore, in Figure 27 we may observe the velocity magnitude profile from the CFD analysis of the sphere. We see that the velocity magnitude in the front face of the sphere ranges from 4-5 m/s. This in turn would result in an experimental error range favorably less than 6.41%.

Table 22: Theoretical Values for Changing Velocities

Velocity [m/s]	Reynolds Number	Force Coefficient [N]	Coef. Drag	Percent Error
11.5	37,690.32	0.026381323	0.462	7.32%
11	36,051.61	0.025179689	0.461	7.08%
10	32,774.19	0.022432055	0.451765	4.94%
9	29,496.77	0.019883914	0.444941	3.35%
8	26,219.35	0.017403536	0.438118	1.77%
7	22,941.94	0.014990922	0.431294	0.18%
6	19,664.52	0.012646071	0.424471	1.40%
5	16,387.10	0.010368984	0.417647	2.99%

$$F_D = C_D\left(\frac{\rho v^2}{2}\right)A$$

$$R_e = \frac{VL}{v}, where\ L = Characteristic\ Length\ = r_{sphere}$$

We may conclude that the range of error between experimental and theoretical results are of good quality given they don't exceed an error percentage of 7%. The experimental drag equal to 0.4305 is considered accurate and our method of analyzing is graded as assertive.

3.3.2.4 Aerodynamic Body Analysis

To perform the analysis for the selected windshield design, we followed the same methodology utilized for the CFD analysis of the sphere. Our main objective is to obtain the Cd for the windshield design and take the corresponding actions if needed to comply with our teams' standards. Figure 28 illustrates the latest windshield design.

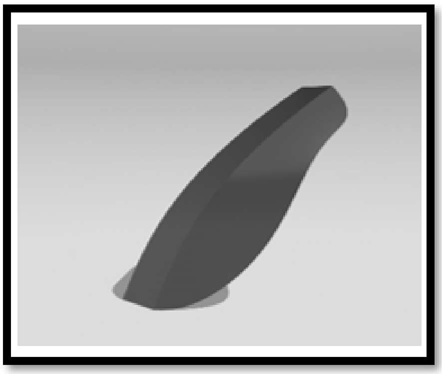


Figure 28: Design

3.3.2.5 Results:

Table 23:

Air Density [kg/m^3]	velocity [m/s^2]	Cd	Area [m^2]	Drag Force [N]	Drag Force [Lb]
1.225	11.18	0.35	1.081	28.978	6.514
		0.44	0.909	30.620	6.883
		0.40	0.5	15.312	3.442

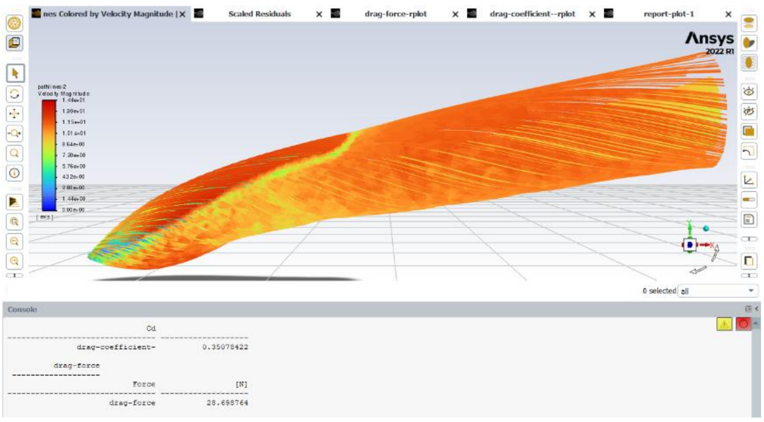


Figure 29: Velocity Path-lines Design 1

3.4 Power Analysis

3.4.1 Modeling

The analysis for the power generated in the transmission systems is done utilizing the gear ratio equation as shown below. The gear ratio is used to calculate the different speed the cassette can generate from the speed generated from the chainring by the pedaling of the driver. For the calculations different parameters are set to such as the diameter of the chainring and the number of teeth and the average cadence that can be generated by a human. In addition, the dimensions of a clincher tire are considered when calculating the overall distance covered from one revolution.

