

California State Polytechnic University, Pomona

2015 ASME HPVC Challenge

**The Cal Poly Pomona Human Powered Vehicle Team
Presents**

The Spirit of Randy

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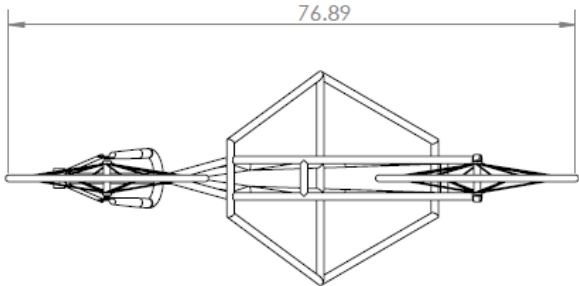
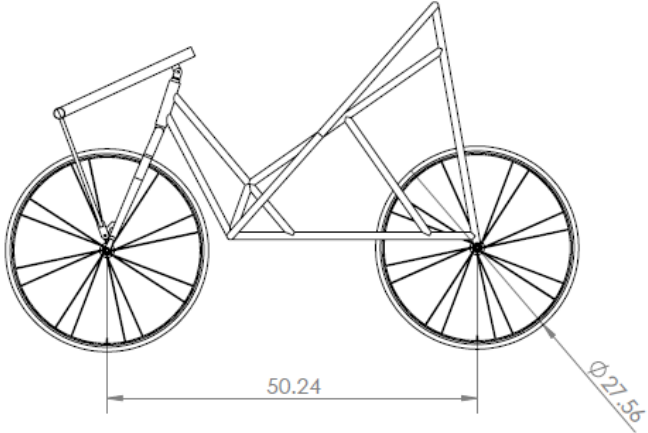
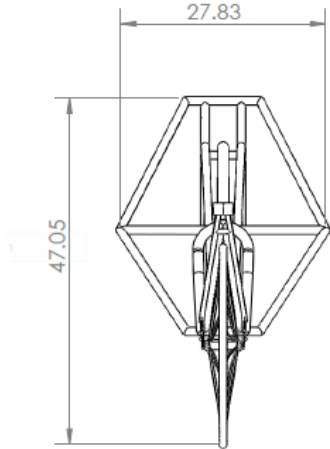
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Spirit of Randy; 3-View Drawing



Abstract

Although it is true that Cal Poly Pomona has competed in Human Powered Vehicle Competitions in the past, there has never been an ongoing organization set up at the university to facilitate annual competition. During the 2014-2015 academic year, the current HPV team at Cal Poly Pomona made it their primary goal to establish an organization made specifically to deal with engineering human powered vehicles.

From initial conception to product completion of this year's vehicle, CPP HPV has built a team that has chartered an organization, acquired sponsors and shop space, dealt with insurance and risk management issues, and then designed and fabricated a competition vehicle.

Our vehicle, the Spirit of Randy, is an un-faired front wheel drive recumbent that is designed to be a practical and efficient vehicle for both competitive and everyday use.

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1. Design

1.1. Background

Mission Statement:

The CPP Human Powered Vehicle Team strives to create an environment that allows its members to gain valuable experience in engineering design, project management, industry relations, manufacturing, business, and performance testing.

1.2. Objectives

Long Term Objective:

To design, fabricate, and compete with human powered vehicles collegiately on an annual basis.

2014-2015 Season Objective:

To set up the foundation of an organization with the purpose of annually competing in human powered vehicle competitions by officially chartering, creating a diverse team of engineering students, and building lasting relationships with the Cal Poly Pomona Department of Mechanical Engineering and businesses that see the importance of investing in the education of tomorrow's engineers.

