

Spring 2018

Human Powered Vehicle Frame Design, Analysis, Manufacturing, and Testing

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**The University of Akron Human Powered Vehicle Team
2017-2018 ASME E-Fest East
Frame Design Report**

Vehicle Name: ZC18

Vehicle Number: 3



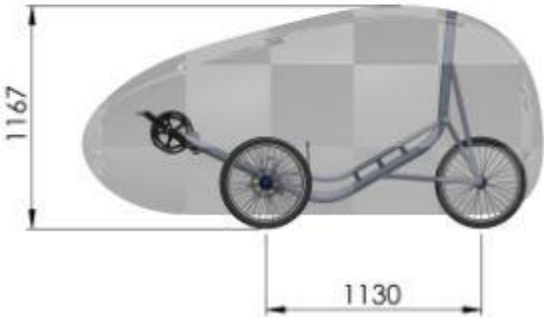
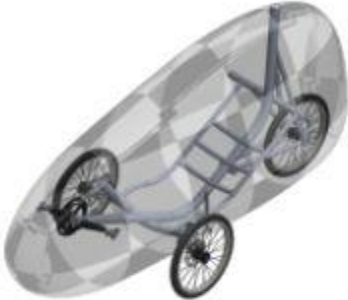
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Assembly Drawing:



ALL DIMENSIONS IN MILLIMETERS

Abstract:

The University of Akron Human Powered Vehicle Design Team began this academic year with a mission to create a practical, lightweight, safe, and efficient human powered vehicle. The main objectives of ZC18 were inspired by competition in the 2018 Human Powered Vehicle Challenge at ASME E-Fest East. In addition to adhering to the rules of this competition, scoring high on the submitted reports, and competing well in the racing events, the team set a goal to assist in furthering knowledge related to the topic of human powered vehicles.

ZC18 was constructed nearly completely in the University of Akron's Design Center with research, design, analysis, testing, and assembly done solely by undergraduate engineering students. These students volunteered approximately 50-60 total man hours per week during the 2017-2018 academic year, while utilizing the university's resources to manufacture a competitive vehicle for the 2018 season.

ZC18 is a recumbent tricycle consisting of a 6061-T6 aluminum alloy frame and a carbon fiber fairing. This vehicle is structurally sound and maintains a team required factor of safety of 2.0. ZC18 utilizes an indirect linkage style steering system, hydraulic brakes, a triangular shaped Rollover Protection System (RPS), a versatile drivetrain for both speed and endurance events, and a carbon fiber fairing that provides a drag reduction and protection from the elements. By encompassing a three-point harness, lights, a mirror, and a variety of other safety equipment, ZC18 is built not only for the Human Powered Vehicle Challenge, but also as a method of transportation for a daily commute.

Design:

Objective:

The University of Akron Human Powered Vehicle Team designed, analyzed, manufactured, and tested ZC18 with specific design goals of constructing a lightweight, safe, and efficient human powered vehicle. Throughout the construction of ZC18, there was a collaborative focus to teach all members aspects of engineering that are not always present in a classroom environment. Skills learned during this process include, but are not limited to: incorporating an engineering design process, applications of 3D modeling software, computational analysis methods, material selection, machining and fabrication techniques, composite layup, and final assembly methods. In addition to expanding personal growth, the University of Akron made an effort to assist in furthering the development of human powered vehicle transportation as a whole.

Background:

In the fall of 2016, the team traveled to the 2016 Cyclecon in Cincinnati, Ohio. While there, team members were able to test drive a variety of different styles of human powered vehicles. The main focus was on the recumbent trikes seeing that the majority of the industry uses a tadpole style design as opposed to a delta or other style trike designs. After this event, the team compared a number of different styles of trikes, and ultimately decided to continue with a tadpole trike design based on safety, familiarity, and industry trends of this style of human powered vehicle. While at Cyclecon, team members heard from current record holders on the keys to achieving high speeds. One common theme was keeping air flow around the vehicle laminar. When running CFD analyses for ZC18, the team made sure the models were exhibiting laminar turbulence so they would hold up at the speeds ZC18 was projected to achieve.

When looking at the record breaking recumbent bikes, the team noticed that many of the fastest bikes had an overall lightweight design, constructed with a carbon fiber frame and a fiberglass fairing [1]. Although a carbon fiber frame and fiberglass fairing would be a lightweight option, the team choose different materials for both the frame and fairing based on continued research. A fiberglass fairing would be light, but it would take several layers of fiberglass to achieve appropriate rigidity [2]. The carbon fiber fairing would be heavier, but it would also use fewer layers. A carbon fiber frame is much lighter than aluminum tubing, however a carbon fiber frame may limit the rider's range of motion, or make the seat uncomfortable [3].

Therefore, from the team's analysis, it was decided that ZC18 would use a carbon fiber-epoxy with a divinycell foam for the fairing and aluminum tubing for the frame.

Design Specifications and Criteria:

The team included many design criteria per the 2018 ASME HPVC Rules and Safety Requirements. These include:

1. Display of school name or initials at least 10 cm high on each side of the vehicle
2. A braking system which allows the vehicle to come to a stop within a distance of 6.0 m from a speed of 25 km/hr. This system must incorporate front brakes.
3. A steering system that allows at least an 8.0 m turning radius
4. Stability such that the vehicle can travel for 30 m in a straight line at a speed of 5 to 8 km/hr.
5. Incorporating a Rollover Protection System that prevents significant body contact with the ground in a rollover scenario, provides abrasion resistance to the rider, has a maximum elastic deformation of 5.1 cm when a 2670 N load is applied 12° from the vertical (towards the rear of the vehicle), and has a maximum elastic deflection of 3.8 cm when a 1330 N load is applied horizontally to the roll bar at shoulder height. For deflection tests, the reaction forces must be applied to the harness attachments or seat of the vehicle.
6. Surfaces of the vehicle must be free of sharp edges and hazards.
7. A forward facing field of view at least 180° wide.
8. A vehicle that allows unassisted starts and stops.
9. A clearance height that will allow navigation of speedbumps with a maximum height of 5 cm.
10. A parcel storage area that can hold a 38x33x20 cm parcel that will not exceed 5.5 kg.
11. Incorporation of an audible signal such as a bell or horn to alert bystanders of the vehicle.
12. A red tail light visible at least 150 m to the rear of the vehicle.
13. A white headlight visible at least 150 m to the front of the vehicle.
14. Reflectors incorporated on each side of the vehicle.
15. A rear view mirror that provides the rider a view to the rear of the vehicle.[4]

In addition to the ASME HPVC requirements, the team incorporated design specifications as decided by the team. These include:

16. An overall weight of ≤ 75 lbs.
17. Drag Coefficient less than .15.
18. Design factor of safety of 2.0.
19. Total vehicle cost less than \$6,000

Concept Development and Selection Methods:

For all major decisions made in designing ZC18, many concepts were evaluated and weighted decision matrices were used to choose the best option.

Rider Configuration:

Before beginning the design process, the desired rider configuration had to be determined. This parameter affects rider comfort and the design of many of ZC18's components. After consideration of prone, recumbent, and upright rider positions, it was determined that a recumbent vehicle was the preferred configuration.

