Franklin W. Olin College of Engineering
Human Powered Vehicle Team

2012 - 2013 Design Report

Vehicle #2

The Plaid Panther

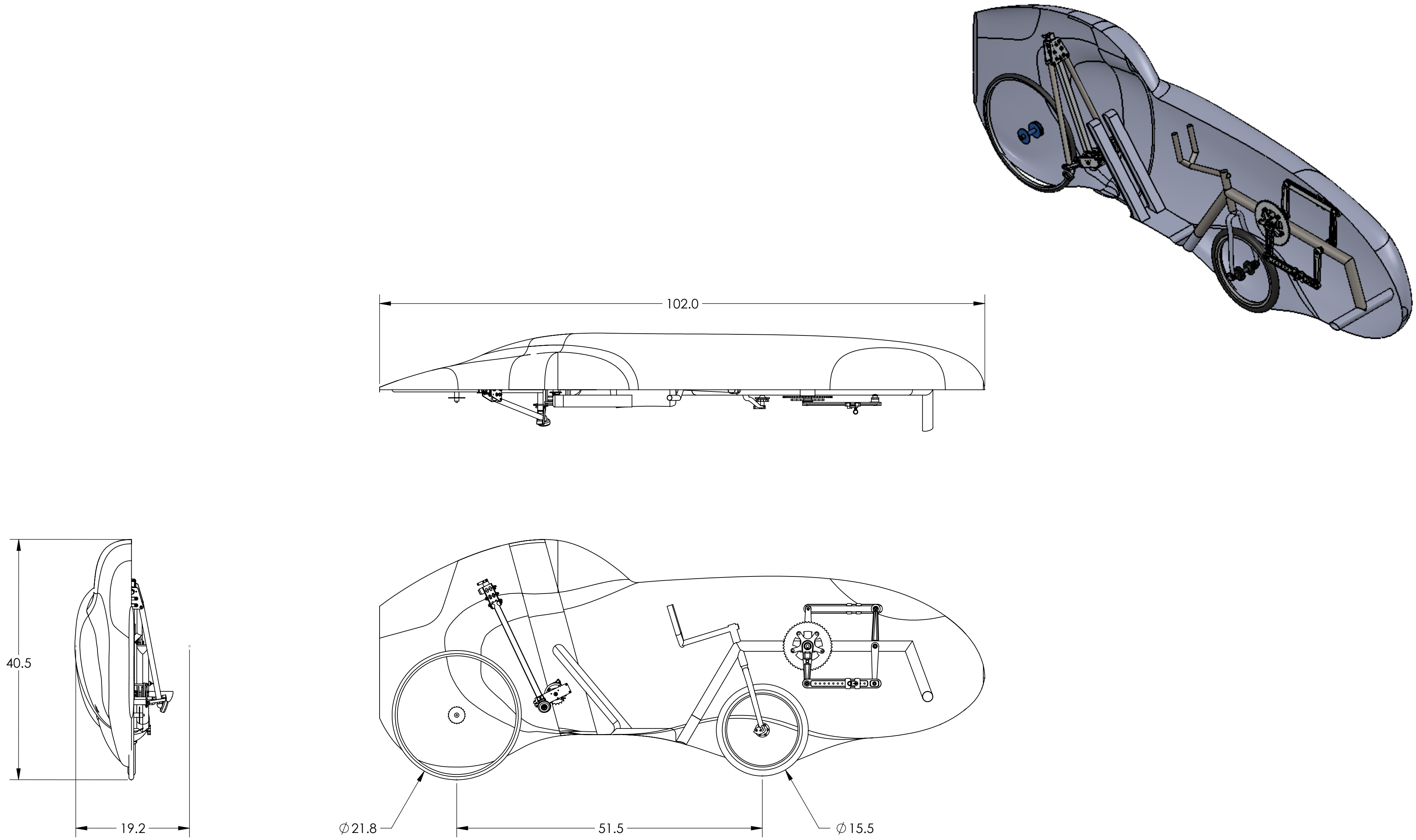
Team Members:

Kari Bender
Ben Chapman
Nick Eyre
Janie Harari
Deborah Hellen
Dan Kearney
Juliana Nazaré
Jay Patterson
David Pudlo
Jackie Rose
Cullen Ross
Alison Shin
Ben Smith
Alex Spies
Maggie Su
Jessica Sutantio
Gaby Waldman-Fried
Mike Warner