Gantt Chart

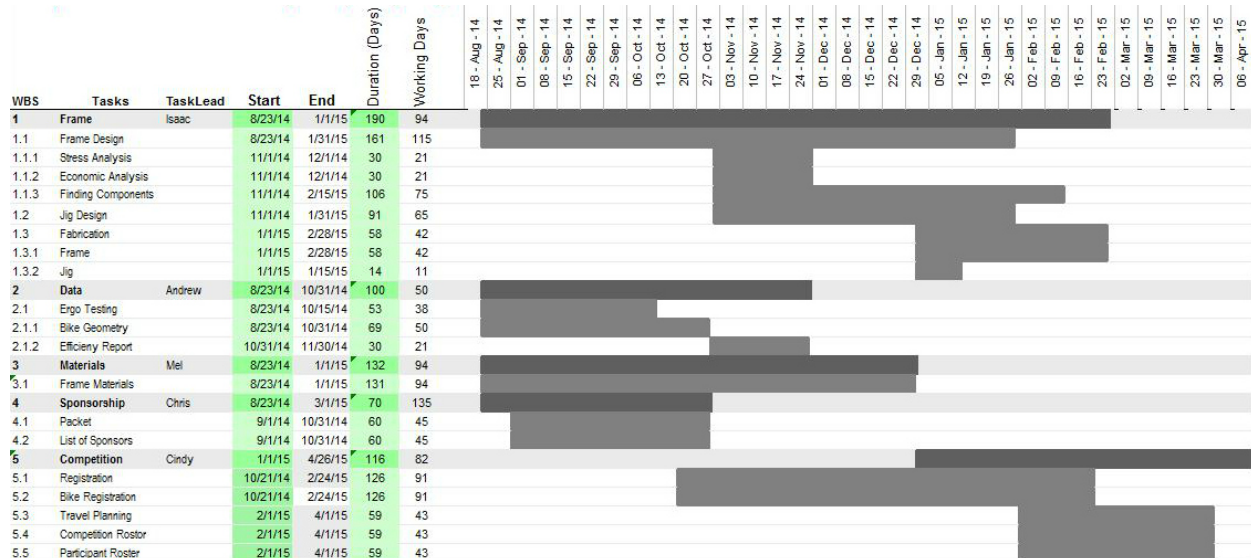


Figure 1: 2015 Gantt Chart

1.3. Prior Work

Because this is the first year that Cal Poly Pomona has competed as an organization, there is no prior work to draw from.

1.4. Design Specifications

The goals of our design this year were to build a vehicle conducive to the specifications outlined in the 2015 HPVC rules. these are:

- 15 ft minimum vehicle turning radius
- Vehicle braking from 15 to 0 mph in less than 20 ft
- Vehicle cargo area large enough to accommodate parcels of dimension 15x13x8 inches
- Rider safety harness
- Roll protection system that can support a 600 lbf toplod with deflection of less than 2 inches
- Roll protection system that can support a 300 lbf side load with elastic deflection of less than 1.5 inches

1.5. Concept Development and Evaluation of Alternatives

In the decision making process for what concept to base our vehicle off of, our team came to five main possibilities: a bicycle with either front or rear wheel drive, a tadpole style tricycle with rear wheel steering, or a delta style tricycle with either the front wheel driven or the back wheels driven. As a first year team considering the lack of experience of its members, it was decided to seek out a design that was feasible for the teams skill level. The team implemented a decision matrix to come to this result (Figure 2).

The front wheel drive bicycle was chosen as the concept to model mainly due to its having the most similarities to a standard bicycle in terms of mechanics. Our team viewed its concept as a standard bicycle that was essentially cut in half and reversed so that the rear drive mechanism could be placed in the front of the bike, while the undriven front wheel was moved to the rear. A second main concern was building a two wheeled vehicle that could not be ridden. Consulting an article featured in the book *Bicycle Science* called *The Stability of the Bicycle*, it was concluded that not only would the design be a reasonably familiar concept to the team, but also, from the article on stability, that while it is possible to construct bicycles that are more difficult to ride than others, building a bicycle that is unrideable is very difficult, even for someone with that as their design intent.

				Tricycle		
		Bicycle		Delta		Tadpole
		Rear Wheel Drive	Front Wheel Drive	Rear Wheel Drive	Front Wheel Drive	Rear Wheel Drive
Time Allotment	Category					
	Design	3	1	2	3	4
Fabrication	2	2	3	3	3	
Design/ Fabrication	Stability	3	3	2	2	2
	Drivetrain	3	1	3	4	4
	Ergonomics	2	2	3	3	3
	Frame	2	2	3	3	4
	Steering	3	4	2	4	3
Total		18	15	18	22	23

Figure 2: Decision Matrix

1.6. Innovation

Although the Spirit of Randy was designed primarily as a competition vehicle, recreational use was considered in the ergonomic setup. Often with racing bicycles, designers sacrifice rider comfort for efficiency. What makes our design innovative is its capacity to accommodate both race and recreation situations. The seat position of the vehicle was decided not only by evaluating efficiency parameters such as speed and visibility, but also taking into account ergonomics and ability to be used by different riders. The steering system of the vehicle allows for unique steering maneuvers such as steering with your feet or pulling on the handlebars in a rowing motion to add power to the pedal stroke. Our goal in design was to create a vehicle that could be used to compete in racing, but was also able to provide a comfortable and enjoyable riding experience for recreational users of various ages.

1.7. Final Design

Our final design is an unfaired front wheel drive recumbent bicycle with a moving bottom bracket (drivetrain turns with handlebars). As mentioned before, the drivetrain setup is essentially that of a conventional bicycle, but with modified orientation and cable routing. The roll protection system completely surrounds our tallest rider to prevent injury in the case of a crash.

1.7.1 Ergonomics

Because the rider of the vehicle is such an important component in human powered applications, it is necessary to incorporate ergonomics analysis into the design in order to create a system that optimizes the power output of the rider while simultaneously offering a comfortable riding experience.