	Weight	Prone	Recumbent	Upright
Rider Comfort	15.00%	2	5	3
Aerodynamics	40.00%	5	3	1
Weight	30.00%	3	3	5
Past Experience	15.00%	1	5	3
	100.00%	3.35	3.60	2.80

Vehicle Style:

Vehicle style affects the aerodynamics, weight, and stability of the vehicle. Styles that were considered for the 2017-2018 season were tadpole tricycle, delta tricycle, streamliner, and quad cycle. It was determined that a tadpole tricycle was the preferred vehicle style.

	Weight	Tadpole Trike	Delta Trike	Streamliner	Quad
Performance	10%	4	3	4	2
Aerodynamics	30%	3	4	4	2
Weight	25%	3	3	4	1
Stability	25%	4	3	1	5
Past Experience	10%	5	3	2	1
	100%	3.55	3.30	3.05	2.40

Frame Material:

The material of the vehicle's frame affects the weight, rigidity, manufacturability, and cost of the vehicle. Three materials that were considered for ZC18's frame were carbon fiber, steel alloy, and aluminum alloy. It was determined that an aluminum frame was the preferable material for the vehicle.

	Weight	Carbon	Steel	Aluminum
Specific Strength	35%	5	1	3
Manufacturability	25%	1	5	3
Cost	25%	1	5	3
Past Experience	15%	3	2	5
	100%	2.70	3.15	3.30

RPS Style:

When choosing the style of the RPS, it had to be carefully considered that its shape could greatly affect the overall shape of the vehicle. In addition to altering the vehicle's shape, the cost, manufacturability, and weight of the RPS were examined. Four RPS styles considered were a roll hoop, a cross shape, a RPS integrated into the fairing, and a full loop that completely surrounds the rider. It was determined that a cross shaped RPS was the most effective for ZC18.

	Weight	Roll Hoop	Cross	Fairing Integrated	Full Loop
Design Envelope	30%	4	4	5	1
Manufacturability	20%	3	5	2	3
Cost	20%	3	3	2	2
Weight	30%	3	3	4	2
	100%	3.30	3.70	3.50	1.90

Steering Type:

When determining a steering type for ZC18, four main styles were considered. Direct steering, a rack and pinion, a steering linkage, and tilt steering were the types of steering systems examined for the 2017-2018 season. To choose a steering type, performance, ergonomics, weight, cost, and the amount of space the steering system utilizes were all deciding factors. It was determined that a linkage style steering would best suit ZC18.

	Weight	Direct	Rack and Pinion	Linkage	Tilting
Performance	20%	5	3	4	1
Ergonomics	25%	3	3	4	2
Weight	15%	4	2	3	3
Cost	10%	3	2	3	1
Design Envelope	20%	1	5	4	3
Past Experience	10%	5	2	3	1
	100%	3.35	3.05	3.65	1.95

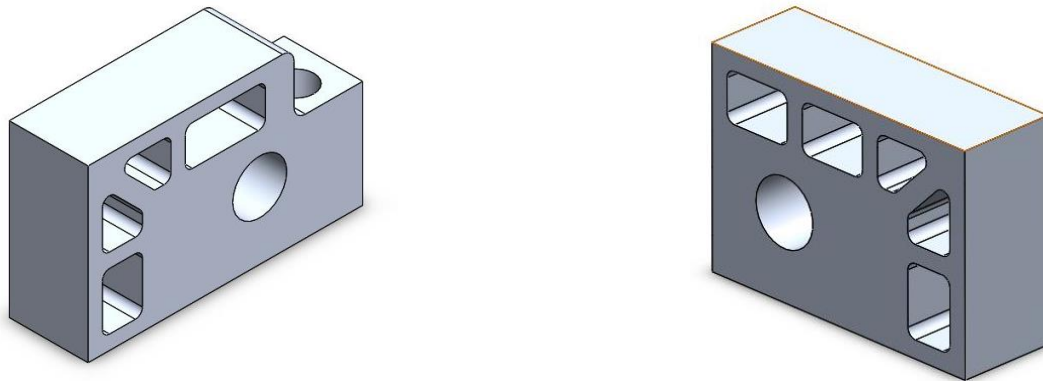
Rear Wheel Size:

Selection of a rear wheel size for the 2017-2018 season was dependent on the lateral stiffness, angular inertia, cost, and rolling resistance of multiple available bicycle wheels. The four sizes considered were 20 inch, 26 inch, 29 inch, and a custom 29 inch wheel with a more rigid hub design. It was determined that a 20 inch wheel would be the most effective for ZC18.

	Weight	20"	26"	29"	29" Custom
Lateral Stiffness	30.00%	5	3	2	4
Angular Inertia	20.00%	5	4	3	3
Cost	20.00%	4	5	3	1
Rolling Resistance	30.00%	2	3	4	4
	100.00%	3.90	3.60	3.00	3.20

Innovation:

One innovative part of ZC18 is the custom rear dropout geometry that was incorporated into the frame. ZC18 utilized a rear through axle connection and off the shelf derailleur hanger, which provoked the design of custom rear dropouts. These dropouts were originally designed to be 17.5 mm thick. Upon manufacturing of the frame, it was determined that the process of welding 1.65 mm thick tubing to a 17.5 mm block was not ideal. To decrease the dropout thickness and increase ease of weldability, pockets were milled into the dropouts. The combination of the thinner walled dropout and preheating the dropouts with a torch greatly increased the weldability of this joint.



Description:

General:

ZC18 is a recumbent, fully-faired trike. This vehicle is designed to traverse terrains that an everyday rider may see, including city roads, sidewalks, and paved or packed trails, making it a great commuter, exercise, or leisure vehicle. Though not ideal, ZC18 could be used in the rain or even hail with the rider being protected from the elements by the fairing. However, once ice or snow would form on the road, traction and handling would be reduced, making ZC18 unrideable.

Frame:

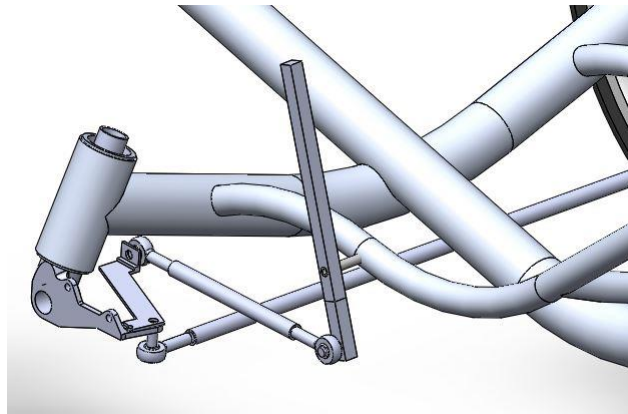
The frame of ZC18 is made of 6061-T6 extruded aluminum tubing, with OD ranging from 1.00 inch to 2.00 inches, and uniform wall thicknesses of .065 inch. The bends in the tubing were designed to reduce manufacturing cost by using repeated bends. This reduced the setup time between bends and drove costs down. The frame was TIG welded together and was held using custom jigging that was cut with a CNC mill. After welding, it was heat treated to a uniform temper of 6061-T6.

**RPS:**

ZC18 unveils a new design of the RPS for The University of Akron. It features a cross that is built into the frame, instead of a traditional roll hoop. This cross creates a "Safety Triangle" around the body of the rider to prevent body contact with the ground and provide sufficient strength in the event of a roll over.

