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Human Powered Vehicle Internal Systems Design

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Senior/Honors Design Project

Advisor: Dr. Scott Sawyer

Class: 4600:471

Spring 2020

Internal Systems of a Human Powered Vehicle

HPVT Internal Systems Senior Design Project

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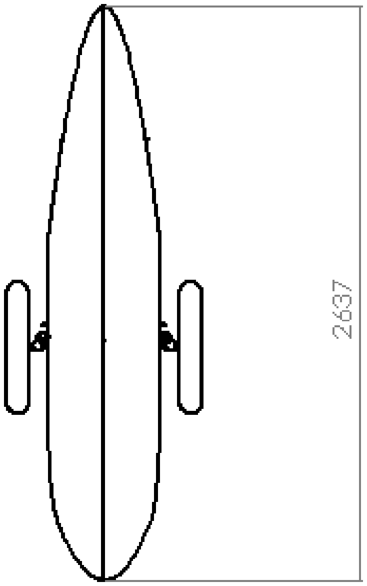
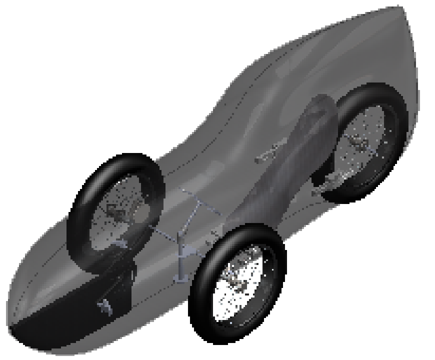
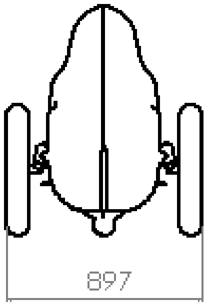
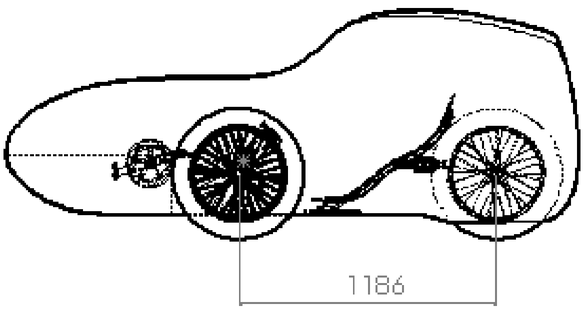
Assembly Drawing









ALL UNITS ARE IN MILLIMETERS

Abstract

In accordance with ASME 2020 Human Powered Vehicle Challenge Guidelines, the University of Akron’s Human Powered Vehicle team created a fully functioning vehicle. This project’s objectives are safety and efficiency in completing the course. Beyond the project’s objectives, it is the goal of every individual to apply engineering principles and classroom knowledge to a real world challenge.

The undergraduate engineering students performed the necessary operations to complete the vehicle at the University of Akron. This work was executed during the 2019-2020 academic year. Due to the amount of work required, this project was broken down into tasks completed by smaller sub-teams. A few examples of the sub-assemblies include wheels, steering, seating, and fairing. This process was beneficial as it allows students to explore their interests and become familiar with the intricacies of the challenge.

The team decided to name the project Roxanne. This vehicle shares many characteristics with Harambe, as they both are recumbent tadpole tricycles. In addition, this is the second year of molding carbon fiber and honeycomb to create a monocoque chassis. In order to improve the design, the team placed more focus on modifying the seating, steering, and wheels. The seating assembly has been redesigned to allow better ergonomics, which leads to a more comfortable experience. The steering assembly was modified to increase robustness. The wheels’ diameter and width have been increased to allow the vehicle to maneuver over a wider variety of terrain. This last feature is critically important for the bypass challenge.

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1. Design

1.1. Objective

This year, The University of Akron Human-Powered Vehicle Team designed and built the competition vehicle with a focus on the following goals:

- To comply with all rules and specifications for the ASME Human-Powered Vehicle Challenge
- To improve on the success of last year's vehicle by using a similar, but updated and optimized design
- To complete the manufacturing process early to allow for more time for testing and further improvement
- To improve the usability of the vehicle with a more easily adjustable and comfortable seat design
- To build an improved communication system for connection between the driver and the pits during competition
- To design the vehicle to perform well despite increased weight for some components

1.2 Background

A standard bicycle is a more efficient means of transportation than on foot, and is less costly and more environmentally friendly than driving an automobile. A bicycle allows a person to travel a greater distance than on foot in a shorter period of time and can be an effective way to exercise. The design of a standard bicycle can be improved upon in the areas of safety and efficiency, improvements allows a rider to travel a greater distance and at a faster speed than with a standard bike. In addition, it can be made safer than a standard one, allowing a rider to more easily withstand collisions, and by designing it such that it does not rely on the balance of the rider to stay upright.

The design of a recumbent trike with a structural fairing can bring about these improvements to a bicycle. The fairing makes the bike more aerodynamic, making it more efficient, protects the rider from unfavorable weather conditions, and the fairing can protect effectively against front and rear impact. Another advantage of the recumbent design is that it is unlikely to fall or roll over. This design is limited by weaker performance in side impacts, lower visibility and the cost of this type of bicycle to a consumer. The cost is the main reason why faired bicycles are not more widely-used. In the development of this year's competition vehicle, the team studied these limitations and developed a solution which would be effective in speed and endurance competition.

1.3 Prior Work

Some of Roxanne's features are extremely similar to those of Harame from the 2018-2019 season, including the shape of the fairing and wheelbase. The fairing for Roxanne was made using the same molds that were created for the original design of Harambe. In the 2018-2019 season, it was noted that producing the molds for the fairing was the most labor intensive part of the manufacturing process. So, the molds for Harambe were designed and created with reusability in mind. This allows us to redirect our resources such as money and manpower from making the molds to other features of the bike that have previously been neglected.

Since the same basic design of fairing is being used for Roxanne as was used for Harambe, the same decision making process will be used for many of the factors. This will include vehicle style, fairing design and fairing material. Also, the same aerodynamic analysis will be used for Roxanne as was used for Harambe.

