2011 HPVC Design Report

NAU ASME Human Powered Vehicle

Vehicle #31

The Orka

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http://www.cefns.nau.edu/Research/D4P/EGR486/ME/11-Projects/HPVC/index.html

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1. Abstract

The NAU HPVC team is designing, fabricating and will be competing with a speed class vehicle in the ASME 2011 HPVC East Competition in Indianapolis, IN. The all new vehicle is a back-to-back, recumbent tricycle capable of achieving a projected maximum speed of 45 miles per hour or greater and features several unique design concepts. These concepts include a frame made from honeycomb structures composed of carbon composite laminate with a Nomex™ core and aluminum laminate with aluminum core, linear push levers, sprag clutch bearings with a spring steel belt drive system, and carbon composite nose and tail cones with a stretched fabric material for the fairing.

2. Design Description

Previous vehicles built by NAU teams include the 2008 Tandem Tank, a side-by-side recumbent tricycle, and the 2010 Mystax Cetus, a tandem recumbent tricycle. This year's vehicle is a back-to-back recumbent tricycle that uses completely new materials from previous entries and a variety of unique designs.

Figure 1. 2008 Tandem Tank

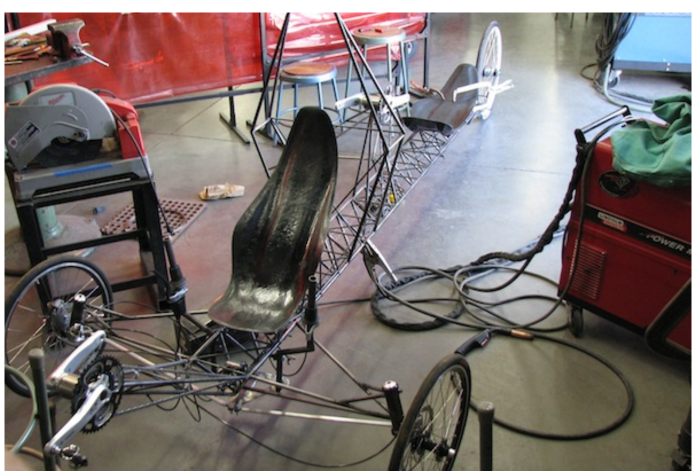


Figure 2. 2010 Mystax Cetus

To prepare for the 2011 HPVC East competition, our team first researched information on the various elements we wanted to incorporate into our vehicle. Initial research topics included materials, components, drive systems, steering concepts, wheels, and rider ergonomics. Additional research was later performed to include revisions to the drive system and steering. Details on each research topic are listed below.

2.1. Research

2.1.1. Advanced Materials and Composites

In our attempt to find unique materials for fabrication of the vehicle, our team considered several options including titanium honeycomb and carbon composites. Titanium honeycomb is exceptionally difficult to obtain, but highly desirable for the application of a vehicle frame. The honeycomb is extremely lightweight and has an immense strength-to-weight ratio. The honeycomb is also relatively easy to work with – it comes in sheets, it is reasonably easy to cut, and components may be easily attached.

We contacted Benecor, Inc™, one of only two possible original equipment manufacturers of titanium honeycomb for the aerospace industry, but determined that they would not be able to assist us with our request for titanium honeycomb. We then established contact with Indy Honeycomb, but found that they manufacture only honeycomb cores and not the laminates needed to provide connective rigid support on the core side walls.

Another material option we considered for the vehicle frame was carbon fiber composites shaped into a continuous tube frame. Carbon fiber is also lightweight and has a very high strength-to-weight ratio. Other teams at the HPVC competitions frequently use carbon fiber in their vehicles for frames due to its admirable material properties, which also means the material does not carry the "unique" aspect we want to achieve. Carbon fiber is also difficult and time consuming to work with, requiring lay-up molds, proper ventilation, and autoclaving to achieve optimal performance parameters. At this time, Northern Arizona University does not have the proper fabrication facilities to support work on large-scale composite fabrication. We would need to sub-contract with local companies such as NovaKinetics, LLC™ or Quintus, Inc™ to obtain materials, workspace, fabrication facilities, and composites expertise.

After the team reviewed all available resources and performed a cost-benefit analysis, we chose to work with M.C. Gill Corp., a nearby honeycomb manufacturer. We were most fortunate to receive two panels of carbon composite laminate with Nomex™ core honeycomb as a donation from M.C. Gill. Another panel made from aluminum honeycomb was also used to provide additional rigid support in the frame. This material was also donated by M.C. Gill Corp. to a previous NAU Capstone team who did not require the extra panel. It was re-allocated at no charge to the 2011 HPVC design team. These materials, epoxied together, will serve as the frame and roll protection in our vehicle.

2.1.2. Components

A variety of high-end bicycle components from different manufacturers were recorded to a database for comparison reference. High quality components are generally quite expensive, but their weight savings and durability are exceptional when compared with their lower-priced counterparts. Since our vehicle will require two riders, it will receive at least twice the weight, force inputs, and "wear-and-tear" during each race event at competition. Thus, our vehicle requires the most robust and lightweight components that we can reasonably afford considering our modest budget.

The components selected for the 2011 HPVC vehicle include custom fabricated seats with matching covers, tandem-specific dual hydraulic disk brakes that actuate simultaneously from a single lever, a custom drive system, sprag bearings, and pedal setup that attaches to a central transaxle via blued spring steel belts.

2.1.3. Belt Drive

Tandem crafts pose a unique problem of weight addition caused by large chain lines connecting the drive components. These large drive systems also require extra idler wheels, tensioners and frequent maintenance. Rather than connecting the drive system of the vehicle with heavy metal chains as in a traditional bicycle, belt drive systems were considered. Belt drive systems are lighter than traditional chain-drive systems, easy to work with, low maintenance, and last twice as long as a conventional bicycle chain. These aspects could help the us achieve the goal of creating a unique, ultra-lightweight vehicle.

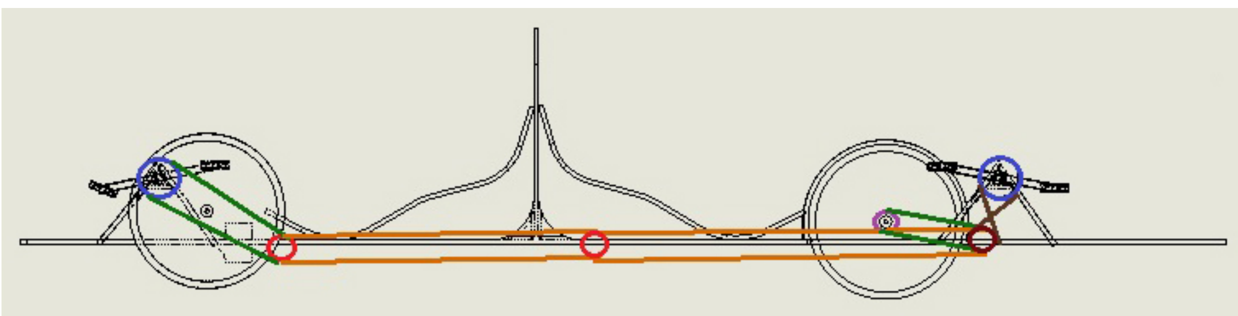


Figure 3. Belt Drive Layout

After contacting a local human powered vehicle enthusiast, the team decided to further explore his unique design ideas for a linear drive system, which eliminates the need for a conventional belt drive system. The new drive system consists of a series of one-way sprag bearings on a shaft that are driven by very thin, high strength, blued spring steel belts. The belts attach to pedal levers that the riders will clip their shoes into, just like a standard racing bicycle crank set. This drive system will increase the efficiency of the riders powering the vehicle by producing less frictional losses than a traditional chain-driven setup.

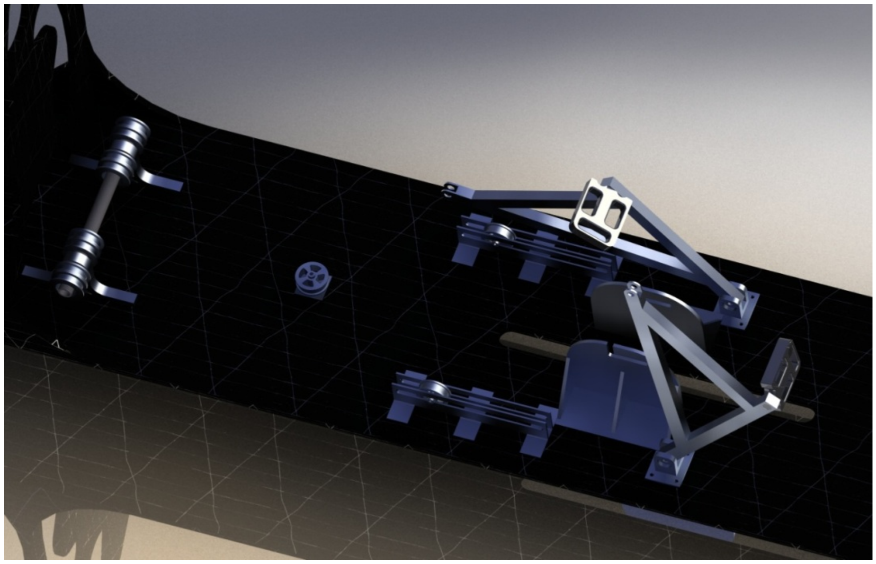


Figure 4. Sprag Bearings on Transaxle and Pedal Levers

2.1.4. Lean Steering

After attending the 2010 HPVC West competition, members of our team were interested in learning more about the lean steering systems that were featured on some of the vehicles. Lean steering incorporates a linkage system that allows the wheels of a trike to lean with the vehicle when making turns, creating the steering dynamics of a two-wheeled craft. This helps reduce wear on the tires and allows riders to lean into turns rather than just turning a set of handlebars or maneuvering a steering joystick. Lean steering also reduces the lateral forces on the wheels created by centripital forces, therefore keeping the wheels from buckling during high-speed maneuvers. Figures 5 and 6 show two similar lean steering concepts the team has created based on our research.