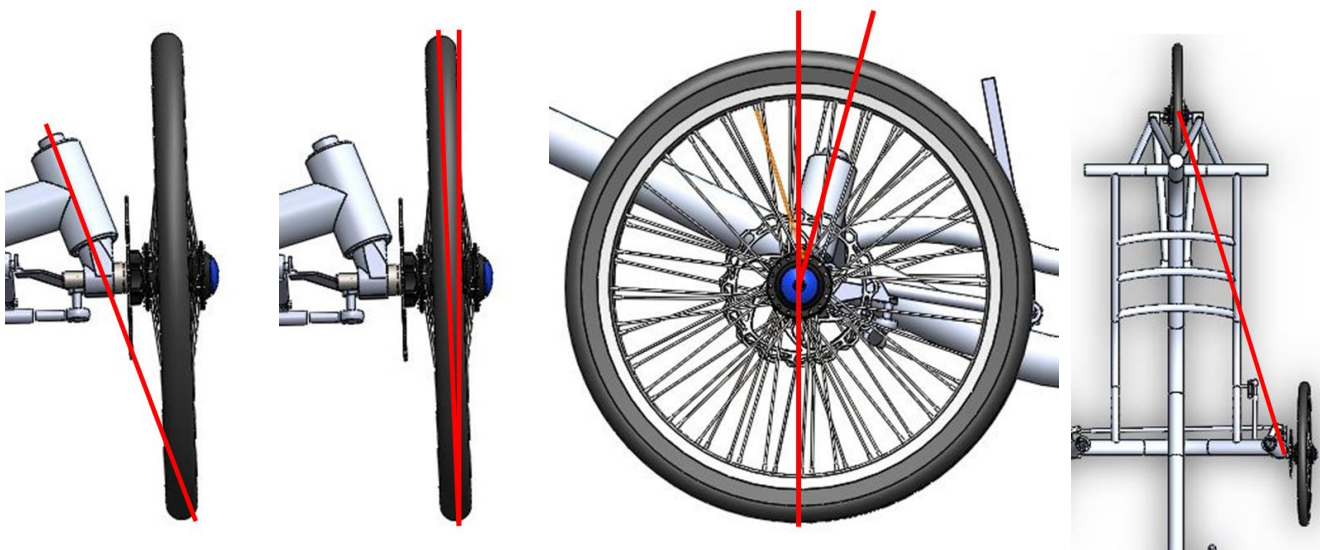
Steering Method:

ZC18 implements an indirect steering method similar to tractor steering. All steering is to be done using only one hand, while the off hand controls braking and shifting. This style of steering was chosen to allow for the system to be controlled within the fairing while reducing the frontal area. The design from 2017 incorporated a direct system that was controlled outside of the fairing. All motion performed by the rider was side to side with the direct steering, but with the tractor style, all motion is forwards and backwards.



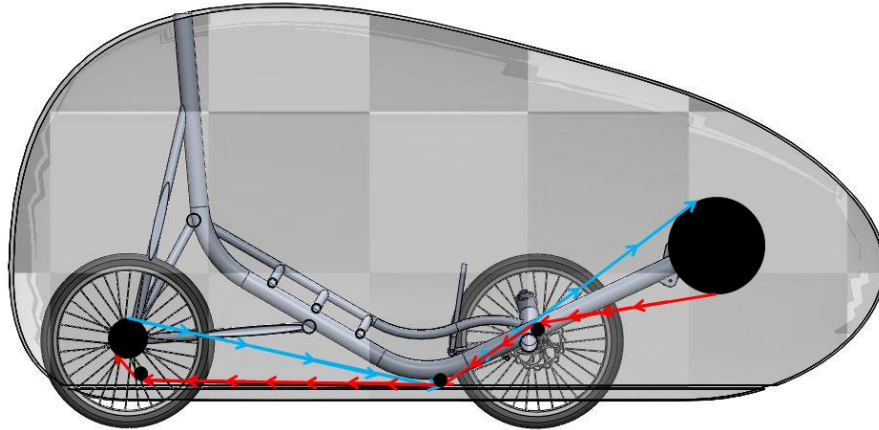
Steering Geometry:

The steering geometry includes a center point steering, camber, caster, Ackerman steering compensation, and an adjustable toe. The head-tubes are welded to the frame so that their axis passes through the contact patch between the wheel and the ground. ZC18 has 2° of negative camber and 15° of positive caster. These were adjusted from the 2017 vehicle to tweak the response of the vehicle. A Catrike kingpin spindle was used as a mounting point for all steering components. The Ackerman compensation worked out naturally with this kingpin spindle to be very close to ideal. No extra bracketing was needed to adjust for Ackerman Compensation.



Drivetrain:

ZC18 is rear wheel driven and uses one continuous chain to deliver power from the crank to the rear wheel. The chain path from front to back has to be unimpeded and efficient to reduce chain weight, reduce friction losses, and improve vehicle performance. Gearing analysis was conducted and results in a need for a 70 tooth front sprocket with a rear cassette ranging between 11 teeth and 32 teeth.

**Seat:**

The structure of the seat is built into the frame of ZC18. The side rails provide exemplary locations to mount a seat. A seat made of ¼ inch diamond braid paracord that was wound back and forth between the rails was chosen as a seat. The tension of the windings provides a natural spring and conforms to the riders for comfort. It is wound in a figure-8 orientation which lowers the center of the seat, pulling the rider towards the center mass of the vehicle.

Safety:

In addition to the safety features required by ASME, ZC18 has a number of additional features that improve rider safety. A protective layer will be applied to the inside of the fairing to shield the rider from raw carbon. Changing the steering method to indirect, moves the riders fingers and hands away from the rotating components on the front wheels, reducing risk of lacerations and getting body parts caught.

Analysis:

RPS Analyses:

The aluminum frame of ZC18 provides the rider with exceptional protection in the case where the vehicle rolls over and becomes inverted or rolls onto its side, by absorbing sufficient energy. The geometry of the RPS also prevents the rider from touching the ground in these cases, therefore preventing injuries from abrasion and preventing significant body contact with the ground. Another step taken to protect the rider is to map the load path from the rider to the ground. Special analyses were conducted to ensure the safety of the rider.

Top and Side Loading Cases:

Objective:

The level of protection required, by ASME, is a maximum elastic deformation of 5.1 cm when a 2670 N force is applied at 12° from the vertical on the top of the RPS and a maximum elastic deformation of 3.8 cm when a 1330 N force is applied horizontally to the side of the RPS [3]. If these criteria are not met, and exceeded, then the rider will be in danger of the top of the RPS collapsing on them when inverted and/or the side of the RPS buckling under them when laying or falling on their side. These could lead to serious head and neck injuries and could lead to lacerations and abrasions on the rider. Load paths are also to be mapped from the rider to the ground.

Modeling Method and Assumptions:

Analysis of these criteria were conducted using Solidworks Simulation. For the top loading case, the model was fixed at the locations that the harness is to be attached, behind the shoulders and on the side rails near the hip. A force of 2670 N was applied to the top of the RPS at an angle of 12° forward of vertical.

For the side loading case, the model was fixed at the locations that the harness is to be attached near the hips, and only one side of the frame for the harness attachment points behind the shoulders. This scenario was chosen because of the understanding that the rider will be hanging from the top side of the harness when laying on their side. Very little or no force will be seen by the other strap. A force of 1330 N was applied horizontally to the side of the RPS.