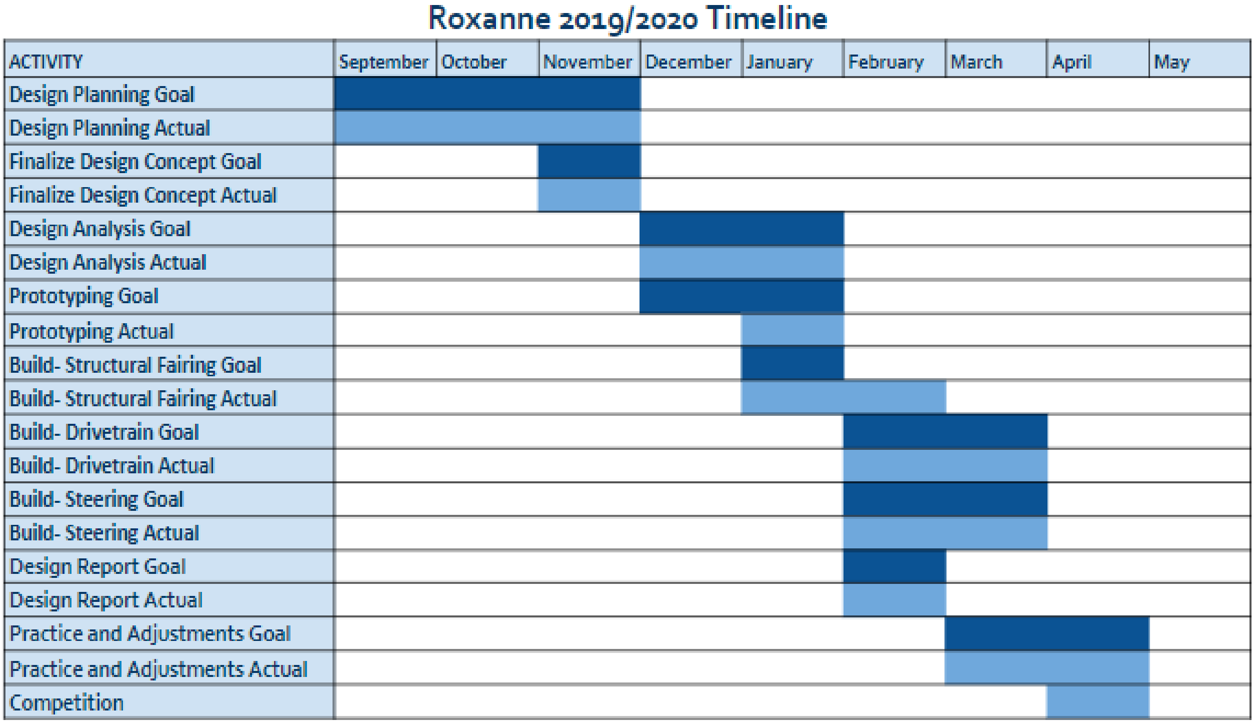
1.4 Design Specifications

The University of Akron Human-Powered Vehicle Team has decided on criteria for the design and manufacture of its 2020 competition vehicle based on the rules and safety requirements of the Human-Powered Vehicle Challenge, as well as design goals set based on the skills of the team's members, areas of improvement based on last year's performance and experiences:

I. The vehicle must be designed with safety and performance in mind.
II. The vehicle must be able to decelerate from 25km/h to a stop in a distance of 6m or shorter
III. The vehicle must be able to start and stop without outside assistance.
IV. The vehicle must demonstrate stability by traveling in a straight line for 30 m at a speed of 5 to 8 km/hr.
V. The vehicle must have a maximum turning radius of 8 m to handle successfully on the endurance course
VI. The vehicle must have sufficient brakes for safety and vehicle control
VII. The vehicle will include a Rollover Protection System, which will be a structural fairing, that will protect the rider from contact with the ground in case of a vehicle roll over.
VIII. The RPS must be able to support a top load of 2,670 N at 12 degrees from the vertical, with no visible permanent deformation and a maximum elastic deformation of 5.1 cm.
IX. A side load of 1,330 N should also have no permanent deformation and a maximum elastic deformation of 3.8 cm.
X. The RPS must fully enclose the rider to sufficiently meet safety requirements.
XI. To protect the vehicle's rider, other riders and spectators, the vehicle should have no sharp edges or other hazards.
XII. The vehicle will have a forward facing view angle of at least 180 degrees and a detachable rear-view mirror for the endurance race.

XIII. The lowest point of the vehicle must be at least 4 inches off the ground so the it can go over speedbumps and complete the bypass challenge in the endurance race.
XIV. The vehicle will be designed in a way that conserves weight, while creating the best possible performance for acceleration and handling.
XV. The vehicle will have an adjustable seat design to accommodate riders of various sizes.
XVI. The vehicle should be able to reach 40mph to be competitive in speed and endurance events.

1.4.1 Organizational Timeline



Roxanne 2019/2020 Timeline

ACTIVITY	September	October	November	December	January	February	March	April	May
Design Planning Goal	■	■	■						
Design Planning Actual	▨	▨	▨						
Finalize Design Concept Goal			■						
Finalize Design Concept Actual			▨						
Design Analysis Goal				■	■				
Design Analysis Actual				▨	▨				
Prototyping Goal				■	■				
Prototyping Actual					▨				
Build- Structural Fairing Goal					■				
Build- Structural Fairing Actual					▨	▨			
Build- Drivetrain Goal						■	■		
Build- Drivetrain Actual						▨	▨		
Build- Steering Goal						■	■		
Build- Steering Actual						▨	▨		
Design Report Goal						■			
Design Report Actual						▨			
Practice and Adjustments Goal							■	■	
Practice and Adjustments Actual							▨	▨	
Competition								▨	

Figure 1: Roxanne organizational timeline

1.5 Concept Development and Selection Methods

The goal of the 2019-2020 season was to improve upon the 2018-2019 design of Harambe. With the same molds being used, the same selection criteria for certain aspects of the vehicle are the same [1].Using the same molds created for Harambe for Roxanne, the team focused on aspects of the vehicle that could be improved upon without changing the shape of the fairing.

1.5.1 Vehicle Style

The style of the vehicle this year is once again a tadpole trike as the style is determined by the shape of the fairing, which is predetermined based on our molds. In the 2018-2019 season, different criteria were considered to determine the optimal style of vehicle. The vehicle style selection matrix from the 2018-2019 season is shown in table 1.

Table 1: Vehicle Style Selection Matrix [1]

Parameters	Weight	Tadpole Trike	Delta Trike	Streamliner	Quad
Performance	20%	4	4	4	2
Aerodynamics	20%	3	4	5	2
Weight	25%	3	3	4	2
Stability	25%	4	3	1	5
Past Experience	10%	5	3	1	1
Total	100%	3.65	3.4	3.15	2.65

1.5.2 Fairing Design

The fairing design for Roxanne was predetermined by the molds since the team chose to use the same ones from the 2018-2019 season. The decision matrix from last year can be found in table 2. One design change that Roxanne's fairing is getting is a change in the number of layers of carbon fiber. Harambe's fairing had two layers of carbon fiber on the outer layer and one on the inner layer, with reinforcing pieces in strategic locations. Roxanne's fairing has one layer of carbon fiber on the outside and one layer on the inside, with reinforcing pieces at strategic locations.

Table 2: Fairing Design Decision Matrix [1]

Parameters	Weight	Upright	Reclined	Prone
Rider Comfort	20%	4	4	2
Weight	25%	3	3	4
Aerodynamics	30%	3	3	4
Power Output	25%	5	4	4
Total	100%	3.7	3.45	3.6

1.5.3 Fairing Material

With the success of Harambe in the 2018-2019 season, the team decided to use the same materials for the fairing in the 2019-2020 season with Roxanne. The decision matrix for Harambe's materials can be found in table 3. The fairing consists of carbon fiber, Nomex honeycomb, oak, and Hysol adhesive.

Table 3: Fairing Material Decision Matrix [1]

Parameters	Weight	Carbon Fiber	Fiberglass	Polycarbonate	Coroplast

Stiffness	35%	5	5	2	4
Manufacturability	20%	2	3	4	3
Cost	20%	2	3	5	5
Weight	25%	5	2	3	2
Total	100%	3.8	3.45	3.25	3.5

1.5.4 Seat Selection

The seat for this vehicle was selected based on ergonomics, strength, and weight. This year, a seat was purchased from an outside vendor rather than fabricated in-house for several reasons. First of all, the seat was purchased for time savings. Last year, the fabricated carbon fiber seat was roughly $50 in materials but that does not take into consideration the man hours required. The purchased seat this year was $200, but required no man hours and is of considerably higher quality than a seat made in house. Next, the purchased seat is more comfortable which greatly adds to the ergonomics of the bike. Finally, the seat makes the bike look more professional with its sleek, minimalist design. The seat was also mounted in a way that it will be adjustable in order to accommodate drivers of varying heights. A decision matrix was created in order to quantify which seat is best for Roxanne. The parameters, ergonomics, cost, adaptability, weight, aesthetics, attachment, and reusability are graded from 1-4 and appropriately weighted. The figure below is the decision matrix for seat selection.

