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Human Powered Vehicle Team Challenge

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Honors Research Project

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HUMAN POWERED VEHICLE TEAM

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Final Report for 4600:471 Senior/Honor Design, Spring 2022

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Abstract

As concerns about global warming and product availability increase, a movement is being made towards more environmentally friendly alternatives. One large facet of this ideology is replacing individual motorized transportation with public transit and Human Powered Vehicles (HPVs). Both electrically assisted and fully manual HPVs have many benefits over traditional automotive transportation, such as lower manufacturing costs, less road wear, cheaper maintenance, long-term sustainability, and providing consistent access to physical activity. These aspects coupled with the wide range of potential designs could contribute to an increase in popularity and performance of HPVs in the future. This report will focus on the design, testing, and fabrication aspects of a Human Powered Vehicle, with an emphasis on safety, ergonomics, and innovation. The continued improvement and research of HPVs will aid future designs and allow this highly versatile field of transportation to continue to expand moving forward.

Figure 1: Human Powered Vehicle Logo

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1. Introduction

In March of 2020, at the beginning of the COVID-19 pandemic, university students across the country, including at The University of Akron, were asked to leave campus and continue the remainder of academic year virtually. Student organizations were required to pause their ongoing projects and research until further notice and design team competitions across the country were cancelled. During the 2020-2021 academic year, students continued to complete a majority, if not all, coursework virtually. Student organizations had limited ability to meet in person to maintain safe practices of social distancing. As a result, the Human Powered Vehicle (HPV) team dissolved. Senior members, who held a majority of the knowledge and experience on the team, graduated from the university without having the opportunity to pass their knowledge on to younger members. The goal of this senior design project is to revitalize the Human Powered Vehicle design team.

The American Society of Mechanical Engineers (ASME) hosts an annual Human Power Vehicle Competition. This year the competition will be hosted virtually in March of 2022. The competition is focused entirely on innovation and design, as opposed to previous years where teams would also race their vehicles as an additional part of the competition. Although the Human Powered Vehicle Team did not compete in this year, the vehicle that was designed was held to the requirements set by the ASME.

1.1 Objectives

As a team, human powered vehicle designs from previous years were evaluated to gain a better understanding of the history of the design team and the vehicles themselves. The main objective of the team was to adhere to the requirements set by the American Society of Mechanical Engineering (ASME) Human Powered Vehicle Competition (HPVC). Through additional research, collaboration, and investigation, the goal was to generate an optimized design. Components included in this design are the frame, steering, braking, the fairing, the seat, and all necessary electrical systems. The design also had to include a custom fabricated harness or a commercially purchased harness, to ensure rider safety. This design had an emphasis on safety factors, potential adjustability for rider personalization and preference, and a reduction in weight from previous iterations. The final stages of this project included manufacturing and assembling a human powered vehicle.

The second objective of this senior design project was to revitalize the Human Powered Vehicle design team. Throughout the design and manufacturing process, the human powered vehicle team worked to promote the team and gain new members. To accomplish this, the team worked closely with the College of Engineering and through social media platforms, including Facebook and Instagram, to promote the team to UA students and gain new team members. This will ensure that the team continues to function and compete for years to come at the University of Akron.

2 Design

To effectively make design decisions, the team specified a lead for each subsystem of the vehicle. Each subsystem leader did extensive research on their chosen subsystem and presented their findings to the entire team, where a final and collaborative decision could then be made. The subsystems included steering, braking, the frame, the fairing, the radio telemetry system and electronics, and the rollover protection system.

2.1 Steering

To decide the specifications for the steering system, a weighted decision matrix was created. The chosen parameters were ease of manufacturing, cost, weight, ergonomics, aesthetics, and performance. The steering types considered for the vehicle were a bell crank, pitman arm, rack and pinion, tractor steering, and push/pull steering. After evaluating the weighted decision matrices, it was determined that push/pull steering would be used for the vehicle. This steering design included two handles on each side of the driver that could be rotated to steer the vehicle. To implement this type of steering, Ackermann geometry needed to be considered and implemented. Ackermann steering, as shown in Figure 2, requires that the inner wheel will rotate at a larger angle than the outer wheel to allow for a tighter turn radius, reduce drag, and increase control of the vehicle.