In order to accomplish this task, an ergometer was constructed in order to test various rider speeds, positions, and experiences (Figure3). pictured below is the solid model of the ergometer and the actual ergometer. Initially, during the design of the ergometer 5 axis of freedom were deemed necessary to provide adequate adjustment for testing. Once built it became aware that a design change would need to be made. To allow for finer height adjustment a scissor lift was thought up and fabricated.

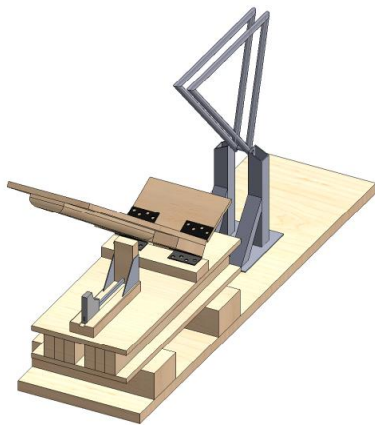


Figure 3 : Left: Solid model of ergometer, Right: Fabricated ergometer

Potential rider measurements were taken prior to designing the ergometer to get an idea of required dimensions for seat distance from pedals and handlebars from seat back (Figure 4). Shoulder width was also another important measurement not for the ergometer but for design of the rollover protection system.

	Height (in)	Weight (lb)	Inseam (in)	Arm Length (in)	Torso (in)	Shoulder Width (in)	Knee to Foot (in)
Male Rider 1	73.5	190	33.5	31	23.5	19	22
Male Rider 2	71	290	30	32	24	21	21
Male Rider 3	71.5	155	32	31	19.5	18	20
Male Rider 4	67	152	28.5	31	19	18.5	20
Male Rider 5	69	160	31	32	19	17	20.5
Male Rider 6	71	165	32	28.8	23.3	17.8	20.5
Female Rider 1	71.5	195	33	33	21.5	19	21
Female Rider 2	65	170	27	27	19	16	18
Female Rider 3	65	140	30	27	19	17	19
Female Rider 4	62	140	29	26	17	17	19.5

Figure 4 : Potential rider measurements

To test for rider comfort three different rider configurations were used. Riders road for one and five minutes in each position multiple times to test for comfort and speed. An average was made for each rider and then combined to get an overall average (Figure 5).

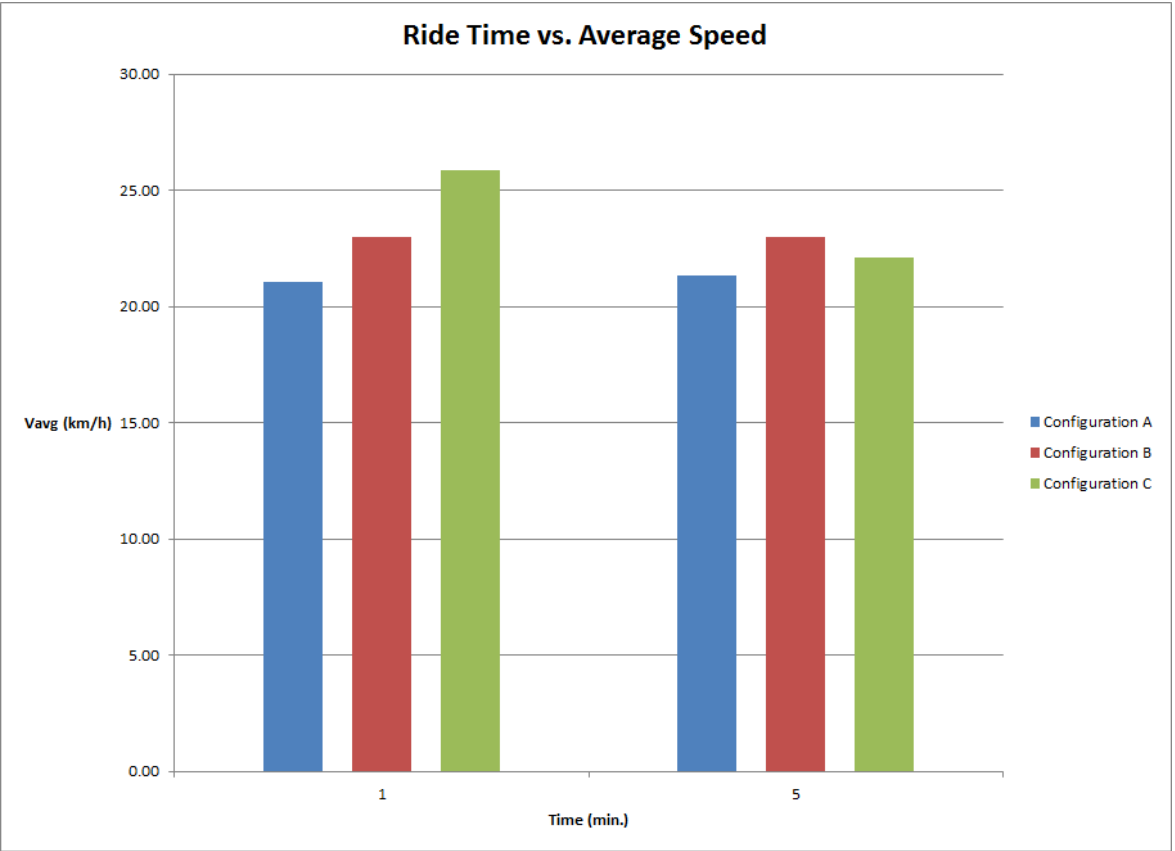


Figure 5: Ride Time vs. Average Speed

1.7.2. Frame

The frame was designed to incorporate two structures (a front portion and a rear portion) which pivot about a point just in front of the rider’s seat. As previously stated, this design was chosen for its feasibility.