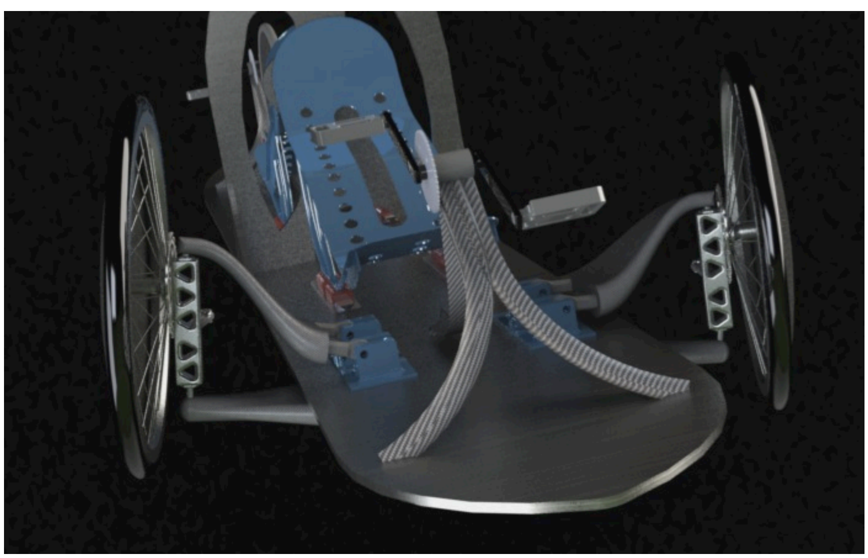


Figure 5. Lean Steering Linkage, Concept #1

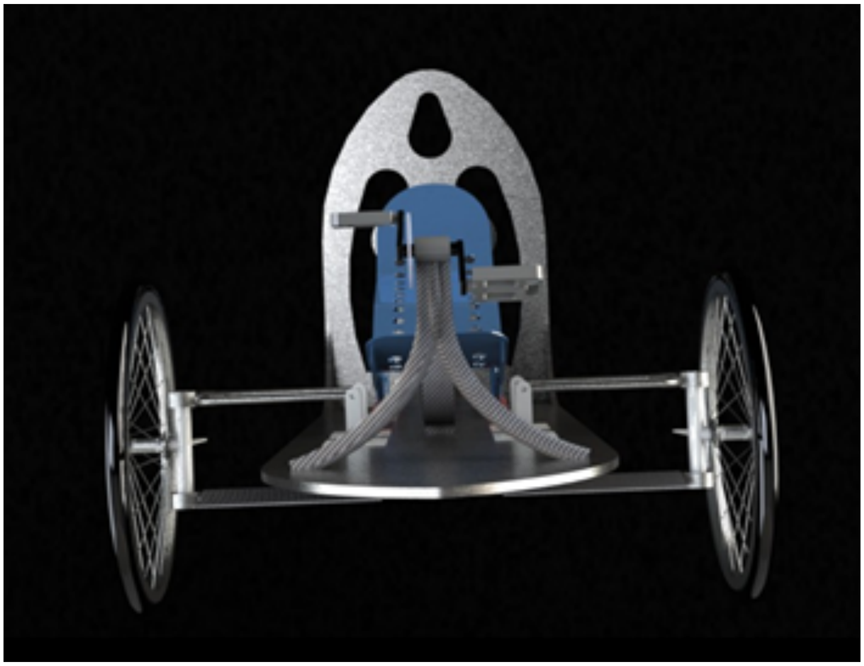


Figure 6. Lean Steering Linkage, Concept #2

Due to time constraints, we decided to abandon lean steering on this year's vehicle. Instead, a steering system similar to the previous year's human powered vehicle will be used. This fixed Ackerman steering setup will reduce weight and material expense in the front of the vehicle, which will allow more room for the front rider's legs. Cutting this design aspect also gives us more time to focus on our designs for the linear drive system.

2.1.5. Wheel Sizes and Gearing

Wheel sizes were chosen carefully in order to maximize efficiency and performance attributes while accommodating rider size constraints and providing smooth handling. Large wheels have the advantage of decreased rolling resistances but experience higher stresses in tight turns. Smaller wheels generally have less aerodynamic drag at high speeds and will allow for quicker acceleration.

Consequently, we have selected 20-inch wheels for the front of the vehicle and a 24-inch wheel for the rear. The rear drive wheel must be larger than the front wheels because it permits greater flexibility in gear ratios when combined with the linear drive system. Our gearing and wheel ratios were calculated so that the riders will be pedaling at an optimum cadence of approximately 80-90 pedal strokes per leg per minute at a velocity of 45 miles per hour.

2.1.6. Rider Ergonomics and Efficiencies

We considered various rider positions and associated efficiencies for pedaling bicycles. It was determined that the most efficient stance for a rider in the recumbent position is with the bicycle seat at a 37° incline. This is a compromise between an aerobic endurance position and an anaerobic sprint position. It is important that the rider be in an appropriate position to maintain proper blood flow though the legs and feet without possibility of thrombosis or cramping. To allow for maximum power output and optimum muscle recovery, the push levers will incorporate adjustable pedals to provide optimal comfort and efficiency for a range of rider sizes. The maximum pedal distance should be 110% of the distance measured from the rider's hip to their heel. This will reduce the angles created at the hips and knees, which will reduce the resultant moments and forces experienced at those joints. This allows for longer recovery periods between pedal strokes and less stress on the riders muscles and joints. Detailed measurements of the appropriate rider stance are shown in Figure 7.

The average person operates at approximately 23% efficiency, which means a cyclist trying to achieve a speed of 45 miles per hour will need to output between 350-400 watts of energy. If 23% of the total energy is used for propulsion, the rider will generate 1000-1200 watts of heat. To keep the rider from overheating in an enclosed fairing, a method of cooling is essential. The human body must say within ±2° Fahrenheit of its optimal average core temperature (98.6° F) to maintain a high power output. Air ducts, fans, and ventilated seats were considered for proper rider cooling. After completing research on rider ergonomics and efficiencies, we have chosen to use carbon fiber seats with highly breathable seat covers at assist with cooling. NACA standard air ducts at the front of the vehicle will also provide airflow to the riders. Vehicle testing will supply additional data to determine if extra cooling systems are required.

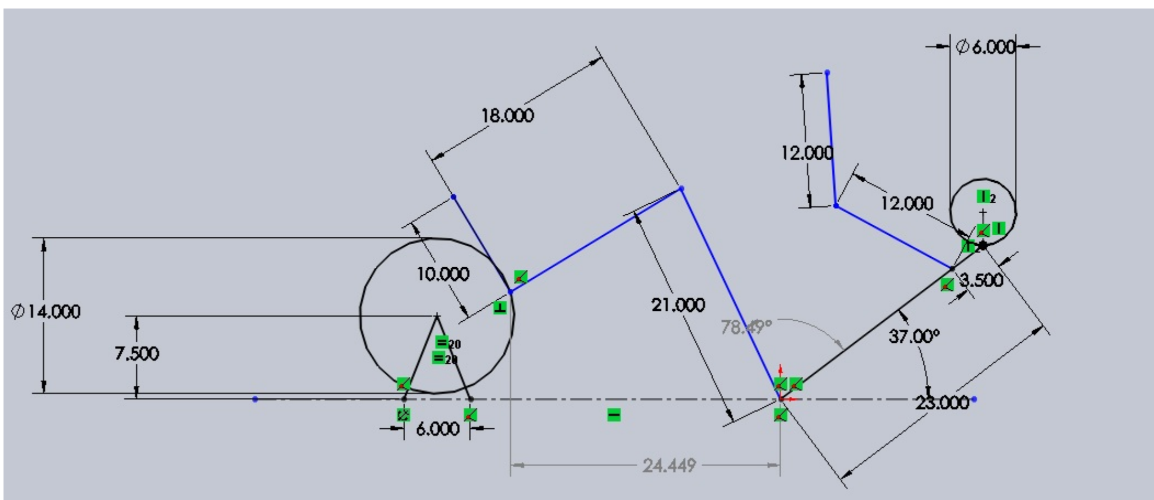


Figure 7. Recumbent Rider Position

2.2. Concepts

Several weeks were spent generating vehicle concepts to help our team decide on a final layout for the 2011 HPV. Three main designs were generated from original concepts that were deemed most advantageous to the competition at hand. Those three designs were then analyzed and further evolved into the final vehicle design that we are now fabricating.

2.2.1. Concept #1: Titanium Honeycomb Frame

Titanium honeycomb was selected as a concept material for several reasons. Titanium honeycomb is remarkably lightweight and incredibly rigid. The stiffness of a titanium honeycomb panel combined with its low density makes it a perfect candidate for a frame material. The weight of a tandem frame and roll cage made of titanium honeycomb could be as low as five pounds and would deflect minimally with the weight of two riders (~320 pounds). Since the honeycomb comes in standard sheets and the inner core is laser welded at every seam, it can be easily cut to the required shape with minimal reduction in structural strength. One cautionary note is the sharpness of cut edges when working with this material. Extra care is advised when handling the fabricated pieces and measures should be taken to reduce the risk for injury.

In industry, titanium and aluminum honeycomb panels are used to manufacture lightweight craft that will be subjected to considerable strain/stress. The aerospace industry uses honeycomb as a primary construction material in aircraft structural framing and wing support. Honeycomb has also been used in Formula One cars to re-enforce the vehicle and create nose cones because of the material's superior damping and impact properties. By using such materials in a frame, road vibration and noise are also reduced.