Faculty Advisors:

Aaron Hoover & Christopher Lee

http://hpv.olin.edu



ALL DIMENSIONS ARE IN INCHES- INTERPRET DRAWING PER ASME Y14.5 -1994

TOLERANCES UNLESS OTHERWISE SPECIFIED:

X.X ± .03 ∠ ± .5°
X.XX ± .01
X.XXX ± .005 125√

REMOVE ALL BURRS AND SHARP EDGES .005 R OR CHAMFER MAX

APPROVED		DATE
PREP BY	N. EYRE	3/23/13
CHECKED	TEAM	3/23/13
RESP ENG		
MFG ENG		
QUAL ENG		

◆ = (CRITICAL DIMENSION)

Franklin W. Olin College of Engineering

Olin College 2013 Vehicle
The Plaid Panther

SIZE	FSCM NO.	PART NO.	PART REV	DOC REV
C		OLIN-HPV13		
SCALE 1:12		WT	SHEET 1 OF 1	

Abstract

For its eighth year, the Olin College Human Powered Vehicle Team will return to the ASME Human Powered Vehicle Challenge with its vehicle, *The Plaid Panther*. The Olin College team's goals are to increase the aerodynamic efficiency and overall quality of the fairing, reduce the total weight of the vehicle, and generally develop superior subsystems. These objectives are second to the team's long-standing tradition of annually building a vehicle that each member of the team can comfortably ride. Our performance at the 2012 competition led us to focus on the following areas:

1. *The Plaid Panther* will be a fully-faired vehicle able to stop and start without assistance. We recognize that this ability is critical for vehicle performance and will develop a robust system to allow for easy, reliable slow speed travel. This mechanism is the second iteration of a similar system in our previous competition vehicle, *Seabagel*.

2. *The Plaid Panther* will weigh significantly less than our previous vehicles. We believe that while most of our subsystems have performed well in the past, our greatest limitation has always been the vehicle's mass. We have spent significant time and effort in reducing weight while also ensuring safety through rigorous testing and analysis.

3. *The Plaid Panther* will have a considerably smaller and higher quality monocoque fairing than previous Olin College vehicles. We understand that the fairing is arguably the most crucial system for overall vehicle performance. Thus, we have developed new manufacturing techniques, performed extensive analysis-backed design iteration and laid out a more conservative fabrication schedule in order to elevate our fairing to a level of quality and safety unparalleled by previous team vehicles.

Contents

Part I

Design

The Plaid Panther was designed to compete in the 2013 ASME HPVC. Although the vehicle shares the same subsystem divisions as our previous vehicle, each subsystem has been revisited from the ground up in accordance with our team's commitment to annually evolve and innovate. The vehicle's components can be divided up into the Slow Speed Stability System, the drivetrain and the aerodynamic fairing.

1 Slow Speed Stability System (SSSS)

1.1 Design Goals and Objectives

A two-wheeled vehicle is inherently unstable when not travelling at a high speed. Because our vehicle is fully enclosed by an aerodynamic fairing, the rider cannot lower a leg for stabilization as one would on a traditional bicycle. *Seabagel*, our 2012 HPVC entry, had a landing gear system which linearly deployed two small stabilization wheels to the ground when actuated by the operator. The system generally worked, but was unreliable and heavy. This year, the system was completely redesigned to be faster, lighter and more reliable.

Figure 1: *Landing gear mounted on* Blueswagon*, an old prototype vehicle.*

In addition to reliability, simple and intuitive actuation was a priority in the system design. The landing gear is to be used when the rider is slowing to or starting from a halt and should not require complicated motions which could destabilize the vehicle. Last year's vehicle had a simple one-handle actuation method, but the landing gear relied on friction with the rear tire and had issues when the ground was wet. Furthermore, the two legs did not always extend and retract simultaneously. Also, the legs were retracted upward with a linear spring, which exerted maximum force when the legs were farthest down, occasionally causing the legs to under-deploy.