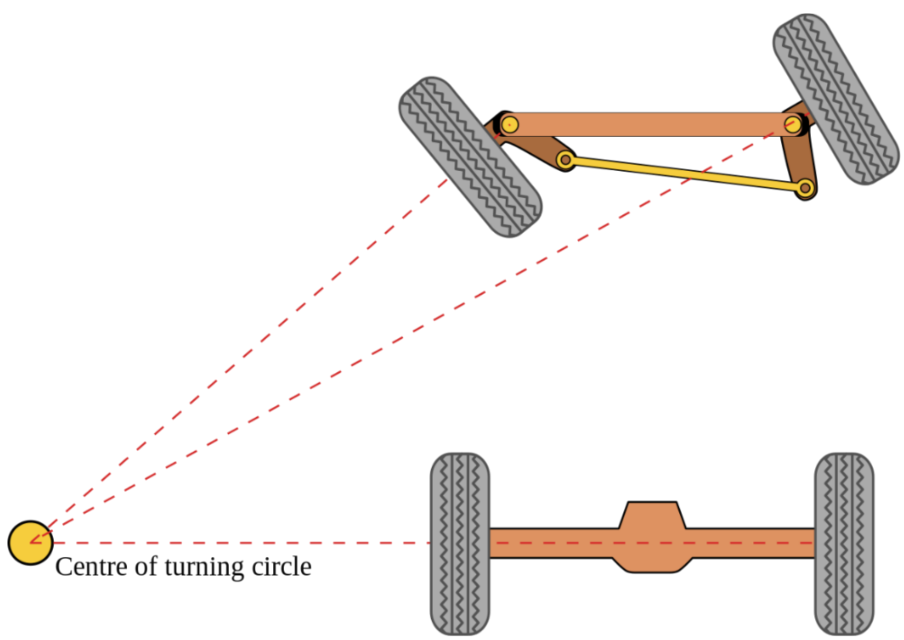

Figure 2: Ackermann Steering

2.2 Braking

The vehicle is outfitted with disc brakes because they are the least affected by adverse weather conditions and have the strongest braking power out of the commonly used braking systems for human powered vehicles. The Human Powered Vehicle competition hosted by American Society of Mechanical Engineers (ASME) set the requirement that the vehicle needed to come to a complete stop within 6 meters from a speed of 25 km/hr, so the vehicle needed the best braking system available. The choice of braking system was finalized with a decision matrix shown in Figure 9, comparing disc brakes with other types of brakes, such as V clamp brakes and cantilever brakes.

Figure 3: Avid BB7 MTN Disc Brakes

2.3 Frame

Two types of recumbent trike frames were considered for the human powered vehicle: a Tadpole frame and a Delta frame. A Tadpole frame is a recumbent trike frame with one wheel located in the back and two wheels located in the front. A Delta frame is a recumbent trike frame with one wheel located in the front and two wheels located in the back. One frame was not inherently superior to the other in design, the choice in frame was determined by the team's needs. The factors considered when choosing between the two were the ASME requirements that needed to be met, abilities, and the intended use of the vehicle.

Through the research and design stages, it was determined that a Tadpole-style frame was the optimal choice because it offered superior stability and allowed for a faster speed to be achieved. One trade-off with choosing this style frame was a larger turn radius, due to the two wheels located in front, which caused maneuverability slightly more difficult. This was mitigated by the selection of steering design. The Tadpole frame also allowed the pedals of the trike to be adjusted using metal sliders, to accommodate drivers of different heights. As the heights of the Human Powered Vehicle Team members varied significantly, this was a prioritized feature for the vehicle.

Additionally, multiple materials were considered when researching the optimal frame design such as 6061 Aluminum, Carbon Fiber, and 4031 Steel. The material properties of each material were considered, as well cost and manufacturability qualities. The 6061 Aluminum was the chosen material for the Tadpole frame as it fulfilled all ASME strength requirements for the frame and because a surplus of 6061 Aluminum tubing stock was available to be worked with from previous year's teams. A 3D model of a Tadpole frame was then created and is pictured in Figure 4 below.