Our team has determined this particular design to be the most unique of the three concepts considered, and thus would like to use this design to fabricate the actual 2011 NAU HPVC vehicle. Aluminum honeycomb was also under consideration as a backup, should titanium honeycomb be unavailable for donation or too expensive to purchase. The vehicle will include a recumbent back-to-back rider setup with the rear wheel between the aft riders legs. A concept drawing of the honeycomb frame design is shown in Figure 8.

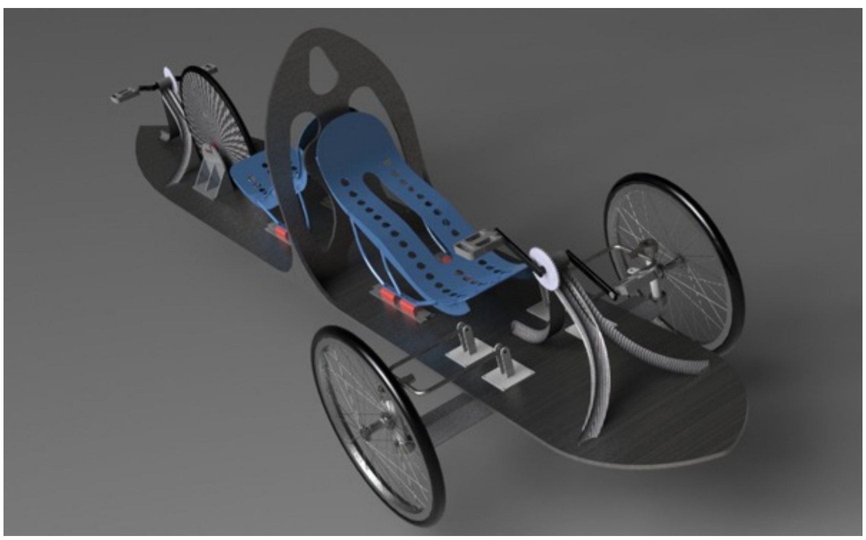


Figure 8. Titanium Honeycomb Frame, Concept #1

2.2.2. Concept #2: Carbon Composite Frame

Carbon composite has been selected as the possible second frame material concept for its strength, weight, and durability. Carbon fibers can be molded into nearly any shape or form and would allow our team to create a uniquely shaped vehicle frame.

In industry, carbon composite is used to manufacture lightweight body panels in automotive and structural aerospace applications. It is also used in many high end consumer products, such as fishing rods, sports equipment, and bicycle frames and components.

We have selected the carbon composite frame as a second choice because, as mentioned previously, composites are difficult to work with, messy, and the epoxy resin needed for bonding is a cumulative toxin when inhaled. The process needed to create a quality mold is very time consuming, and laying-up the carbon composite on the mold requires skill and knowledge of the material. We also do not have an autoclave at our disposal at NAU, so we would need to sub-contract the curing operation to a local contractor. Due to the limited time that we have to fabricate a vehicle, this option is not time efficient, but would still produce a unique vehicle frame. This vehicle design will preferably include lean steering and a recumbent back-to-back rider setup. A concept drawing of the carbon composite frame design is shown in Figure 9.

Figure 9. Carbon Composite Frame, Concept #2

2.2.3. Concept #3: Chromoly Truss Frame (2010 Mystax Cetus Modification)

The SAE 4130 chromoly truss frame concept is the third frame option chosen by our team. A similar frame design was used on the 2010 Human Powered Vehicle, the Mystax Cetus. The frame is made from thin-wall chromoly tubing welded into a truss design. Since chromoly is relatively easy to weld, this frame is very versatile when mounting components and is easy to modify. The current 2010 vehicle would be shortened, a roll bar removed, lean steer linkage added, and the rear seat flipped and repositioned to fit a second rider in the back-to-back setup.

This concept is the third option and will only be used if there is insufficient funding to fabricate Concepts #1 or #2. While the truss frame design is unique, it is the heaviest of the three concepts we have considered, weighing roughly sixteen pounds in its current condition on the 2010 vehicle. A concept drawing of the modified truss frame design is shown in Figure 10.

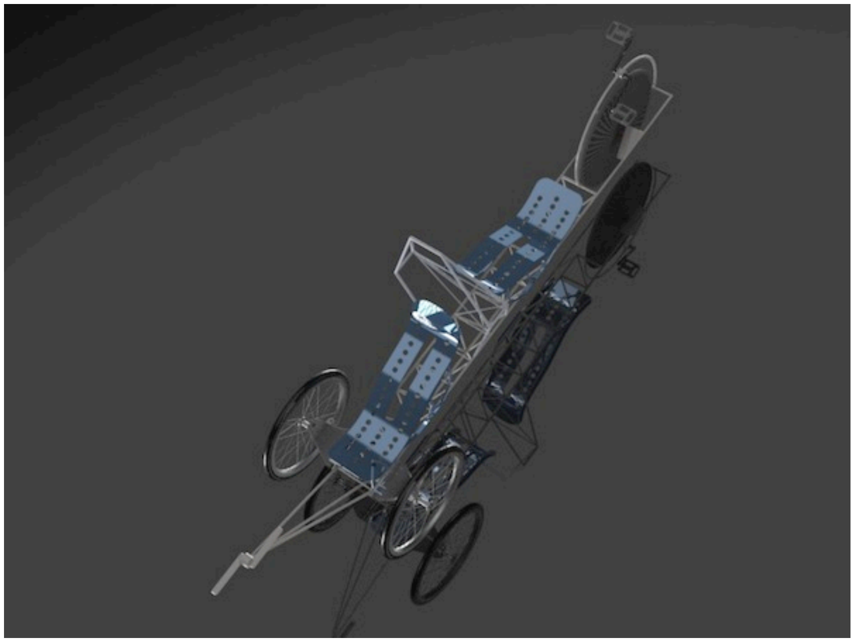


Figure 10. Chromoly Truss Frame, Concept #3

2.3. Final Design

Our team chose to work with vehicle Concept #1 with the intent of using a titanium honeycomb panel for the frame. Due to unforeseen issues when obtaining materials, we had to make some necessary changes to the concept in order to accommodate alternate materials and designs. The following are descriptions of each major component of the vehicle and how the original design plans have evolved into the final vehicle design that is currently in fabrication.

2.3.1. Frame

After learning that titanium honeycomb would not be readily available to us, the decision was made to seek alternative materials for the honeycomb vehicle frame base. A honeycomb panel comprised of a Nomex™ core and graphite epoxy laminate will be bonded to an aluminum honeycomb panel and cut into an aerodynamic shape. All components of the vehicle will bolt or bond to the honeycomb, which will serve as the structural frame. The roll bar will also be made out of the same honeycomb materials and mounted to the frame with a series of fillet supports to keep it from breaking away during the load tests.

The advantage to using a honeycomb sheet as a frame material over other materials is that it provides a flat, rigid surface that can easily be drilled or epoxied for the purpose of mounting vehicle hardware. It is easy to cut and shape, which allows us the opportunity to produce a matching fairing, which will effectively seal the vehicle and reduce aerodynamic drag.

2.3.2. Drive System

Original designs for the vehicle included a system of drive belts specifically created for use in bicycles. The system had great potential as a unique drive system that would reduce component weight and standard maintenance required by standard chain driven bikes. Market research and technical data were gathered and a layout was created for fabrication consideration. Design analysis and vehicle revision reports will highlight these systems for use in future NAU vehicles.

After the initial design process for the vehicle's drive system, we were approached with a unique proposition from David Calley; a local engineer and business owner. We were commissioned to implement a linear drive system incorporating flat steel belts, sprag clutch bearings, and an infinite variability shifting system to the vehicle. David Calley provided funding for the drive components and technical advice in order to create a working prototype of the idea.

Because this type of linear drive had not been applied in human powered transportation before, producing components for a working prototype became a design-heavy task. Force inputs, material strength calculations, sizing concerns, shifting controls, component dynamics and rider efficiencies were all taken into consideration through the various iterations of the drive system design. Once authorization was given to employ the system, the design was re-modified in order to comply with all original vehicle specifications requested by our client.

2.3.2.1. Drive System Research and Development

Brainstorming sessions for the linear drive system produced dozens of arrangements and component models that would meet client needs and competition requirements. All of these concepts followed common criteria. Belts made from 0.5" wide blued spring steel, lever arms instead of rotational cranks, sprag clutch bearings on a transaxle, and independent rider shifting were deemed as crucial system components.

Early idea development favored a structure where straight, narrow levers were used to pull the belts over an idler pulley housed in a vertical fixture. Movement of the idler pulley impacted the effective belt pull per lever stroke to create a continuously variable shifting ratio. Rough prototypes were created from scrap materials in order to test the feasibility of vertical movement in the shifting idler. These tests exposed significant efficiency and weight problems indicating a need for major revision.

Figure 11. Drive System Prototype #1

Figure 12. Drive System Prototype #2

It became apparent that tall, vertical shifting components would need to be eliminated in order to reduce moment forces acting on the frame composites. New shifter housing designs were created and modified slider shapes were analyzed for efficiencies. It was eventually determined that the slider system could be arranged horizontally with simple modifications to the lever arms.