1.2 New Design and Improvements

After a full-team ideation session, the team zeroed in on a linkage inspired by the legs of a retracting music stand. The system has a carriage which slides on bearings over a welded aluminum frame. The carriage is attached to two legs which pivot about a sliding point lower on the frame (Figure 2). As the carriage moves downward, it pushes the wheel-tipped legs down and out of the fairing. The carriage is actuated by a winch at the base of the frame which uses power from the rear wheel to deploy the landing gear. Similar to our system from last year, a ratcheting system allows the landing gear to deploy when a brake lever is pulled all the way and retracts when the lever is pulled halfway. When the ratchet is released, a constant-force spring pulls the carriage upward, tucking the legs back inside the fairing.

Figure 2: *SSSS actuation motion*

The problems with last year's landing gear are addressed in our current design. Last year's method of power transfer from the rear wheel was problematic in that it would often lose friction and slip due to water and grit on the road; this year we decided to use a slip clutch separate from the rear wheel. Our old system also had flaws in the cable, pulleys, and elastic tubing system. The cables would occasionally escape their guides, wrapping around other components and jamming the system's operation. Problems with the elastic tubing would sometimes cause the legs to under-deploy. These problems were fixed by putting nylon webbing around a well-flanged spool along a straight pulley-less path and by replacing the elastic tubing with two constant-force springs. The new design also addresses the issue of weight, as the rollerblade wheels were replaced with custom-made plastic wheels mounted to the legs which hold up well under use.

1.2.1 Carriage

The sliding carriage (Figure 3) is the primary moving part of the SSSS deployment mechanism. The carriage constrains the leg movements to the plane of the welded frame and ensures that both legs deploy simultaneously. The carriage slides vertically on the welded aluminum tube frame and is guided by bearings (two pairs on one side and one pair on the other) and low-friction plastic sliders. On the front plate, two constant-force springs are connected from the top of the carriage to the top of the welded frame post to quickly retract the landing gear.

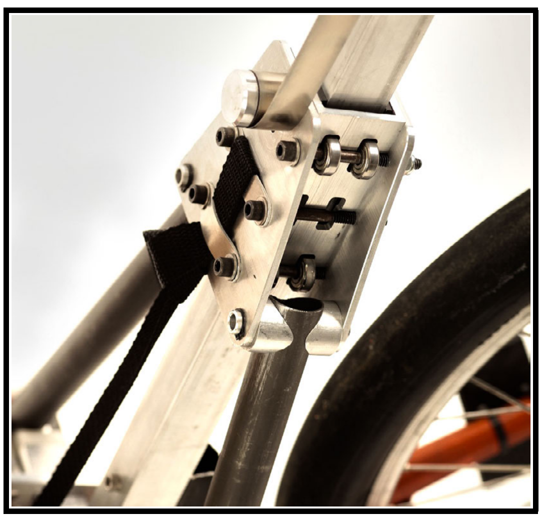


Figure 3: *SSSS carriage*

1.2.2 Power Transfer

The SSSS power transfer system did not initially work as designed. Our first prototype was a ratcheting winch where each pull of a lever on the handlebars brought down the landing gear by a fractional amount. This system failed because of unexpectedly high friction in the long brake cable line from the handlebars to the winch. So much power was lost to friction that it took an unreasonably high number of lever pulls for the landing gear to deploy.

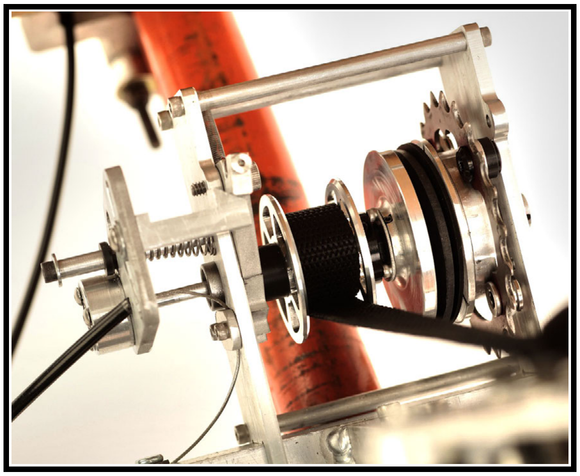


Figure 4: *SSSS deployment mechanism*

In our second prototype, we redesigned the winch to be powered by the rear wheel. To do this, a free-spinning sprocket in the winch was chained to a fixed cog on the wheel. The sprocket in the winch is also attached to a slip clutch disc with a rubber contact surface. The mating half of the slip clutch slides on the hexagonal torque-transferring winch shaft. When the brake lever is fully depressed, the slip clutch is pushed together with a concentric shaft and torque is transferred from the rear wheel into the winch. A spool pulls down the carriage with a length of nylon webbing, lowering the legs. The spool is rotationally locked by a ratchet and pawl on the winch shaft. When the brake lever is pulled halfway, a one-way latch disengages the pawl from the ratchet and the constant-force springs pull the carriage and legs upward into the fairing.