Figure 4: Tadpole Frame

As the team had a Tadpole frame that was going to be used in a 2020 competition, and through recommendation by the team advisor, this frame was optimal for use. Ergonomic changes were made to the existing frame to meet the goals of the team as well as the ASME requirements. These changes included: the adjustment of the angles of the steering handles so that they did not interfere with the driver's legs when turning, the addition of a 5-point safety harness to meet ASME requirements, the addition of a Velcro sleeve to the frame for driver comfort, the consolidation of the braking handle and gear shifter to one handle-bar for ease of accessibility and to minimize driver confusion when operating the vehicle, and the addition of a chain tensioner pulley to the underside of the frame to eliminate having to manually adjust the drivetrain for divers of different heights. An assembly of the Tadpole frame, wheels, and steering are pictured in Figure 5 below.

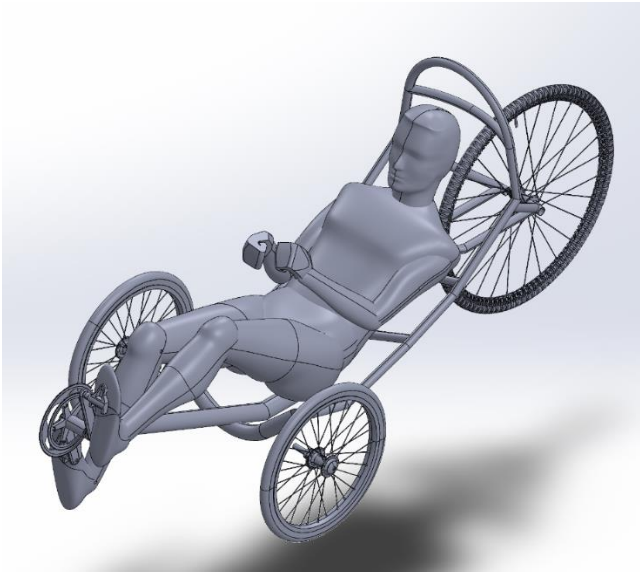

Figure 5: Full Frame and Steering Assembly

2.4 Fairing

The primary focus this year was to create an aerodynamic fairing to minimize resistance when pedaling, to fulfill the rollover protection system requirements, and protect the driver from any debris, insects, or weather while operating the vehicle. The design stages began with a 3D model created in SolidWorks. The ideal aerodynamic shape was achieved by dividing the model into connecting panels. The final design contained a total of 80 panels, arranged as eight connecting 10-sided polygons. This can be seen in Figure 6 below. This design encompasses the entire recumbent trike frame and wheels, making the human powered vehicle "fully faired."

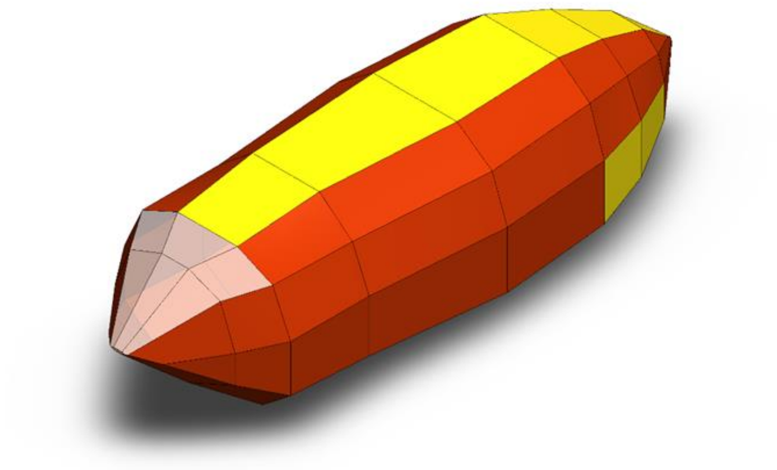

Figure 6: Fairing Solidworks Model

After creating a Solidworks model, Pepakura Design Space software was used to transform the 3D model into a 2D stencil. Pepakura Design Space is a software commonly used in the creation of paper mache projects, but its ability to unfold a 3D model and allow for personalization and editing made it the ideal application for the fairing. Once the 3D model was unfolded into 2D, each stencil was then numbered within the software according to an alphanumerical system decided upon by the team. This system was implemented to avoid confusion during the assembly process regarding the placement of any of the panels. Each panel can be seen pictured in the Figure 7 below within the Pepakura Design Space software.