Table 4: Seat Selection Decision Matrix

Parameters	Weight	Off the Shelf Seat	Custom Made Seat
Ergonomics	25%	4	3
Cost	20%	2	1
Adaptability	15%	3	2
Weight	10%	4	4
Aesthetics	15%	4	3
Attachment	5%	2	4
Reusable	10%	2	1
Total	100%	3.15	2.4

1.5.5 Steering Design

The steering design for Roxanne will match that of Harambe with a few slight alterations in manufacturing and stability. Roxanne's steering design will implement a bell crank system in order to balance weight and ergonomics []. Harambe's steering design was successful in theory however it lacked precision and stability. Much of the steering was connected using fasteners last year which created opportunities for play in Harambe’s steering system. Components in Roxanne’s steering system will be welded when possible to provide a more rigid system. Roxanne’s steering column will substitute a ball bearing in place of Harambe’s sleeve bearing for added support and reduced friction. In addition, the steering wheel has been improved upon the previous year’s design. This has largely been done to accommodate safety features and to provide extra strength to areas where control components are fastened. A decision matrix was implemented in order to be sure that the best steering is selected for Roxanne. Parameters are graded from a scale of 1 to 4 and weighted appropriately. These parameters are ergonomics, cost, weight, aesthetics, and attachment. This matrix can be found below in table #.

Table 5: Steering Decision Matrix [1]

Parameters	Weight	Bell Crank Steering	Rack and Pinion Steering	Tractor Steering	Swing Steering
Ergonomics	10%	4	4	2	1
Cost	15%	2	1	4	3
Weight	35%	2	1	4	4
Aesthetics	15%	3	3	2	1
Attachment	25%	4	4	2	2
Total	100%	3.0	2.35	2.65	2.6

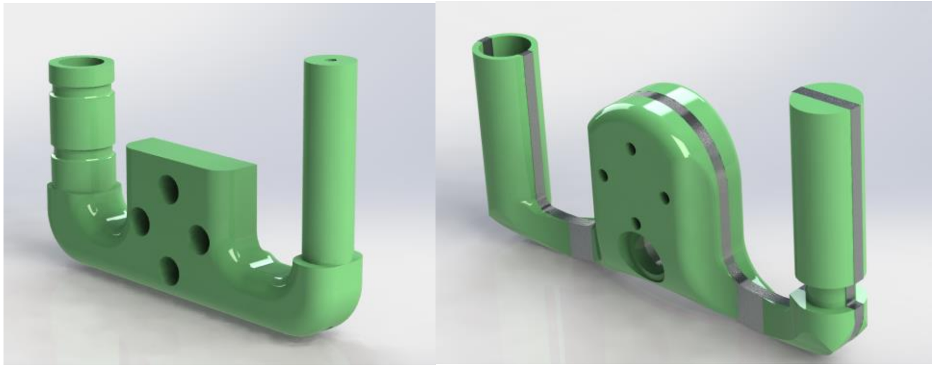


Figure 2: Last year’s steering wheel design. (left) New design. (right)

Figure 3: Isometric view of steering

1.5.6 Description of Vehicle

Fairing

Roxanne features a carbon fiber monocoque fairing, much like its predecessor, Harambe. This design was extremely light since it eliminated the need for an aluminum frame. Roxanne also uses the same combination of carbon fiber, honeycomb, oak, and Hysol as Harambe. Roxanne is designed to be lighter by reducing the number of layers of carbon fiber and amount of resin used to lay up the carbon. A majority of the honeycomb is 0.25” within the fairing, with the exception of a few areas that have 0.375” honeycomb to compensate for the strength lost with the reduction of carbon.

Seat

After deciding to purchase rather than fabricate a seat, it was necessary to find a method to mount the seat. One complication with the purchased seat is that it does not contain engineered hard points for optimal mounting with fasteners. In order to protect the holes drilled into the carbon fiber, a custom spacer made of a UV cured resin will be 3D printed to match the contour of the seat. This will dampen vibrations and relieve stresses in the carbon fiber at the mounting holes. This spacer is sandwiched between the seat and a steel plate. The seat will be adjustable to ensure that the driver will be seated comfortably while riding. In order to promote alignment and support the load of the rider in the seat, the seat will ride on two linear bearings with a mechanical locking system to ensure rider safety. The back of the seat will be supported in a similar way but there will be no elastic spacer because the back of the seat will not experience the same forces that the bottom mount will while riding so the added protection is not necessary.

Manufacturing

Having decided upon a monocoque chassis, the team once again had to decide upon a method of manufacturing. The choices were once again narrowed down to either prepreg or lamination methods to gain the desired strength. Prepreg was found to be more expensive than lamination, and above the budget of the team. The team had also gained experience with lamination in the 2019 manufacturing of Harambe, making lamination an obvious choice. The same method of lamination that was outlined in the design report for Harambe was used. “Lamination is a process where carbon is laid over a release film and then epoxy is pulled through the fabric using a handheld squeegee. Another layer of release film is laid on top and then the carbon can be cut into the desired shape using templates.” [1]

After the carbon was cut into the desired pieces, it was laid into the molds, covered with peel ply, and put into the vacuum bagging. The part was then taken to an autoclave to fully cure the epoxy at high pressure and temperature. The first layer of carbon to go into the molds, which ends up being the outer skin, is cured at 551.5 kPa (80psi) and 82.2°C(180°F) for 4 hours. After the first layer is fully cured, Hysol is spread on the inside of this cured layer, and sections of 0.25” and 0.375” Nomex Honeycomb were placed into the molds. The entire monocoque has 0.25” honeycomb, with the exception of the area surrounding the head tubes and the location of the RPS, which have 0.375” honeycomb. This was done to provide more strength at these locations which are expected to have load concentrations. Oak hardpoints to be used for mounting the seat, harness mounts, axle, and steering were bonded into this layer as well. Then, another sheet of carbon was laminated. One side of this sheet was laminated with epoxy, and the other side was laminated with Hysol so it would bond to the inner core of honeycomb. This layer was covered with release film, bagged, and sent back to the autoclave. This layer of honeycomb and carbon was cured at 137.9 kPa (20 psi) and 82.2°C(180°F) for 4 hours. After both halves of the fairing were removed from the molds, they were wet sanded, clear coated, and bonded together with Hysol.

Roxanne’s pedals are mounted into a bottom bracket panel just as Harambe’s were. The bottom bracket panel consists of five layers of carbon fiber on each side of a layer of 0.75” aluminum honeycomb. The area that will surround the crank will have a 3.5” by 3.5” oak hardpoint to provide extra rigidity at the stress concentration.

All methods of manufacturing done this season were done with the intent of making a more marketable product. The team wanted to make the lightest, fastest, safest, easiest to use, most cost effective and visually pleasing vehicle possible. The goal of the team was to make Roxanne perform and look more like a human powered vehicle one would buy from a retailer.

2. Analysis

2.1 RPS Analyses

Table 6: RPS Analysis Summary

Item	Description
Objective	Design an RPS capable of protecting the driver in the event of a collision or rollover.
Assumptions	The hatch is considered negligible in this analysis.
Methods	Use Solidworks Simulation to study deformation caused by loading representative of various accident scenarios. Simulate impact by applying force over a small surface area where contact will occur.
Results	The maximum deflection in the top load case was 3.487 mm. The maximum deflection in the side load case was 4.095 mm.

2.1.1 Methods

Safety has always been the first consideration for this team. The vehicle's RPS is the main source of protection for the rider in the event of a rollover or crash. Two loading scenarios were considered in analyzing the RPS of Roxanne. The first was a top load of 2,670 N (600 lbf) downwards 12 degrees toward the rear of the vehicle. This simulates loads that could be expected in a complete rollover. The second was a side load of 1,330 N (300 lbf) at the harness mount location. This loading simulates a tip over only onto the side of the vehicle.