1.2.3 Deployment Indicator

The team encountered an issue last year during the endurance race: with the landing gear located behind the rider and out of sight, riders could not see the status of the mechanism. To resolve this issue, an LED indicator triggered by switches at the system limits will be included on the vehicle. With this addition, the operator will be aware of the state of the SSSS and able to safely decide whether to rely upon it when riding.

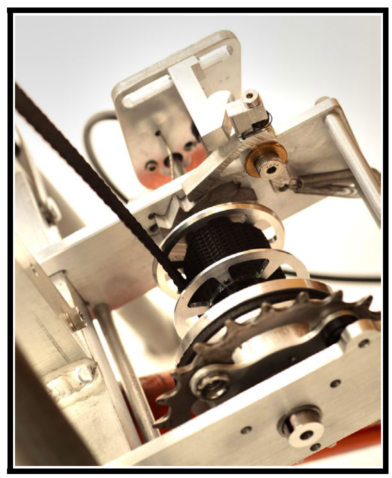


Figure 5: *SSSS actuation*

2 Drivetrain

The Plaid Panther features a unique drivetrain comprised of several assemblies connected by a monocoque fairing. Power is generated by the rider through the Rider Variation Compensation System then transmitted through the interchange to a derailleur on the front wheel of the vehicle. The vehicle's rear wheel is unpowered and is supported by the structural fairing.

The general configuration of our drivetrain design is extremely similar to the one on *Seabagel*, our 2012 vehicle. Although this report will focus on the changes made from last year in the Rider Variation Compensation System, information on the rest of the drivetrain can be found in our *2012 Design Report*.

2.1 Rider Variation Compensation System (RVCS)

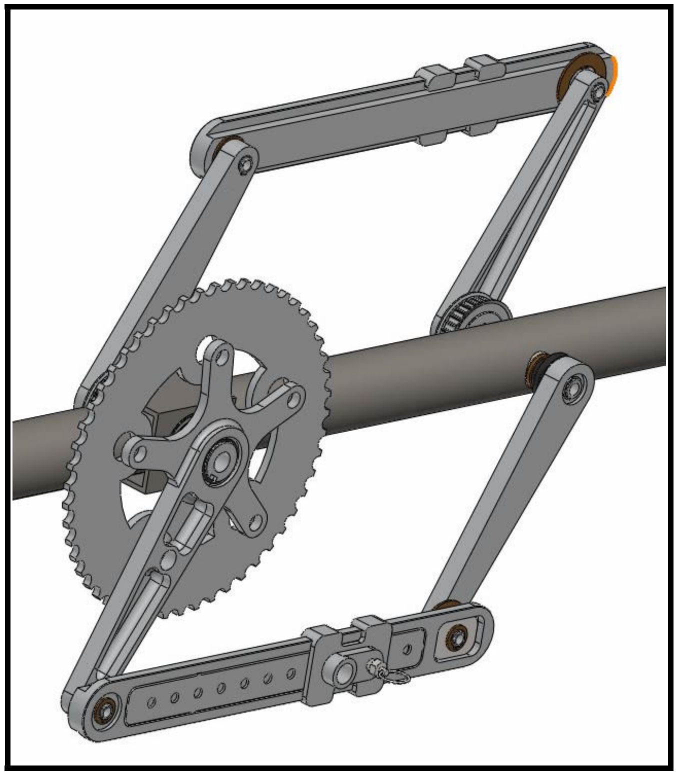


Figure 6: *Rider Variation Compensation System*

Our team members vary in height from 5'2" to 6'2". It is important to us that all of our team members are able to ride the vehicle and, as such, a mechanism is necessary to adjust for differences in size. Traditional adjustable seats work well but are slow to reposition and shift the position of the rider's body and head dramatically, necessitating a larger fairing and window. In order to keep the vehicle as compact as possible and reduce pit stop time, we designed a system of adjustable pedals for our 2012 vehicle. This system won the Design Innovation award at the 2012 HPVC East and we have developed a similar system for *The Plaid Panther*.

