College of Engineering and Computer Science
Department of Mechanical Engineering

ME 486: Human Powered Vehicle
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2023-2024 Human Powered Vehicle Spring Report

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ABSTRACT

The 2023-2024 CSUN Human Powered Vehicle Senior Design team aims to maintain the successful reputation established by our predecessors. This year's vehicle is the first of its kind in CSUN HPV history: three-wheeled, aluminum frame, recumbent vehicle equipped with a lean/tilt, over-seat hybrid steering, a pedal assist device, a telemetry system, a carbon fiber seat, and a carbon fiber partial fairing. Research, testing, and design were largely the focus of the Fall 2023 semester. This included the Preliminary Design Review in which our innovative design was critiqued by alumni. Utilizing the feedback gathered during this presentation, the five sub-teams (Components, Fairing, Frame, Innovation, and Systems, Integration, and Testing (SI&T)) implemented design changes which were presented in the Critical Design Review. Following the presentation, our team will use the practical engineering knowledge we have gained to manufacture, test, and ride another successful Human Powered Vehicle. The following report recaps the actions items from the Fall 2023 CDR, along with showcasing the detailed work completed over the Spring 2024 semester.

INTRODUCTION TO HUMAN POWERED VEHICLE

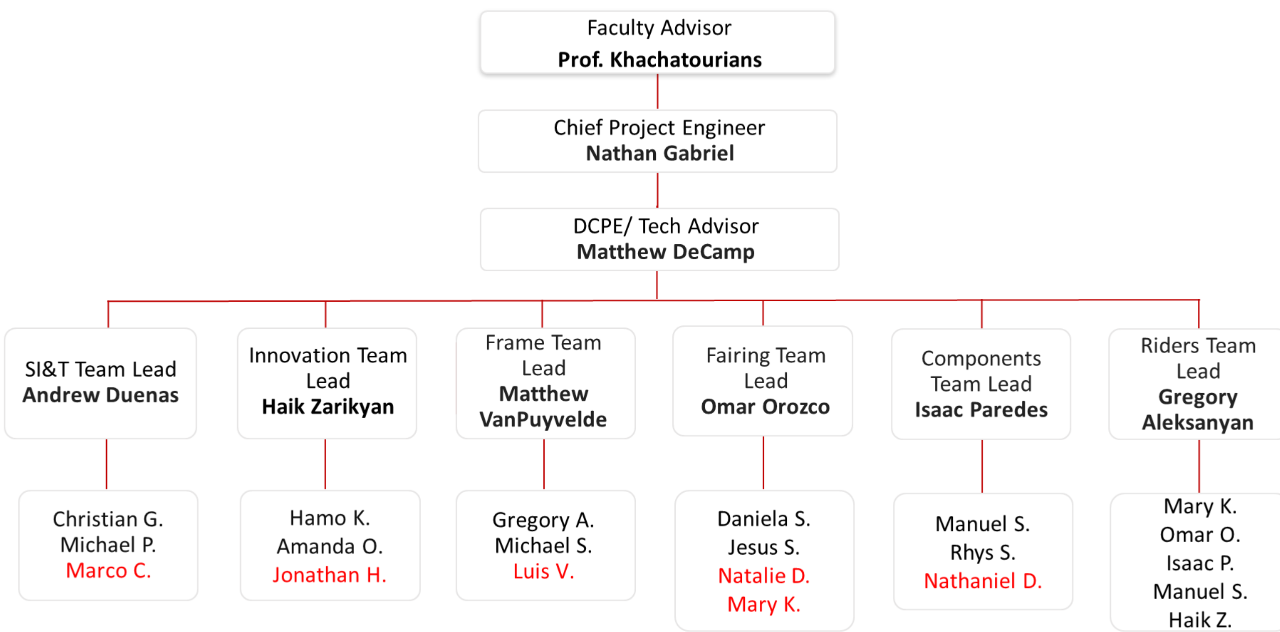
The Human Powered Vehicle Team is a CSUN senior design project consisting of 24 mechanical engineering students who combine their skills to design and manufacture a recumbent trike capable of competition. Each year, ASME hosts the eHuman Powered Vehicle Challenge (eHPVC), where teams from across the country race their vehicles in a series of events that test speed, durability, and functionality. This year, the teams will be judged based on a static design event which includes a presentation, a drag race event, and a 2.5 hour endurance race event.

The 2023-2024 CSUN Human Powered Vehicle team will apply engineering principles to design, manufacture, and test a safe, reliable, and competitive vehicle that will transition the team members from students to professional engineers.

2023-2024 TEAM STRUCTURE

The organizational chart below shows the structure of the 2023-2024 CSUN Human Powered Vehicle Senior Design team. The faculty advisor, Professor Aram Khachatourians, will guide, teach, and advise the team while working closely with the project's Chief Project Engineer (CPE) and Deputy Chief Project Engineer (DCPE). The CPE and DCPE will oversee the project while providing support to each of the five sub-teams: Components, Fairing, Frame, Innovation, and Systems, Integration, Testing (SI&T), and Riders. The Riders subteam is added on to the list of subteams every spring semester, as the team prepares a few members to compete. These teams will work together to design, manufacture, test, and ride the Human Powered vehicle. Team members who's names are in red will be graduating Fall 2024, members who have been on the team will have new positions, and the teams' volunteers will be added to the team.

During this semester, the team incorporated the role of Change Board Controller and Project Technical Advisor as a secondary role to the DCPE. The CBC and PTA roles are only active during the spring semester. They are responsible for overseeing the manufacturing of the vehicle and managing the various changes to design through the manufacturing process. Other responsibilities include assisting the CPE, DCPE, and Professor Khachatourians in decision-making and scheduling, as well as providing additional support to each of the five sub-teams. With the inclusion of this role, work can more easily be distributed to better manage the project towards success.



FRAME:

CDR Action Items

In the initial structural analysis of the frame the team did not model the torque applied from pedaling; instead, the assumption was made that the seat load and RPS top load would be the critical loading scenarios. However, during the question-and-answer section of the CDR presentation, some HPVC alumni cautioned about the dangers of not considering the torque load. The alumni mentioned that in their year's analysis, the torque load was greater than expected and resulted in a factor of safety below their threshold. With that feedback, the current frame team decided to model the torque that the frame would experience from both the motor and rider input.

In order to model the torque load in a FEA, a numerical value for torque that the frame would experience was needed. This value was determined by both calculations and a comparison to known values from research. First, it was assumed that a rider would be capable of delivering a force slightly less than their weight at the cranks; similar to how a rider would stand on the pedals of a traditional bicycle. This force would be applied at the pedals, which is one crank arm's length (7 inches) from the crank tube. The frame was designed for a 300lb rider, so it seemed reasonable that a 300lb rider could apply a 250lb force into the pedals. The torque from the rider would be equal to the force times the crank length; 250lb * 7in, which equals 146ftlbs or 108Nm. This value also aligned with the research the team had done, which estimated the maximum torque produced by a strong rider to be 100Nm at the cranks. The motor was specified from the manufacturer to deliver 80Nm of torque. Adding the torque from the motor and the rider together resulted in 188Nm. The team decided to round this value up and use 200 Nm of total torque in the analysis. This slightly higher torque was used to account for any potential twisting of the main frame tube as the rider would pedal. The table below summarizes the total torque value used in the FEA.

	Torque (Nm)
Rider	108
Motor	80
Total (rounded)	200

Table 1: Total torque applied at crank tube

In the first FEA torque load analysis with 200Nm applied at the cranks the frame failed and deformed plastically. To solve this issue, the team attempted to first increase the wall thickness of the main frame from 0.125" to 0.25". Increasing the wall thickness did achieve an allowable factor of safety and displacement, but it added over 5lbs of weight to the frame. So instead, the main frame diameter was increased from 1.5" to 2" and kept at the original 0.125" wall thickness. This diameter increase resulted in a larger second area moment of inertia, thereby reducing the bending stress. Ultimately, this increase in main frame diameter reduced the bending stress and achieved a FoS of 1.7, with less than a 1lb increase in frame weight.