The Solidworks Simulation was used to analyze the RPS. The fairing was modeled the same way it was in the 2018-2019 season for Harambe. "The monocoque was modeled as a surface and meshed with shell elements. Three shell element compositions were developed and assigned based on the three types of sandwich configurations used in the monocoque. Custom materials were created to verify the materials modeled into Solidworks had the same characteristics as those used in construction. Material properties were found using CES software." [1]

2.1.2 Results and Conclusions

The top load of 2,670 N resulted in a maximum deflection of 3.487 mm. This deformation is within the allowable limit of 5.1 cm. This result varies from that of Harambe due to the change in number of layers of carbon throughout the vehicle. Results of this analysis can be seen in Figure 4.

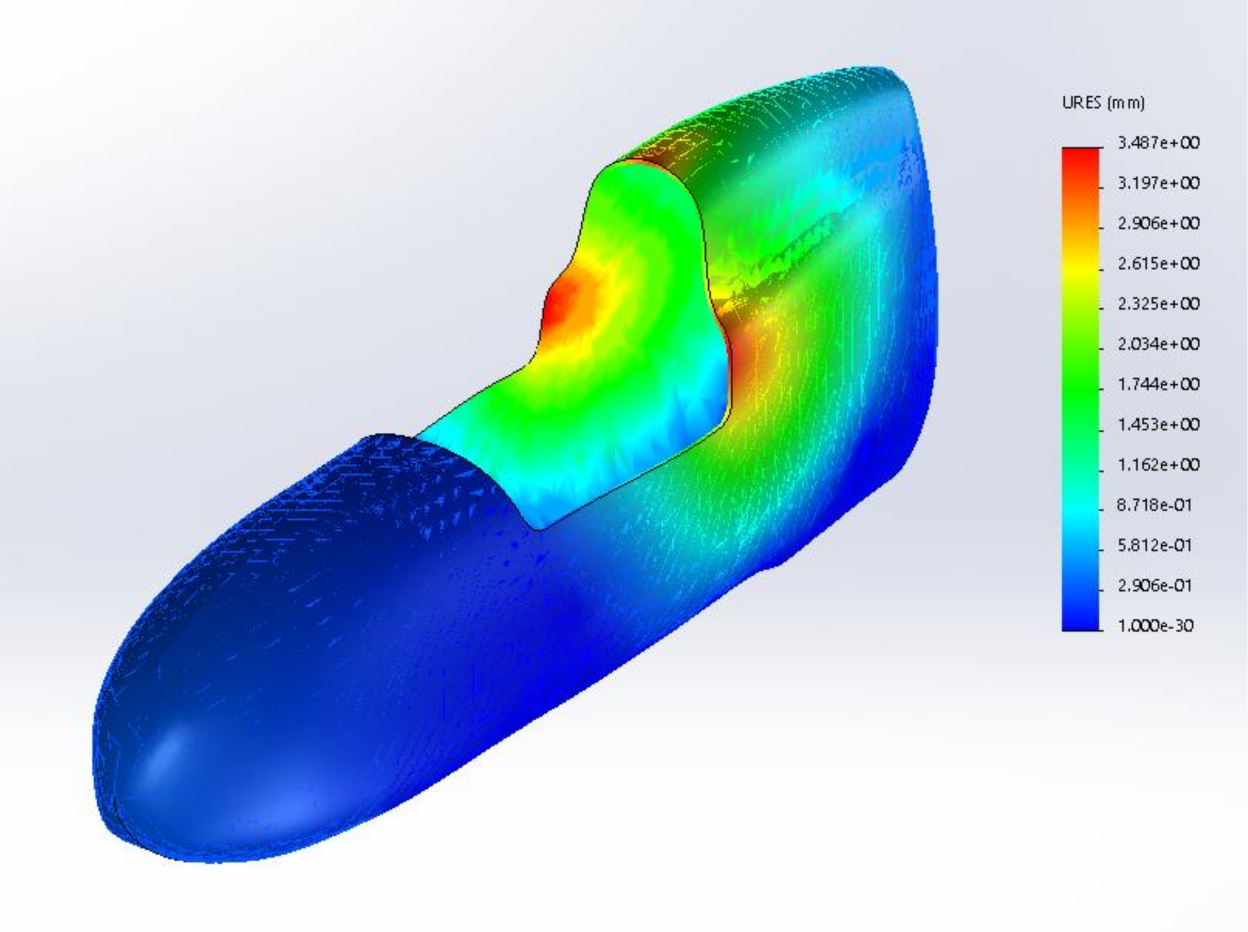


Figure 4: RPS FEA top load condition

The side load of 1,330 N resulted in a maximum deflection of 4.095 mm. This result outperformed Harambe due to differences in the number of layers of carbon and differing thicknesses of honeycomb used. This deformation is within the allowable limit of 3.8 cm. Results of this analysis can be seen in Figure 5.

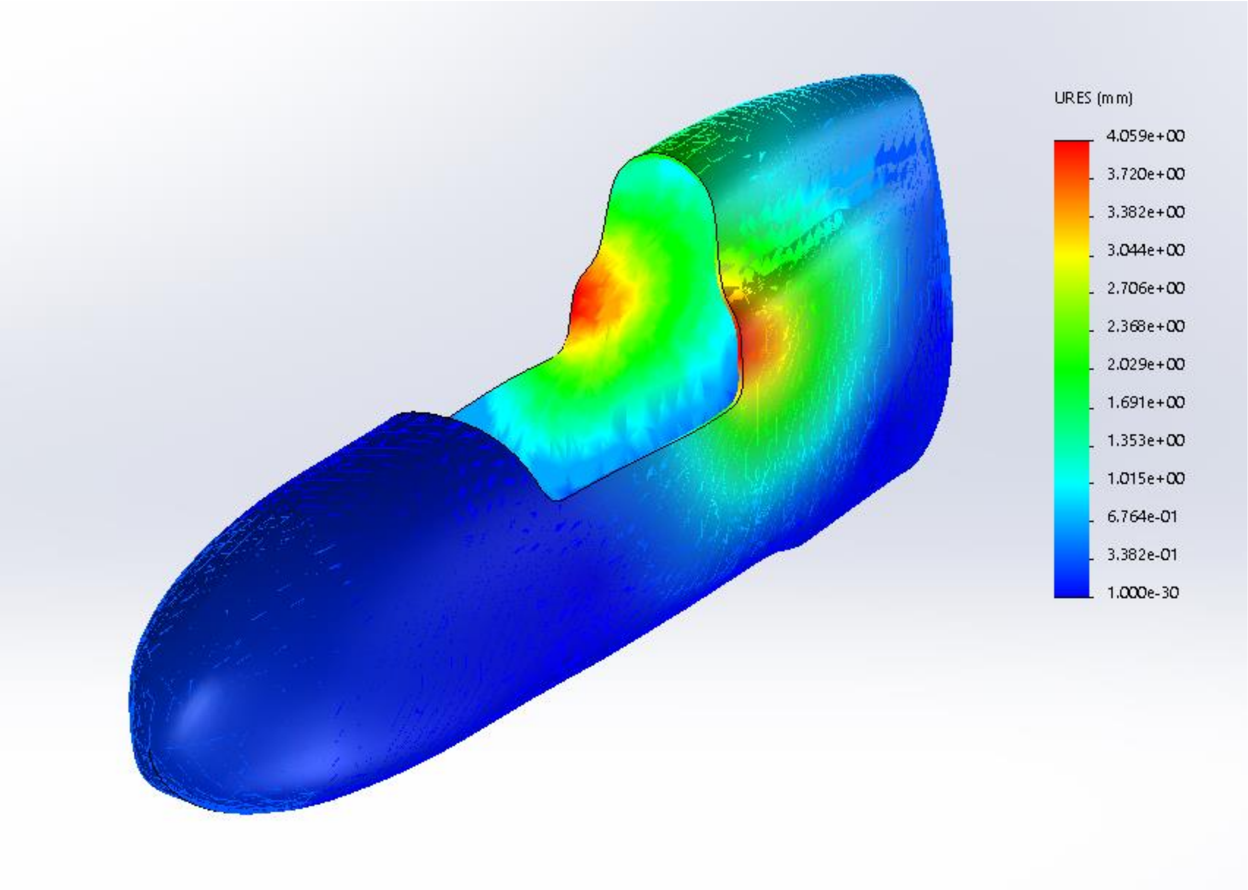


Figure 5: RPS FEA side load condition

With the results from this analysis the team can be sure that the rider will be fully protected in the event of a collision or rollover.