Figure 13. Slider Concept #1

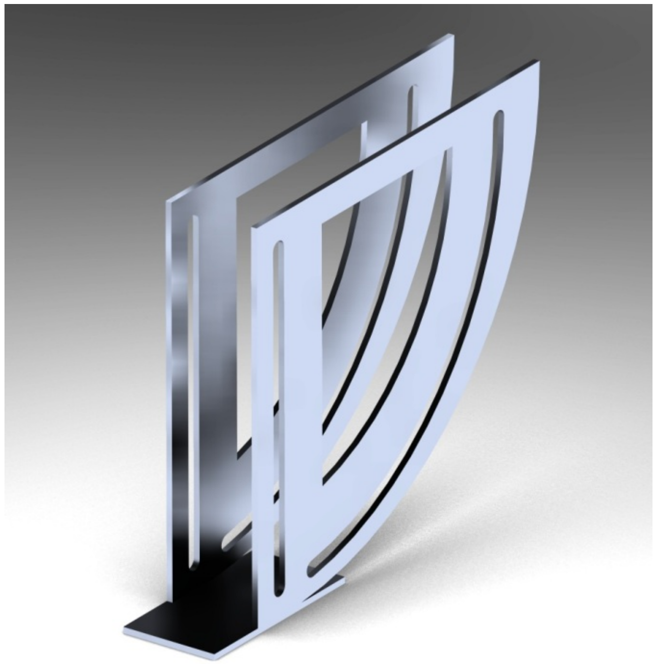


Figure 14. Slider Concept #2

2.3.2.2. Drive System Final Design

A design freeze was imposed on shifting mechanisms when a horizontal linear slider that met project criteria was found. The new system uses an extension on the lever arm to create efficient geometries while allowing shifting components to lay parallel to the frame. This reduced overall weight and many of the large moment forces acting on the honeycomb inserts. Forces on shifting linkages and belt idlers were also re-distributed parallel to the frame making overall stability much greater.

Figure 15. Slider and Modified Lever Layout

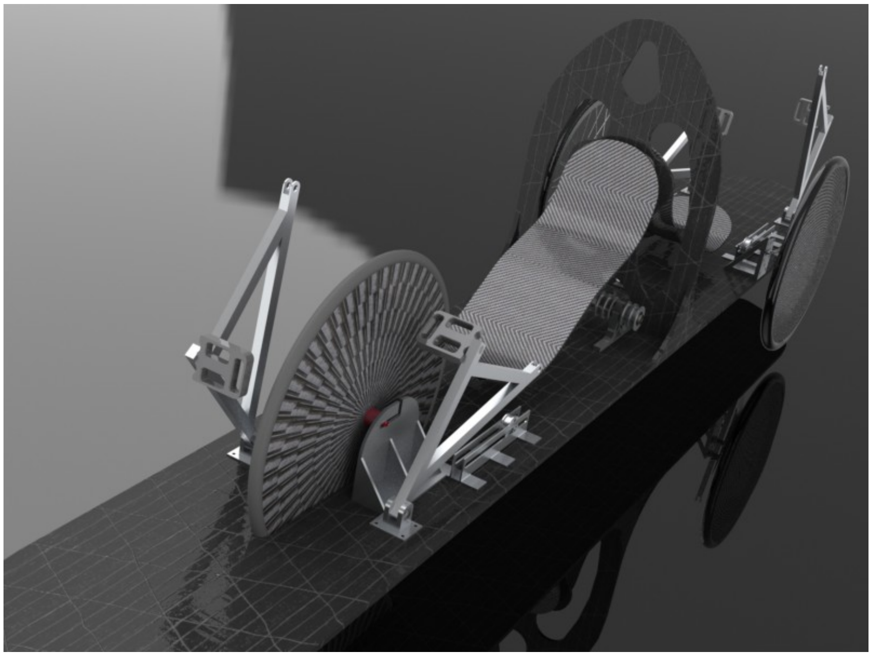


Figure 16. Lever Mounted on the Vehicle

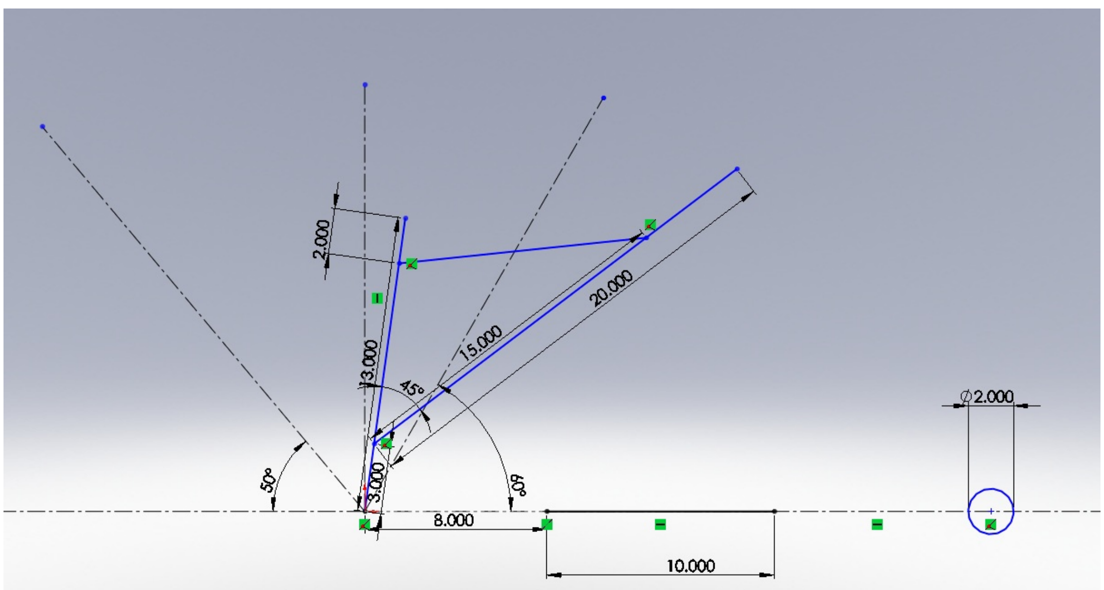


Figure 17. Lever Geometries Used in Design Analysis

2.3.3. Fairing

The aerodynamic drag of any vehicle is the main constraint of a faster top speed. At high speeds, aerodynamic drag dwarfs all other inefficiencies of the vehicle. A full fairing on the vehicle is very important in order to minimize the overall drag force. Significant differences in pressure along the shell of the vehicle constitute a break in the streamline of air causing vortices and turbulence. A smooth change in vehicle geometry is needed in order to reduce large pressure differences on the outside of the fairing. A forced induction of slight turbulence at the back of the vehicle is helpful because it increases the normal forces in the air. This air sticks to the vehicle and helps reduce the low pressure eddies that form at the rear of the vehicle.

The fairing on our vehicle consists of a carbon fiber nose and tail section connected by stretched fabric over the main part of the frame. The rigid carbon fiber structures are shaped evenly and have a smooth elongated look. A teardrop shape would have been optimal for drag reduction, but time was a constraint and it was much easier to construct a single mold to create both the front and back cones. The shape of the vehicle has a high aspect ratio, which helps it slice through the air. Stretched fabric is used for the mid-section to reduce time in fabrication and weight of the vehicle while maintaining the same aerodynamic properties. Pressure spikes will occur at the changing geometry of the nose and tail section and should remain relatively similar throughout the mid-section so distortion of the fabric should be minimal.

The carbon fiber sections were created with the help of an external vendor, Quintus Inc. Since our team did not have any prior experience working with high-end composites, Quintus provided technical expertise and advice on the fabrication process. The initial design was created in SolidWorks and optimized through multiple iterations. The final design was separated into 1-inch slices and traced onto 1-inch sheets of blue polystyrene foam. The foam was then cut, shaped, and sanded into a smooth surface with the proper geometry. Fiberglass epoxy was laid over the foam plug to provide a rigid surface for the application of vehicle repair Bondo. This was then sanded and layered multiple times to create a near perfect surface. A female mold was then created out of fiberglass epoxy using the smoothed male surface and later used to make the final carbon fiber fairing using a vacuum bag process.

The fairing has two NACA air ducts in the high-pressure frontal area and low-pressure back end to increase air ventilation inside the fairing. NACA inlets have a geometry that will not significantly impede the aerodynamics of the vehicle. These inlets are being used to combat rider overheating. The human body has an optimal temperature range and if overheated, it will limit the energy used by the muscles and drastically decrease output power. The air ducts have directional vents inside the fairing to direct air over the rider's core to increase evaporative cooling and keep the rider cool. Additionally, a white color was chosen for the fairing's stretch fabric to reduce irradiative heating by the sun and surroundings.

3. Analysis

Computer generated models of major structural components were created and tested using SolidWorks 3D CAD software. The integrated COSMOS software was used to generate finite element analysis for vehicle components with crucial structural properties. Verification of designs were performed using maximum estimated loads and a minimum safety factor of 1.5. Component deflection, Von-Mises, stress analysis, and overall factor of safety tests were ran on all final parts that will be under direct rider input stresses or function under rider weight loading. A 200-pound rider weight was used to estimate loading parameters yielding a 600-pound test weight under a two rider analysis with an applied safety factor of 1.5. Force outputs generated by the riders are estimated to a maximum of 600 lbf over both feet. Analysis of drive system components are tested under half of that force assuming 300 lbf per leg. Again, safety factors are checked to comply with the chosen 1.5 FOS standard.

3.1. Wheel Supports

Wheel supports were originally designed using a 6061 aluminum plate but were later changed to steel. The material was changed after reviewing 2010 competition failures due in aluminum bending and fatigue. Wheel support is essential in the safety and well being of the riders and higher factors of safety were chosen over weight concerns for these components.

3.1.1. Rear Dropouts

The rear wheel supports were analyzed with a centered hub at full 600-lbf rider weight loading. Torsion tests (not shown) were run by applying 200lbf at each edge of the modeled hub to create a 400-lbf moment. Safety factors over the entire structure were at or above 9.68.