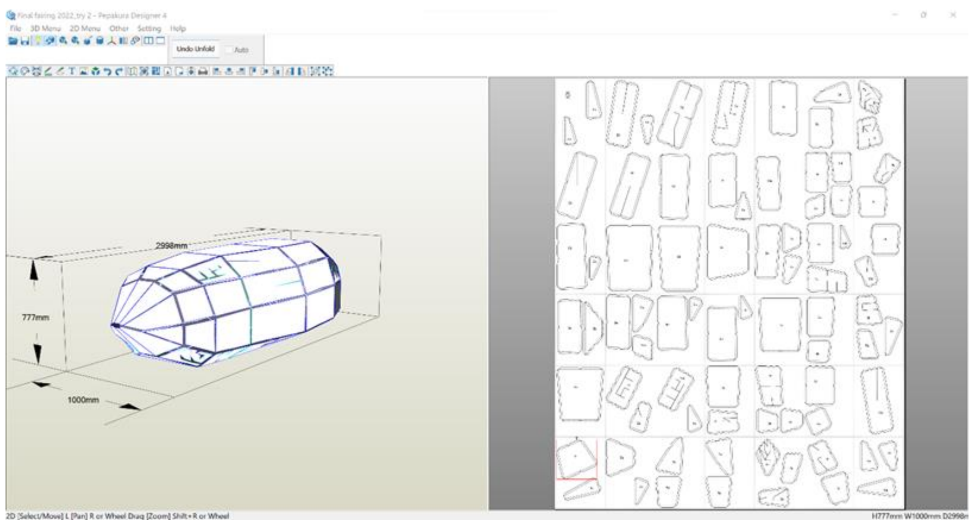

Figure 7: Pepakura Design Space

After extensive research, coroplast was the material that was chosen for the fairing. Coroplast was chosen because it is lightweight, weather-proof, sturdy enough to maintain the structural integrity of the fairing, able to be folded or cut when needed to achieve the fairing shape, and cost effective. Carbon fiber was also considered for the fairing material, as it also meets the requirements of being lightweight and sturdy, but was ultimately decided against due to the time restrictions of the project. The stencils were then able to be printed, to scale, directly from the software. After printing these stencils, the assembly stage for the fairing was able to begin.

2.5 Radio Telemetry System/Electronics

The Radio Telemetry System, or RTS, is an electronics bundle set to be connected to the underside of the frame. The RTS is designed to communicate wirelessly from an onboard Arduino Nano to a software program on a nearby laptop. These communications would show real-time updates on sensor conditions and location. The sensing capabilities of the RTS include acceleration in all three axes, velocity, and GPS location. The wireless communication aspect is achieved with an XBee Pro Modular Pair, one of which is connected to the Arduino, and the other is connected to a specific board to mount the XBee to with a male USB adapter to plug in to a computer.

The brake lights currently flare when the braking system is initiated, however work is still being done to convert the strip lights from a Boolean system to a variable force activated system. This would entail wiring the brakes to the Arduino, and using the information from the accelerometer, would adjust the number of brake lights that are illuminated indicating the strength at which the brakes are being applied.

2.6 Rollover Protection System

The Rollover Protection System, or RPS, is imperative to the safety of the driver. In the event of rollover, collision with another vehicle or nature, or any potential weather conditions that could be harmful, the RPS acts to negate or mitigate the harm caused to both the vehicle and driver. The Rollover Protection System is comprised of two components, acting independently to safely minimize a variety of threats. The fairing, while not as structurally rigid as the frame, is larger and the initial point of contact any incoming objects connect with. The coroplast panels are connected by tension to the frame and can absorb light to medium impacts from incoming objects. In the event of a rollover, this fairing would stop any rocks, gravel, dirt, or other small debris from buffeting the driver and potentially causing harm. For larger or stationary objects, such as trees and walls, the fairing can act to slow down the vehicle as it impacts, reducing the force transferred to the driver. This is akin to how car hoods crumple easier than the body of a car to protect passengers. The second component of the RPS is the top of the frame. This semi-circular tubing extends above the driver’s head and is designed to be sturdy and rigid. This addition to the frame prevents the driver from impacting the ground in the event of a rollover and will not deform under higher loads to further protect the driver from harm. Together with the fairing, most potentially harmful situations can be minimized or negated, and the driver can remain free from harm.