The load path for both the top and side load in Roxanne are the same as the load paths in Harambe. The load path travels from the lower harness mount, through the upper harness mount, up the RPS through the fairing and is ultimately transferred to the ground.

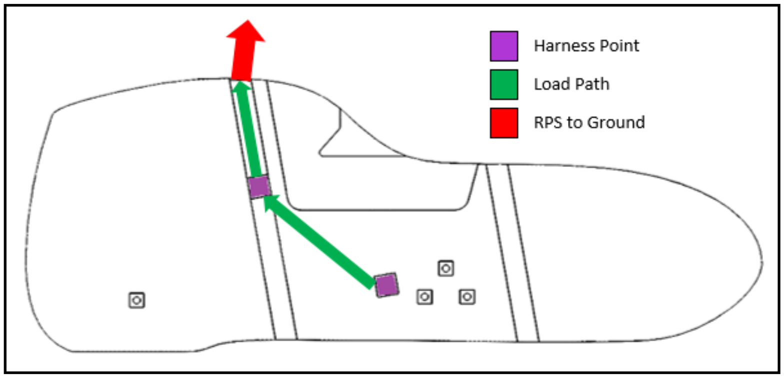


Figure 6: Top Load Path

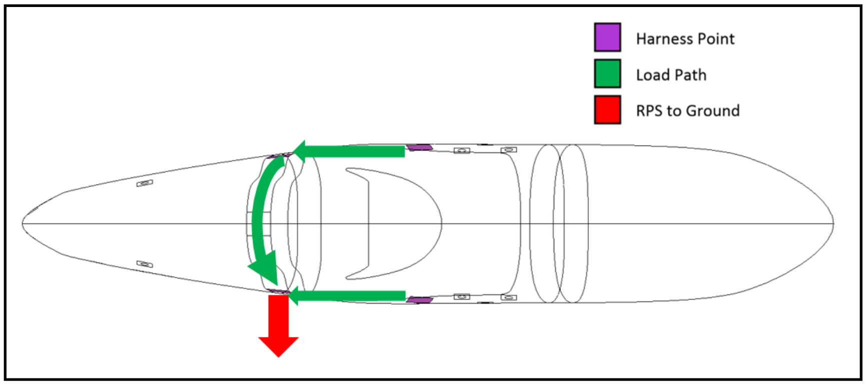


Figure 7: Side Load Path

2.2 Structural Analyses

2.2.1 Clamp Force Testing

Table 7: Structural Analysis Summary

Item	Description
Objective	Test the force required to cause the linear bearing to slip on the rail when its locking mechanism is engaged.
Assumptions	Assume the maximum force applied is the force to slip and eccentricity is negligible.
Methods	Use an Instron compression test to measure force applied and where slip occurs
Results	A friction based locking system is not suitable for this application. A mechanical lock must be designed.

The linear bearings used to adjust the seat have a friction-based locking mechanism using a knob. The clamping force of this locking mechanism was not rated so it was decided that this should be determined. The clamping force was tested using an Instron compression test to apply a load to the rail and bearing in order to determine the force required to cause the bearing to slip. This setup can be seen in figure 8.

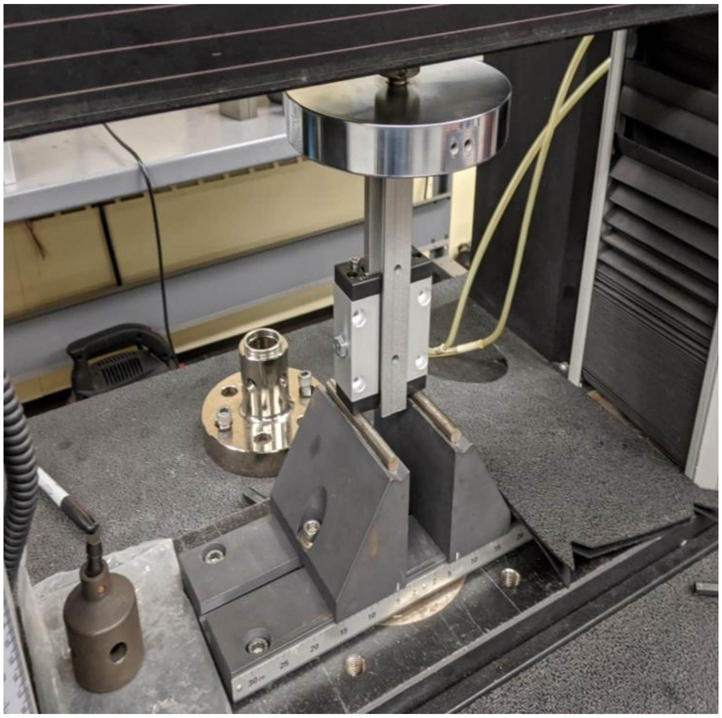


Figure 8: Clamp Resistance Test Setup

The test was run under two conditions: a screw tightened to 10 N-m and a simple hand tighten. The results tabulated below show the force necessary to cause slip. The screw slipped at 119.8 N while the hand tightened knob slipped at 702.6 N. The graph below shows the load vs. displacement of the test. Note that because the Instron was set to constant displacement, the peak in the graph is the load required to cause slip because the machine will decrease load once the bearing begins to slip.