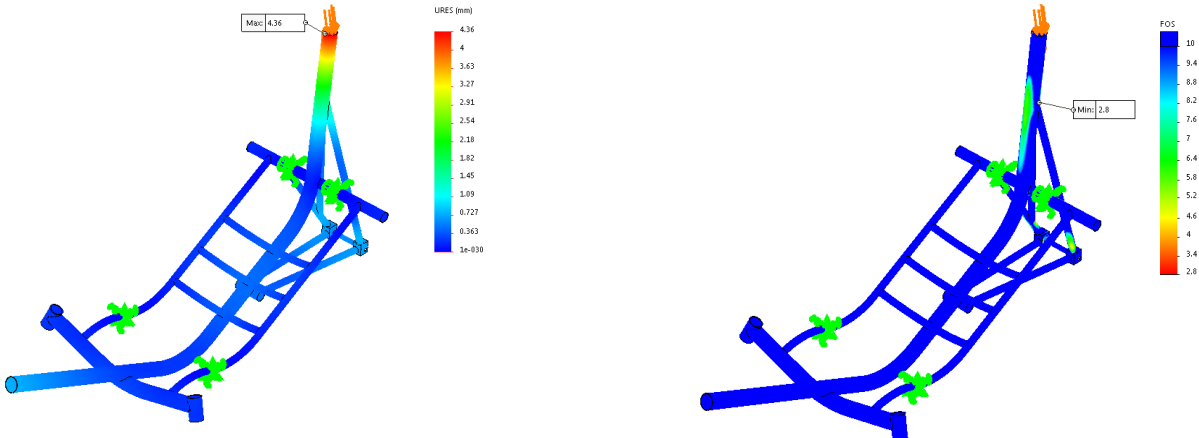
These analyses were set up using a curvature-based mesh with a maximum element size of 8.2 mm and a minimum element size of 1.63 mm.

Some assumptions that must be made are that the safety harness is fixed in place and will not move at all, and that the aluminum frame material is completely homogeneous, with no flaws or impurities. Also, a uniformly distributed load is to be applied to the RPS.

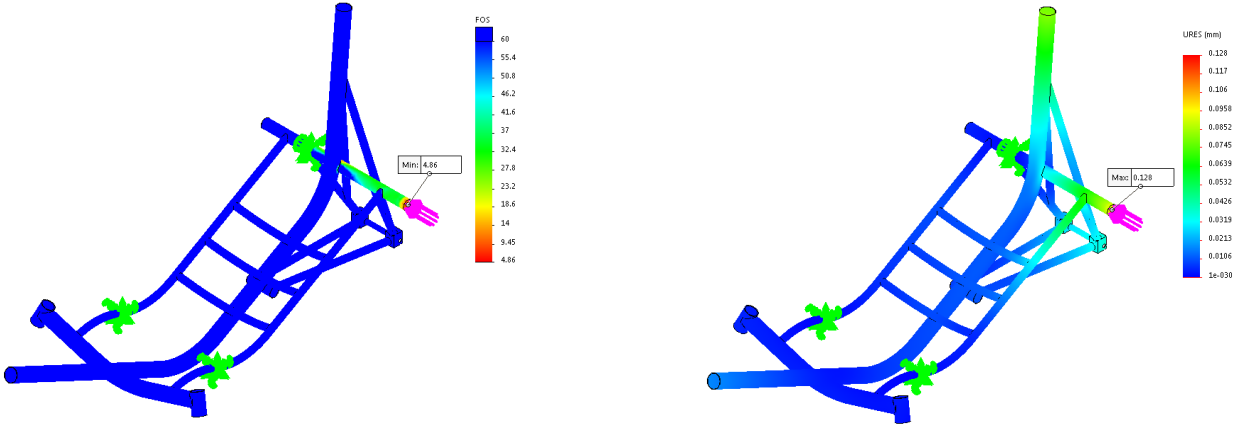
Results:

The above methods were followed and results were obtained for the top load and side load RPS analyses.

For the top loading case, the maximum resultant displacement of the frame was 4.36 mm. Using the Von Mises Stress calculation, and comparing that to the material strength, the minimum factor of safety was found to be 2.8.

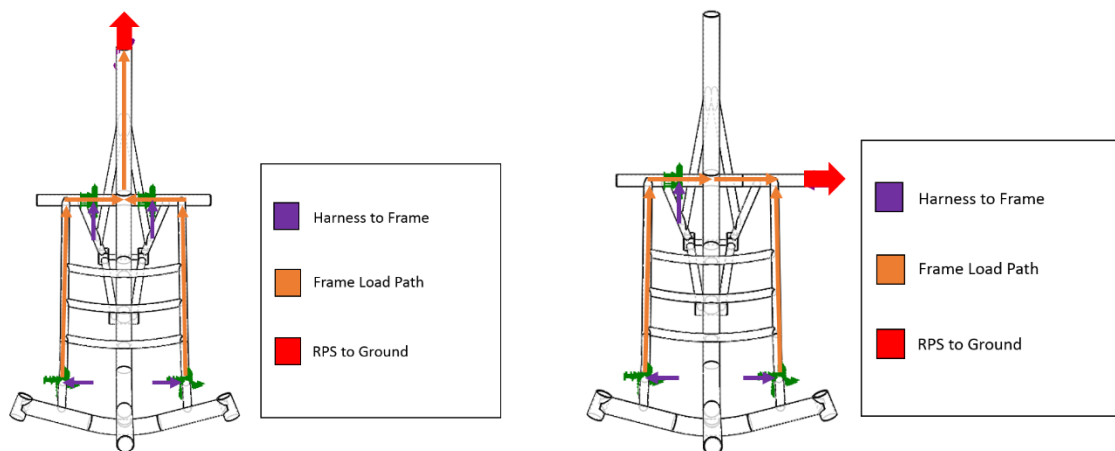


For the side loading case, the maximum resultant displacement of the frame was .128 mm. Using the Von Mises Stress calculation, and comparing that to the material strength, the minimum factor of safety was found to be 4.86.



A load path from the rider to the ground was generated for the top load case. The path consists of the force being transmitted through the rider into the safety harness. The harness attachment points behind the shoulders provides a load path directly to the RPS. The force moves into the horizontal portion of the RPS, towards the center of the vehicle. Finally, it travels up the vertical portion of the RPS and out the top, to the ground. The harness attachment points near the rider's hips have a load path that travels up the side rails of the vehicle to the horizontal portion of the RPS where the path meets with the previously described path.

A load path from the rider to the ground was generated for the side load case. The path consists of the force being transmitted through the rider into the safety harness. The harness attachment point behind the shoulder provides a load path directly to the RPS. The force moves into the horizontal portion of the RPS and travels directly through it to the ground at the end of the segment. The harness attachment points near the rider's hips have a load path that travels up the side rails of the vehicle to the horizontal portion of the RPS where the path meets with the previously described path and follows to the ground.



Conclusions:

For each loading case, both the maximum displacement and the minimum factor of safety show that the designed RPS will perform exceptionally well. The maximum displacement for the top loading case was 11.7 times less than the required maximum displacement. The maximum displacement for the side loading case was 296.9 times less than the required maximum displacement.

The factor of safety for each case exceeds the team's design factor of safety of 2.0. This analysis analytically shows that for the top load case and the side load case, the designed RPS for ZC18 meets and exceeds the requirement set forth by ASME and for the team.