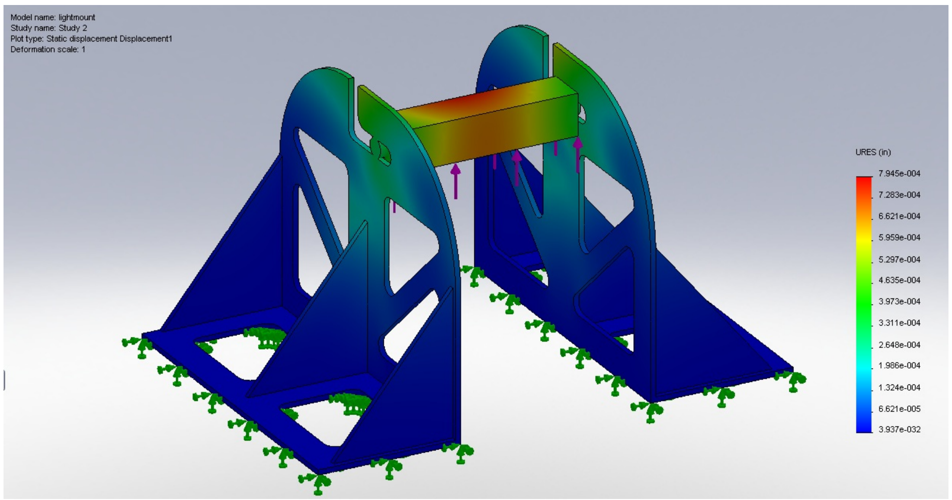


Figure 18. Rear Dropout Deflection Analysis

Deflection results indicate a maximum deflection of .00079 inches at 600-lbf loading. This is well within acceptable tolerances.

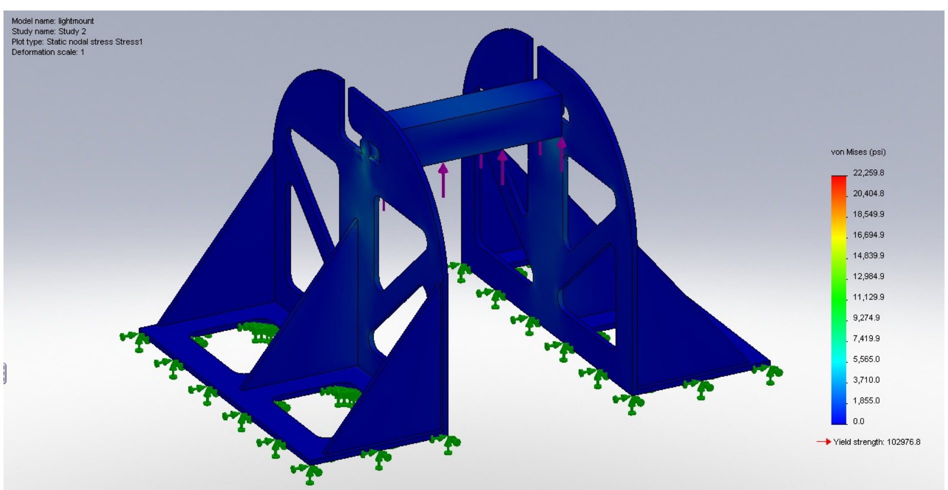


Figure 19. Rear Dropout Von-Mises Plot

The Von-Mises plot shows larger stresses over the hub attachment points, but reasonable levels.

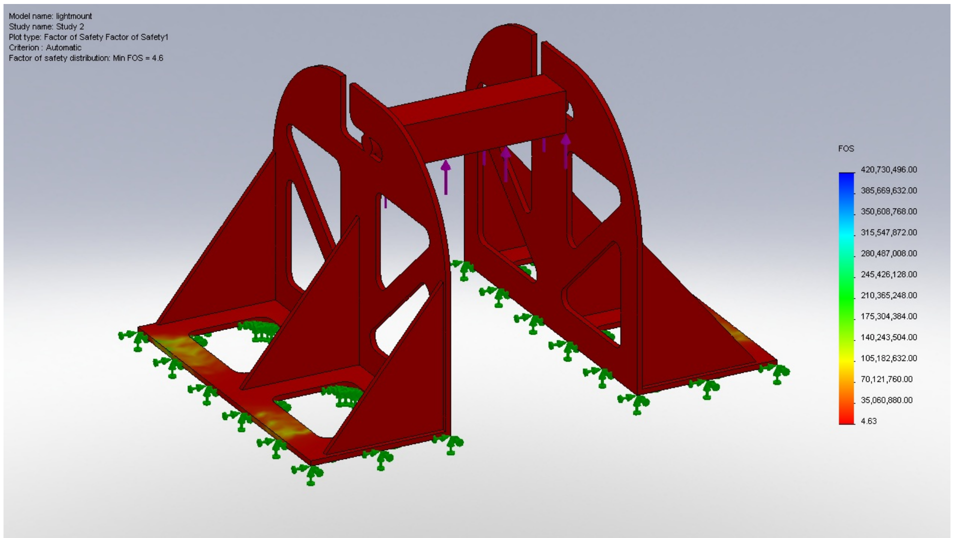


Figure 20. Rear Dropout FOS Diagram

The FOS diagram suggests a 4.63 minimal factor of safety. This is more than needed for our frame design and may be re-designed with speed-holes drilled for weight savings. An extra inch of material may also be added in order to raise the wheel and lower the vehicles ground clearance. This modification would lower the safety factor but would be checked to ensure full safety compliance.

3.1.2. Front Wheel Mounts

Front wheel mount analysis was done assuming a 600-lb load spread over the two front wheels. This becomes a 300-lb force exerted directly upwards on the bottom of the headset bearing. In this model, the bearing is excluded and force is applied directly onto the bottom edge of the steer tube. By omitting the bearing, a more comprehensive test with a larger safety factor will be seen as a result. It should be noted that the force exerted is in an upward direction normal to the ground. This is important to the structure as a 9.5° negative camber and 11° caster are incorporated in the king pin steer tube and create rotational forces.

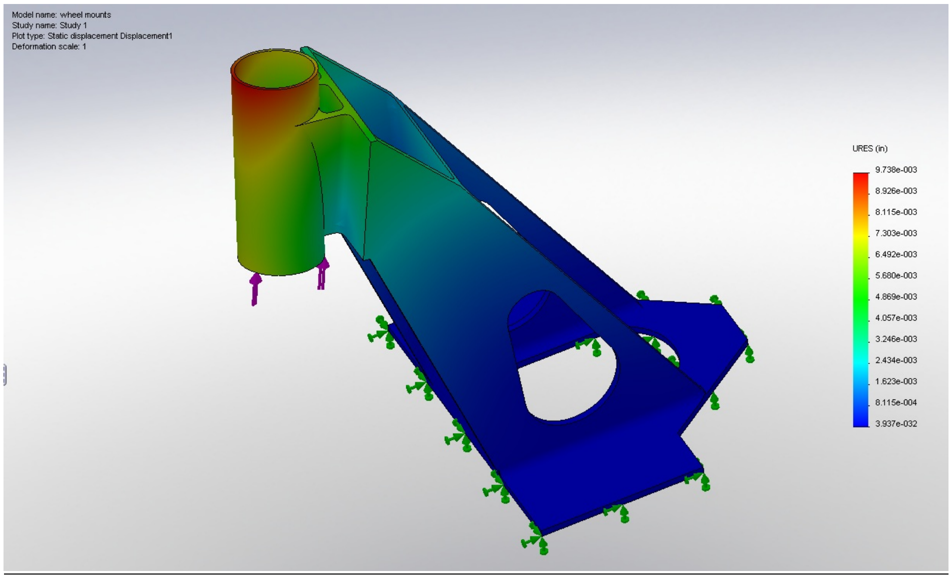


Figure 21. Kingpin Steer Tube Deflection Analysis

A maximum deflection is seen at the top of the king pin steer tube of .009 inches. This is more than expected but it is an incomplete model. Steering linkage, a press fit headset, and a rotational moment caused by the wheel will all slightly change the displacement diagram. Should the actual measured deflection be greater than the FEA model, a small amount of steel will be welded to the tube in order to combat deflection.

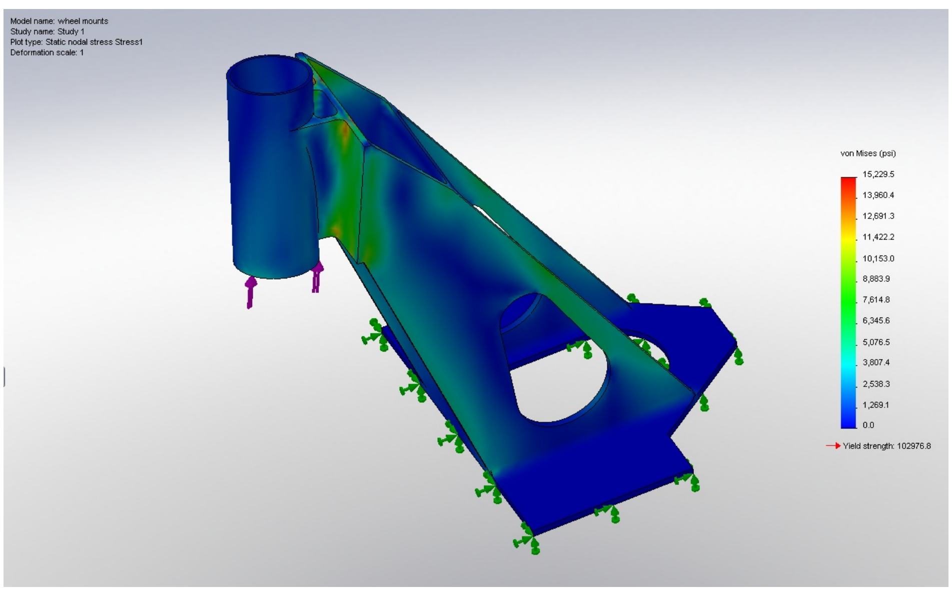


Figure 22. Kingpin Steer Tube Von-Mises Plot

The Von-Mises Diagram for the front mounts shows stress concentrations at welded joints and at the members connecting the tube to the tower frame. These stresses are well below the material yield strength and should not cause concern.