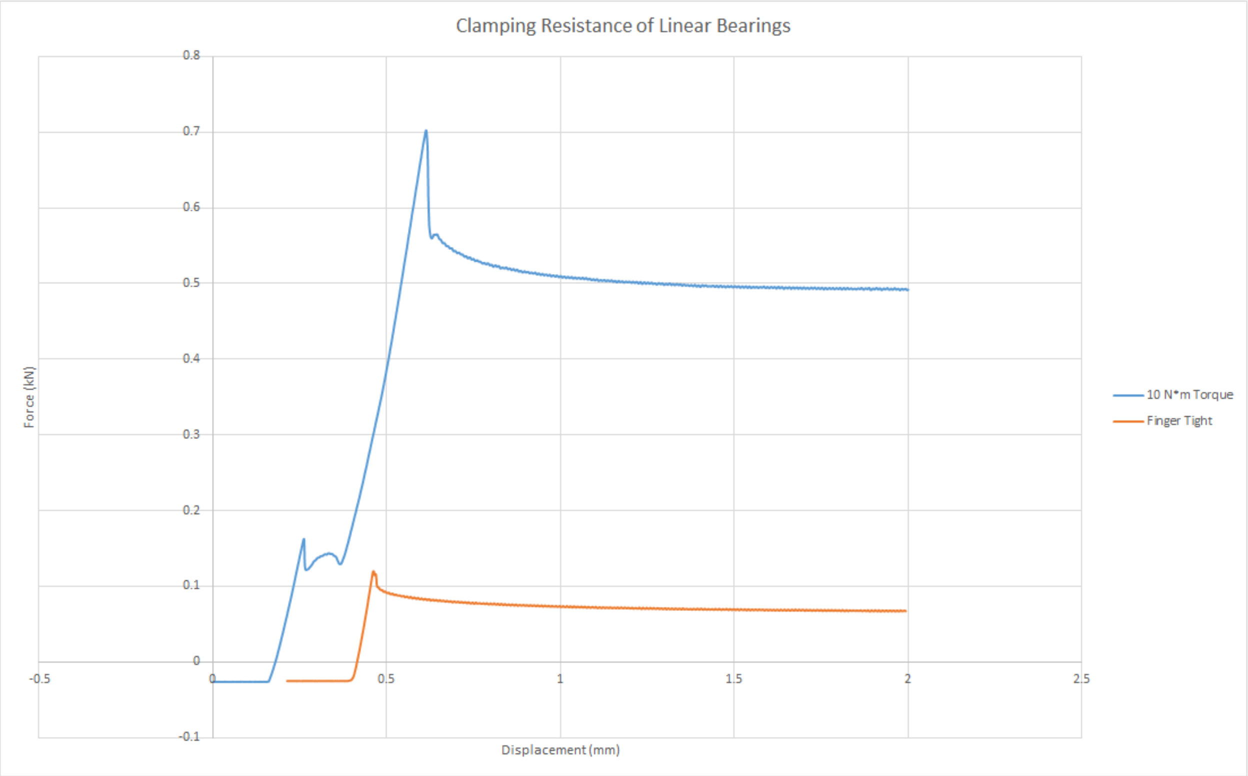


Figure 8: Clamping Resistance of Linear Bearing

There are issues with both tightening methods. First, while tightening the screw to 10 N-m provided a suitable clamp force, the screw was overtightened and damaged the bearing and it would be impractical to tighten a screw that quickly in the time that it takes to change riders. The issue with hand tightening the knob to clamp the bearing is that it simply could not withstand enough force before the bearing slipped from the rail. Because the manufacturer locking mechanism is not suitable for our application, the linear bearing will be retrofit with a mechanical locking mechanism.

2.2.2 Bottom Bracket Deflection

When the bottom bracket panel was analyzed with the Solidworks Simulation, a maximum deflection of 0.28 mm was observed, which is the same as the previous year's analysis.

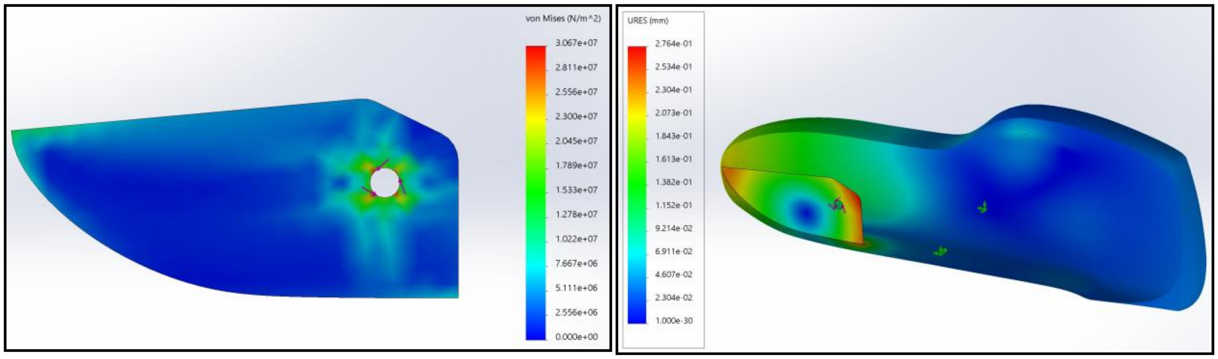


Figure 9: Structural Analysis of Bottom Bracket Panel

2.3 Aerodynamic Analyses

Since Roxanne has the same profile as Harambe, the same aerodynamic analysis can be applied to the vehicle. The analyses done for this section yield the same results as the analyses done to Harambe. [1]

Table 8: Aerodynamic Analysis Summary

Item	Description
Objective	Design a fairing with a minimal drag force and drag coefficient.
Assumptions	The wheels have a negligible effect, as well as the rivets securing the windows and hatch. Conditions are at sea level.
Methods	Use SolidWorks Flow Simulation to analyze the aerodynamics of the proposed fairing design.
Results	Maximum drag force of chosen design is 6.15 N and maximum drag coefficient is 0.25.

2.3.1 Methods

The Solidworks Flow Simulation was once again used to simulate airflow at multiple velocities to predict the drag force and drag coefficient of Roxanne. Tests were performed at 10 mph to 40 mph in increments of 10 mph. A test was also run with a 10 mph crosswind with a velocity of 40 mph.

2.3.2 Results and Conclusions

As expected, all the results of the aerodynamic analyses of Roxanne match exactly to the results from Harambe. This is due to using the same fairing model and molds. The force perpendicular to the fairing due to the 10 mph crosswind was 53.410 N. This force, along with the coefficient of drag found from the analysis, is what led the team to choose the current fairing design.

Table 9: Effects of Velocity on Drag

Speed	Drag Force (N)	C_D	C_DA (m^2)
10 mph	0.425	0.252	0.034
20 mph	1.458	0.216	0.030
30 mph	3.371	0.222	0.031
40 mph	6.146	0.228	0.031

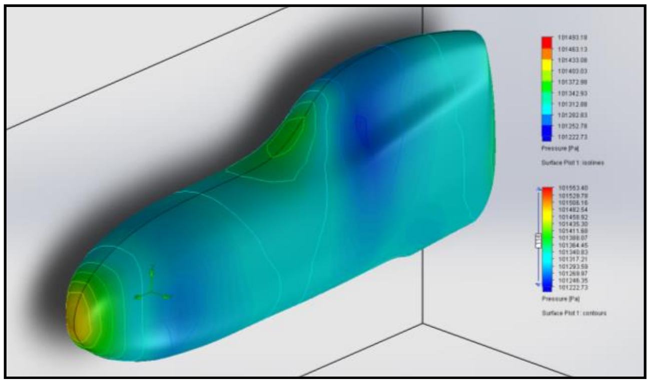


Figure 10: Pressure Distribution at 40 mph

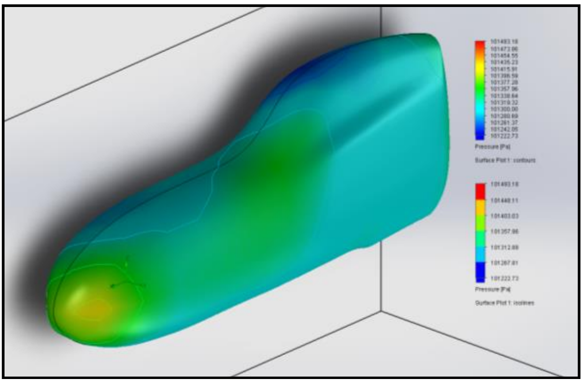


Figure 11: Pressure Distribution at 40 mph with 10 mph crosswind

2.4 Cost Analyses

Based on the success of Harambe, the University of Akron's Human Powered Vehicle Team decided to again design a monocoque trike for the competition year. Given that the molds for the fairing were already fabricated, this meant that more capital could be invested into areas of the vehicle design that required more improvement, such as steering and seat systems. For example the purchasing of a seat instead of the fabrication of one and investing in fat hub bike rims and tires instead of standard road tires. In addition, the team wanted to again keep the total cost of Roxanne under $6,000, similar to that of Harambe.

The total production cost of Roxanne was $6,138.34, as seen in table # below. The cost of Roxanne was broken down into fairing, seat, steering, drivetrain, and electronics. Although this cost exceeds the $6,000 goal set during the design cycle, the team deemed this allowable due to the research that went into systems like seat and steering in order to improve on them from Harambe.