Abrasion and Ground Contact Case:

Objective:

It is required that the rider have adequate abrasion resistance and be protected from significant body contact with the round in the event of a fall. The designed RPS of ZC18 should provide enough safe area between the ground and the rider to prevent any contact, therefore eliminating the risk of abrasion and serious injury.

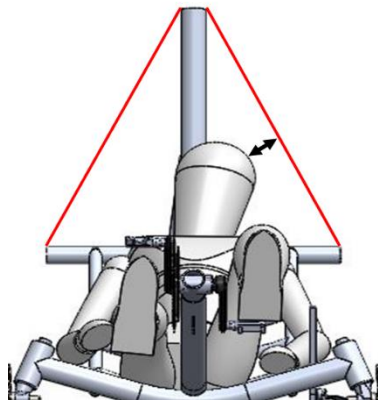
Modeling Method and Assumptions:

The model of the frame was outfitted with a human stand-in that was designed using the results of our Ergonomics study. This person was created using the 95% upper limit dimensions and placed into the vehicle as its rider. Lines were then drawn between the three ends of the RPS components (top, left, and right) to create a "Safe Zone." This is the area that the rider can be within and be geometrically protected from any contact with the ground.

Some assumptions that must be made include, the harness will not move at all, the rider is properly attached to the harness so they will not move, and the RPS will not deflect. These can all be assumed because the harness will be properly installed and used, and the top and side load RPS analyses show that the deflection of the RPS is negligible on this scale.

Results:

This analysis yields an absolute minimum distance between the ground and the riders head/shoulders of 7.8 cm.



Conclusion:

The rider of ZC18 is well protected from abrasion and contact with the ground because of the RPS that has been designed. There is excellent clearance for the worst case scenario between the rider and the ground. This RPS meets the requirements set forth by ASME.

Structural Analyses:

In addition to the RPS analyses required by ASME, ZC18's frame design was examined in three other load scenarios that will be seen during competition. The three additional analyses that were simulated were crank deflection, rider load, and a turning simulation.

Objective:

A crank deflection scenario was observed to show the maximum load applied to the crank during a pedaling situation. If this were to cause a failure, the boom that the crank is attached to would break off and permanently cripple the vehicle.

A rider load deflection scenario was observed to show the effect the weight of a rider has on the structural integrity of the frame. If this were to cause a failure, a rider may risk falling through the frame, putting them in danger of abrasion with the ground, and in danger of lacerations from the broken members of the frame.

A turning simulation deflection scenario was observed to show the effect of a hard left/right turn where the vehicle is on the verge of rolling. If this were to cause a failure, one of the front two tires may break off and cause a violent crash. This crash would send the remaining part of the vehicle and the rider, off tangential to the turning path, risking abrasion injury and endangering spectators and other competitors. This would also permanently cripple the vehicle.

The objective of these three analyses is to confidently show that the strength of the frame exceeds the induced stresses by a design factor of safety of 2.0.

Modeling Method and Assumptions:

To model the crank deflection, the vehicle's frame was fixed at the attachment points of the wheels. For this simulation, an assumption was made that the majority of the force on the crank was applied parallel to the ground towards the front of the vehicle. During this FEA, a load of 670 N (150 lbs) was applied on the end of the boom.

For the rider load scenario, the vehicle's frame was fixed at the attachment points of the wheels. Assumptions were made that the load of the rider was symmetrically distributed to each side of the vehicle and normal to the ground. A load of 900 N (~200lbs) was applied to the

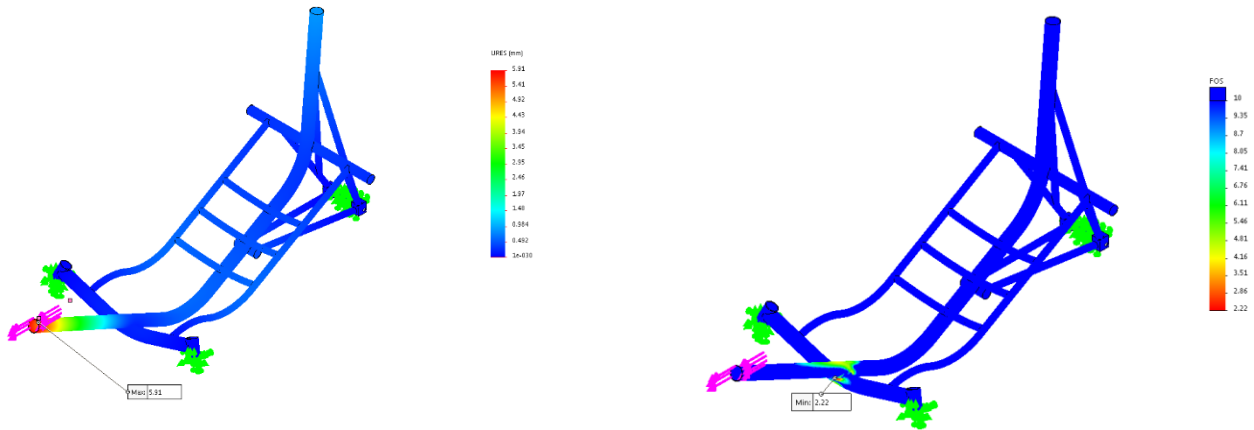
side rails of the frame, where the seat is mounted. This load is slightly heavier than the team's heaviest rider.

In simulating turning, the vehicle's frame was fixed at the attachment point for the rear wheel and for the front wheel on the outside of the simulated turn. This was due to the assumption that the vehicle was at the point of rolling, so zero force was being applied to the other wheel. A total load of 900 Newtons was applied horizontally between the two harness attachment points opposite of the fixed wheel. This is assuming that the rider is observing 1G when turning and weighing 90.7 kg (~200lbs), which results in a horizontal force of 900N

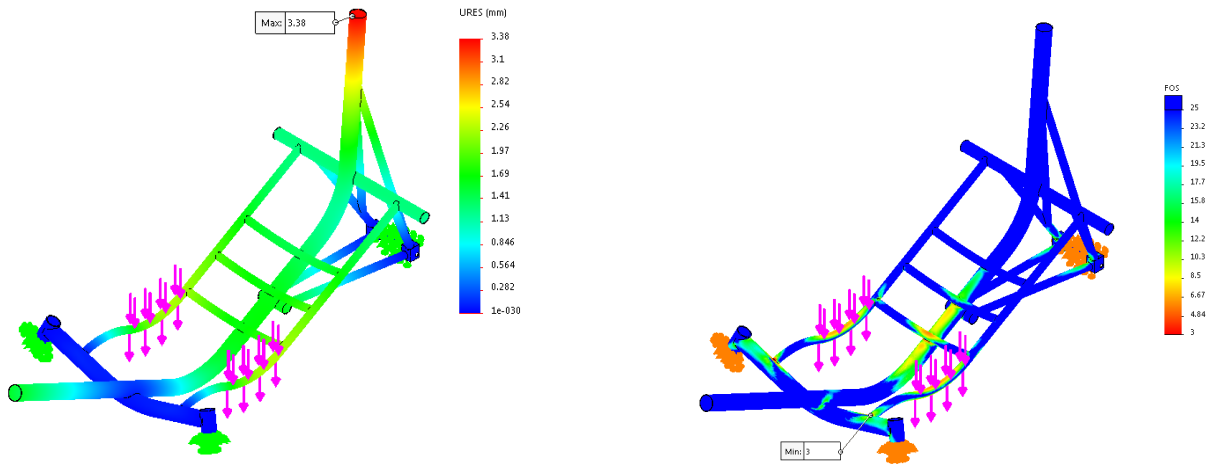
Results:

The above methods were followed and results were obtained for the three loading analyses. Von Mises Stress calculation and the material strength of 6061-T6 aluminum were used to find the factor of safety for each case.