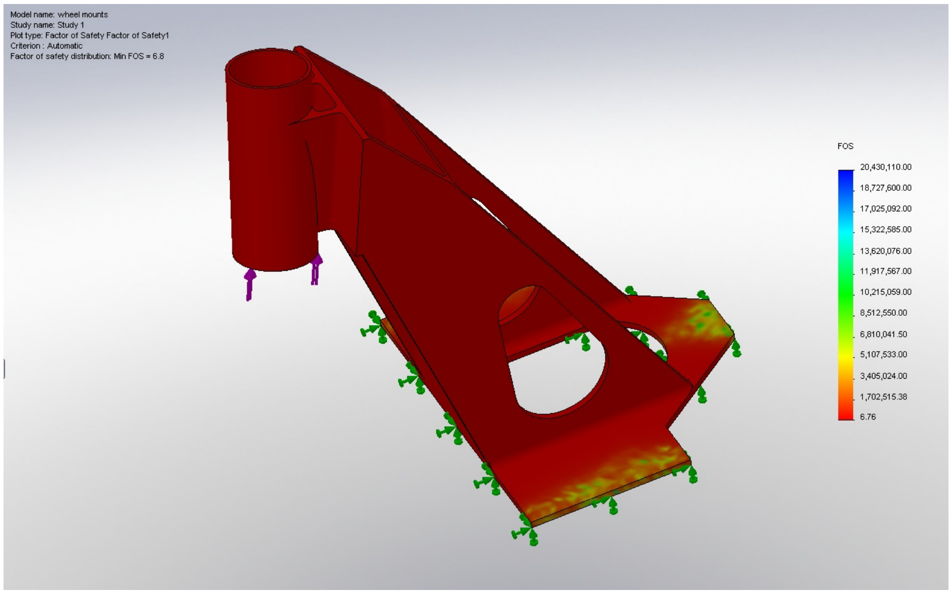


Figure 23. Kingpin Steer Tube FOS Diagram

All members of the front wheel mounts comply with a 6.76 factor of safety or better. It can be deduced that this part will remain structurally sound during race events in actual loading.

3.2. Shifter Mechanism

The shifting mechanism is fixed to the frame and undergoes considerable forces due to belt tension. A worst-case scenario of a dead center, 300-lbf loading on the idler is used to verify structural integrity of the slider mechanism.

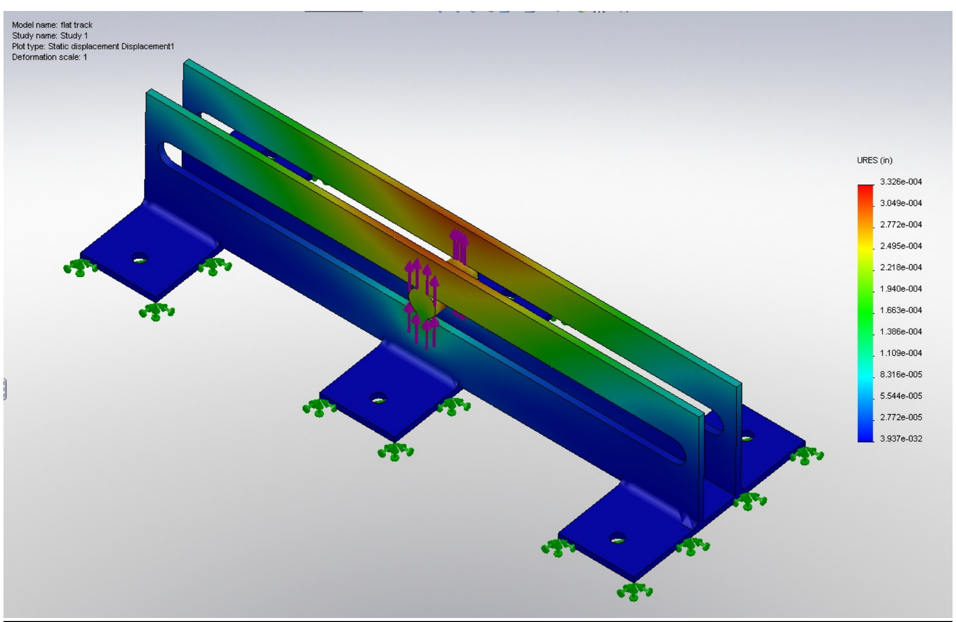


Figure 24. Shifter Mechanism Deflection Analysis

Deflection modeling shows a maximum deflection of .0003 inches under a 300-lbf load.

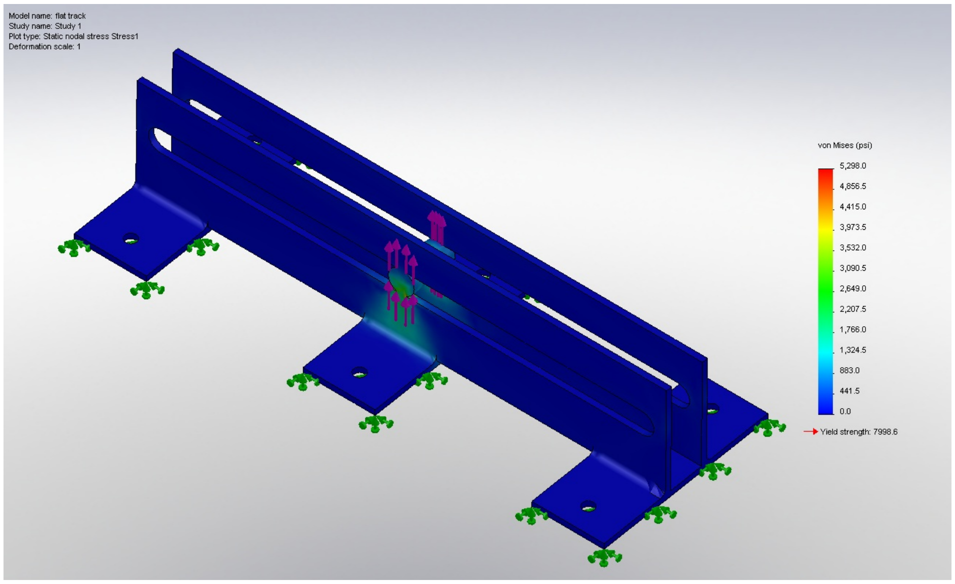


Figure 25. Shifter Mechanism Von-Mises Plot

Von-Mises stress analysis shows maximum stresses are well under the yield strength of the aluminum.

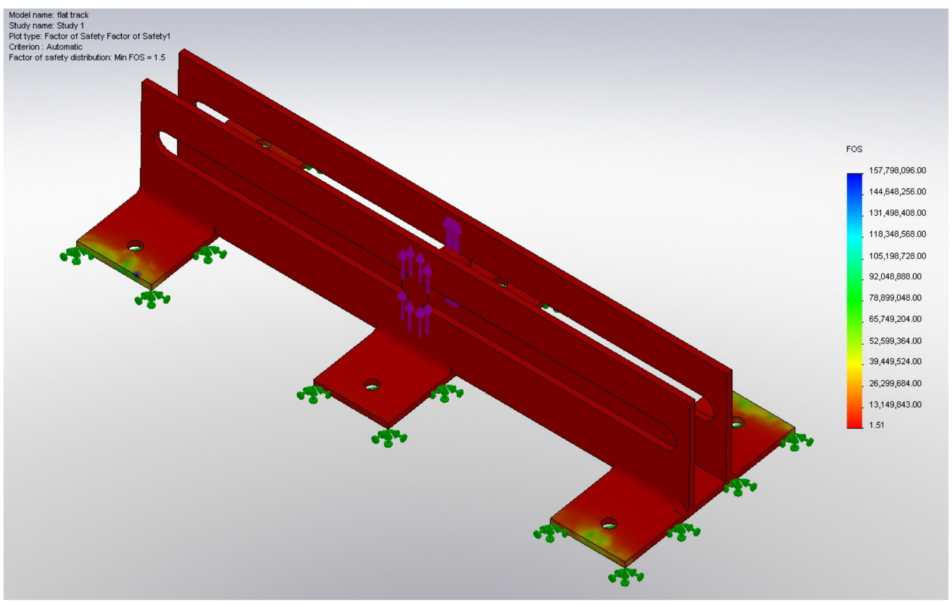


Figure 26. Shifter Mechanism FOS Diagram

The factor of safety plot shows that all component bodies adhere to a safety factor of 1.51 or greater.

3.3. Frame

The frame analysis performed in a CAD environment failed to produce realistic results when compared to actual material testing. This is largely due to a lack of specific material data for honeycomb panels. While some material properties are available from manufacturers, the custom nature of the panels makes exact properties difficult to find. Multiple composites were analyzed and an entirely different composite was shipped. Frame deflection and strength testing were done in an actual test environment by weighting the panels while they were simply supported on six-foot point centers. Deflection was minimal and the panels were deemed worthy of use in the competition vehicle.

3.4. Cost Analysis

Frame material Materials, shipping	$3000
Fairing material Cloth, epoxy, foam, tools, shipping	$2500
Components Seats, wheels, steering, drive train	$3100
Total	$8600

Table 1. Bike Materials

Labor workers (6)	10/hr	$14,400
Machine Shop Workers (2)	18/hr	$8640
Engineers (3)	30/hr	$28,800
Total	800	$51,840

Table 2. Labor and Design

	1	**2**	**3**	**4**
Materials	$8600	$8600	$8600	$8600
Manufacturing	$51840	$37440	$32000	$32000
Tools	$3000	$1000	$1000	$1000
Building Space	$5000	$5000	$5000	$5000
Misc.	$1000	$1000	$1000	$1000
Total	$69,440	$53040	47600	47600

Table 3. Yearly Costs

4. Testing

We are using two types of honeycomb panel for the vehicle frame. One is a graphite epoxy panel with Nomex™ honeycomb core, and the second is an aluminum honeycomb panel with aluminum core. To test the strengths of these panels under various loads, we are using an Instron testing machine to place the panels in compression and tension. In order to get accurate readings from these tests, we are using five 1-foot length pieces of each honeycomb structure. Results from the Instron testing machine will help us determine how to best assemble our frame with these two honeycomb panels in order to provide the most support for our riders and vehicle components while reducing weight. These tests will also help us determine the safety of our roll cage, which will also be constructed from the same honeycomb panels. Additional tests to the roll cage will include applying a 600-pound load at a 12° angle to ensure that our vehicle complies with ASME HPVC safety requirements.