Production Category							
Fairing	$3,188.26	**Seat System**	$662.32	**Steering**	$583.93	**Drivetrain**	$1,703.83
Carbon	$576.38	Seat	$250.00	U-joint	$86.45	rims	$120.00
Honeycomb	$818.82	Carriages	$282.32	Tubing	$37.61	Tires	$179.97
Peel Ply	$236.70	Rails	$130.00	Sheet metal	$114.03	tubes	$38.97
Vacuum bagging	$372.88			Ball Bearings	$15.84	front hubs	$116.00
Release film	$117.20			headset	$60.00	rear hub	$115.00
Structural Adhesive	$506.13			catrike spindles	$270.00	spokes	$75.00
Hardener	$300.00					labor (wheel build)	$120.00

Mold Refinisher	$74.75					Rear axle	$20.00
Steel flanges	$185.40					front axles	$42.00
						Brake lever	$11.89
Total	$6,138.34					brakes	$55.00

Table 10: Breakdown of financial allocations for Roxanne

Given the team's experience with human powered vehicles, there was little need to buy new tools for manufacturing purposes. As well, outside labor was not needed given the team's experience with machining new parts for the vehicle, such as the new rims, seat rail modifications, and rail carriage modifications.

Percent of Budget	
Fairing	51.94%
Seat systeem	10.79%
Steering	9.51%
Drivetrain	27.76%

Table 11: Breakdown of Roxanne costs by percentage

As expected, the fairing costs were a majority of Roxanne's budget at 51.94%, followed by the drivetrain components at 27.76%. This was expected due to the cost to manufacture Harambe, however Roxanne has a greater portion of its budget allocated to the fairing. This is mainly due to the amount of materials needed to manufacture the fairing leading to an overall production cost about $500.00 greater than that of Harambe.

2.5 Other Analyses

2.5.1 DriveTrain Gearing Analysis

Table 12: Drivetrain Gearing Analysis Summary

Item	Description
Objective	Determine optimal gearing ratio for best performance for both drag and endurance vehicle configurations.
Assumptions	No change in cadence for each study.
Methods	Calculating speed and power.
Results	Chainring size was chosen using the results of these studies.

A drivetrain with a single chainring was chosen because this allows the use of chain guides and/or retainers as well as the use of a narrow-wide ring which both significantly reduce de-chaining. If the chainring size is chosen properly a sufficient gear range for our applications can be achieved. The derailleur choice of a shimano Zee RD-M640-SS was also based on minimizing de-chaining and cost, this derailleur is designed for downhill mountain biking, and so has a short cage and a stiff clutch, providing good leverage and resistance, for keeping chain tension and reducing 'chain slap' respectively with Roxanne's longer, heavier chain. A 11-32 cassette was chosen because a 32 tooth cog is the largest size that can be accommodated by the chosen derailleur. The cassette was chosen to be 10 speed instead of the increasingly popular 11 speed because as a team we have a source to purchase 10 speed chain by the foot eliminating the need to string together multiple chains and reducing the number of quick-links and the chance for one to fail, however remote this chance may be.

Given the choice to use 20x4" fat tires for the endurance event this year, and to use 20x1.5" tires for drag racing, this means that wheel diameter changes between drag and endurance. This increases our gear inches values for the endurance event which is not desirable given the slower speeds of the event. This led to the decision to use a smaller chain ring for the endurance event.

A 20 inch drive wheel necessitates a larger than standard chainring if no intermediate gearing is to be used. For drag racing, a 68 tooth chainring was chosen because this was the readily sourced and provided a balance of gearing for take-off and top-end speed given the wheel and cassette size. For endurance, a 50 tooth chainring was chosen because the fat tires increasing the wheel diameter and lower necessary top end speed, allows use of smaller chaining. 50 teeth is within standard chainring sizes and allows for off-the-shelf sourcing of a narrow-wide chainring. A 50 tooth chainring also gives a good range of gearing for endurance.

For speed calculations, 3 pedal cadences were used, 55, 80, and 100 to represent struggling up a hill, steady cruising, and sprinting respectively. Speed was calculated with the following equation.

$$v = N_{cadence} \frac{N_{chainring}}{N_{cassette}} c_{wheel} \ (1)$$

Cadence (rpm)	Cassette teeth	Speed (mph)
55	11	20
80	11	29
100	11	37
55	32	7
80	32	10
100	32	13

Table 13: Results of calculation for speed with 20" dia wheel with 68t chainring

Cadence (rpm)	Cassette teeth	Speed (mph)
55	11	18

80	11	26
100	11	32
55	32	6
80	32	9
100	32	11

Table 14: Results of calculation for speed with 24” dia wheel with 50t chainring

2.5.2 Fat Tire Analysis

For years our team has considered some form of suspension due to difficulty encountered with rumble strips, speed bumps, and rough pavement with our rigid designs. But the downsides of increased cost, complexity, and weight have always been deemed to outweigh the benefits of suspension. It was briefly considered last year using fat tires as suspension during endurance, but the increased weight and rolling resistance were determined to outweigh the benefit, also sourcing a 20” fatbike wheelset is quite difficult.

However with addition of the bypass challenge to the possible venue specific events, and the fact that the obstacle is a sand pit, the benefit of having fat tires is greatly increased. The time saved on the bypass will more than offset the time loss from increased rolling resistance on the rest of the track, and fat tires are by far the easiest way to traverse sand on a bike/trike.

Other special considerations must be made for fat tires specifically. Given the tendency fat tires have to self-steer, camber has been removed from the front wheels in this year's design.
As fat tires obviously have a wider profile, they are more likely to interfere with steering by making contact with the faring, this has to be taken into account when putting the final dimensions on Roxanne's head tube mounts with regards to vehicle track.

There is some fat tire specific testing to be done as well. Vehicle testing needs to be performed to see how self-steering affects vehicle handling at different tire pressures. Self-steering decreases with increasing tire pressure, but the suspension and flotation benefits also decrease with increasing tire pressure, so finding and optimum tire pressure for front and rear tires will be important. Also testing to quantify time savings over rumble strips and bypass vs time loss due increased rolling resistance is scheduled upon completion of building the wheels. Finally, while slick tires have been sourced for minimized rolling resistance, a trip to the beach for sand testing is in order to determine how well a slick rear tire performs in sand in regards to traction.
This is in order to explore, but hopefully dismiss the need for a treaded rear tire to traverse the sandpit.

3. Testing

3.1 Developmental Testing

3.1.1. Carbon Fiber Tensile Testing

Table #: Carbon Fiber Tensile Testing Summary

Item	Description
Objective	Quantify the material properties for layers of carbon fiber in both continuous
Assumptions	End Lamination Theorem holds true.
Methods	Use Instron 5582 to perform tensile test.
Results	

For this test, samples were composed of six layers of carbon fiber. The samples were cut into 101.6x12.7 mm (4x0.5 in) strips. Tabs, also carbon fiber, were attached to the testing strips, so that the grips on the Instron would not prematurely fracture the sample. The Instron 5582 performed a tensile test on these strips, with the head moving at a rate of 1.27 in/min (0.05 in/min).

For this test, there were three distinct samples tested. The samples were all of original length, width, and thickness. The first two pieces were traditional dogbone shape, while the third test piece contained a notch in the gage length. This is shown in table #:

Test	1	2	3
Length Original (mm)	101.6	101.6	101.6
Length Original (m)	0.1016	0.1016	0.1016
Width Original (mm)	12.7	12.7	12.7
Width Original (m)	0.0127	0.0127	0.0127
Thickness Original (mm)	1.5	1.5	1.5
Thickness Original (m)	0.0015	0.0015	0.0015
Front Area (m)	0.00129032	0.00129032	0.00129032

Table #: Original measurements of three test pieces

In order to calculate strain, Young's Modulus, Poisson's Ratio, and Shear modulus, the following equations were used.

$$\text{Young's Modulus } E = \frac{\sigma}{\varepsilon} \text{ (\#)}$$

$$\text{Strain } \varepsilon = \frac{\Delta L}{L} \text{ (\#)}$$

$$\text{Poisson's Ratio } \nu = -\frac{\varepsilon_{trans}}{\varepsilon_{longitudinal}} \text{ (\#)}$$

$$\text{Shear Modulus } G = \frac{Ft}{A\Delta L} \text{ (shear stress / shear strain) (\#)}$$

Using these equations, the team was able to calculate the data in table # and graphically represent it in figure #.