The mechanism consists of two parallel sets of cranks connected by a timing belt and horizontal members to hold the pedals. The blocks that hold each pedal house a spring plug that is easily retracted in order to slide the pedal and fix it at one of various positions along the horizontal member. More information about the general workings of the system can be found in our *2012 Design Report*.

Although last year's system worked well and had no failures over the vehicle's life, it was quite heavy. This year, we kept the concept but lightened the components as much as possible. This decision allowed us to focus our design efforts on other aspects of the vehicle. The current system design can be seen in Figure 6.

In last year's RVCS, the pedal blocks ran in channels machined out of the center of the horizontal members, as seen in Figure 7. In order to reduce weight and increase stiffness, this year's pedal blocks run on tracks on the exterior faces of the horizontal members, as seen in Figure 8. This system will be easier to machine with greater precision which will in turn more tightly restrict the rotation of the pedals along a vertical plane. The horizontal member is hollow to further reduce weight. The spring plug holes are on a plate that will be welded in place.

In addition to these changes, we have made many modifications to the crank axle connections. Previously, we used heavy shoulder bolts to attach the cranks to the horizontal members. We replaced these bolts with hollow aluminum pins with snap rings on each end, as seen in Figure 9. Each pin is used along with a flanged bushing and a thrust bearing. The pin on the front of the horizontal bar is mounted in a sliding block, allowing for an extra degree of freedom and avoiding over-constraint in the system.