In addition to materials testing, we will also field test our HPV prior to competition for rider safety and to address any changes that should be made before the vehicle is deemed competition ready. Since we will have a minimum of twelve students riding our bike at competition, we want to be sure that the vehicle is as safe as possible, both on and off the track.

5. Safety

Our team took safety into account with every decision. For vehicle design, we chose to use the tadpole tricycle design over a two wheeled or delta trike design because of its higher safety rating and increased handling characteristics. Prior competitions have shown a tendency for two wheeled single rider recumbent vehicles to crash or skid often, and we believed this would be even more of an issue with a tandem vehicle. Previous NAU HPV teams have had success using a trike design to increase vehicle stability while eliminating the requirement for both the front and rear rider to be in perfect balance. Our research on the benefits of a tadpole versus a delta trike design also showed greater braking performance due to the fact that the front wheels provide the majority of the braking force. Further findings have shown that placing two wheels in the front provides greater stability in turns.

Another important safety aspect of the vehicle that has been taken is to ensure that the roll cage has been designed to exceed the 2011 HPVC rules for vehicle and rider safety. The roll cage has been fabricated out of the same honeycomb material used for the frame of the vehicle, and is supported with fillets that bond the frame and roll cage together with a high strength industrial epoxy mixture. The fillets used to strengthen the roll cage also serve as a measure of protection because they create a buffer zone between ground and rider in a side skid scenario.

A rear wheel guard will be installed to protect the rear rider from rubbing against the drive wheel. The drive system being integrated into the bike has never been used for, and therefore carries some risk. We performed analysis and testing on this system to insure rider safety and will be implementing a belt guard system to protect our riders in the event of a belt snapping. We will also have a cell phone with one of the riders at all times should they need assistance during competition. Resting team members will be placed throughout the course to inform the riders of any hazards that may come up.

Previous craft have not incorporated breathable seats and riders have complained about comfort. To improve previous seating issues, we ordered carbon fiber seats from Poland with custom matching seat covers from the Netherlands that are highly breathable and very comfortable. The improved breathability of the seats help keep riders cool while the improved comfort reduces the back pain induced by previous craft's seats. The seat angle was also taken into consideration to keep the riders heart above their legs. The seats, along with angle measurement can be seen in Figure 27. Despite this optimal position, the riders will still be outputting a large amount of heat. The team is investigating additional rider cooling methods, including an on board hydration system and a reflective coating on the belly of the vehicle to reduce irradiative heating from the hot competition tarmac.


Figure 27: Seat Angle Testing

6. Aesthetics

In keeping with the previous year's whale theme, we have chosen to name the 2011 vehicle the Orka, which is due in part to the size and shape that our NAU human powered vehicles usually take on. The black coloring of the carbon fiber nose and tail cone of the vehicle in combination with the white stretched fabric of the fairing gives us the edgy black and white killer whale look, while also protecting our riders and keeping them cool. The carbon fiber nose and tail cones are rigid enough to keep the aerodynamic shape of the front and rear of the vehicle fairing, while also protecting our riders and pedal system from the elements. The white stretch fabric will also serve the purpose of deflecting heat and sunlight, which will help keep our riders cool, comfortable, and operating at their maximum efficiencies.

The frame of the vehicle is constructed from sheets of honeycomb panel, both aluminum and carbon graphite with Nomex™ , which gives our vehicle a very unique look and feel. The honeycomb is the backbone of the vehicle structure, but also provides a futuristic look and feel that is sure to turn heads.

Our final, and perhaps most innovative concepts on this year's tricycle, is our drive system. Not only is it functional and efficient, but it is unique is appearance. Rather than using traditional bicycle crank sets, we have a set of pedal levers for each driver that connect back to a central drive shaft with blued spring steel belts connected to sprag bearings. This drive system, in conjunction with our other vehicle aesthetics, guarantees a unique, visually pleasing vehicle on both the inside and outside.

7. Bibliography

"20092010 CSUN HPV Final Design Report." Web. 25 Oct. 2010. <http://www.ecs.csun.edu/hpv/20092010_CSUN_HPV_Final_Design_Report.pdf>.

Alysion.org Home Page. Web. 26 Oct. 2010. <http://www.alysion.org/ebiketours/etrek.html>.

Autonomic Materials. Web. 26 Oct. 2010. <http://autonomicmaterials.com/>.

"Bicycles and Aerodynamics." Sheldon Brown-Bicycle Technical Information. Web. 23 Oct. 2010. <http://www.sheldonbrown.com/rinard/aero/aerodynamics.htm>.

Capelli, Carlo. "Energy Cost and Mechanical Efficiency of Riding a Human-powered Recumbent Bicycle." Web. 15 Oct. 2010. <http://www.ncbi.nlm.nih.gov/pubmed/18803095>.

Chris King Precision Components. Web. 22 Oct. 2010. <http://chrisking.com>.

Coxworth, Ben. "Auto Designers Compete to Create 1,000-pound Car." Gizmag New and Emerging Technology News. Web. 8 Oct. 2010. <http://www.gizmag.com/la-auto-show-design-challenge-2010/16697/>.

DaVinci Designs - Performance Handbuilt Tandem Bicycles with Independent Coasting Drivetrain. Web. 22 Oct. 2010. <http://www.davincitandems.com>.

DragonPlate Carbon Fiber Composite Components - Carbon Fiber Sheet, Carbon Fiber Sheets, Nomex, Square Tubes & Splices, Carbon Fiber Panel, Carbon Fiber Tube & Rod. Web. 24 Oct. 2010. <http://dragonplate.com/>.

"Engineered Honeycomb Structures of Titanium, Aluminum, Stainless Steel, and Nickel for Commercial and Aerospace." Benecor, Inc.- Honeycomb Core Using Titanium, Nickel, Aluminum, & Stainless Steel. Web. 25 Oct. 2010. <http://www.benecorinc.com/materials.php#titanium>.

Fastest Provider of CNC Machined and Injection Molded Parts - Proto Labs. Web. 26 Oct. 2010. <http://www.protolabs.com/>.

Gross, A. C., D. J. Malewicki, and C. R. Kyle. The Aerodynamics of Human-powered Land Vehicles. 1983. Print.

Hanlon, Mike. "The TWEEL - Radical New Wheel Technology (UPDATED)." Gizmag New and Emerging Technology News. Web. 8 Oct. 2010. <http://www.gizmag.com/go/3603/>.

Honeycomb Panels for Void Fill in Packaging and Cargo Securement Shipping. Environmentally Safe Shipping and Packaging Products. Web. 24 Oct. 2010. <http://www.kraftcomb.com/index.htm>.

"How Does Chainless Technology Work?" Chainless Technology : Commuter Bicycle : Dynamic Bicycles. Web. 21 Oct. 2010. <http://www.dynamicbicycles.com/chainless/>.

"HP Velotechnik." Liegerad / HP Velotechnik Liegeräder, Dreirad Und Recumbent Infos – Willkommen / Welcome. Web. 12 Oct. 2010. <http://www.hpvelotechnik.com/index_e.html>.

"Huff12.pdf." OzHPV Home Page. Web. 25 Oct. 2010. <http://www.ozhpv.org.au/huff/docs/>.

"Index of /engineering/documents/senior Projects_fall_2008." University of San Diego. Web. 26 Oct. 2010. <http://www.sandiego.edu/engineering/documents/senior projects_fall_2008/>.

"Modeling and Analysis of Dynamic Behavior of Tilting Vehicle." SAE Technical Papers. Web. 28 Oct. 2010. <http://papers.sae.org/2007-01-2869>.

Mountain Bike Components, Pedals, Wheels, Stems, Tools :: Crankbrothers.com. Web. 22 Oct. 2010. <http://www.crankbrothers.com>.

Mountain Bike Product Reviews Forums Classifieds Trails. Web. 27 Oct. 2010. <http://www.mtbr.com>.

The Official Campagnolo Web Site - Bicycle Parts and Components Cycling. Web. 22 Oct. 2010. <http://www.campagnolo.com>.

Price Point - Discounts on Mountain Bike and Road Bike Parts, Accessories and Cycling Clothing. Web. 27 Oct. 2010. <http://www.pricepoint.com>.

Quick, Darren. "Student-built E-Quickie Electric Vehicle Draws Energy Wirelessly from the Road."

Gizmag-New and Emerging Technology News. Web. 8 Oct. 2010. <http://www.gizmag.com/e-quickie-electric-vehicle-with-wireless-energy-transmission/16346/>.

The Recumbent & HPV Information Center. Web. 11 Oct. 2010. <http://www.recumbents.com>.

"Recumbent Bicycle." Wikipedia, the Free Encyclopedia. Web. 23 Oct. 2010. <http://en.wikipedia.org/wiki/Recumbent_bicycle>.

Ridden, Paul. "Going Chainless with the Stringbike." Gizmag New and Emerging Technology News. Web. 8 Oct. 2010. <http://www.gizmag.com/stringbike-symmetric-alternating-bicycle-drive-system/16483/>.

"Rose-Hulman Human Powered Vehicle Team." Rose-Hulman Institute of Technology. Web. 12 Oct. 2010. <http://www.rose-hulman.edu/hpv/>.

"Schlumpf Advanced Belt Drive System." EcoVelo. Web. 15 Oct. 2010. <http://www.ecovelo.info/2010/09/07/schlumpf-advanced-belt-drive-system/>.

Shimano Cycling. Web. 22 Oct. 2010. <http://bike.shimano.com>.

Sorrel, Charlie. "Modular Cogs Bring Belt-Drives to Any Bike." Wired.com. Web. 14 Oct. 2010. <http://www.wired.com/gadgetlab/2010/09/modular-cogs-bring-belt-drives-to-any-bike/>.