During the design process, the commercially available Cruzbike Vendetta was used for inspiration (Figure 6). This recumbents design relies on turning the bike by leaning into the turns as opposed to turning the front wheel. This aspect is crucial since turning the front wheel sharply is difficult due to the riders legs operating in the plane of the front wheel. Riders operate the Vendetta in near-fully reclined position which maximizes their power output due to the fully extended pedalling motion. This rider configuration is well suited for fast rides with wide turns, but proves disadvantageous when maneuverability in tight spaces is desired. This issue was addressed in the Spirit of Randy’s design.



*Figure 6: Cruzbike Vendetta V20
(courtesy of cruzbike.com)*

The final design was very similar to the Vendetta in terms of operation, however our vehicle features a steeper 35 degree seat back to put the rider in a more upright position. This gives a shorter wheelbase for the vehicle, making its steering more responsive than the Vendetta by reducing the lag associated with the dragging of the rear wheel. While this reduces top speed, it makes the vehicle more roundly suitable for the events at competition which require tight turning and the ability to mount and dismount the vehicle quickly as well as recreational riding.

In designing the frame the main concerns were simplicity and strength. Since this is our first year designing a recumbent vehicle we wanted to be sure that what was designed was reasonable to fabricate and safe to use.

The front triangle pivots about a standard 1- $\frac{1}{8}$ " threadless, non tapered head tube. This is the common point between the front and rear of the frame. The front triangle of our vehicle can be thought of simply as the rear triangle of a conventional bike transposed about the seat stays (with the seat stays changed to a fork). To accommodate the cassette on our front wheel, the back-most side of our front triangle is a 135mm wide fat bike fork. The top side of the triangle (the steer tube) is a segment of 1.375 inch outer diameter, 0.028 inch thick, 4130 steel tubing which attaches to a pin connection at the top of the head tube. A front chainstay is constructed from 0.5 inch steel tubing. The bottom bracket occupies the front most corner of the triangle. The total calculated weight of the front frame was 9.14 lbs.



Figure 7: Front Triangle Assembly

The rear portion of the frame comprises the bulk of the vehicle's weight. It consists of roughly 43 feet of 1 inch outer diameter, 0.035 inch thick, 4130 steel tubing. Aside from the head tube and dropouts the entirety of the rear frame was made in house. Since the tubes were relatively thin walled the initial plans were to tig weld the frame which would have produce clean weld joints. In the end the frame was mig welded due to a lack of experience with tig welding. Care was taken to ensure the joints were solid while minimizing excessive creation of heat affected zones. The machined, 1018 steel dropouts were purchased from Paragon machine works and welded directly onto the ends of the two rear-most tubes. The total calculated weight of the rear frame is 15 lbs.

The seat was made out of 6061-T6 aluminum sheet of 0.10 inch thickness weighing in around 4 lbs when completed. When designing the seat the main concerns were slimplicity, weight, and strength. Initially a 12"x33" rectangle was cut from the aluminum sheet stock and bent to the desired angles. This seat proved to be uncomfortable and ultimately we decided to build a 3 piece, wooden seat consisting of a headrest, backrest, and seat bottom (as shown in figure 8).