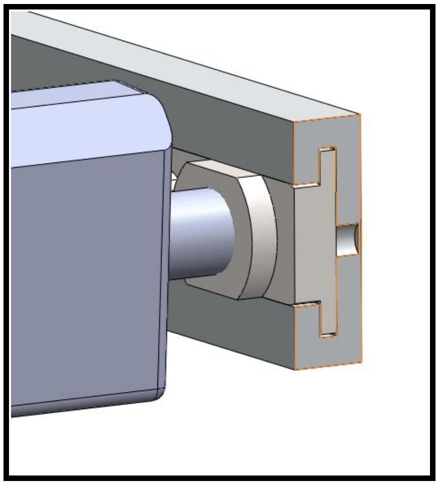


Figure 7: *2012 Vehicle RVCS pedal block on inside of horizontal member*

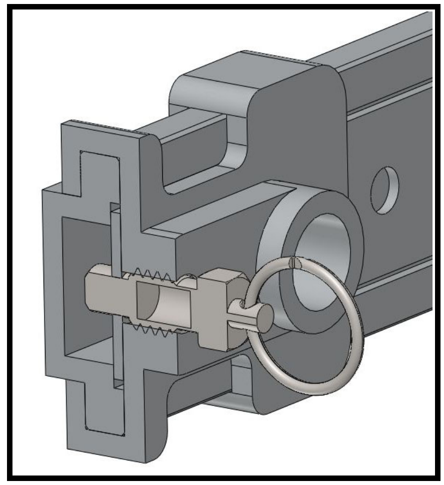


Figure 8: *2013 Vehicle RVCS pedal block on outside of horizontal member*

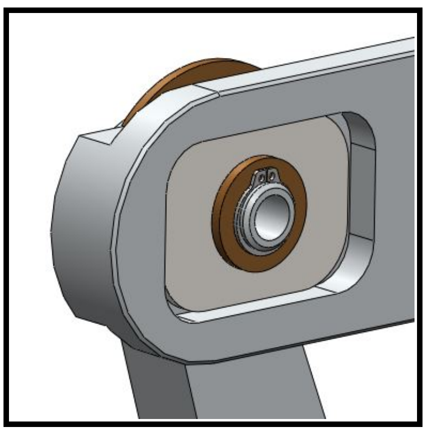


Figure 9: *Hollow pin connection with snap rings*

The front crank axle was formerly a heavy steel keyed shaft but has been replaced with a high-strength aluminum hex shaft for simplicity and weight reduction. After having success with an aluminum hex shaft in the SSSS, we decided to use the same material for this shaft. Because no load is transmitted through the front crank axle, the shaft support bearings have been replaced with bushings to reduce weight, as seen in Figure 10. Snap rings are also used on this axle to replace bolts and clamps previously used to fix each crank horizontally in place. The bushings on the shaft are within a tube that passes through the frame to keep them in place. The back crank axle has also been altered slightly. It still uses a keyed shaft and bearings. However, snap rings once again replace bolts and clamps on the cranks. The back crank axle is pictured in Figure 11. Expanding wave washers are used to take up axial slack on all shafts and pins in the system.

Through redesign, we have reduced the weight of the RVCS from 6.0 lbs to 4.0 lbs. We have also simplified manufacture and improved precision. We have greatly refined what has already proved to be a reliable system, helping us to maximize the efficiency of the vehicle.

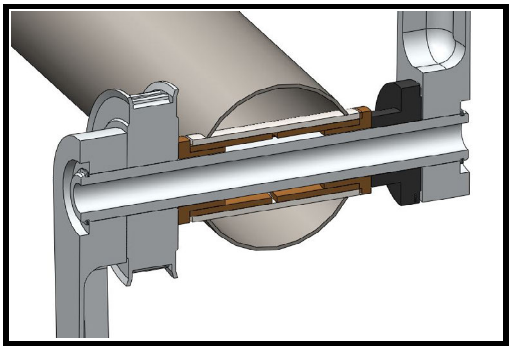


Figure 10: *Front crank axle using snap rings, hex shaft, and bushings*

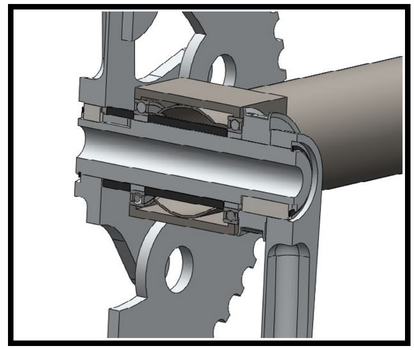


Figure 11: *Back crank axle using keyed shaft, snap rings, and bearings*

3 Aerodynamic Fairing

3.1 Design

3.1.1 General Shape

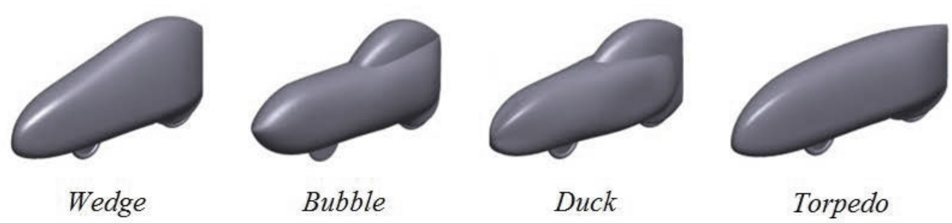


Figure 12: *Four fairing paradigms from which fairing design begins.*

In Fall 2011, the team worked to identify four promising fairing shape concepts, shown in Figure 12. Our 2011 and 2012 final fairings were closely designed around the *Wedge* shape due to its very low coefficient of drag and good ridability. However, our previous experience with the *Wedge* highlighted that its large surface area adds unnecessary mass to the fairing. The wedge has no convenient window surfaces, forcing us to build a large window with mediocre visibility which limits rider confidence in the vehicle. We created the design matrix seen in Figure 13 to reanalyze our fairing design direction for this year and decided to move forward with the *Duck* shape.

	Importance Factor	**Torpedo**	**Wedge**	**Duck**	**Bubble**
C_dA	1x	1	0	0	-1
Visibility	2x	-1	0	1	1
Weight	1x	1	-1	0	0
	Total	0	-1	2	1

Figure 13: *Decision matrix leading us to design around the* Duck *paradigm.*

3.1.2 Cross Section Reduction & Taper Length Maximization

In order to decrease aft air flow separation, the team worked to maximize the length, and thus decrease the curvature of the fairing's tapered rear portion. Previously, the vehicle's taper began at the rider's widest point, the shoulders. However, *The Plaid Panther's* design leverages the fact that a rider's shoulders only constrain one point on the fairing's surface rather than an entire cross-sectional plane. *The Plaid Panther* uses the rider's hips, shoulders and head to constrain the shape. Because these body parts are located at different positions along the vehicle's length, some tapers (i.e. the taper at hip height) are started before others. This difference is best highlighted in Figure 14.