Spinergy. Web. 27 Oct. 2010. <http://www.spinergy.com>.

SRAM. Web. 22 Oct. 2010. <http://www.sram.com>.

"Stability Analysis of a Three-Wheeled Motorcycle." SAE Technical Papers. Web. 28 Oct. 2010. <http://papers.sae.org/2008-32-0062>.

Stig, Leirdal. "Freely Chosen Pedal Rate during Free Cycling on a Roller and Ergometer Cycling." Web. 15 Oct. 2010. <http://www.ncbi.nlm.nih.gov/pubmed/19466445>.

"Three Wheeled Vehicle Dynamics." SAE Technical Papers. Web. 28 Oct. 2010. <http://papers.sae.org/820139>.

"Three Wheeler - Citizendia." Citizendia Encyclopedia - Citizendia. Web. 26 Oct. 2010. <http://www.citizendia.org/Three_wheeler>.

"Three-Wheel Passenger Vehicle Stability and Handling." SAE Technical Papers. Web. 28 Oct. 2010. <http://papers.sae.org/820140>.

"Trek Bikes | Bikes | Urban | District." TrekBikes.com. Web. 22 Oct. 2010. <http://www.trekbikes.com/us/en/bikes/urban/district/district/>.

Welcome to Adventures of Greg. Web. 10 Oct. 2010. <http://www.adventuresofgreg.com/>.

Welcome to the Pantour Suspension Hub. Web. 24 Oct. 2010. <http://www.pantourhub.com/>.

"Wiki: Bicycle Performance." Wapedia. Web. 27 Oct. 2010. <http://wapedia.mobi/en/Bicycle_performance>.

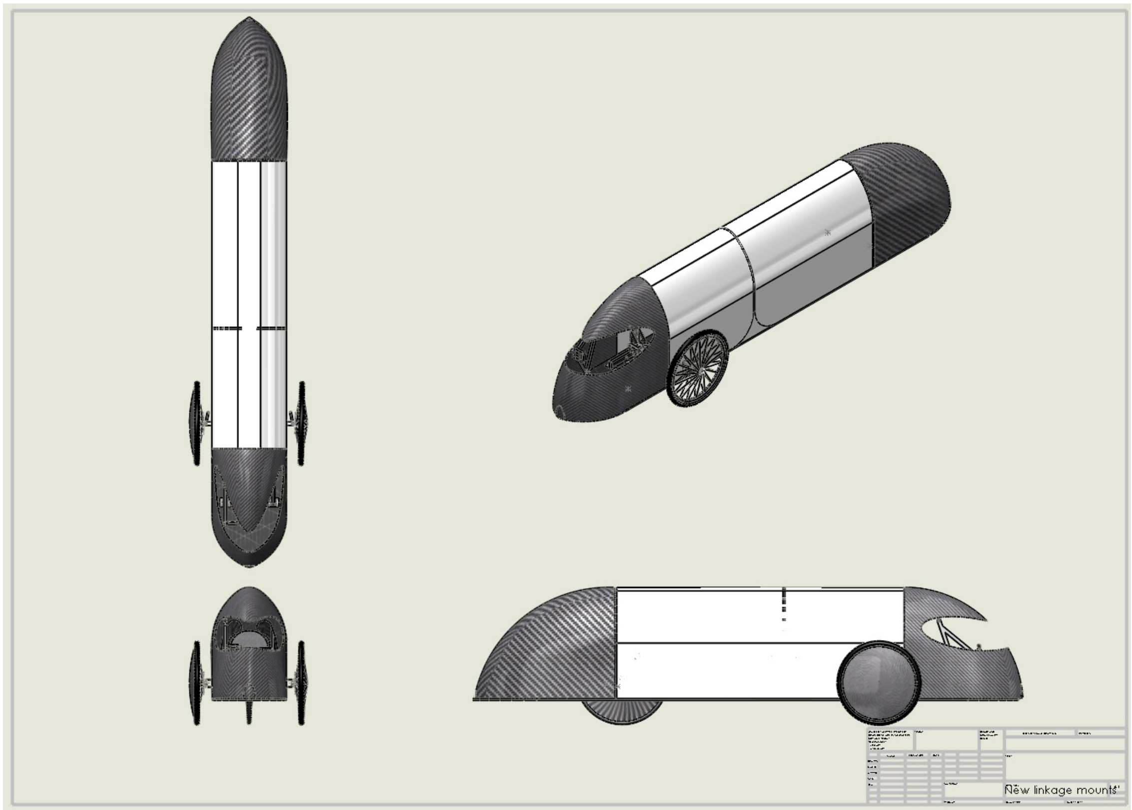
"Wiki: Recumbent Bicycle." Wapedia. Web. 27 Oct. 2010. <http://wapedia.mobi/en/Recumbent_bicycle>.

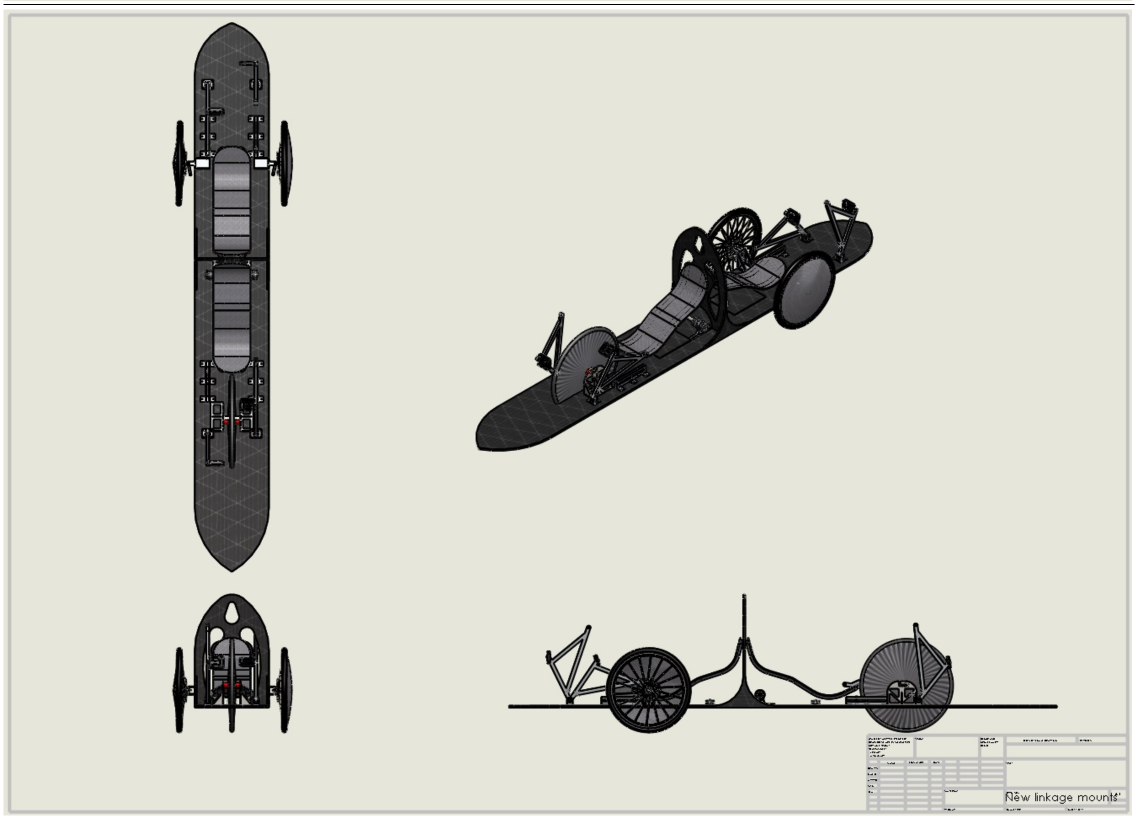
Williams, Christopher D., and Danny Too. Biomechanics of Human Movement and Sport. Dubuque, IA: Kendall/Hunt, 2005. Print.

Wilson, David Gordon, Jim Papadopoulos, and Frank Rowland. Whitt. Bicycling Science. Cambridge, MA: MIT, 2004. Print.

The Worlds Most Advanced Human Powered Boat. Web. 9 Oct. 2010. <http://www.pedaltheocean.com/>.

Appendix A: Three View Drawing





Vehicle Description Form

(HPVC Form 6)

Human Powered Vehicle Challenge 2011

East Event Host: Rose-Hulman Institute of Technology, Indianapolis, IN. Apr 29-May 1, 2011

West Event Host: Montana State University, Bozeman, MT. May 13-15

http://www.asme.org/hpv

*** *This is a required document for all teams. Please incorporate it into your Design Report* ***

EAST		WEST
March 28, 2011	***Please Observe Your Due Dates***	April 11, 2011

Vehicle Description

Competition Location: Indianapolis Motor Speedway, Indianapolis, Indiana

School name: Northern Arizona University

Vehicle name: The Orka

Vehicle number: 31

Vehicle type: Unrestricted ______ Speed X

Vehicle configuration

Upright ______ Semi-recumbent X

Prone ______ Other (specify) ______

Frame material: 1" aluminum honeycomb & 0.4" carbon laminate honeycomb with Nomex™ core

Fairing material(s): Carbon composite and stretch fabric

Number of wheels: 3

Vehicle Dimensions *(please use inches, pounds)*

Length 168" Width 20"

Height 44" Wheelbase 72"

Weight Distribution Front 50 lbs Rear 30 lbs Total 80 lbs

Wheel Size Front 20" Rear 24"

Frontal area 532 in^2

Steering Front X Rear ______

Braking Front X Rear ______ Both ______

Estimated Cd 0.66

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

This vehicle is an all-new design that has never been used by Northern Arizona University before in competition or otherwise. The vehicle fabrication is taking place during the spring 2011 school semester, and will be ready for competition at the 2011 ASME HPVC East at the end of April.