Table 24: Parameter Values

Parameter	Value
Tire Thickness (mm)	38.1
Rim Size (mm)	406
Chainring Teeth	52
Chainring Diameter (mm)	225.1
Cadence (RPM)	80

$$Gear\ Ratio = \frac{\omega_1}{\omega_2} = \frac{n_1}{n_2} = \frac{d_2}{d_1} = \frac{T_2}{T_1}$$

3.4.2 Results

In Table 25 the speed in mph, rpm and rad/s is calculated alongside the dimension of the sprocket and the torque generated. For Figure 30, Figure 31, and figure 32, the speed of the vehicle increases exponentially as the sprocket teeth become fewer and the sprocket become smaller. In addition, in figure 31 and figure 32 the teeth of the sprocket and the sprocket size and torque are proportional to each other. As the number of teeth increases the size of the sprocket the torque increases.

Table 25: Power Analysis

Sprocket teeth	Speed (MPH)	RPM	Angular Velocity (rad/s)	Diameter (mm)	Torque (N-m)
9	26.60	471.111	49.334	38.225	2.867
11	21.76	385.455	40.364	46.719	3.504
13	18.42	326.154	34.154	55.213	4.141
15	15.96	282.667	29.601	63.708	4.778
17	14.08	249.412	26.118	72.202	5.415
20	11.97	212.000	22.201	84.943	6.371
23	10.41	184.348	19.305	97.685	7.326
26	9.21	163.077	17.077	110.426	8.282
30	7.98	141.333	14.800	127.415	9.556
34	7.04	124.706	13.059	144.404	10.830