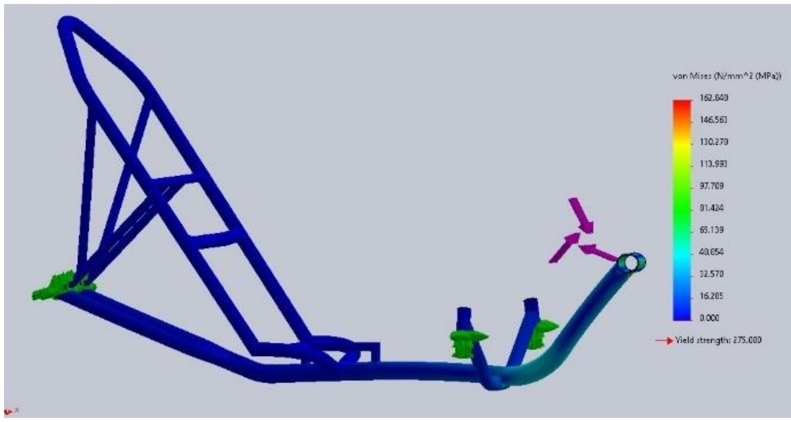


Figure 1: Torque Load Stress. Max Stress = 162.648MPa

The frame sub team was extremely grateful for the feedback from CDR to consider the torque load in the structural analysis. Without that feedback and subsequent analysis, the frame was likely to fail from bending while pedaling. Thankfully, the team was able to solve the issue quickly before the manufacturing process, with minimal weight impact. The table below summarizes the converged FEA results of max von Mises stress and factor of safety for each loading scenario.

Load Scenario	Max Stress (MPa)	Factor of Saftey
Top RPS Load	181	1.5
Side RPS Load	44	6.2
Seat Load	78	3.5
Torque Load	163	1.7

Table 2: FEA stress and FoS results

Manufacturing Process

Working with aluminum presented a unique set of challenges in manufacturing the frame. Specifically, bending aluminum tubing was something that the team and machine shop associates at CSUN were not familiar with. There were concerns about the tubing cracking and if the tube bender at CSUN could handle aluminum. In addition to bending the tubing, welding aluminum comes with its own difficulties such as the higher power welder that must be used, and a more unforgiving welding process as compared to steel. After welding, the frame would also need to be heat treated to achieve the T6 temper strength in the design. These hurdles were overcome as the manufacturing process progressed, often on a very tight timeline and with minimal room for errors.

The figures on the page below show an exploded view of frame, and the welded assembly. The frame consists of 18 individual pieces of aluminum tubing which would be cut, bent, notched, and TIG welded together to create the final assembly.

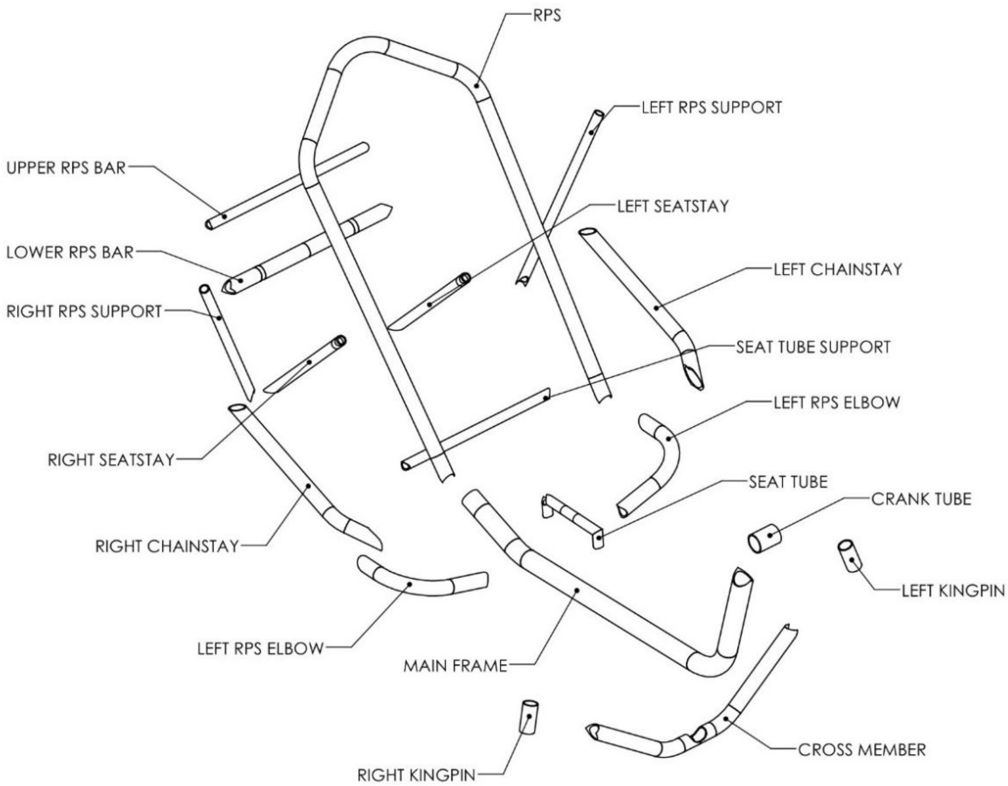


Figure 2: Exploded frame

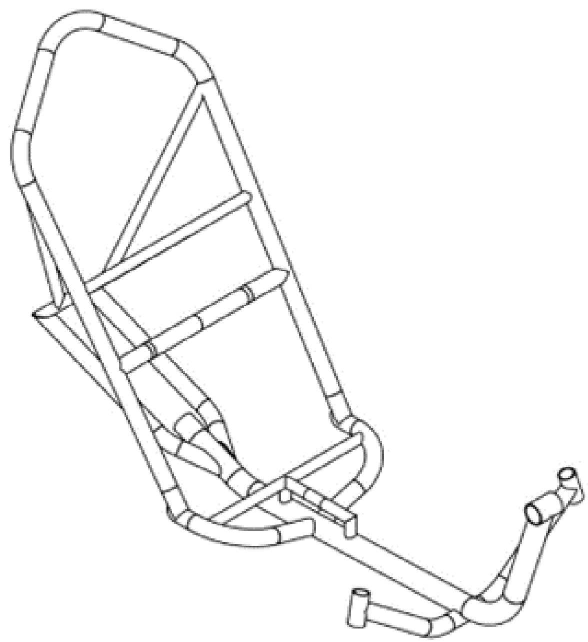


Figure 3: Assembled frame

Many of the frame's individual tubes had non-typical bend angles and notches. So, to aid the welding and fit-up process, a steel welding fixture was designed that would locate the location and angles of the frame tubes. The fixture consisted of steel plate that had steel posts welded at specific locations. At the top of these posts sat 3D printed inserts upon which the frame would rest. A model of the welding fixture and the frame are shown in the image below.

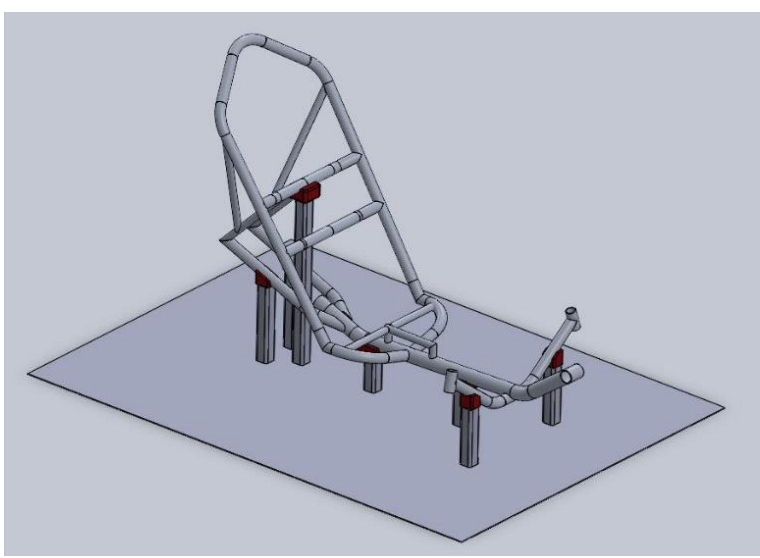


Figure 4: Welding fixture and frame

The location of the weld fixture posts was critical, because they would ultimately locate the frame tubes. In order to increase the accuracy of the welded location of the posts, a template was water-jet out of a thin piece of 16ga mild steel. The waterjet cutouts in the sheet metal located the posts on the steel plate. The posts were located onto the plate with the template, welded to the steel plate, and the sheet metal template was lifted up and off of the fixture. The locating and welding process was fast and allowed for the location tolerance of the posts to be within 0.010", much tighter than what could be accomplished with a tape measure and sharpie. The welding fixture and inserts decreased the fit-up tolerances, which allowed for a faster and easier fit-up and welding of the frame.