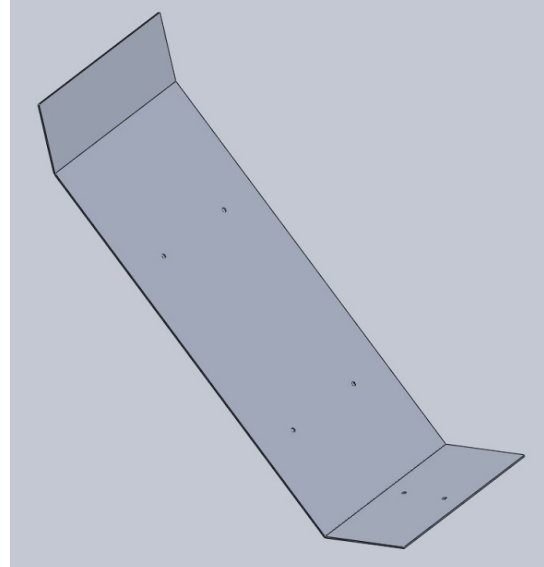


Figure 8: Left: Seat Dimensions, Right: Aluminum Seat

1.7.3. Drivetrain

The drivetrain of the Spirit of Randy utilized a traditional road bicycle setup, but in a modified orientation. because of the standard setup, it was unnecessary to custom design or fabricate parts. The components used (Listed in Appendix A), are all in a standard road bicycle configuration except for the cable routing throughout the vehicle. due to the change in frame geometry from a traditional road bicycle, the routing of the cables for braking and gear shifting had to be placed in a way that allowed full functionality while not inhibiting rider experience or performance. because the Spirit of Randy is a moving bottom bracket type vehicle, the possibility of a rider hitting a brake or shifting cable with their legs while riding can cause unwanted braking or shifting and therefore is a major concern when determining a proper cable routing scheme. The Spirit of Randy's cable routing is as minimalist as possible in order to avoid unwanted rider cable contact.

When choosing components for the Spirit of Randy's drivetrain, the following was considered.

FSA Gossamer cranksets offer good strength for a relatively low price. The chainrings are 50/34t, also known as a compact crankset. This allows a wider gear range needed to accelerate a heavy recumbent bicycle and still have high enough gears for higher speeds. Its 24mm axle fits the threaded bottom bracket that is specified. The Driven 11-28t cassette has durable steel cogs riveted to an aluminum spider to reduce rotating weight. This gear combination allows a wider gear range needed to accelerate a heavy recumbent bicycle and still have high enough gears for higher speeds. Connecting the two is a KMC X10.93 chain. It is 10 speed compatible, and shifts well due to the shaping and chamfers on each link. The crankset

spins on a standard BSA threaded bottom bracket because of the ease of maintenance and availability. It measures 68mm wide to fit standard road cranksets, and has a 1.370"-24 thread with the right side being left hand thread.

Shimano's Tiagra rear derailleur is 10 speed compatible and can shift up to a 30t cog on the cassette. The cage is also long enough to accept the wide tooth difference from the front chainrings. The Shimano 105 band clamp front derailleur because is easy to mount to a round tube and doesn't require any complex hardware. Shimano 105 components are cost effective and reliable. Shimano 105 brake and shifter hoods control the brakes and shifting. Although the left shifter is made for 11 speed drivetrains, it will work with 10 speed front derailleurs because the pull ratio is the same. They have indexing for easy and reliable gear changes, and also has trims for the front derailleur. Connecting the shifters to the derailleurs is shimano SP41 4mm shifter housing and cables. These are standard bike cables that are very smooth and dependable with little friction. The inner cables are stainless steel to prevent corrosion

Tektro dual pivot brakes were chosen because they offer more power than conventional single pivot brakes. The extra power will help decelerate the heavier recumbent bike in a controlled and acceptable manner. M-system 5mm brake housing connects the brakes to the hoods.

Since the Moonlander fat bike fork by Surly uses a 1 1/8" non-tapered steerer tube, a 1 1/8" headset must be used. The DK headset has sealed cartridge bearings making it easy to assemble and very reliable.

The first priority for the wheelset is strength. This bike will weigh more than typical bikes and will have to withstand uneven surfaces in the endurance competition. Typical strong wheelsets have 32 spokes with a three cross lacing. Mavic rims laced with straight gauge spokes in a three cross pattern offer tons of strength. Shimano hubs are very reliable and roll on rebuildable cup and cone bearings. Bontrager T1 25c tires have an all weather tread pattern and the slightly larger volume absorbs more road imperfections than skinnier tires.

Recumbent bikes don't need drop bars because there is no advantage in changing hand positions. Pursuit handlebars offer good ergonomics, accept road brake and shifter levers, and are available at bicycle retailers.

2. Analysis

2.1. Roll Protection System

The roll protection system was designed to protect the rider in the event of a crash, ensuring that the rider would not contact the ground if the vehicle were to completely roll-over. The design parameters were those stated in section 1.4 (Design Specifications) and are reproduced here.

- Roll protection system that can support a 600 lbf topload with deflection of less than 2 inches
- Roll protection system that can support a 300 lbf side load with elastic deflection of less than 1.5 inches