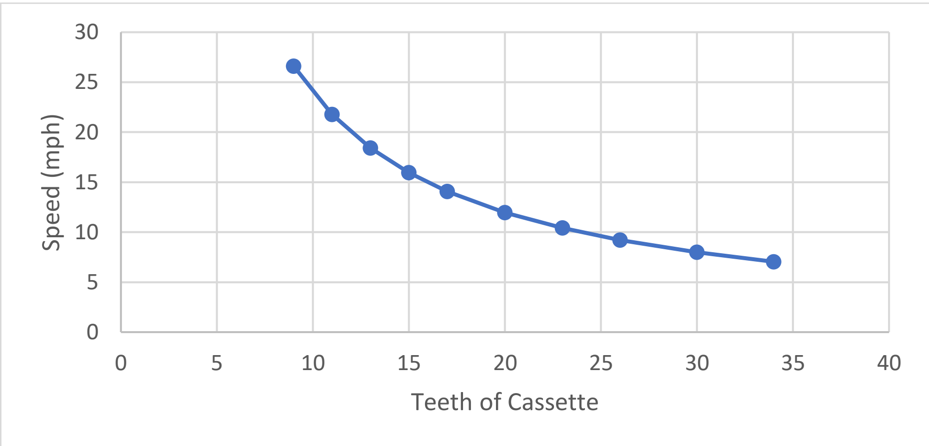


Figure 30: Vehicle Speed vs Cassette Size

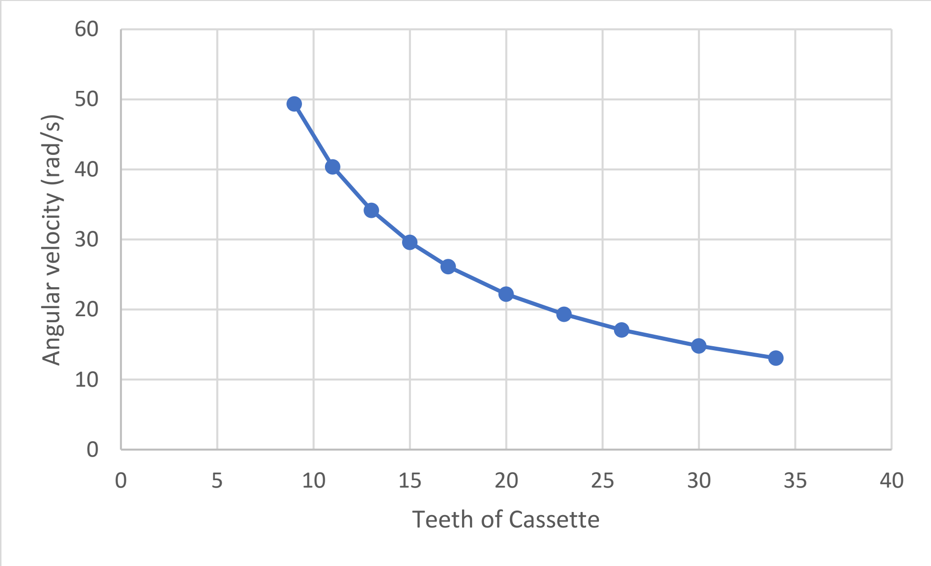


Figure 31: Wheel Angular Velocity vs Cassette Size

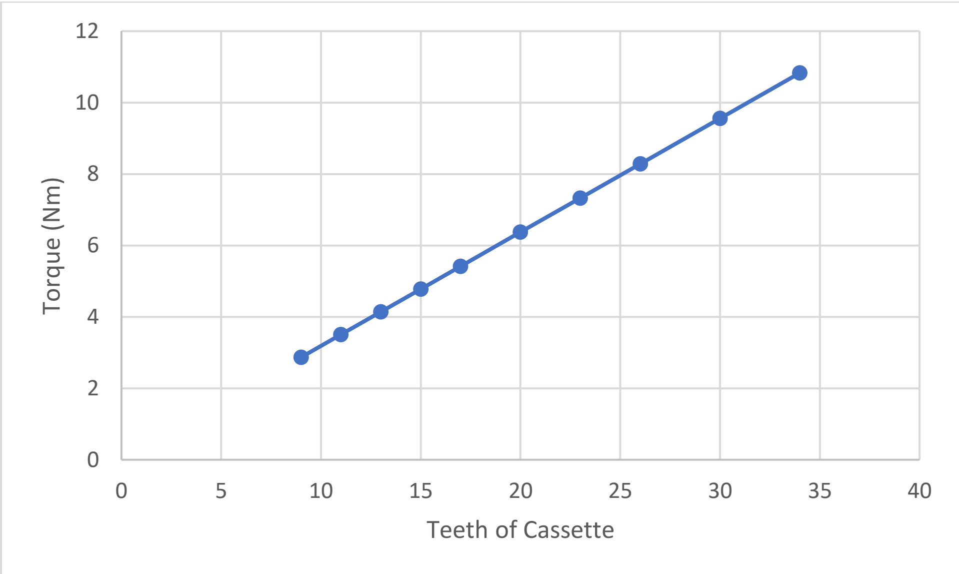


Figure 32: Torque vs Cassette Size

3.5 Braking Analysis

3.5.1 Modeling

For the braking analysis, the calculations are done off different set parameters such as the radius of the braking disk rotors, the dimensions of the braking pad in the caliper, the dimensions of wheels, the dimension of the brake line, and the speed of the vehicle established for the stopping distance requirements. To obtain the initial data for the stopping distance of a braking disk brake in the vehicle the equations shown below must be used, where the following equation is used to calculate the radius for the wheels and the rotor to locate the caliper. The braking pads were given an area based on the dimensions of real calipers and the vehicle is given a mass of 30kg based on the components and assembly. The vehicle speed is established as 25kmph and converted to a speed of 6.94m/s.

$$R = \frac{D}{2}$$

Table 26: HPVC Braking Parameter Values

Parameter	Values
Front Rotor Diameter (mm)	160
Front Rotor Radius (m)	0.08
Rear Rotor Diameter (mm)	160
Rear Rotor Radius (m)	0.08
Brake Pad Width (mm)	13.1
Brake Pad Length (mm)	26
Brake Line Diameter (mm)	5
HPV Weight (kg)	30
Front Wheel Diameter (m)	0.508
Front Wheel Radius (m)	0.254
Rear Wheel Diameter (m)	0.6604
Rear Wheel Radius (m)	0.3302
Speed of Bicycle (kmph)	25
Speed of Bicycle (m/s)	6.94

Furthermore, in the parameters of the vehicle, additional calculations were done to appropriately establish the energy the caliper dissipated, and distance travelled. Then the angular velocity for the rear and front wheels are calculated. The maximum force applied to the brakes was assumed to be 70 newtons based on research about handles and forces on bikes. The coefficient of friction is the value given for a dry asphalt road. The pressure within the cable is calculated next. This pressure is then transmitted to the caliper. The force done by the caliper is calculated utilizing the dimension of the brake pads and the cable pressure. The force done by the caliper is multiplied to the coefficient of friction to get the friction force. The torque for both the front and rear rotors are calculated.