Figure 5: Locating fixture posts using sheet metal template

Figure 6: Completed welding fixture

ABS plastic inserts were designed to support and locate frame tubes. These inserts were 3D printed which allowed for ease of manufacturability and multiple iterations on short time notice. Inserts were printed using ABS as this filament material has a higher thermal resistance than conventional PLA. This was an important material decision as the heat conducted through the aluminum tubing would warp PLA.

Another challenge was in bending the aluminum tubing. In order to bend the tubing, it was necessary to have it annealed to O-condition. However, the aluminum tubing that was purchased from IMS was in T6 condition. So, the tubing was sent to the 2023-2024 team sponsor, Astro Aluminum Treating Co., for an annealing process. This allowed for the malleability and ductility needed to create the bends without cracking. Bending was done a Baileigh RDB-050 Manual Tube Bender, which resulted in high quality bends with no wrinkles, cracks, or kinks, and was accomplished completely in-house.

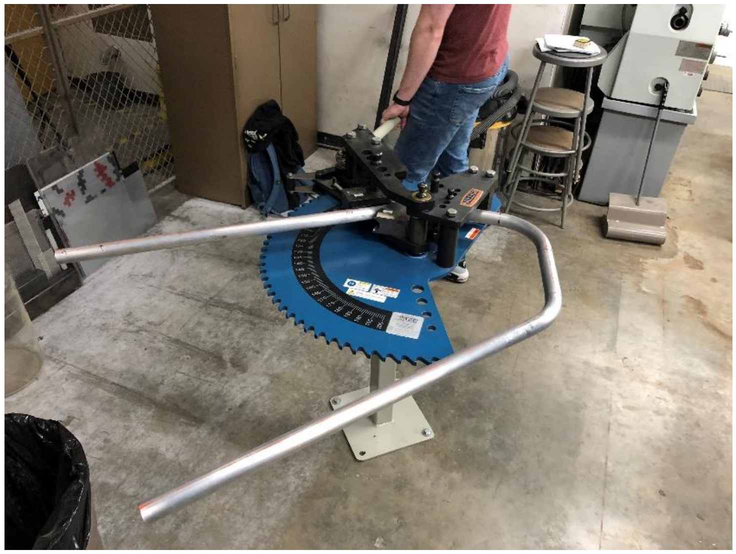


Figure 7: Bending the RPS with the manual tube bender

After bending, the tubes were notched and welded together utilizing the welding fixture. Welding was done on a Miller Syncrowave 350 AC/DC Tig machine with 1/8” EWG tungsten and 3/32” 4043 filler rod. This filler rod alloy was chosen because of its ability to be heat treated with the 6061 alloy. While the alloys are not identical, when welded together the 4043 filler has enough weld dilution from the parent 6061 material to be heat treated and have the same material properties.

Figure 8: Welding the frame

After bending and welding, the frame was still a welded body of 6060-O pieces. In its O-condition, aluminum has a yield strength of only 23% the yield strength of a T6 temper. So, a heat treatment had to be done in order to achieve the higher stiffness and strength values in the design. After welding, the assembled frame went back to Astro Aluminum Treating Co, where it was solution heat treated. This process took the frame from an O-condition to a significantly stronger T-6 condition.

Figure 9: Complete frame

The frame was modeled in CAD at a weight of 20.1lbs, and the final manufactured weight was 20.36 lbs. This was one of the closest designed vs actual weight differences that the team has accomplished. This accuracy was likely due to the detail of the model; each and every bend and tube, including the small sections, was modeled.

Figure 10: Final frame weight

Lessons learned.

There were a few lessons learned in the frame design and manufacturing process; the biggest lesson was in designing the frame geometry. When modeling the boom crank height, the frame team forgot to check for interference of the rider’s foot that would be off of the pedals. Nearly 8” from the ball of the foot to the heel hangs off under the pedal. Just before welding the main boom, the team realized that a rider’s heel would hit the cross member when trying to pedal, rendering the pedals useless. Luckily, this mistake was caught early, and the height of the cranks was increased to accommodate for the rider’s foot.

Another lesson was in checking the tooling specs before designing. The frame was initially designed with 5” radius bends. However, each bending die has a specific material diameter and bending radius, none of which matched the design. Consequently, with only a few days till the start of manufacturing, the frame had to undergo many revisions in order for the model to match what was possible to manufacture.

Lastly, there are only a handful of tubing wall thicknesses that are commonly available. In the design, some sections of tubing were made with a specific wall thickness only to find out that it was not available. So, the thickness had to be upsized to an unnecessarily thicker and heavier tube.

Ultimately, checking for interference, tooling sizes, and common raw materials would have saved the team from multiple revision changes and time delays.

Components:

Manufacturing Prep:

After designing our CAD models and creating the drawings, our team printed the drawings out and checked with our in-house machinists to see if our parts are machinable or not. Many changes were done to the drawings as some dimensioning didn't make sense or change a couple of tolerances to accommodate the creation of the component. After making changes to the drawing or the model itself, the team planned out which parts are going to be machined by a student who is a machine shop certified or by the shop machinist.

The majority of our parts such as the dropout components, idler brackets, and end clamps were planned to be student machined as they were simple to manufacture for people who have machine shop experience. For the more complicated components such as the steering hub, upper seat clamp, kingpin, and knuckle hubs were planned to be manufactured by the shop as it needed the CNC machine to create the complex geometry that is needed. Additionally, with such tight tolerances, the machinists in the house are able to accommodate those tolerances and double check with the gauges. To organize which part has been manufactured or not, an excel sheet was created in order to keep track of which parts will be in progress to manufacture. Additionally, the team looked at how much stock material is needed in total as a lot of material would be needed to manufacture the components.

For the seat, the team looked at the amount of foam that is needed for CNC and the materials needed for the carbon fiber seat. Additionally, the team learned Aspire/Vectric to learn how to do the toolpaths that will be used for the CNC when cutting the foam. Some materials that were needed for manufacturing the carbon fiber seat were carbon fiber, breath cloth, vacuum film, tacky tape, and PB Bond/Gorilla Glue. Primarily the tool paths need to be made appropriately to the CNC dimensions as it is important to have proper tool paths so that the CNC machine doesn't go in the wrong path direction.

Machining/Process:

Most of the components that were needed needed to be manufactured in the machine shop. With the stock material that was bought and provided by the machine shop, people who are machine certified were tasked to machine certain parts throughout the month. A list of what parts are needed to be manufactured was created in order to keep track of the progress that has been made and how many components were needed. While only one member in the components sub team was machined certified, we asked some of our team members from other sub teams to help us manufacture the parts that were needed and they were willing to help out create them in the machine shop. For the team members who are going to help us manufacture our parts, they will be manufacturing parts that have simple geometry or that is doable for a student that is machine shop certified. For the complex parts (ex: dropouts, knuckle hubs, seat clamps) that were needed to manufacture or needed the CNC machine, the machinist in the shop will be helping us out as they have the experience with the CNC machine and are able to create the complex parts that are needed. While 11 people in total were machine shop certified in our team, there were some time constraints that happened throughout the manufacturing phase which led to delays on when our parts were going to be manufactured. With the parts that were CNC machined/done by the machine shop, some issues came along with the drawings which needed to be redone in order for them to manufacture it. Nevertheless, the team managed to have all the parts manufactured in a timely manner in order to proceed to assemble the HPV bike.