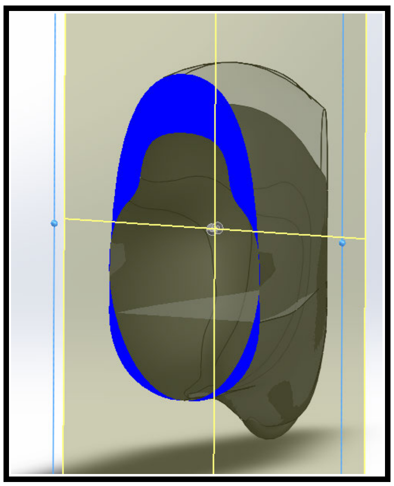


Figure 14: *Comparison of fairing cross-section at rider's shoulders. Note the reduction in fairing width at the head and hips, but not at the shoulders. This allowed for smoother rear tapers.*

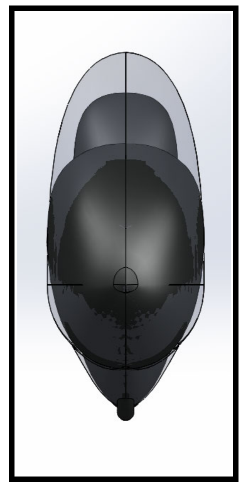


Figure 15: *Comparison of fairing front profiles. Testing showed that* Seabagel's *fairing contained far more head room than necessary. This change creates our greatest source of frontal area reduction.*

3.1.3 Rollover Protection System (RPS)

The Plaid Panther's RPS design incorporates a hoop of carbon fiber, XPS foam and Kevlar on the interior of the fairing. Two $\frac{7}{8}$" horizontal steel cross tubes provide additional support. The top tube will serve as a head rest while the lower tube supports the SSSS. For the composite construction, the base layer consists of two sheets of carbon fiber followed by a strip of XPS foam with a cross section of $\frac{1}{4}$" x 4" to provide structure. A 4-layer carbon sheet holds the foam strip to the base layer and adds to the overall strength. The innermost Kevlar layer was added to provide more protection for the rider. The RPS shape and layer structure are shown in Figure 16.

3.1.4 Door

The team's previous vehicles have had a fully removable top to allow easy rider access. In order to keep the RPS contiguous and allow faster entry and egress, we have decided to employ a door for vehicular access. Our chosen door design pivots on two hinges mounted along the horizontal centerline of the vehicle. This method keeps the hinges in line, pro-

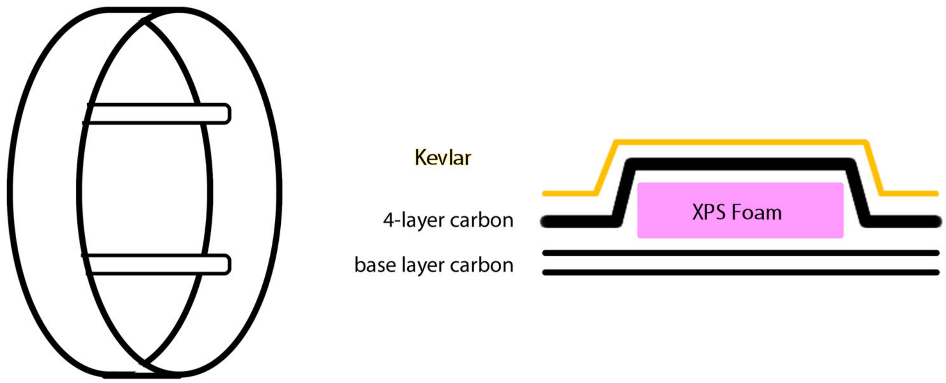


Figure 16: *Rollover Protection System geometry and composition*

vides a well-attached door and allows us to run a composite rib over the centerline of the monocoque, protecting the rider from impacts.

In order to avoid unnecessarily weakening our monocoque, we kept the door as small as possible. The door profile was shaped around the area needed for the largest rider to exit the vehicle.