$$\omega = \frac{V}{R}$$

$$\sigma = \frac{P}{A}$$

$$F_f = F\mu$$

$$T = F * R$$

Table 27: *Angular Velocity, Forces and Torque Calculations*

V	Value
Front Angular Velocity (rad/sec)	27.340
Rear Angular Velocity (rad/sec)	21.031
Force applied on brake (N)	70
μ (Coefficient of Friction)	0.8
Pcable (N/mm^2)	3.57
Fcaliper (N)	1214.26
Fclamp (N)	2428.53
Ffriction (N)	1942.82
Torque on front rotor (Nm)	155.43
Torque on rear rotor (Nm)	155.43

To calculate the weight and energy of the wheel the, the mass of the rider was distributed between 45kg to 95kg. By adding the mass of the rider and the ass of the vehicle total mass of the system can be estimated. Multiplying the mass and the gravitation acceleration, the weight of the vehicle can be calculated. It is assumed that the weight is distributed proportionally between the three wheels. Using the following equation, the energy can be calculated.

$$E = \frac{1}{2} m V^2$$

$$d_s = \frac{E}{F_f}$$

3.5.2 Results

In table 28 the stopping distance for a variety of weights, based on the vehicle and the rider, are demonstrated. The behavior of the stopping distance and the mass are proportional to each other. As shown in Figure 33 The distance required to stop the vehicle increases as the total mass of the vehicle increases. At 45kg, approximately 100lb, the stopping distance is 0.93m, while at 95kg approximately 200lb, the stopping distance is 1.55m. The stopping distance is found within the range of the competitions range of a maximum of 6m of stopping distance.

Table 28: Total Weight, Energy of Wheel, and Stopping Distance

Rider Mass (kg)	Total Mass (Kg)	Weight on Single Wheel (N)	Kinetic Energy for single wheel (J)	Stopping Distance (m)
45	75.000	245.25	602.82	0.93
50	80.000	261.60	643.00	0.99
55	85.000	277.95	683.19	1.05
60	90.000	294.30	723.38	1.12
65	95.000	310.65	763.57	1.18
70	100.00	327.00	803.76	1.24
75	105.00	343.35	843.94	1.30
80	110.00	359.70	884.13	1.37
85	115.00	376.05	924.32	1.43
90	120.00	392.40	964.51	1.49
95	125.00	408.75	1004.69	1.55

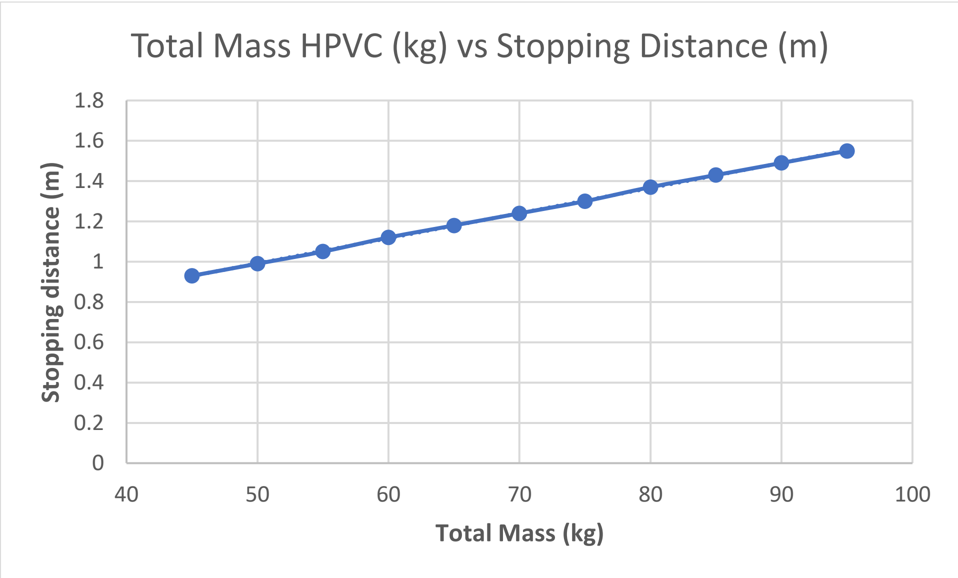


Figure 33: Brake Stopping Distance vs e-HPVC Mass

3.6 Kinematic Analysis

3.6.1 Modeling

The objective of performing a kinematic analysis is to, through iterative calculations and graphical methods, determine the turning angles and turning radius. To calculate the turning angles of the inner and outer wheels, the team relied on various combinations of wheelbase and wheel track measurements. These parameters can affect the vehicle's stability as well as the steering mechanism as a whole. The turning angles for different target turning radii were calculated in such a way that would satisfy the Ackermann Compensation Principle. With those calculations as guides, GeoGebra was used to perform a kinematic analysis of how the linkage system would behave to obtain an ideal turning radius.