3. Design Verification

When designing the human powered vehicle, it was imperative that the design choices made meet the codes and standards set forth by ASME. Human powered vehicles must be able to withstand the forces they could be subjected to during operation to a degree that protects the driver as much as possible. Decision matrices were an effective way to compare elements of different design considerations for the subsystems on the human powered vehicle. The matrices display the ranking of the different parameters in terms of importance and displayed each different design considerations next to each other, which allowed for easy comparison. This method greatly assisted the decision-making process. Finite Element Analysis (FEA) is a simulation that takes inputs properties of materials and the 3D model of the design and tests the design quality and structural integrity of the design. This allows for a clear understanding of how the design will react to various simulated forces. FEA provides a great way to simulate conditions without devoting resources to live tests that could be time consuming and occupy limited resources, such as aluminum tubing stock. Adhering to codes and standards are essential to the design process to ensure the safety of the driver and the quality of the work being done. The codes and standards set by the ASME influence design choices and implement imperative requirements to achieve.

3.1 Decision Matrices

To narrow down design decisions for the vehicle, weighted decision matrices were created for the steering and braking systems. The chosen parameters were ease of manufacturing, cost, weight, ergonomics, aesthetics, and performance. As shown in Figure 8, the steering systems considered for the vehicle were bell crank, pitman arm, rack and pinion, tractor steering, and push/pull steering. As shown in Figure 9, the braking systems considered for the vehicle were Disc brakes, V brakes, clamp brakes, and cantilever brakes. The weight of the vehicle was considered the highest priority, or 30%, to ensure that the vehicle could maintain high speeds and that maneuverability would not be compromised. Ease of manufacturing and ergonomics were both 20% to allow the team to accomplish the assembly within the required time frame and allow for safety and comfortability of the driver. Next, performance was considered 15%, but was lower than other parameters as this year's ASME competition focused less on the racing ability and more on the ergonomic aspect of the vehicles. Finally, cost was considered at 10% and aesthetics was considered 5%. With these considerations and wights, the push/pull steering and disc brakes were determined to be the final designs for this year's human powered vehicle.

Steering						
Parameters	Weight	Bell Crank	Pitman Arm	Rack and Pinion	Tractor Steering	Push/Pull
Ease of manufacturing	20%	3	4	2	2	3
Cost	10%	3	3	3	4	3
Weight	30%	3	4	2	1	5
Ergonomics	20%	4	3	2	1	5
Aesthetics	5%	5	3	3	1	3
Performance	15%	3	4	4	2	3
Total	100%	3.3	3.65	2.45	1.65	4

Figure 8: Steering Decision Matrix

Braking					
Parameters	Weight	Disc Brake	V brake	Clamp Brake	Cantilever Break
Ease of manufacturing	20%	4	2	2	2
Cost	10%	4	3	4	4
Weight	20%	4	2	2	2
Ergonomics	15%	4	3	3	3
Aesthetics	5%	3	3	3	3
Performance	30%	5	4	3	3
Total	100%	4.25	2.9	2.7	2.7

Figure 9: Braking Decision Matrix

3.2 Finite Element Analysis

For the competition standards, ASME had specific guidelines that were required to be met for the frame of the human powered vehicle. It was stated that the frame must meet both the loading requirements as well as the functional requirements. The forces that the frame had to withstand were a 1330N force to the side shoulder of the frame and a 2670N force from the top of the frame at a 12-degree angle, as seen in Figure 10. The frame was placed into ANSYS Workbench under these conditions and passed the simulation. The images of those results in Workbench can be found in Figures 11 and 12.