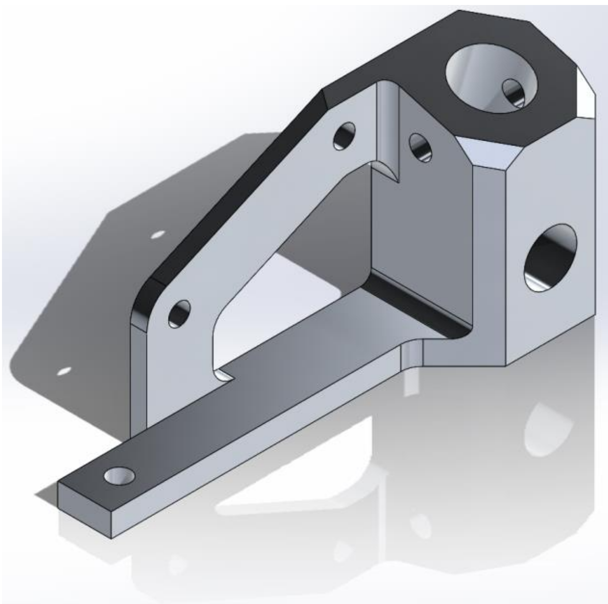


Figure 11: Complex Geometry
Knuckle Hub Simple Geometry

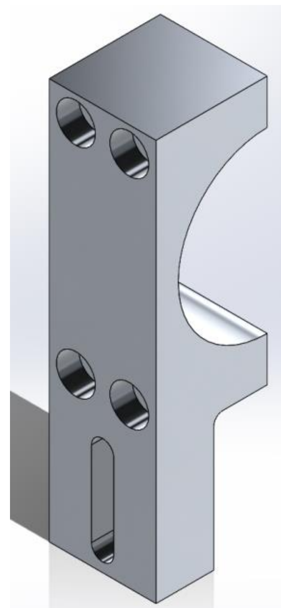


Figure 12: Simple Geometry
Idler Bracket Left Side

Manufacturing for the seat began with creating the mold. Using the layers of foam we previously cut during preparation, we set them in the work area and uploaded the toolpaths we created in Aspire/Vectric into Carbide 3D. For preparation of each layer, we had zeroed our tool paths at the bottom left corner on top of the sheet. When running the program, we had to pay careful attention to the CNC mill. Due to the nature of cutting foam, the foam particulates clogged up the CNC's bearings. While the machine was running, we would brush down the guide rails and use an external vacuum to clean up any particulate near the end mill. We repeated this process for all 6 layers of the mold.

Creation of the mold continued with bonding the layers together. Initially we used PB bond as was standard practice for the fairing sub team and other senior design teams. Due to running low on PB bond, the team found that using Gorilla glue with the surface pre sprayed with water was an effective alternative. For the remaining layers, we used Gorilla glue to bond them and began to use Bondo on the mold. Bondo was used to fill in the various cracks and imperfections on the mold. After letting the Bondo dry, the team moved on to spackle. We got the spackle as smooth as we could and moved on the Duratech.

Spraying Duratech took multiple attempts due to issues. Our first two attempts resulted in failure due to the fact that we forgot the catalyst. We brought thinner which by itself wasn't even close enough to getting the duratech sprayable. During our third and final attempt we had the catalyst, and spraying the mold was a success. After letting the duratech dry, we finished the mold by wet sanding, making the surface as smooth as possible. When wet sanding was done and the surface finish was as best as we could make it, we moved on to the final step of performing the wet layup.

Figure 13: Seat Mold Duratek

Figure 14: Wet Layup Vacuumed

Wet layup took place soon after wet sanding. We prepped the mold with a release agent to make sure the seat would release properly. Layers of carbon fiber were placed on top of each other along with the resin. After the layers of carbon fiber was the release film and then the breather film. We placed tacky tape all around the mold to stick the vacuum film to and placed our vacuum valves connectors before laying the film atop. After all that the connectors were joined together and the seat was left overnight to cure. After curing, the final touches we did on the seat were trimming the excess material off, polishing for a nicer finish, and drilling the holes where the seat would be fastened to the frame of the bike.

Figure 15: Finished Carbon Fiber Seat with Polisher Applied

Design Changes:

Originally the control rods were created with carbon fiber rods and machined insert. This enabled us to change the steering angle if necessary in order to have stability when riding/steering the bike. Previous teams have done similar designs so we stuck with the same design for the control rods. Some problems occurred with the controls rods as the inserts were easily removed when steering left and right. The first solution that was brought up and done was to apply some sort of advice (PB bond & JB Weld) to the tube/insert so that it can withstand the turning force that the person is doing. While it worked for a couple of test trials when riding the bike, the insert would eventually be removed from the carbon fiber tube due to the amount of steering force that was being applied. Knowing that this may happen during the competition, it was decided that a solution is needed to prevent this from happening. An idea was brought up that instead of a carbon fiber rod with threaded inserts, it should just be an aluminum rod with tapped threads as the control rods. While it increased the weight by a small amount, we decided to replace the component as aluminum control rods. Manufacturing the component was done quickly and put in the bike. After placing the new component in the bike, testing was done to see if it can hold up when a steering force is applied. It held up fairly well and solved the issue that could've happened in competition.

Figure 16: Aluminum Control Rods applied in the HPV Bike

With the creation of the steering bar, some issues arise when bending the steel tube stock that was bought. Many attempts were made to create the steering bar for the bike which cost more material. The first try for the creation of the steering bar, kitty litter was used while bending the steel bar. Eventually while bending it, it compacted which led to breaking the steel stock. There was a possibility as well that it was being bent fast which led to it breaking. After ordering new steel tube stock, another attempt was made but with more careful planning. With the same process which was using kitty litter as a substitute than sand and careful bending, a steering bar was made for the bike. While it is not a perfect bend to the designed one with CAD.

Figure 17: Finalized Steering Bar with Brake lever Applied

Originally the steering hub design was quite complex when made in CAD. The design of the steering hub was more of a cylindrical design that accommodated the use of the left idler bracket to bolt it together. After one of the machinists in our machine shop inspected the drawing for it, they recommended redesigning it to be more simple which will make manufacturing it much easier. After some changes to the steering hub design and creating the drawing, the in house machinist checked it. With the approval of our drawings, manufacturing for the steering hub started as soon as possible.

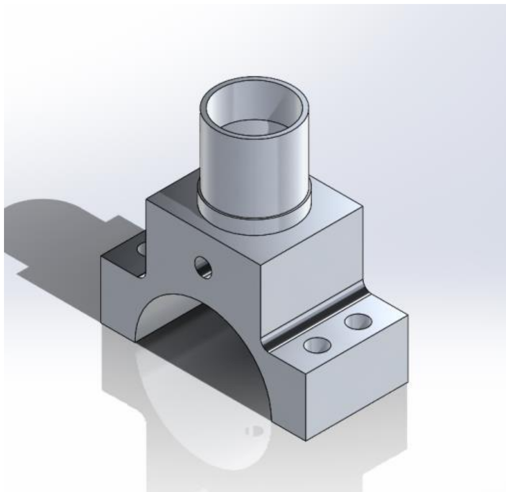


Figure 18: Redesign of the Steering Hub

Lessons Learned:

During manufacturing we ran into a few issues with the bike, in particular we had many issues with the chain and derailment. Our idlers would walk up while riding the bike, disturbing the tension in the chain and causing derailment. This was a constant issue for us that kept happening through multiple attempts at fixing. What we thought would be our best solution in creating a spacer inside the idler bracket caused another issue. The critical thing that we missed with this design that was used by other teams and was suggested by a bike shop owner was a chain guard. Essentially a cover that goes over the rear gear that would block the chain from moving too far and back into its proper position.