3.6.2 Results

To comply with the Ackermann Compensation, the inner wheel must have a larger turning angle than the outer wheel. After performing the analyses, a wheelbase and wheel track of 4.2 ft and 2.4 ft, respectively were determined and the results shown in Table 29 for the turning angles were obtained.

Table 19: Wheel Track, wheelbase, Turning Radius, and Wheels' Turning Angles

Wheel track (ft)	Wheelbase (ft)	Top (ft)	Outer Wheel Angle δ_o (rads)	Inner Wheel Angle δ_i (rads)	Outer Wheel Angle δ_o (deg)	Inner Wheel Angle δ_i (deg)
2.400	4.200	14.337	0.279	0.309	16.000	17.730

The following equations were used to calculate the wheels' turning angles and the turning radius:

$$R = \frac{W}{\tan(\delta_{in})} + \frac{T}{2}$$

$$\delta_{in} = \tan^{-1}\left(\frac{W}{R - \frac{T}{2}}\right)$$

$$\delta_{out} = \tan^{-1}\left(\frac{W}{R + \frac{T}{2}}\right)$$

Where R is the turning radius, W is the wheelbase, T is the wheel track, and $\delta_{in,out}$ are the inner and outer wheels' turning angles, respectively. This information, along with the GeoGebra analysis (see Figure 34) was used to calculate a turning radius of 14.34 ft (4.37 m), well within the competition requirements as well as the team's goal.

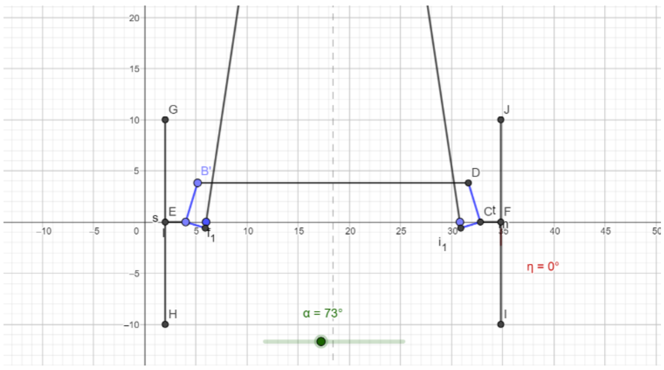


Figure 34: Kinematic Analysis of the Linkage System

3.8 Cost Analysis

The total cost for the manufacturing process of the human powered vehicle is $3772.69. The required parts for each technical department can be seen in Table 30 and Table 31. Each material has its respective cost and quantities for the manufacturing process of the eHPV.

Table 30: Material Cost Breakdown (Frame, Steering, Brakes, Wheels, and Transmission)