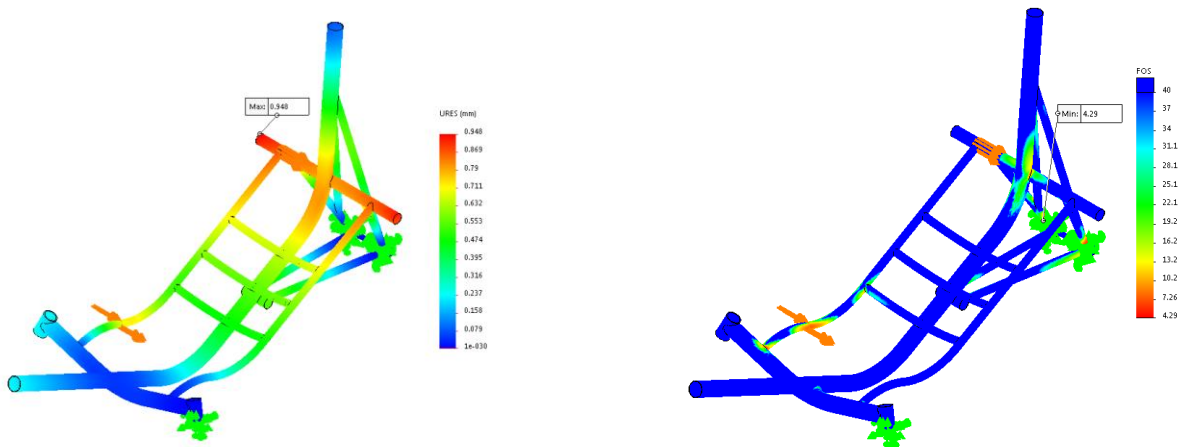
The crank deflection simulation yielded a maximum resultant displacement of the frame of 5.91 mm and a minimum factor of safety of 2.22.



From the rider loading, the maximum deflection observed is 3.38 mm and a minimum factor of safety was found to be 3.00.



Finally, in the case of the turning simulation, the maximum deflection was .948 mm with a minimum factor of safety of 4.29.



Conclusion:

The frame of ZC18 exhibits exceptional resistance to the three loading cases applied. All factors of safety meet and exceed the design factor of safety of 2.0. These analyses show, analytically, that this design can resist failure for these three common loading conditions.

Cost Analyses:

Objective:

In designing and building a vehicle for competition, there are many challenges faced by a student design team. One of the most critical things throughout this process is managing expenses and keeping costs to a minimum.

Modeling Method and Analysis:

Through fundraising, university sponsorship, and outside donors, simple CAD designs have the opportunity to come to life. Previous experiences help the team develop goals for the vehicle early on in the process. Specific areas can be prioritized as to where spending more will provide greater benefits, and where strategizing how to cut cost in other areas where the return will have less of an impact on performance.

Results:

There was a heavy focus this year on the manufacturing of the fairing. In looking for areas to cut cost that would allow for more funding to be allocated to this area, the seat of the vehicle stood out. Previously, a custom made seat had been used that fit the vehicles from the past two years. With the changes in the frame this year, that custom made seat was no longer going to be adequate. Instead of spending more funding on a custom made seat, an alternate, cheaper solution was found. This type of budgeting allows the team to use their budget wisely and where their funding will make the greatest impact on the quality of the designed vehicle.

Conclusion:

Summarized in Table 1, the purchases that do apply to the total cost of manufacturing the vehicle have been organized into five categories: components, frame, fairing, innovation, and miscellaneous. The team’s efforts in setting and sticking to a budget, fundraising, and acquiring sponsorship allowed for maximizing limited funds while still producing a well manufactured vehicle.

Product/Labor	Price
Components	\$2,346.61
Frame	\$740.43
Fairing	\$2,043.37
Innovation	\$345.98
Misc	\$125.00
Total	\$5,601.39

Table 1: Cost Analysis Chart

Other Analyses:

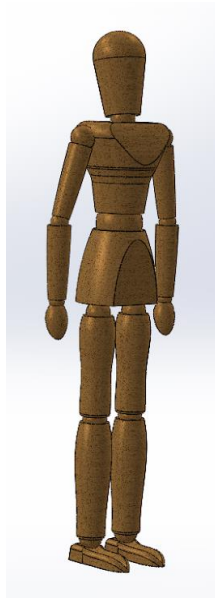
The Human Component of “Human Powered Vehicle”

Objective:

It is important for each rider to train in preparation for competition, however, they can only perform as well as the designed vehicle will allow them. It is critical for riders of all shapes and sizes to be accommodated so that they may demonstrate the capabilities of the design of the vehicle.

Modeling Method and Assumptions:

Previously, the team had based the frame and fairing design on a 95th percentile male model. This year, measurements of the determined riders and any alternates were taken to the nearest half inch to create a model that would be a more accurate representation of the team’s current members. These basic measurements were used to develop a life size model in Solidworks that could be used to obtain a rider volume, and used with renderings of the frame and fairing.



Results:

Rider	Total Height with shoes off (in)	Leg length with shoes off (in)	X-seam with shoes off (in)	Heel to Toe Length (in)	Shoulder width (in)	Hip width (in)
Average	68.48	36.36	42.22	9.69	19.08	14.50
95% Conf. Maximum	70.58	37.55	43.5	10.15	19.79	15.11
95% Conf. Minimum	66.78	35.17	41.13	9.39	18.21	13.62

Rider	Total Height With Shoes Off (in)	Leg Length With Shoes Off (in)	X-Seam With Shoes Off (in)	Heel to Toe Length (in)	Shoulder Width (in)	Hip Width (in)
Chris Reed	69.5	37	44	10	19	15
Kole Williams	64.5	34	40.5	9.5	18	12
Eric Miller	71	37	44	11	20	14.5
Jordan Boos	69.5	34.5	41	10	18.5	14.5
Leland Hoffman	69	37.5	41	9	19	13.5
Hari Rangarajan	68.5	39	43	9.5	18.5	13.5
Marlee Reynolds	63	32	39	9	16.5	15
Daniel Brown	70	37	41	10	19.5	13.5
Patrick Gaertner	71.5	37	45	10.5	22	17
Noah Gresser	67	37.5	42	9	19	14.5
Ryan Best	72	37.5	45	10	19	15
Average	68.35	36.36	42.05	9.75	19.00	14.30
95% Conf. Max	70.58	37.55	43.50	10.15	19.79	15.11
95% Conf. Min	66.78	35.17	41.13	9.39	18.21	13.62

Table 2: Rider Measurements

Conclusions and Resultant Design Modifications:

The Rollover Protection System relies heavily on rider measurements. The RPS cross lengths are designed utilizing the measurements so that no rider's body will ever make contact with the ground should the vehicle roll. The data from the rider measurements also presented options for streamlining the design of the fairing. The general size of the fairing relies on the size of the frame, and thereby the average rider size. Knowing where the average rider's head will rest, the fairing can be constructed with windows that give the rider a more direct line of sight at their eye level. Having information specific to this team's riders allowed for the design of the vehicle to fit the rider, rather than the rider having to fit the vehicle. A more personalized design provides comfort to the rider so that he or she may have a maximum performance output without the constraints of the vehicle getting in the way.