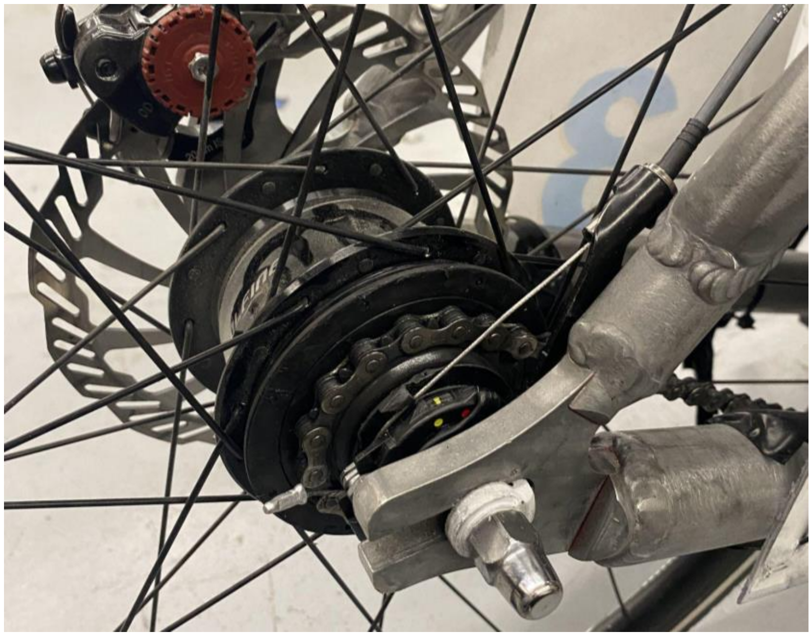


Figure 19: Rear Cog with Chain where Derailment issue arises

Another lesson learned would be that around the composite seat. The seat was a good learning experience and a cool component to manufacture. A lot of manpower and hours were put into the seat that were taken away from the other components. Moving forward if the team decides to ever do another composite seat time before the semester needs to be spent preparing material and learning the process for creating molds for manufacturing composites. Specifically we should have had our layers, and toolpaths created as soon as possible to get through the mold creation process faster.

We ran into another issue regarding our steering linkage clamps. Due to the nature of aluminum and us having to insert and remove fasteners multiple times throughout the assembly of the bike, the threads on the aluminum clamp became worn and stripped over time. The issue was solved actually by using a slightly larger fastener. Allegedly during our assembly, we used the wrong size fastener but sizing up very slightly alleviated the issue. Moving forward, some ways to preemptively deal with problems like these include using a tougher material such as steel, using key inserts, and or having spare versions of these components.

Fairing:

The fairing of the Human Powered Vehicle is an aerodynamic component that serves to reduce air resistance, also known as drag, and as a result, enhances performance. This semester the team focused on the fabrication of a partial fairing through the use of a Polyurethane foam mold. The following sections will cover the entirety of the manufacturing process, such as the preparation, fabrication, and lessons learned.

Manufacturing Preparation

This year, the team opted for a partial fairing configuration due to its lightweight nature and simplified fabrication process. Moreover, we took on the challenge of utilizing a male mold instead of the traditional female mold typically used by the CSUN HPV team. Since the change presented a unique challenge, it was necessary to conduct developmental testing to demonstrate the ability to create a partial fairing out of a male mold.

Consequently, as we progressed toward the manufacturing stage, we prepared by practicing the fabrication of a miniature-scaled mold and fairing. This process allowed the team to familiarize themselves with the Vetric Aspire and Carbide Motion software used for generating the g-code for the CNC, as well as learning the wet layup process for carbon fiber. However, most importantly this preparation served as proof of concept that utilizing a male mold was indeed feasible.

CNC Puzzle Pieces

Although the miniature mold was a successful experiment, the next big obstacle was creating the full-size mold for a 44x24x79-inch fairing. It was a two-part challenge created by the lack of foam material for the mold and size limitations of the CNC bed. To overcome this obstacle, the team divided the mold into smaller sections and strategically organized them to prioritize the limited high-density polyurethane foam. The layout process, coined the Cake Method, arranged the low-density foam within the inner part of the mold and the high-density foam in the outer layers as shown in Figures A & B. The principle behind this approach was that the high-density foam was better suited for sanding and applying Bondo and Duratec, while low-density foam tends to absorb these materials.

Figure 20: Mold Assembly: Image of the final male mold after assembling all the individual sections of foam.

Figure 21: Cake Method: Diagram of the cake method layout. The blue region represents the high-density foam and the grey region represents the low-density foam.

Wet Layup Process

After assembling the CNC puzzle pieces, we proceeded by applying a layer of Bondo, followed by spraying on Duratec and carefully sanding the surface to achieve a smooth finish as shown in Figure 20. This step was crucial to ensure the success of the subsequent wet layup process.

Wet layup involves saturating a reinforcing material, such as carbon fiber, with epoxy resin. To begin, we applied a thick layer of wax to prevent the carbon fiber from adhering to the mold upon curing. Then, the carbon fiber was positioned over the mold and impregnated by applying epoxy resin within each layer. Our fairing utilized four layers of carbon fiber in a 2x2 twill weave pattern and a single layer of Lantor Soric XF Reinforcement between the carbon fiber sheets to enhance mechanical properties. Upon completion, the mold was enclosed within a perforated film and breather cloth before vacuum-sealed. The perforated film served the purpose of allowing excess epoxy to escape during vacuuming, while the breather cloth absorbed any excess epoxy, ensuring a clean and uniform finish.

Figure 23: Male Mold: Image of the mold post-Bondo, Duratec, and sanding, ready for the wet layup process.

Windshield

The fairing's windshield is made of 1/16 inch polycarbonate sheet, positioned at the front of the fairing for optimal visibility. Our team chose polycarbonate due to its strength, lightweight, malleability, and ease of rework ability, making it an ideal choice for a windshield. To mount the windshield to do the carbon fiber, bolts and screws were utilized along with vinyl tape to create a seamless transition to the carbon fiber.

Lessons Learned

After fabricating the fairing and participating in the competition, several lessons were learned. Firstly, we discovered the importance of thoroughly planning the removal of the fairing from the mold. Ensuring proper release techniques are applied during the molding process is crucial to prevent damage to the fairing and ensure a smooth removal process. Additionally, although not a major issue, it is important to acknowledge that the stability of the mount to the faring could have potentially caused larger problems. We learned the significance of thorough testing and evaluating at every level to identify and resolve potential issues. By recognizing even minor issues we can mitigate risks and ensure the overall success of the vehicle.

Figure 24: Image of the finished fairing used for competition.

Innovation:

Background

Our innovation sub team was tasked with developing new systems to improve the vehicle dynamics and enhance the riding experience. We were all about practical innovations that actually make a difference—improving safety and adding value to the vehicle. We took what we've learned in class and from other sources, and put it to the test, not just to add innovation to our vehicle but also to beef up our own skills in design, manufacturing, and working together as a team. This whole project was a real chance for us to take theory out of the textbooks and see how it works in the real world. The ultimate goal of this project is to become professional engineers towards the end with real world experience.

In taking on this project, we also embraced the challenge of working within the constraints typical of real-world engineering tasks, such as budget limits, manufacturing abilities and material choices. Our aim was to come out of this project with a deeper understanding of the practical aspects of engineering design and a stronger foundation in teamwork and problem-solving skills, essential for our future careers as professional engineers.

ASME's requirements and constraints regarding the electrical systems of this year's human powered vehicle are mostly carried on from last year, but there were a few alterations and additions that are worth noting. For the rules that remain unchanged, the maximum power rating for the electric motor remains at 500 W. The traction battery powering this motor is still required to be stored inside a rigid bulkhead while being paired to an accessible emergency shutdown switch. These constraints ensure safety precautions in the event of any electrical fires. On the other hand, this battery's capacity requirement has changed from a maximum charge of 10 Ah to a maximum capacity of 500 Wh. This allows the battery's voltage and charge to vary, so long as it meets the capacity requirement. Additionally, the vehicle is not limited to the use of only one battery, which allows for more electrical systems to be installed, such as our telemetry system. However, the maximum voltage for each system cannot exceed 50 V.

The innovation phase involved exploring eight initial ideas, ranging from suspension systems to telemetry systems, evaluated through a design matrix based on cost, safety, power consumption, reliability, manufacturability, weight, and impact. This analysis led to prioritizing the Sound Safety System, Telemetry System, and Pedal Assist due to their potential for significant impact on rider safety and performance. As we researched more on the integration of these systems on the vehicle, it was noted that developing and implementing them would be overwhelming. We then reconsidered our decision and shifted our focus primarily to the Pedal Assist and Telemetry Systems. This decision was based on the considerations of time constraints that other systems imposed and the necessity of incorporating a pedal assist system.