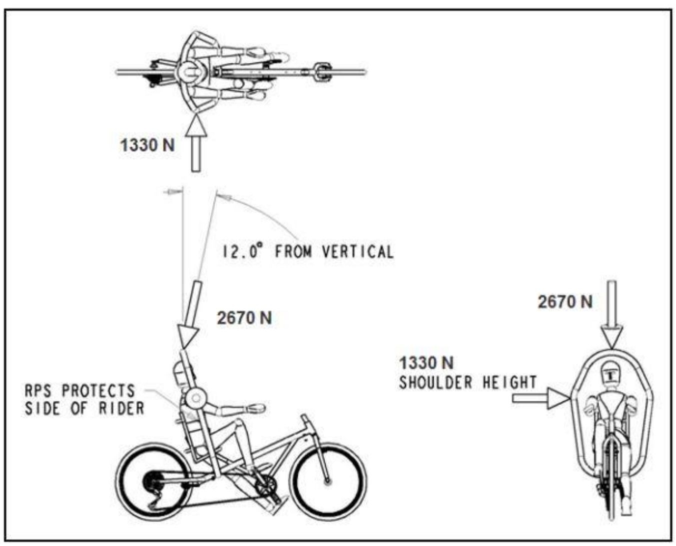

Figure 10: ASME Competition Standards for FEA

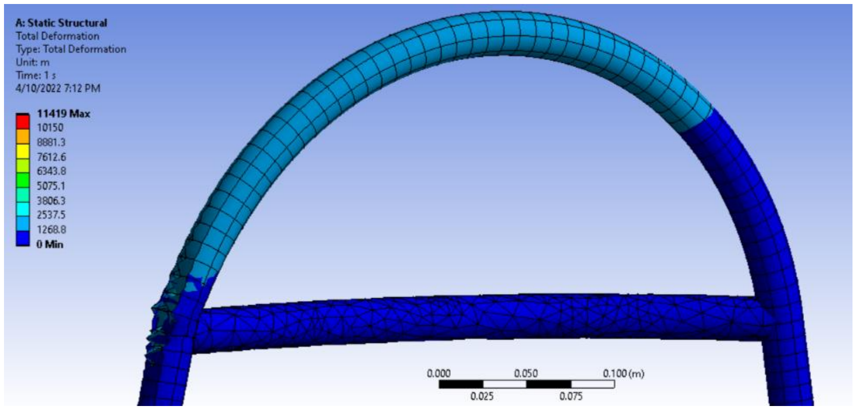

Figure 11: 1330N Force to Side Shoulder

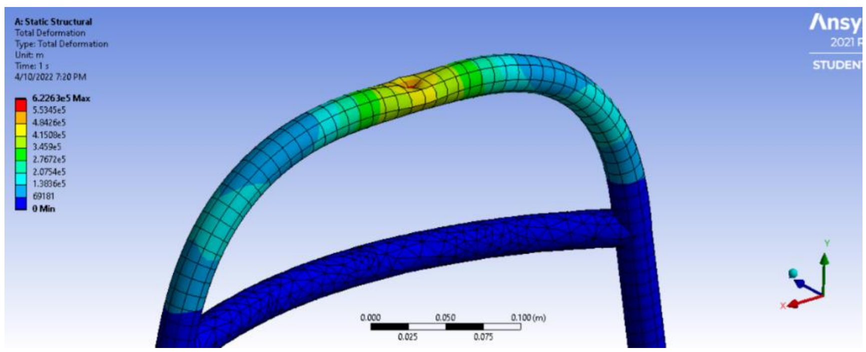

Figure 12: 2670N Force to Top of Frame

3.3 Codes and Standards

The ASME Human Powered Vehicle Competition lists requirements necessary for competing vehicles to meet. One of the requirements was that the vehicle is needed to be able to come to a complete stop within 6 meters from a speed of 25 kilometers per hour. To verify this requirement, disc brakes and Schwalbe Pro One TLE Evo Faltreifen 28-406 tires were implemented. Another requirement that was the vehicle's frame must be able to withstand a force of 2670 newtons at an angle of 12 degrees from vertical and 1330 newtons at shoulder height. ANSYS Workbench FEA for the 6061 aluminum tadpole frame was used to verify this requirement. For safety reasons, the vehicle was required to have a 5-point safety harness, which added to the vehicle and attached to the frame. The human powered vehicle also had to have a maximum turn radius of 8 meters and must be able to remain stable while traveling in a straight line for 30 meters at a speed between 5 and 8 kilometers per hour. The vehicle was test driven both with and without the frame to verify this requirement. Finally, AMSE requires that there is a brake on every front wheel on the vehicle, and the team met this requirement with disc brakes on each front wheel.