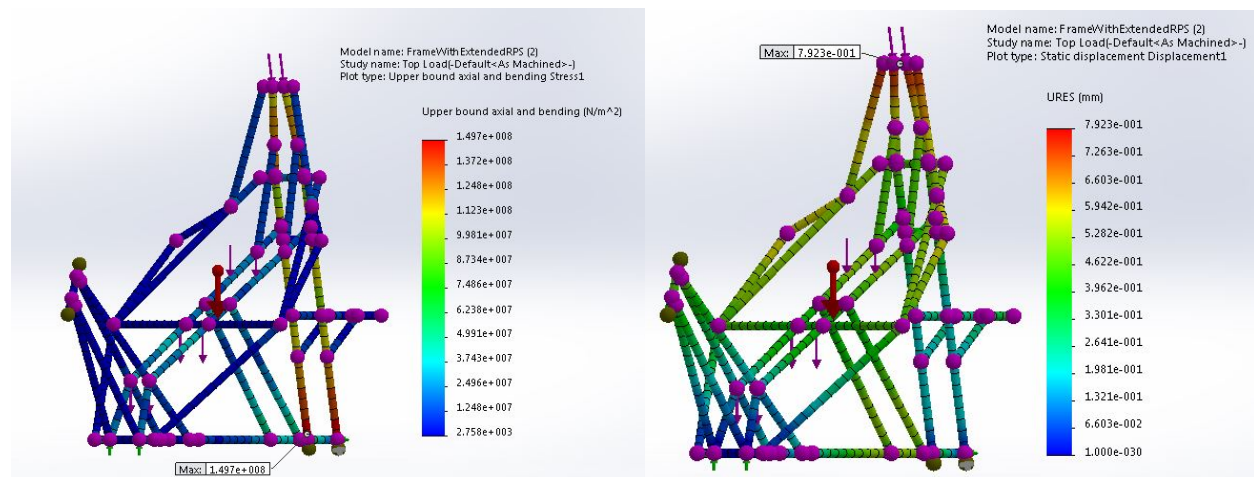


Figure 9: FEA of the frame with a static 1440 lbf load oriented at the top of the roll protection system oriented at a 12 degree angle. Stress is shown on the left and deflection is shown on the right.

Theoretical stress analysis was performed using SolidWorks Finite Element Analysis (FEA) tools. Solidworks allowed the team to quickly and easily analyze the frame under multiple production situations by applying custom weldment profiles that reflected commercially available tubing. The roll protection system joins to the frame in many locations and essentially is one with the frame. The selection of the fixed geometry to be used during the stress analysis was based on the ASME HPVC west challenge criteria as well as how the frame would be tested in real life. The rear drop-outs and the bottom of the front part of the RPS were constrained during the FEA analysis, as seen by the green arrows in figures 9 and 10. The material studied was AISI 4130 normalized which was the selected frame material. A design factor of 2.4 was applied and so a 1440 lbf (~6.4 kN) load was applied to the top of the roll protection system at an angle of 12 degrees with respect to the vertical. A 300 lbf load was also distributed across the

seat rails in order to simulate the pressure induced by the operator during operation. Under this static condition, with the effects of gravity considered, the maximum induced stress was found to be along the rear vertical rails concentrating at the drop-outs with a magnitude of approximately 150 MPa and the maximum deflection was found to be at the top of the roll protection system with a magnitude of approximately 0.79 mm (~ 0.031 inches) as seen in Figure 9.

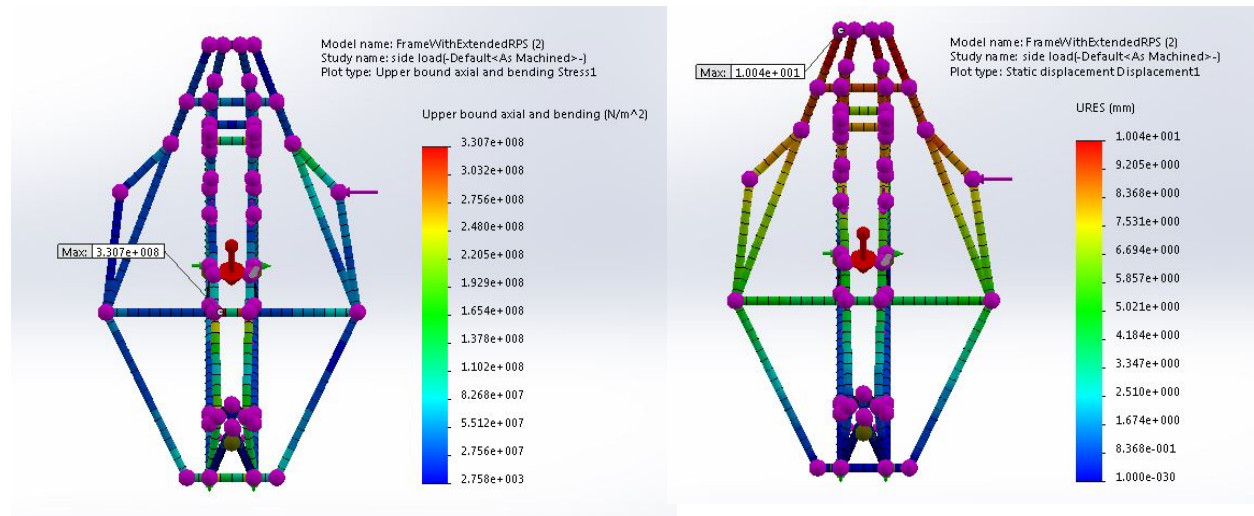


Figure 10: FEA of the frame with a static 600 lbf load oriented at the side of the roll protection system. Stress is shown on the right and deflection is shown on the left.