Cost Analysis				
Department	**Part**	**Qty.**	**Price**	**Cost**
Frame	0.875” OD- 0.058” Thickness (7$ per ft)	9.83 (ft)	$ 7.00 per ft	$ 68.81
	Bends	5 (ft)	$ 25.00 per ft	$ 125.00
	1.25” OD – 0.058” Thickness (8$ per ft)	5.58 (ft)	$ 8.00 per ft	$ 44.64
	1.25” OD – 0.095” Thickness (11$ per ft)	3.625 (ft)	$ 11.00 per ft	$ 39.88
	Harness	1	$ 30.00	$ 30.00
	Hooks	4	$ 10.00	$ 40.00
	FRAME TOTAL			$ 348.33
Steering	Steel rod (D 0.5”) (20 ft)	1	$ 11.36	$ 11.36
	Steel rod (th 0.25”) (20 ft)	1	$ 44.00	$ 44.00
	Chrom rod (D 2”)	1	$35.00	$ 35.00
	Chrom Tube (0.75” x 0.058”) (7$ per ft)	6	$ 7.00	$ 42.00
	Air shock	1	$ 300.00	$ 300.00
	Ball joints	6	$ 12.00	$ 72.00
	Bearings (OD 40mm, ID 17mm)	6	$ 15.00	$ 90.00
	STEERING TOTAL			$ 594.36
Brakes, wheels & transmission	Cassette	1	$ 45.00	$ 45.00
	Rear Transmission Derailleur	1	$ 65.00	$ 65.00
	Caliper	3	$ 23.00	$ 69.00
	Caliper adapter	3	$ 14.00	$ 42.00
	Braking disk	3	$ 20.00	$ 60.00
	Rim 24”	1	$ 65.00	$ 65.00
	Wheel 24”	1	$ 28.00	$ 28.00
	Wheel 20”	2	$ 18.00	$ 36.00
	Chain rig (52 teeth)	1	$ 15.00	$ 15.00
	Pedal ½	1	$ 15.00	$ 15.00
	Chain (9 speed)	1	$ 33.00	$ 33.00
	Motor bafang 500 W 48V	1	$ 466.00	$ 466.00
	Bearing	4	$ 16.00	$ 64.00
	Constant velocity joint	2	$ 35.00	$ 70.00
	Drive shaft	2	$ 200.00	$ 400.00
	Brake handles	2	$ 25.00	$ 50.00
	B,W,T TOTAL			$ 1,652.00

Table 31: Cost Analysis Breakdown (Innovation and Aerodynamics)

Cost Analysis				
Department	**Part**	**Qty.**	**Price**	**Cost**
Innovation	Differential	1	$ 548.00	$ 548.00
	Holder bearings	2	$40.00	$80.00
	Wheel Axis	2	$200.00	$400.00
	INNOVATION TOTAL			$ 1028.00
Aerodynamics	Labor to create the windshield is donated	1	$ 0.00	$ 0.00
	Mount	1	$ 150	$ 150
	AERODYNAMICS TOTAL			$ 150.00

The parts that are already in the team's possession can be seen in Table 32: Materials Available in Team Workshop or Donated by Team Members~~Table 32: Materials Available in Team Workshop or Donated by Team MembersTable 32: Materials Available in Team Workshop or Donated by Team Members~~. The value of these parts is subtracted from the final cost of the manufacturing process.

Formatte

Formatte

Table 32: Materials Available in Team Workshop or Donated by Team Members

Department	**Part**	**Qty.**	**Price**	**Cost**
Brakes, wheels & transmission	Wheel 20”	2	$18.00	$36.00
	Total Cost			$ 36.00

By adding up the material cost of each department and subtracting the value of stored and donated items, we get the total cost for the materials required to build the HPV, which can be seen in Table 33.

Table 33: Cost Summary

Cost Summary		
Parts and labor cost	Frame	$ 348.33
	Steering	$ 594.36
	Brakes, Wheels, & Transmission	$ 1,652.00
	Innovation	$ 1028.00
	Aerodynamics	$ 150.00
Value of Stored and Donated Parts		$ 253.74
Total Cost of every HPVC department		$3,772.69

4. Testing

4.1 Drivetrain

Regarding the testing of the eHPV's drivetrain, once the manufacture and installation of the various components is completed, the team must begin by inspecting the chain, electric motor, derailleur, and differential to make sure everything is in working order. Concerning the chain, it must be transmitting power smoothly without risk of snapping or twisting. The derailleur and its mechanism must be aligned and adjusted properly.

4.2 Steering

To test the steering system and make sure it meets the competition's requirements, the riders will push and pull the handles to turn and measure the angle of the path. This angle determines the turning radius of the vehicle. When pushing and pulling the handles, the team will also have to make sure all moving components are responding accordingly. When handling with a high amount of force applied to the input of the steering mechanism (bars) the team has to make sure the ball joints will not try to push out of their sockets.

4.3 Brakes & Wheels

The testing for the eHPV's brakes will commence after they are installed and inspected. The team will run various tests on a straight path in which the vehicle will reach a certain speed and then start braking. The braking time and distance will be measured to make sure the vehicle follows the competition requirements concerning the stopping distance.

4.4 Fairing

Concerning the test of the eHPV's fairing, the manufacturing process must be completed to compare the vehicle's speed using the fairing (case #1) and without it (case #2). The test must be performed under the same conditions. The terrain, driver, day, and distance must be the same for both cases. An additional test could be performed by using a 3D printed scale model of the vehicle and measuring the drag coefficient of the vehicle with the fairing and without the fairing by introducing it into a wind tunnel in the facilities of the University of Puerto Rico at Mayaguez and testing if the design works.