4. Costs

The team had many purchasing needs during the project, which spread across many different industries. Figure 13 below is a complete itemized list of materials that were purchased by the team from the beginning of the project to the end. As seen below, most of the purchasing was required during the construction phase of the coroplast fairing and for the electrical components for the RTS system. This was due to an increased need of materials and resources as the construction of the coroplast fairing proved to be much more complicated than the team initially anticipated. Overall, the team was able to efficiently use the resources at their disposal along with the purchased goods to successfully create the human powered vehicle.

Item	Description	Category	Manufacturer	Part Cost
Simpson 5pt Harness	Simpson Standard 5 Point-Connection Harness	Seat	Simpson	$ 59.99
Neck Brace	EVS Neck Brace	Utillites	EVS	$ 39.50
Daoki Speed Sensor	Daoki 5Pcs Speed Measuring Sensor	Electrical	Daoki	$ 6.69
Arduino Board	Arduino UNO SMD Rev3	Electrical	Arduino	$ 27.39
Anti Static Mat	Anti Static Mat Soldering Mat	Electrical	ESD	$ 20.97
Soldering Iron	YIHUA Digital Soldering Station	Electrical	YIHUA	$ 59.99
USB Cable	UGREEN USB to USB Cable	Electrical	UGREEN	$ 6.99
GPS Module	GPS Module NEO-6M	Electrical	Arduino	$ 11.59
USB 2.0 Cable	USB 2.0 Printer Cable	Electrical	Amazon	$ 6.69
Clear Vinyl	30 Gauge Clear Vinyl	Frame	Fabric by the Yard	$ 51.78
Schwalbe Tires	Schwalbe Pro One Folding Tire	Steering	Schwalbe	$ 146.14
Breadboard	ELEGOO 3pcs Breadboard	Electrical	ELEGOO	$ 14.51
Breadboard Jumper Wires	MCIGICM Breadboard Jumper Wire Cables	Electrical	MCIGICM	$ 11.46
Dominos	Dominos Pizza for Recruitment Event	Advertising	Dominos	$ 31.96
Coroplast	Corplast for Vehicle Fairing	Frame	Home Depot	$ 155.51
Truck Rental Gas	Gas for Truck Rental for Coroplast Transport	Travel	BP	$ 4.71
TechBond	TechBond for Putting Coroplast Fairing Together	Frame	TechBond	$ 162.89
Office Supplies	Offices Supplies for Stencil Prep	Office Supplies	Target	$ 16.35
Program License	PepaKura Program License	Software	MYCOMMERCE	$ 40.57
Fairing Supplies	Supplies for Coroplast Fairing Construction	Maintenance	Home Depot	$ 169.03
Fairing Supplies	Supplies for Coroplast Fairing Construction	Maintenance	Home Depot	$ 52.82
Paint Supplies	Painting Supplies for Fairing	Maintenance	Home Depot	$ 78.74
Fairing Supplies	Supplies for Coroplast Fairing Construction	Maintenance	Home Depot	$ 90.20
Electronic RTS Components	Supplies for Electronic RTS System	Electrical	SparkFun	$ 51.63
Accelerometer	Adafruit Accelerometer for RTS System	Electrical	AdaFruit	$ 26.87
Binder Clips	Staples Binder Clips for Coroplast Construction	Frame	Staples	$ 15.87
Sharpies	Sharpies for Coroplast Panel Labeling	Frame	Staples	$ 5.99
			Total:	$ 1,366.83

Figure 13: Total Team Spending

4.1 Labor

This project required an immense amount of teamwork through all stages of design and assembly. During the research and design stages, the team researched subsystems individually and then met multiple times a week to discuss their findings and make collaborative design decisions. Once the assembly process began for the vehicle, the team began meeting four to five times a week to stay on schedule with the project. The team spent many hours in the design center cutting and gluing coroplast to create the final desired shape of the fairing. Building the fairing took an immense amount of trial and error as the team was learning how to translate a Solidworks model into a tangible vehicle. Throughout the building process the method for successfully aligning each panel of the fairing shifted, as easier and more efficient ways to create the fairing were found. This project required an immense amount of collaboration, teamwork, and communication that was successfully achieved by this team.