Our mission was clear from the start—to enhance the experience of the human-powered vehicle and prioritize the safety of the rider by incorporating innovative concepts. This led us to developing systems that could provide real-time feedback to the rider and pit crew, thereby enabling better decision-making during use. By using such systems, we made improvements in vehicle function, directly impacting the efficiency of the bike in competitive scenarios. The idea was to gather as much data as possible and have it transmitted to the pit crew so improvements and adjustments could be made accordingly in real time.

For our new design of the electrified human powered vehicle, we focused on creating a telemetry system that allows us to gather and analyze real-time data to enhance the riding experience and performance. We chose to use an Arduino microcontroller paired with various sensors to collect data points critical for both the rider and the support team. These data points include the bike's position, speed, tilt, the rider's heart rate, and both the temperature and charge level of the battery. This information is sent wirelessly to the pit crew and recorded on an Excel sheet for detailed analysis, future reference and real time improvements. With this data, the pit crew then makes decisions during the race to ensure the safety of the rider and the vehicle. An example would be the rider’s heart rate reaching critically high levels during the endurance race. If such an event were to occur, the pit crew would signal the rider to perform a pit stop and switch places with another rider on the team. Another instance would be the battery’s temperature reaching a dangerous level. After the battery’s temperature crosses a certain threshold, fans inside the battery box would be activated in the effort to cool down the system. If the battery’s temperature continues to increase, the pit crew would signal the rider to make a pit stop and remove the battery before any electrical fires occur. Through these functions, our design specifications of the telemetry system are geared towards making the e-bike not just faster and more efficient, but also safer and more responsive to the rider's needs and the competition's demands. The integration of real-time data transmission and analysis stands at the core of our innovation strategy, ensuring that our e-bike is a step ahead in terms of technology and performance.

Testing

Our telemetry system is equipped with a range of components, including an Arduino Mega, Screw Terminal board, a 14.4 Volt Battery, and various sensors such as Voltage, Temperature/Humidity, Heart Rate, GPS, and acceleration/tilt sensors. At final stages the decision was made to not use the acceleration/tilt sensor. The construction process for this system was planned and executed step by step.

Initially, we analyzed each component to understand its functionality. For each sensor, we developed specific code to ensure it performed correctly, which also provided us with practical coding experience and taught us how to integrate these components into our larger system. Following this, we wrote additional code to define each sensor's role in data acquisition.

The point of this coding effort was our main code, which gathered all individual sensor codes. This main code is responsible for collecting data, storing it in an array, and transmitting it using electromagnetic waves.

In terms of hardware setup, each sensor was connected as per the manufacturer's instructions. Before assembling the final system on the bike, we built and tested a prototype to ensure both the hardware and software were fully functional. After successful testing, we constructed the actual system, ensuring all connections were secure for mounting on the bike. Like with the prototype, we thoroughly tested the hardware and software once more. During this final test, the system transmitted data to a receiver, where it was recorded and verified for accuracy and completeness.

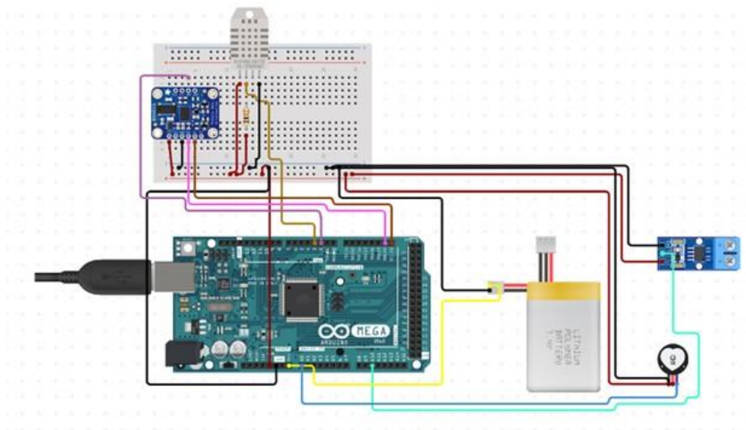


Figure 25: Telemetry Circuit Schematics

Manufacturing

One of the primary challenges in manufacturing was securely attaching the telemetry system and pedal assist kit to the bike. Specifically, the battery for the pedal assist system needed to be both mounted securely and easily removable. Our solution was a custom design involving a mount that connected to the bike’s frame and a battery box. The box, designed to latch onto the mount, was equipped with fans controlled by an Arduino to ensure proper ventilation.

The mount itself was 3D printed out of ABS plastic, providing a sturdy and precise fit to the bike’s frame. The battery box was manufactured from polycarbonate sheets, cut and assembled with additional 3D printed parts and brackets sourced from McMaster to ensure secure assembly. The largest piece (Battery box mount) was manufactured by our machine shop, which offered both cost-effectiveness and timely production. The machine shop also handled the CNC cutting of the polycarbonate panels, which gave it a smooth and professional finish.

For the telemetry system, our approach prioritized 3D printing for all component mounts. This included mounts for the sensors, the 14-volt battery, and the transmitter, integrating all elements into the design from the start. Some parts were printed using personal 3D printers, while others were produced using the machine shop 3D printers.

Overall, the manufacturing process was straightforward, heavily leveraging 3D printing to create the necessary parts efficiently and effectively.

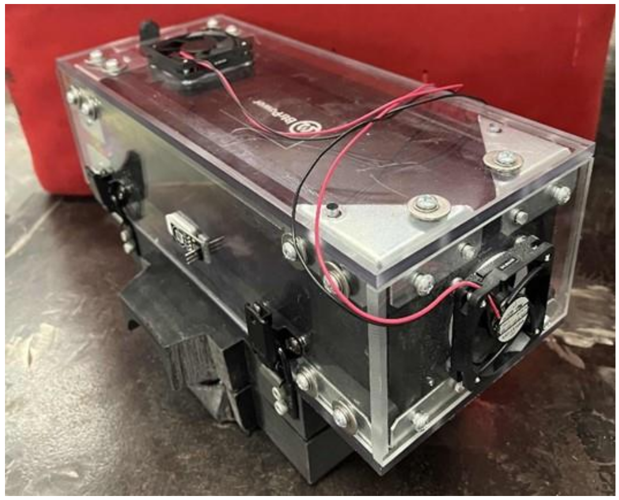


Figure 26: Battery Box

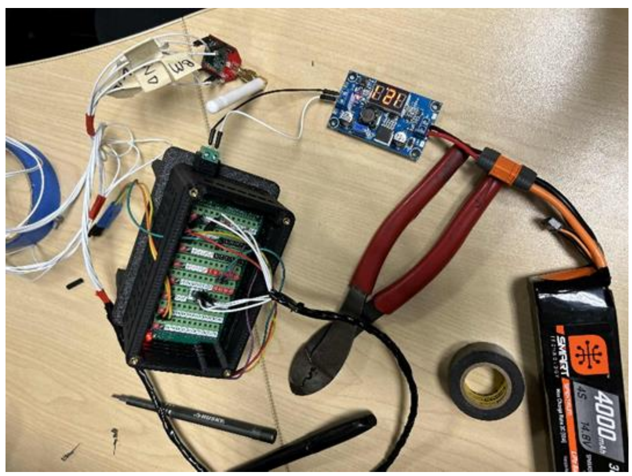


Figure 27: Assembly of the Telemetry System

Figure 28: Antenna/Fairing Mount

Lessons Learned

One crucial lesson we learned was the importance of having a backup plan. During the final stages of our project, we encountered a significant issue when we damaged the pin on our transmitter. Despite our best efforts to repair it, the transmitter failed to function. Fortunately, we had a backup transmitter ready, which allowed us to adapt and integrate the new unit, ensuring our project stayed on track.

This scenario wasn't unique; having a backup great plan consistently proved to be significantly valuable. Another key factor in our success was the decision to build a prototype. Being able to assemble and test a physical version of our possible final design was crucial. It gave us a realistic insight into how the final product would function, allowing for adjustments before the final build.

Teamwork was another crucial element. This project would not have been possible without a dedicated team working seamlessly together. From coding and manufacturing to design and electrical tasks, every aspect was challenging. Regular communication and concerted effort from every team member were essential to overcome these challenges and achieve our goals.

We also learned important design lessons, particularly when our battery mount failed to secure the battery during the race due to loosening latches. The possible cause for this could have been extreme force upon impact of the vehicle with a bump or incorrect tolerances. This incident highlighted the need for more careful consideration of load dynamics in future designs, ensuring that all components can withstand the rigors of use without failure.