Testing

RPS Testing:

Three tests were completed to physically test the safety of the RPS on ZC18; a top load, side load, and ground contact test.

Top Loading:

Objective:

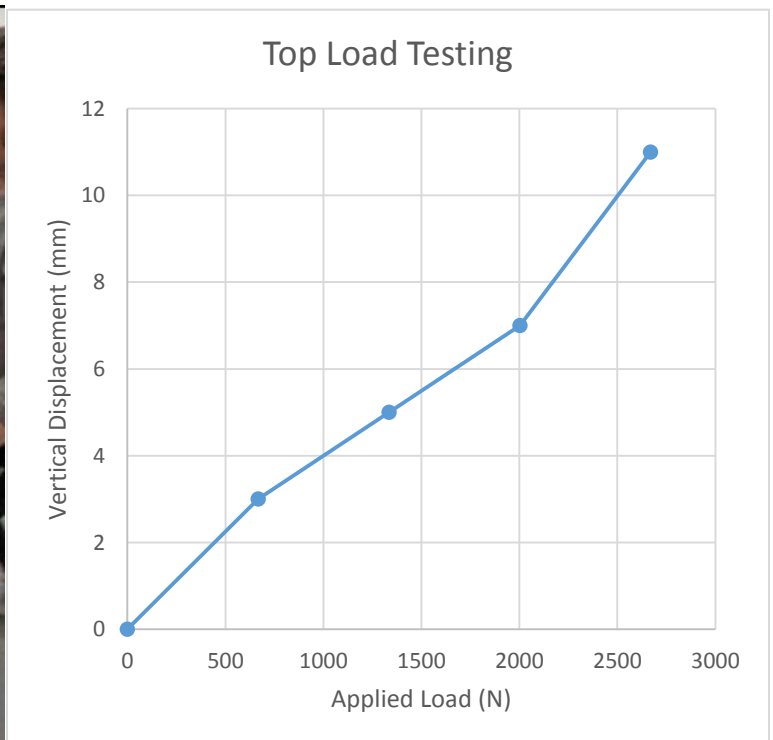
Show with physical test results that the RPS of ZC18 can protect a rider from the force of rolling over and landing directly on the top of the vehicle. This is required by ASME as a safety precaution to protect riders from serious injury. When 2670N is applied, the maximum deflection must be less than 5.6 cm and show no plastic deformation.

Methodology and Assumptions:

As per the rules set forth by ASME, a load of 2670N will be applied to the top of the roll hoop at an angle of 12 degrees forward of vertical. To accomplish this, the frame was jugged to the weld table using standoffs that held it backwards at 12 degrees. The weld table was wheeled down to the rec center and a small pallet was hung from the top of the frame. 600lbs of dumbbells were applied to the pallet and the deflection was measured. 600lbs is equivalent to the 2670N requirement.

Results:

The total vertical deflection measured was 1.0 cm. No plastic deformation was observed. The frame for ZC18 passes the top load requirements set forth by ASME.



Side Loading:

Objective:

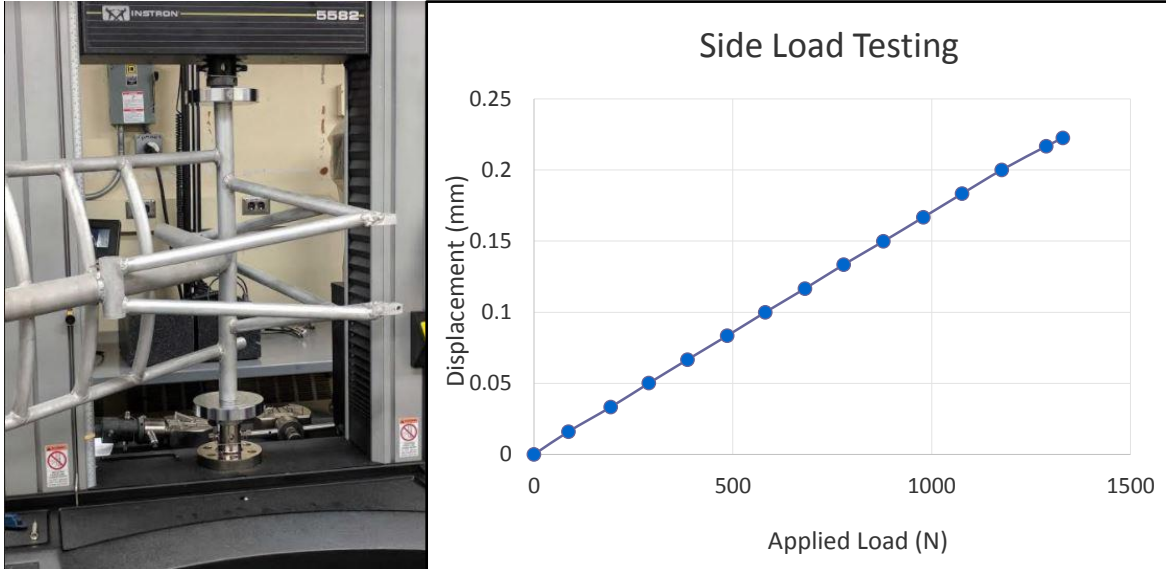
Show with physical test results that the RPS of ZC18 can protect a rider from the force of rolling over and landing on its side. This is required by ASME as a safety precaution to protect riders from serious injury. When 1330N is applied, the maximum deflection must be less than 3.4cm and show no plastic deformation.

Methodology and Assumptions:

As per the rules set forth by ASME, a load of 1330N will be applied to the side of the roll hoop. To accomplish this, an Instron compression machine is used to squeeze the frame across the side RPS. The deflection is measured and analyzed.

Results:

The total deflection was measured to be .116mm, well below the limiting 3.4cm. There was no plastic deformation observed. The frame for ZC18 passes the side load requirements set forth by ASME.



Ground Contact:

Objective:

Show with physical proof, that in the case of a rollover at any inversion angle, the rider will not come in contact with the ground. This is required by ASME as a safety precaution to protect riders from abrasion injuries in the event of a rollover.

Methodology and Assumptions:

The largest rider was strapped into the vehicle as if they were riding. Other members of the team rolled the vehicle on its side and inverted it completely. Ground contact was checked for in these conditions.

Results:

The rider never touched the ground, therefore, ZC18 passes the requirements for protecting the rider from ground contact when inverted.



Developmental Testing:

Three developmental tests were conducted to make design decisions for ZC18. They include a seat development test and a crank deflection test.

Seat Development:

Objective:

For competition in 2016 and 2017, a custom designed seat was purchased and reused, as the frames had similar designs. This year, the frame design is much different, and the custom seat from two years ago is not adaptable to it. The team looked at many different options for a seat for their 2018 competition vehicle, and narrowed the possibilities to a list of the most feasible options.

Methodology and Assumptions:

Quarter inch and three eighths inch diamond braid rope were evaluated. These two types of rope were tested on the team's vehicles in previous competitions to give an approximation for the ergonomic benefits, weight difference, and other factors. This was then compared to the performance of an off the shelf seat, as well as the custom seat from years previous.



Results:

A weighted decision matrix was created to evaluate and rank the benefits and drawbacks of the four seat types for the vehicle. The quarter inch diamond braid rope was selected for the vehicle.