A 300 lbf (~1335N) side load was applied to the two member joint of the roll protection system, which is approximately shoulder high of the operator, as seen above in figure 10. Again taking into account the effects of the riders distributed load (300lbf) and the effects of gravity, the maximum induced stress was found in the midsection of the frame with a magnitude of approximately 330 MPa and the maximum deflection was found to be at the top of the roll protection system with a magnitude of approximately 10 mm (~0.39 inches) as seen in Figure 10.

According to MatWeb, the tensile yield strength of AISI 4130 is 435 Mpa in which case the stress produced from FEA is well within the safe range with a maximum theoretical factor of safety with respect to yielding of 1.32. Throughout the FEA analysis the Spirit of Randy never showed signs of plastic deformation and was determined to have a maximum factor of safety with respect to allowable elastic deflection of 3.75.

Initial simulations showed that 1in. x 0.028in. tubing, the thinnest gauge tubing available to the team, would satisfy the design criteria and keep the frame weight to a minimum. However, due to issues with material availability this tubing was not used in production and the team increased the wall thickness up to the next available size of 0.035in. The frame passed the initial design criteria and was cleared for fabrication

2.2. Material Selection

Material selection for the frame was based off the current popular bike frame materials such as alloy steel and aluminum. With a small budget in mind and a skillset as mentioned before, an affordable yet competitive material was sought after. The two materials selected for researched and comparison were 6061 aluminum due to its weight and 4130 steel due to its strength. Aluminum, which has a density approximately a third of that of the steel was initially chosen for its lighter characteristics. However, after conducting both cost and fabrication analysis, AISI 4130 was chosen for its known weldability and (how much less than aluminum?) reduced cost of nearly ___ that of aluminum.

4130 Steel, commonly referred to as Chromoly, is one of the lightest steels capable of supporting a considerable amount of weight and is commonly used to manufacture bike frames. It can also withstand a significant beating without damaging it's integrity. The pros for picking steel 4130 are its flexibility, durability, and cost efficiency.

4130 Steel has more give than aluminum and can handle stress up to 63,000 psi, which is higher than that of aluminum, which is 31,000 psi. In addition, steel 4130 is cheaper than aluminum. However, the primary con of 4130 steel is its weight. To combat this, thinner gauged tubing was used which cut down weight while still maintaining the integrity of the bike's structure.

2.3. Cost Analysis

The following cost analysis compares the cost of the Spirit of Randy as a prototype, the cost to produce ten vehicles in one month, and the production cost to produce ten per month for three years.

Category	Spirit of Randy as presented	Monthly Production Run (10 per month)	Three Year Production Run
Capital Investment	\$0.00	\$3,800.00	\$136,800.00
Tooling	\$35.00	\$35.00	\$1,260.00
Parts and Materials	\$1,662.64	\$14,153.83	\$509,537.88
Labor	\$0.00	\$2,000.00	\$72,000.00
Overhead	\$0.00	\$1,728.47	\$62,224.92

Total	\$1,697.64	\$21,717.30	\$781,822.80
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Figure 11: Cost Analysis Summary

The above cost summary includes only the costs associated with the construction of the vehicle, with expenses such as travel are not reflected in the analysis. For the Spirit of Randy as presented, costs including capital investment, labor and overhead are noted as \$0.00 due to the fact that no students were paid to work on the project and that the Cal Poly Pomona Department of engineering provided the project with rent free space to work in. For more detailed cost analysis refer to appendix A.

3. Safety

3.1. Design for Safety

The Spirit of Randy incorporates a roll protection system, 4-point harness, reflectors, Brakes, and a padded seat (for long rides).

3.2. Safety Harness

The Spec D Tuning JDM Style four point universal racing harness seat belt was selected as the vehicles primary and only safety harness. Weighing in around three and a half pounds this harness will minimize the overall weight of the vehicle. The Spec D Tuning harness features 2 in. nylon webbing straps with 80 inches of arm strap, a quick release buckle and extra wide pads located at the waist. The four point seat belt design applies pressure to the riders chest and waist securely harnessing them to the seat. When applied correctly the Spec D Tuning harness will keep the rider's torso secure and in place allowing their legs and arms to move freely. In the event that the rider should put the vehicle through a complete roll-over, the Spec D Tuning harness will keep the rider safely inside the vehicle. This component couples nicely with the Spirit of Randy's roll protection system. The 2 in. width of the strap allows more tension to be produced and adds to the durability of the strap increasing its lifetime. The quick release buckle makes entry and exit quick and simple for riders of various discipline and age. The extra wider pads increase rider comfort by distributing the pressure across a larger area of the riders body. These reasons make the selected harness a safe and long lasting component of the vehicle.

3.3. Safety Accessories

The Spirit of Randy is equipped with front lights, rear lights, and reflective stickers to

increase visibility during all hours of operation. The rider will not be encased in a vehicle shell and therefore standard hand turn signals are to be used in the event of traffic maneuvers.