Systems Integration and Testing (SI&T):

Background

The Systems, Integration and Testing sub-team is responsible for ensuring seamless integration within the Human Powered Vehicle sub-teams. Within our sub-team, we have set out a mission statement for ourselves. We will collectively take responsibility for ensuring the vehicle's organization and quality, prioritizing effective communication and diligent project monitoring to achieve efficient budgeting. Through a comprehensive study, the SI&T Team will successfully manage the vehicle, ensuring it meets all the objectives and specifications outlined by the ASME. As a result, we will enhance the design abilities, manufacturing expertise, and collaborative experience of our team members.

Budget

Overseeing team finances and outlays is a key duty of the Systems, Integration, and Testing (S.I.T.) sub-team. To create a team budget for the entire semester, every semester from prior semesters we are given new amounts from the different Accounts added up and combined with university financing. The first budget breakdown for the team is shown in Table 1.

Account	Funds
A. S. Agency	$6,018.00
Cash Box	$2,908.00
IRA	$16,550.00
Total	$25,476.00

Table 3: Initial Overall Budget Breakdown for 2023-2024 HPVC Team

Following the determination of an overall budget, the budgets of each sub-team were computed according to their respective team requests. Every team's budget was roughly the same as that of the HPV sub-team from the previous year, but some teams received a little bit more, based on the cost of the supplies that needed to be bought in case of any unforeseen costs. Since competition-related costs must also be taken into consideration when determining the Systems, Integration, and Testing budget, a specific portion of the starting total will be placed in the management reserve depending on the location of the competition. Table II displays the sub-team budgets that were allocated by each sub-team, Year to Date, and remaining balance for each.

Team	Allocated Budget	Year to Date
Frame	$3,200.00	$33.62
Components	$3,200.00	$458.58
Fairing	$3,500.00	$0
Innovation	$2,500.00	$0
SI & T	$2,000.00	$53.24
Total	$14,400.00	$545.44

Table 4: Budget Breakdown for Sub-teams

Each sub-team is assigned a purchaser to handle purchase orders; this purchaser must request approval from S.I.T., CPE, and DCPE. It includes reviewing any purchases made by teammates who have personal accounts for reimbursement. Currently, most of the orders placed by our team have been filled; the remaining funding amounts are shown in the table above in the far-right column.

Logistics

One of the biggest challenges we faced last semester was not knowing any details about the competition. This semester, we have learned that the competition will be held in Boise, Idaho. This raised new challenges such as the logistics of getting the vehicle and students to Boise, Idaho safely and how we would handle traveling and food/drink expenses. After deliberation with CSUN and votes taken by the team, we have decided on driving to Boise. caravan style with a two-day trip there and a two day trip back, using Reno, Nevada as the stopping point. This trip will comprise six days total, four travel days, and two days at the competition from Thursday, April 25th to the following Tuesday, April 30th. This trip will cost us approximately 7,657.00 total with certain students being reimbursed for their contributions, $1,000 from our cashbox fund, and the remainder coming from IRA. The vehicle itself cost the team $8,450.00 from IRA and $2,869.00 from the ME Department budget and will be trailered to Boise using a rented trailer.

Fundraising

Fundraising	Profits To Date	Projected Profits
Last Year T-Shirts	$1,185.00	$1185.00
New T-Shirts	$280.00	$1,780.00
Food Locations	$307.00	$500.00
iPad Raffle	$1,880.00	$1,880.00
Total	$3,652.00	5,345.00

Table 5: Fundraising Effort

This of course, can be a very costly trip, which is where our fundraising has really shined. Last semester, we had fundraising success with selling apparel and fundraisers at restaurants near the school. This semester we stepped into a much more profitable territory of raffling off an iPad, which profited nearly $2,000. We didn't do any fundraising at local businesses, but we did sell more of our T-Shirts, Sweaters, and Zip Ups. These fundraisers have been big contributors to being able to afford the creation of our vehicle and the competition.

Integration

CAD Management

We used the M-drive to help us store all of our CAD Files and all of our important documents for each sub-team. The Systems, Integration, and Testing team needed to establish mechanisms that track and manage the vehicle's design lifetime, including parts that are built and those that are acquired. Figure 1 illustrates the detailed standards and part and file naming conventions that are part of our configuration management system, which help us maintain consistency and quality in our models and drawings.

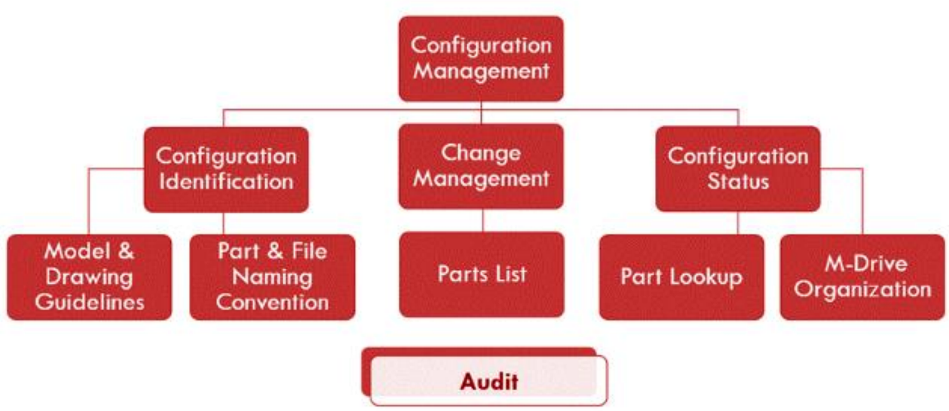


Figure 29: Configuration Management Block Diagram

Top-Down Assembly

The systems and integration team is responsible for the management of the top-down assembly. This includes tracking the weight, center of gravity and any interferences. It is essential to be in close communication with each team, as any small change can affect the entire top down greatly. Each sub team must be made aware of any placement changes, and adjust the design based on others. Integrating is one of the most important aspects to this entire project and is the only way to successfully produce a working vehicle.

Vehicle Dimensions with Fairing	
Height	49.5 in
Length	51.6 in
Width	33 in
Weight	77.14 lb

Table 6: Vehicle Dimensions with Fairing

Figure 30: Vehicle with Fairing

Vehicle Dimensions w/out Fairing	
Height	49 in
Length	90.6 in
Width	33 in
Weight	60.18 lb

Table 7: Vehicle Dimensions without Fairing

Figure 31: Vehicle without Fairing

Center of Gravity

The center of gravity location plays an important role in the stability and performance of any vehicle. It is also important to note where the CG of the rider will fall, as this helps improve stabilization. After extensive research and calculations, the team decided on an "ideal" CG zone where the final center of gravity needed to fall into. When finalized, the bike's CG did fall within this range, ensuring optimal vehicle performance and safety. Tracking the CG location throughout the semester provided insight in areas in which the team should add or remove material to lower the CG. It also helped keep the bike centered as there was little deviation in the y-direction as can be seen below in the final CG location.

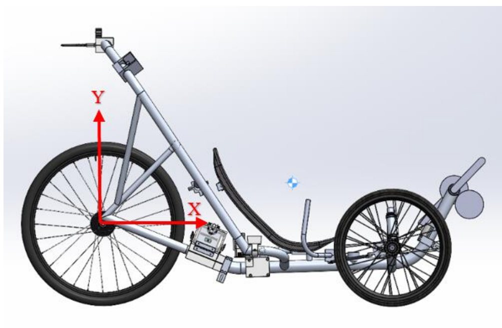


Figure 32: Center of Gravity without Fairing

X	Y	Z
31.35 in	6.33 in	0.27 in

Table 8: Location of Center of Gravity without Fairing

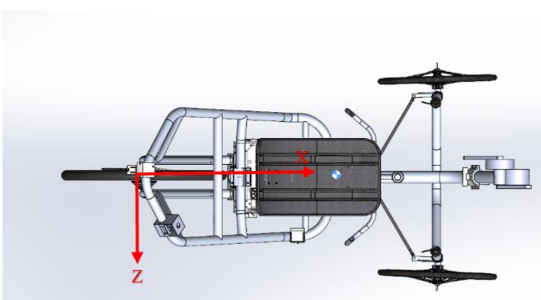


Figure 33: Top View of Center of Gravity with Fairing

X	Y	Z
31.87 in	7.11 in	0.27 in

Table 9: Location of Center of Gravity with Fairing

Figure 34: Actual Center of Gravity with Fairing

Adding the fairing shifts the CG upwards and towards the front of the bike as more weight is added above the central axis and the front half. However, this shift is still within the ideal zone, and adding the fairing provides many benefits in terms of aerodynamic performance and drag.