Parameters	Weighting	Ranking for Each Type of Seat			
		Off the Shelf	Custom	1/4 Inch Cord	3/8 Inch Cord
Ergonomic	25%	1	4	3	2
Cost	20%	2	1	3	4
Adaptable	15%	1	2	4	4
Weight	10%	4	3	1	2
Aesthetics	15%	1	4	3	2
Attachment	5%	3	4	2	2
Easily Recyclable	10%	2	1	4	4
Total	100%	1.7	2.7	3	2.9

Table 3: Seat Decision Matrix

Conclusions and Resultant Design Modifications:

The adaptability of the rope allows it to be formed to the frame. It also allows for support and give that can differ in location per rider. As any team will have many body types powering their vehicle, this allows for each rider to feel support where they need it. With the rope design being the cheaper option, the team was able to focus their limited budget on other areas in the vehicle’s design and construction. The rope ranked highly among the other types of seats considered for cosmetics, and is anticipated to contribute to the overall aesthetic appeal of the vehicle.

Crank Deflection Testing

Objective:

The goal of this experiment was to determine if wrapping the crank in carbon fiber will substantially lessen the deflection of the end of the crank when force is applied by the rider to the pedals. Reduced deflection will increase the efficiency of the vehicle, as less energy will be spent bending the crank and more will be delivered to the drivetrain.

Methodology and Assumptions:

The frames from the two previous years' competitions were used for testing, as they have identical designs. Both cranks were fabricated out of the same material, 6061 Aluminium, and were made to the same length. The only difference between them was one frame was set up with carbon wrapping around the bottom of the crank's spine, and the other frame was left as is for a control value.

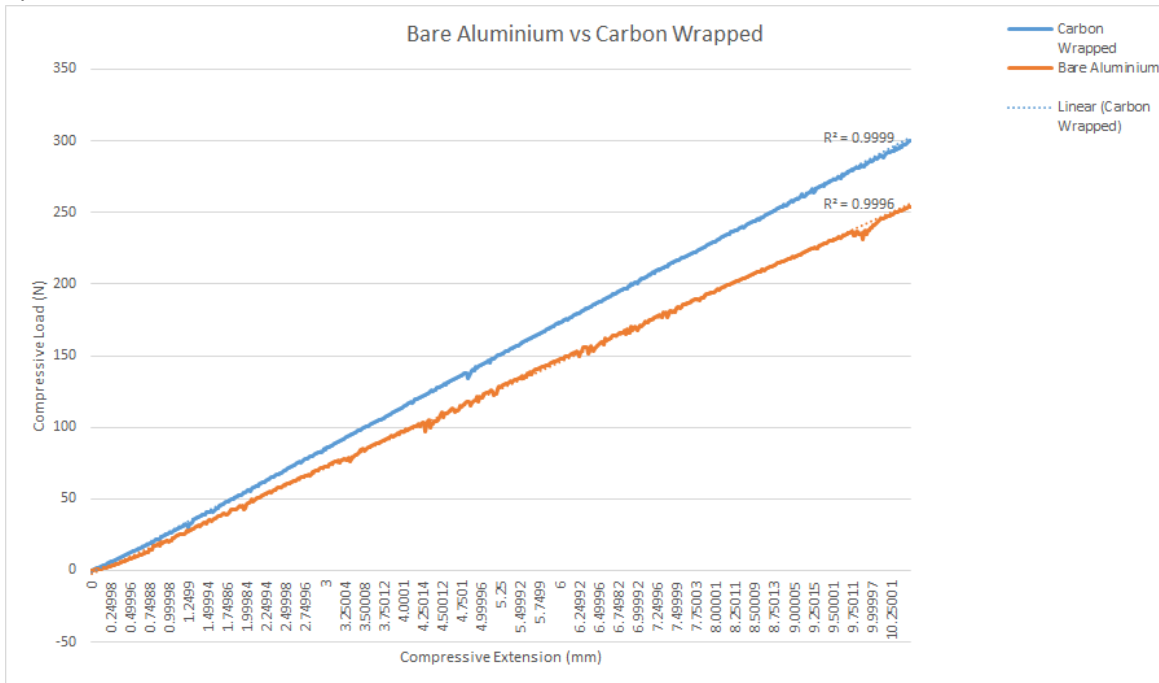
Test Setup:

The cranks were set up as shown in Image # on the Instron 5582 universal tester, ensuring that the length of the crank was consistent between tests. The highest point of the crank was centered on the bullseye of the universal tester. Due to the desire to simulate a rider applying force to the pedals, the speed at which the load was applied was set at a creep. Each run involved gradually and continuously applying the same compressive load at a speed of two millimeters per minute to the end of the boom and recording crank deflection in millimeters. The same program was run for each frame, applying the same load at the same speed so that the results could be compared.



Results:

The slope of the unwrapped crank is 24.6 N/mm and the slope of the carbon wrapped crank is 29 N/mm.



Conclusions and Resultant Design Modifications:

The carbon wrapped crank deflected 16.7% less than the bare aluminum crank. This is attributed to the carbon reinforcing the crank and providing more rigidity. In recent years, the team had minor trouble dealing with the deflection of the crank, especially when starting from rest and pedaling uphill. Having this knowledge from participating in competition over the past few years, the team recognized the need to explore various solutions to the problem, and honed in on the method of reinforcing the crank with carbon. By adding this reinforcement to the bottom of the crank's spine, riders may apply more force to the pedals, translating to more speed for the vehicle while also lessening the effects of deflection as proven through testing.

As the crank deflects, a rider has to stretch his or her body or move down the seat to keep pedaling the vehicle. In the situation of a fully faired vehicle, the vision of a rider can be skewed by a fairing's panels or by a window not being wide enough for a rider who is sitting lower on a seat. Making the crank deflect less lowers the risk of a rider having to stretch to reach the pedals and compromise safety while driving the vehicle. Also, as a rider is pushing on the pedals, the force applied is causing the crank to become spring-like with the deflection. This transforms part of the force applied by the rider into the bending of the crank, limiting the amount of force that can be transferred to the pedals.

Conclusion

Comparison:

Parameter	Target Value	Actual Value	Reasoning
Elastic deformation of RPS under specified top load	51 mm max	4.36 mm	Finite Element Analysis
Elastic deformation of RPS under specified side load	38 mm max	.128 mm	Finite Element Analysis
Forward facing view	180° min	190°	Windshield Design
Total vehicle weight	75 lbs max	TBD	
Drag coefficient	.15 max	0.1261	Computational Fluid Dynamics
Manufacturing duration	8 weeks	TBD	
Total vehicle cost	\$6000 max	\$5,601.39	Cost Analysis
Factor of safety for all analyses	2.0 min	minimum value of 2.22	Finite Element Analysis

Evaluation:

The University of Akron Human Powered Vehicle Team designed, analyzed, manufactured, and tested ZC18 with specific design goals of constructing a lightweight, safe, and efficient human powered vehicle. It was also designed to meet and exceed the ASME Design Requirements and the team imposed Design Specification. The design requirements were met through use of simulation and testing. RPS analysis was conducted to prove out the safety of the design. Other minor design decisions, such as brake components, and visibility components, satisfy all other requirements. Analysis of the fairing and of the drivetrain show that the team imposed specifications are attainable using these designs. All design requirements and design specifications were fulfilled by ZC18.