5. Conclusion

Given the large-scale outlook for this project over the course of a year, the team had to communicate and work together to accomplish all the set goals. An immense amount of learning was included in this process, including understanding the ins and outs of what a human powered vehicle entailed. Outside of the engineering aspects of this project, the team worked on recruiting members for the upcoming 2023 competition season and making a list of future potential changes and innovations. The team’s biggest accomplishment lies in the coroplast fairing, which was designed and produced completely by the human powered vehicle team. Once the Solidworks model was translated using the Pepakura software, the 80 panels were plotted out to be cut out of coroplast. Each individual panel was then cut out and painted a designated color, then bonded together one by one until the entire fairing was complete. Slight adjustments were made as the process went along, to ensure that the coroplast fairing would be optimized.

Altogether, from the research and design phase to the building of the fairing to the recruitment of new members for the human powered vehicle, the team accomplished all set goals. The team is interested and excited to see what the future holds for the next generation of the Human Powered Vehicle Team at the University of Akron.

5.1 Accomplishments

Alongside the design and building accomplishments, the team was also working on recruitment for the 2022-2023 school year. In February, the team hosted a new member meeting in the Student Union where 4 additional active members of the team were recruited. The new members have been a huge help as the team worked to turn a design into a physical vehicle. Social media pages were also created for the team and an audience of 576 followers on Instagram and Facebook was reached.

5.2 Uncertainties

Despite the team’s successful recruitment efforts, it is still uncertain whether the new underclassmen members will return next year after the senior design group graduates. The team will also rely on these new members to continue recruitment until there is a significant influx of new members to support all the roles needed to efficiently progress as a team. Additionally, this year’s group is hoping to see the team compete in the 2023 ASME Human Powered Vehicle Challenge in California.

5.3 Ethical considerations

Safety of the vehicle was a highly important aspect that the team focused on this year. While previous team’s vehicles were primarily focused on the speed and racing, ASME requirements for the 2022 competition focused on an ergonomic and safety-oriented approach. With these requirements in consideration, the team made sure to include a five-point safety harness so that in case of emergency the driver would be safe. A Velcro-sleeve was also placed on the frame, along with widening the steering so that the driver would be more comfortable. It was also imperative that the frame meet all ASME requirements and a Roll Over Protection System (RPS) be concluded in the final design of the vehicle.

5.4 Future work

Due to time constraints this year, there are several modifications the team could make next year to improve this year's human powered vehicle. To increase visibility, side coroplast panels of the fairing could be replaced with clear vinyl. This would allow for the driver to have visibility to both sides of the vehicle in addition to the visibility at the front of the vehicle. Additionally, pedal assist and restorative braking systems could be added to assist the driver in pedaling when going uphill. The team would also like to add adjustable brake lights that not only allow observers to see when the driver is braking, but also the intensity at which they are braking. Finally, if there was a larger time frame and the team could access more outside resources, a carbon fiber shell would be considered as it is lightweight, aerodynamic, and sturdier than the coroplast fairing. Carbon fiber also offers more rollover protection than coroplast, which would increase safety.

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Appendix A Requirement and Verification Table

Table 1 System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Vehicle required to stop within 6 meters from a speed of 25 km/hr.	1. Implementation Disc Brakes 2. Implementation of Schwalbe Pro One TLE Evo Faltreifen Tires 28-406	Y
2. Frame required to withstand a 1330N force to the side shoulder	3. ANSYS Workbench Finite Element Analysis for 6061 Aluminum Tadpole Frame	Y
3. Frame required to withstand a 2670N force from the top of the frame at a 12-degree angle	4. ANSYS Workbench Finite Element Analysis for 6061 Aluminum Tadpole Frame	Y
4. The vehicle must have a 4-point or 5-point safety harness	5. Aces Racing 5-point Safety Harness purchased and secured to the Tadpole Frame	Y
5. Vehicle must have a maximum of an 8-meter turn radius	6. Vehicle was test driven without the fairing attached and with fairing attached	Y
6. Vehicle must be able to travel straight for 30 meters at a speed of 5-8 km/hr while maintaining stability	7. Vehicle was test driven without the fairing attached and with fairing attached	Y
7. Braking system implemented on all front wheels	8. Implementation of Disc Brakes on both front wheels of the Tadpole frame	Y

Appendix B List of Figures