5. Conclusion

5.1 Comparison – Design goals, analysis, and testing

Table 34: Guacamaya Comparison of specifications and results

Criteria Evaluated	UPRM HPVC Specification	Analysis Results
Brake System	Stop in a range of 5 m at 15 mph	4.2 m
Minimum Turning Radius	Less than 5 m	4.37 m
Top Speed	Higher than 25 mph	26.67 mph
Steering Mechanism	Show stability traveling 15 mph in a straight line	Yes
Top Load Deflection	A non- elastic deformation less than 0.70 cm	0.58 cm
Top Load Safety factor	A minimum safety factor 1.2	1.7
Side Load Deflection	A non- elastic deformation less than 0.50 cm	0.0054 cm
Side Load Safety Factor	A minimum safety factor 1.2	11.6
Speed Bump Safety factor	A minimum safety factor 1.2	1.8
Production Cost	Less than $4000 per unit	$3,772.69
Fairing Impact	Drag Coefficient less than 0.44	0.35
Vehicle Weight	Less than 36.3 kg	21.7 kg

6. References

1. Google image result for https://cdn- 0.totalmotorcycle.com/wp-content/uploads/2018/11/2019- yamaha-fjr1300p-police-bike4.jpg. [Online]. Available: https://images.app.goo.gl/Hj9XumK GECfmeiX57. [Accessed: 22-Aug-2023].
2. “Automatic universal 3 point adjustable car seat belt(set of 2PCS),” Shopee365. [Online]. Available: https://www.shopee365.com/automatic-universal-3-point-adjustable-car-seat-belt-set-of-2pcs. [Accessed: 22-Aug-2023].
3. “Venta Privada Sena Sena 10u -sistema de Comunicación Bluetooth Casco Arai Black en private sport shop,” Private Sport Shop. [Online]. Available: https://www.privatesportshop.es/25444/sena/2795438-sena-10u-sistema-de-comunicacion-bluetooth-casco-arai-black.html. [Accessed: 22-Aug-2023].
4. “Espejo Para Bicicleta consejos de ciclista bicicletas Y piruletas,” Bicicletas y piruletas, 05-Aug-2022. [Online]. Available: https://bicicletasypiruletas.com/espejo-para-bicicleta/. [Accessed: 22-Aug-2023].
5. “Espejo Para Bicicleta consejos de ciclista bicicletas Y piruletas,” Bicicletas y piruletas, 05-Aug-2022. [Online]. Available: https://bicicletasypiruletas.com/espejo-para-bicicleta/. [Accessed: 22-Aug-2023].
6. “US6970691B2 -sports helmet having integral speakers,” Google Patents. [Online]. Available: https://patents.google.com/patent/US6970691B2/en. [Accessed: 22-Aug-2023].
7. “25.52US $ 12% off: BUHESHUI polycrystalline silicon solar panel small solar panels 1W 6V with black/red wire solar cells w/cable 110*60mm 10pcs/lot: Solar cells: - aliexpress,” aliexpress.com. [Online]. Available: https://www.aliexpress.com/item/32815375639.html. [Accessed: 22-Aug-2023].