3.4. Safety in Manufacturing

Safety was a top priority during the manufacturing process of the ergometer, the frame jig, the frame, and during vehicle assembly. The two shops used both required their own separate safety certifications that were completed by each individual team member. While working in the shop the team wore safety glasses, noted proper emergency procedures and filed the MSDS paperwork for all chemical products used. The members notching the frame tubes also used both ear muffs and ear plugs to prevent damage to their hearing.

4. Conclusions

4.1. Evaluations

In its first organized competition effort, the 2015 Cal Poly Pomona Human Powered Vehicle Team developed and constructed a vehicle that meets safety criteria and that offers a unique rider experience. The Spirit of Randy was designed to achieve the team's objective of competing in the HPVC, and while the vehicle's fabrication is not yet fully complete, the team is confident that there is adequate time to finish manufacturing, complete the frame and component testing and assemble the vehicle prior to the competition date.

4.2. Recommendations

While the Cal Poly Pomona Human Powered Vehicle Team will strive towards improvement in design and manufacture in the coming years, the focus of this year was kept simple to encourage feasibility in practice. While the practice of feasibility driven design kept our team from being overly ambitious, in future design competitions the establishment of HPV as an organization at Cal Poly Pomona will undoubtedly lead the team to pursue more complex designs due both to having a running start with shop space and sponsors, and to having a reasonably sized team at the beginning of the project.

The Cal Poly Pomona Human Powered Vehicle Team dedicated its effort for countless hours of time this year to accomplish its main goal of organizing a lasting program. Having a solid foundation is essential for any project that is reoccurring. After experiencing the lengthy, up and down process of chartering an organization this year, the team still recommends chartering as a means to not only obtain a fuller experience of what real world project development is like in terms of management, documentation, money handling and external

relations, but to also establish the opportunity for future engineering students to take advantage of what has been done and improve on it rather than starting from absolutely nothing every year and working hard to accomplish things that have little to do with design and fabrication.

4.3. Conclusion

At this point in the Spirit of Randy’s development, the team has been successful in achieving its main goal of building an organization, and is well on its way to competition. As the design process progresses, the team continues to learn new things in various areas such as design practice, manufacturing, business relations, and most importantly, slack and lead times. As the competition approaches team is confident it will perform well at its first competition.

5. References

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

"MatWeb - The Online Materials Information Resource." *MatWeb - The Online Materials Information Resource*. N.p., n.d. Web. 01 Apr. 2015.

Appendix A: Cost Analysis

The following is cost information for the production of one Spirit of Randy vehicle.

Capital Investment	
Tlg Welder	\$1,000.00
Tube Notcher	\$2,500.00
Cut-Off saw	\$200.00
Assorted Small Tools	\$100.00
total	\$3,800.00

tooling	
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angle grinder	\$15.00
hole saws	\$20.00
Total	\$35.00

Components per Vehicle	Quantity	Price
FSA Gossamer 50/34T	1	\$189.99
Shimano 105 St-5800 left shifter	1	\$119.99
Shimano 105 St-5700 right shifter	1	\$119.99
Shimano 105 FD-5700 front derailleur	1	\$29.99
Shimano Tiagra RD-4601 rear derailleur	1	\$50.00
Rotor ceramic bottom bracket	1	\$250.00
Tektro R539 caliper brakes	1	\$85.99
KMC X10-93 chain	1	\$39.99
Driven 28-11T cassette	1	\$79.99
Moonlander Fork	1	\$58.00
700c Mavic CP wheelset	1	\$160.00
Bontragger T1 700x25 tire	2	\$40.00
Origin8 Rim tape	1	\$4.00
Pursuit Handlebars	1	\$20.00
Giant Ultra Slick Road Brake cable kit	1	\$34.99
Shimano Road Shift Cable set	1	\$10.00
DK 1-1/8 in headset	1	\$29.99
Demolition Pedals	1	\$25.00
XLC 700x23/25 presta tubes	2	\$10.00
Total		\$1,357.91

Materials	
6061-T6 Aluminum sheet	\$60.20
4130 steel tubing (1/2x.035)	\$26.18
4130 steel tubing (1x.035)	\$143.69
4130 steel tubing (1-3/8x.035)	\$29.33
4130 steel sheet (.1 thick)	\$12.33
Wood for Ergometer/jig	\$3.00
Total	\$274.73

Labor	Per Month
Per Hour	\$25
Hours per week	40
Number of workers	2
total	\$2,000

Overhead		
Facility	Per Month	1000 Sq ft. area
	Rent	\$600.00
	Utilities	\$1,000.00
	Website Maintenance	\$25.00
	New Tools/Repair	\$50.00
Consumables	Per Month	
	Welding Filler Rod	\$20.00

	Hole Saws	\$23.47
	Spray Adhesive	\$10.00
	Total	\$1,728.47