Test	1	2	3
End Tensile Stress (MPa)	103.74552	94.26474	95.6871

Longitudinal Strain	0.1471981299	0.1457687008	0.1727951772
Longitudinal Young's Modulus (MPa)	704.8018888	646.6733907	553.7602471
Transverse End Displacement (mm)	-2.77	-3.08	-3.26
Transverse End Displacement (m)	-0.00277	-0.00308	-0.00326
Transverse End Stress (MPa)	0	0	0
Transverse Strain	-0.2181102362	-0.242519685	-0.2566929134
Transverse Young's Modulus (MPa)	0	0	0
Poisson's Ratio	1.481678	1.662291	1.481999
Shear Modulus (Pa)	153625.0857	140954.872	120702.6607

Table #: Calculated values for each specimen

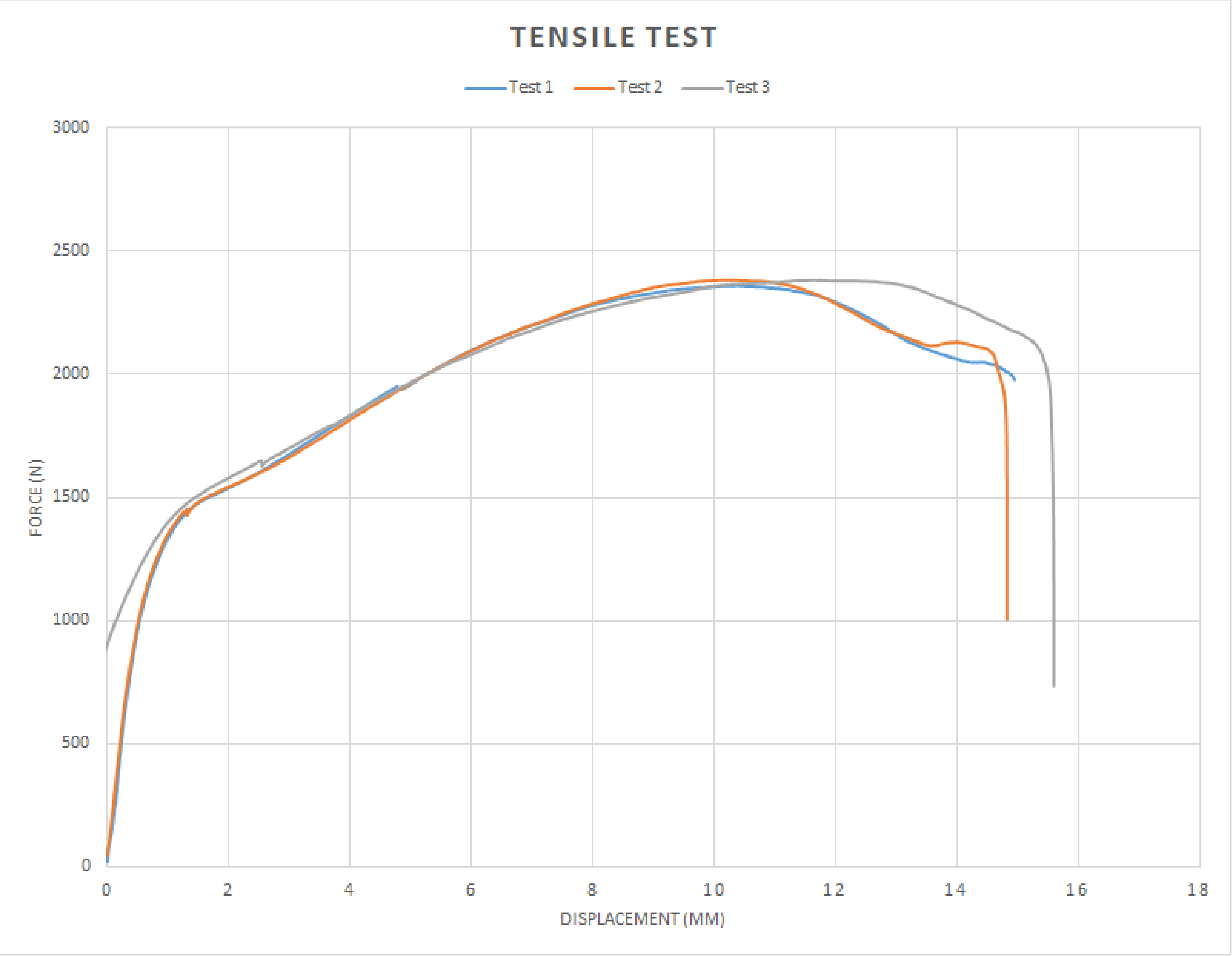


Figure #: Tensile Test Results

4. Conclusion

4.1 Comparison

Table #: Comparing design goals, performance analysis predictions, and experimental results

Parameter/Objective	Outcome
Design that incorporates fat tires to better rider comfort and vehicle mobility.	Modifications were made to allow for fat tires. Fat tire analysis results
Design a seat that accommodates a range of rider heights and an easy to use adjustment mechanism.	Roxanne’s seat can be adjusted approximately 4 inches, which is within the necessary range for the riders.
Design the vehicle with an overall weight of no more than 55lbs.	The total weight of Roxanne is projected to be 55lbs
The vehicle can have a maximum turning radius of 8 m.	The turning radius will be tested and shown in the safety video.
The vehicle must satisfy HPVC rollover system requirements.	Finite Element Analysis shows that Roxanne will comply with ASME specifications.

4.2 Evaluation

The University of Akron Human Powered Vehicle goal for the 2019/2020 season was to take what worked well with Harambe and incorporate those into the design of Roxanne while modifying some features that needed improvements. Using the same fairing molds as last season allowed for additional focus on parts of the design that in previous years were less of a priority. Rider comfortability was an important factor in the design process which led to the incorporation of fat tires. The fat tires help in obstacles such as rough terrain, the rumble strip obstacle, and the bypass obstacle. The seat design also further improved ride comfort and is able to accompany a wide range of rider heights. The steering system was designed to be sturdy and reliable. All design goals for Roxanne were met.

4.3 Recommendations

In the future, there are changes that could be made to improve the performance of bikes to come. One improvement could be implementing a more complex steering design. The current steering is based on a four-bar linkage. While a four-bar linkage is suitable, there may be some benefit to exploring more complex linkages such as a focal six-bar equivalent. Applying this theory could improve the dimensional balance as well as the transmission quality of the linkage [2].

Additionally, for new fairing molds the team should look into using CNC machined molds for optimal results with the fairing. The male mold could be CNC and sanded until smooth, this would reduce the labor intensive process used during the making of Harambe’s molds.

5. References

[1] The University of Akron Human Powered Vehicle Team, "2019 HPVT Design Report - West - Harambe," Akron, Ohio, 2020.

[2] J. Yao and J. Angeles, "The Kinematic Synthesis Of Steering Mechanisms," *Transactions of the Canadian Society for Mechanical Engineering*, vol. 24, no. 3-4, pp. 453–476, 2000.

[3] Archibald, Mark. *Design of Human-Powered Vehicles*. The American Society of Mechanical Engineers, 2016.

6. Appendices

Appendix A: Material Selection Data