Interferences

A large part of SIT's role is to ensure that there are no top-level interferences. This problem mostly arises when teams do not coordinate the placement of their items, resulting in overlaps. It is SIT's job to make sure that there are no interferences whatsoever, and to guarantee the model is accurate and buildable.

Rollover Angles

In general, a vehicle will roll over if the tip angle exceeds a line drawn from where the wheel touches the ground and the center of gravity. However, this angle can also be calculated if there is a known turning radius. In this case, ASME provides a radius of 8 m, and the calculations can therefore be based around this.

Figure 35: Front and Backwards Tipping

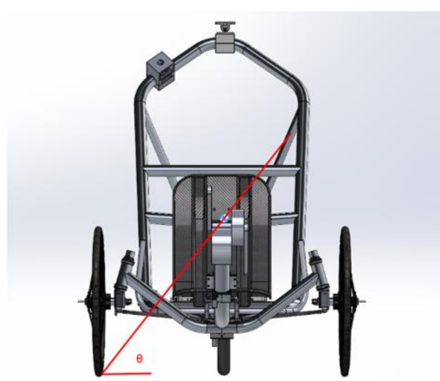


Figure 36: Sideways Tipping

Stability and Braking

Ideally, the weight is distributed 2/3 to the front and 1/3 to the rear for optimal stability. Below is the ideal versus the actual weight distribution that was achieved. The design of the entire vehicle is based around this golden ratio.

Ideal vs Actual Weight Distribution Table

Furthermore, the braking force and weight transfer under braking can be calculated using some dynamics equations and free body diagrams. If successful, 90% of the weight should be transferred to the front wheels when braking quickly to ensure safe and reliable braking. These values can be calculated using ASME's given requirements of a 19.7 ft braking distance and an initial velocity of 15.5 mph. The braking force came out to be 21.5 lbf using those requirements, allowing for a weight transfer of over 90% to the front axle. Breaking

	Ideal (lb)	Actual (lb)
Wf	51.427 (66.7%)	45.829 (59.4%)
Wr	25.713 (33.3%)	31.311 (40.6%)

Table 10: Ideal vs Actual Weight Distribution

Testing

ASME Requirements

ASME provides specific requirements which are needed in the construction of the vehicle competition. The RPS system shall be evaluated using two specific load cases representing an accident in a crash. The loads specified are horizontal and vertical which shall be reacted by constraints at the safety harness simulating forces exerted by the driver in a crash. The horizontal load shall resist a side load of 1330 N on the RPS system with a maximum deflection of 3.8 cm while the vertical load shall resist a top load of 2670 N at a 12°angle to the RPS system with a maximum deflection of 5.1 cm. Sit will perform these types of tests upon completion of the frame, by mocking up test stands capable of handling these tasks.

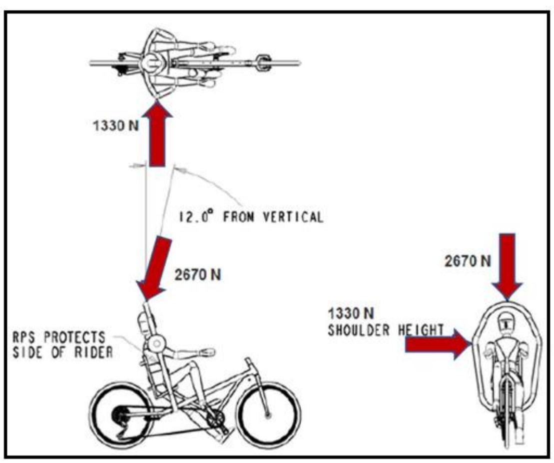


Figure 37: RPS System of Load Cases

When measuring deflection during this test, a weighted string with a knot will be hung from the desired locations of the measurement. A ruler will be mounted on the ground, where it will be standing perfectly perpendicular to the ground so that when the string moves, it will be possible to get an accurate measurement. For safety, our phone cameras will be set up to view and record each measurement point before, during, and after the load is completed. An example is provided in Figure 11.

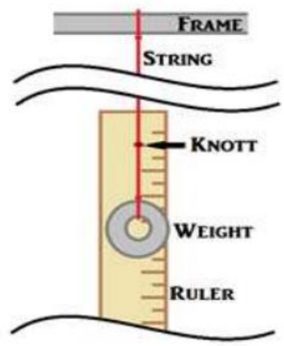


Figure 38: Example of how deflection will be measured

Testing

Before our load testing for the test required by ASME for the HPVC competition. Penetrant tests were done before and after doing load testing and no cracks were found in any welds. The deflection for our top load case came to be 0.4 inches, and the side load came out to be 0.4 inches as well, which are both well within ASME required deflection guidelines. Additional testing includes that the vehicle can come to a stop from a speed of 25 Km/hr(15.5mph) at a distance of 6.0m (19.7ft). Also, the test will demonstrate that the vehicle will be able to turn within a radius of 8.0m(26.2ft), and one that will show that the vehicle can roll a distance of 30m(98.4ft) with a speed between 5-8 km/h. Our vehicle successfully completed these tests with the turning radius being around 1.6m, which can be seen in figure 14, and the vehicle stopped from a speed of 25 km/hr well before hitting the 6m mark. These tests will be presented via a safety video compiled by the team and submitted to ASME judges before the competition.


Figures 39 & 40: Top load and side load methods

Figure 41: Turning Radius Testing

Lessons Learned

One of the biggest lessons learned is begin testing earlier on the vehicle. During competition there were some issues faced that could have been avoided by doing additional testing before competition and ensure all parts work well. Another issue that was faced was during load testing. When the frame is at a 12-degree angle, the load applied cause the angle to increase. To combat this, the whole of the base of the frame was strapped down to prevent this angle from increasing.

Conclusion

The team is confident with their final design and is excited to move on to the manufacturing phase. Multiple members in the Human Powered Vehicle team are expected to operate the recumbent tricycle in time-sensitive situations. With an aluminum frame and components, along with a partial fairing, the total weight of the bike is about 77 pounds. The total length of the bike is about 92 inches, the total height around 50 inches, and a minimum ground clearance of 2 inches. The team has met all the ASME requirements for maximum top/side deflection loads, turning radius, and breaking distance.

This year's team is expected to compete in a static design event which includes a presentation, a drag race event, and a 2.5 hour endurance race event. Although the location for the West Coast competition is yet to be announced the team is building a trike that is safe, reliable, and competitive.

Competition:

Drag Race Event:

Figure 42: 3rd Place in Drag Race

During the drag race event, we scored third place (trophy seen to the right) and learned a lot along the way. During the drag race, we learned that we should have fine tuned the tension in the shifter a bit better to reduce derailing of the chain. This is easily preventable in the future by setting aside a good chunk of time for stress testing before competition. We also learned that having a hub gear kind of messes with the ability to pedal and shift gears at the same time, so next year should avoid using a hub gear if possible. Despite that, we also had a very decent motor that the riders did a great job of taking advantage of. Note to future teams, train your riders well and let them get as much experience as possible in your vehicle.
Event

Endurance Race Event:

During the endurance event, we scored fourth place and learned the importance of stability. Our vehicle struggled to deal with the rumble strip and went fast over rough terrain. I would suggest for the future teams to consider prioritizing stability over speed as that will win in the end. Stability will allow for the riders to give their all towards the race, and not have to worry about a derailing chain or tipping around sharp turns.

Design Event:

For the design event, we scored second. I personally think we did great but could have improved with a bit more preparation and organization. We even earned the spirit award for our horn honking and the safety award for hitting all the check boxes on the safety inspection. This netted us a 3rd place overall trophy.

Figure 43: Team with all of Awarded Trophies