8. n.d., “E-Z-On Vest VehicleRestraintHarness”, askned.com. [Online]. Available: https://askned.com.au/images/detailed/42/ezon-006_c545ecd0bf6f524c6492ccd6ac6b457d.jpg[Accessed: Sept. 5, 2022].
9. n.d., “How Door Latch Mechanism Works”, cartreatments.com.June15,2022. [Online]. Available: https://cartreatments.com/car-door-wont-shut/. [Accessed: Sept. 5, 2023].
10. Google image result forkirkhill.com.[Online].Available: https://kirkhill.com/wp-content/uploads/2019/11/AdobeStock_77189632-1.jpeg.
11. S. Newbauer, “Front Wheel Drive Tadpole Trikesby David Bruce”, tadpolerider.com.[Online]. Available: https://tadpolerider.com/2014/05/27/front-wheel-drive-tadpole-trikes-by-david-bruce/. [Accessed: Sept. 2, 2023].
12. “HPVC,” *ASME UPRM*. [Online]. Available: https://www.asmeuprm.com/hpvc.html. [Accessed: 2023].
~~12.~~13. “Sena Sena 10u - Neotec Shoei helmet bluetooth communication system - black private sale on Private Sport Shop,” *Private Sport Shop*. [Online]. Available: https://www.privatesportshop.com/en/25444/sena/2795440-sena-10u-neotec-shoei-helmet-bluetooth-communication-system-black.html. [Accessed: 2023].
~~13.~~14. www.cardiosistemas.com, “Scottcare1989: Cleveland, Ohio, Estados Unidos Holter ECG: Holter Presión Arterialtelemetría: Administración Dispositivos implantables,” *Scottcare Telesense | Telemetria Cardiaca Movil*. [Online]. Available: http://www.cardiosistemas.com/Scottcare-Telesense-Monitor-Cardiaco-ECG-Remoto-3-en-1-Telemetria-Cardiaca-Movil.html. [Accessed: 2023].
~~14.~~15. M. L. Pard, “2019 Yamaha FJR1300P police bike guide • total motorcycle,” *Total Motorcycle*, 12-Nov-2018. [Online]. Available: https://www.totalmotorcycle.com/motorcycles/2019/2019-yamaha-fjr1300p-police-bike. [Accessed: 2023].
~~15.~~16. R. Coddington, “6 reasons your car door won't shut or latch (and how to fix it),” *CarTreatments.com*, 15-Jun-2022. [Online]. Available: https://cartreatments.com/car-door-wont-shut/. [Accessed: 2023].
~~16.~~17. “E-HPVC: E-human powered vehicle challenge,” *ASME e-Fests*. [Online]. Available: https://efests.asme.org/competitions/human-powered-vehicle-challenge-(hpvc). [Accessed: 11-Oct-2023].
~~17.~~18. Artedinamico, “Baterías (electricidad),” *Equipos y laboratorio de Colombia*. [Online]. Available: https://www.equiposylaboratorio.com/portal/articulo-ampliado/baterIas-(electricidad). [Accessed: 10-Oct-2023].
~~18.~~19. R. Smith, “Free CAD designs, Files & 3D models: The grabcad community library,” *Free CAD Designs, Files & 3D Models | The GrabCAD Community Library*. [Online]. Available: https://grabcad.com/library/rotary-latch. [Accessed: 11-Oct-2023].
~~19.~~20. Terho, “Free CAD designs, Files & 3D models: The grabcad community library,” *Free CAD Designs, Files & 3D Models | The GrabCAD Community Library*. [Online]. Available: https://grabcad.com/library/enve-m930-carbon-fiber-wheel-29-rear-1. [Accessed: 11-Oct-2023].
~~20.~~21. *“Hase Trigo Differential.” Hostel Shoppe, hostelshoppe.com/products/hase-trigo-differential. Accessed 14 Oct. 2023.*
~~21.~~22. S. Shreve, “Free CAD designs, Files & 3D models: The grabcad community library,” *Free CAD Designs, Files & 3D Models | The GrabCAD Community Library*.

[Online]. Available: https://grabcad.com/library/20-bike-tire-1. [Accessed: 11-Oct-2023].
~~22.~~23. “Professional Fall Protection Electrician parachute polyester safety harness belt,” *Professional Fall Protection Electrician Parachute Polyester Safety Harness Belt - Buy Body Harness,Restraint Belts Safety Harness,Full Body Safety Harness Safety Belt Product on Alibaba.com*. [Online]. Available: https://www.alibaba.com/product-detail/Professional-fall-protection-electrician-parachute-polyester_62481790361.html. [Accessed: 2023].
~~23.~~24. “49 CFR § 571.209 - standard no. 209; seat belt assemblies.,” *Legal Information Institute*. [Online]. Available: https://www.law.cornell.edu/cfr/text/49/571.209. [Accessed: 24-Oct-2023].
~~24.~~25. “Jackson Palmer 2,050 Piece Hardware Assortment Kit with Screws, Nuts, Bolts & Washers (3 Trays).” [Online]. Available: https://www.amazon.com/Deluxe-Hardware-Assortment-Professional-Washers/product-reviews/B076CVQZWG. [Accessed: 2023].
~~25.~~26. “Make your bike electric,” *GeoOrbital*. [Online]. Available: https://geoo.com/. [Accessed: 22-Nov-2023].