The rider's safety was kept in mind when choosing door location. Analysis of past vehicles showed noticeably more scrapes on the left side than the right. This evidence led us to place the door on the right hand side, reducing the chance it will be landed on. We also adjusted its position to stop the vehicle from resting on it when it lies on its side. As an additional safety feature, hinges with removable pins accessible from both the inside and outside allow the rider to easily escape if the vehicle falls on the door.

3.1.5 Window

The team's previous vehicles have all had windows which could be very closely approximated as conical sections, allowing them to be simply cut out of a flat sheet of flexible and impact-resistant polycarbonate plastic. The *Duck* shape, which was chosen for *The Plaid Panther*, does not have this property, and the window would need to be molded to take the exact designed window shape. After brief testing in the 2011-2012 season, we do not feel confident in our ability to mold polycarbonate without significant optical distortion. To address this, we used Lamina Design to approximate the curved window as a flat sheet with a single bend, allowing us to easily manufacture the window.

3.1.6 Access Hatches

The Plaid Panther features two access hatches, one at the vehicle's nose and one at the rear. The hatches, shown in Figure 17, allow for easy maintenance and cargo storage.

3.2 Fairing Manufacture

Last year, we developed a fairing manufacture process which has been the primary inspiration for this year's fabrication. This report will highlight the improvements upon this process but will not detail every aspect. More information on the overall process can be found in our *2012 Design Report*.

Figure 17: *The vehicle's two access hatches allow for easy storage and maintenance.*

3.2.1 Mold Design

Last year's female mold was made up of four quarters split along the vehicle's length. The quarters were bolted together along flanges in multiple configurations to allow for various lay-ups. The top half of the vehicle was built in two quarters while the bottom half was a single lay-up. After building mating lips between the top and bottom, the top quarters were joined with additional carbon layers. Further composite work was done to produce the RPS and reinforcing ribbing around the fairing.

This process had notable flaws including a high labor cost due to the large number of lay-ups and a heavy fairing from the rejoined top halves and the joining lip design. This year's mold design ameliorates these two issues.

This year's fairing mold was made up of three sections with mounting flanges: two bottom halves and one top section, roughly dividing the fairing's exterior into thirds. These sections have a hole at the door which allows interior access when all three mold pieces are united. This design allows us to produce the fairing body, including the RPS and all ribs, within a single united female mold. This method saves weight by removing the need for any reattachment of fairing sections, improved strength by using continuous fiber lengths, and reduced the total labor cost of producing the fairing.

3.2.2 Door Mold

This will be the team's first year with a door in our fairing rather than a removable top half. To construct this feature, we decided to create an additional female mold from the male plug. The door mold shape extends around the planned door location on all sides to grant flexibility in door latching. To produce clean and safe edges, the carbon weave will be folded onto itself, creating a rounded termination as opposed to the rough edges produced by a cut-off wheel.

3.2.3 Mold Materials

Last year's molds used one layer of bi-directional weave fiberglass as the innermost surface of the female molds with three layers of chopped fiberglass mat to add thickness and rigidity. The issue with fiberglass mat is that it dries into very sharp, hard spikes on the exterior of the female mold. These spikes cause minor physical damage to team members during fairing lay-ups and poke holes in vacuum bags, reducing the pullable vacuum level. These issues led us to pursue an alternative material for the exterior of our molds. Our composites supplier recommended a thick fiberglass-basalt weave. After an initial test showed the superior stiffness and the smoother exterior produced by the basalt weave, we applied it to our mold.

Our final mold composite structure has the aforementioned single layer of bi-directional fiberglass weave, one layer of fiberglass mat (while our remaining supplies held), and then a final layer of fiberglass-basalt weave cut in large patches on the exterior of the molds. This structure provided a suitably stiff mold and is less likely to puncture bags. The mold is shown in Figure 18.

Figure 18: *Fiberglass and basalt top mold.*

3.2.4 Mold Preparation

For the 2012 fairing, a combination of wax and polyvinyl alcohol (PVA) was used as mold release on both the male plug and female molds. These methods were successful but labor intensive both in application of wax and PVA and for finally releasing the mold. To find an improved method, we tried a technique developed by Rose-Hulman's HPV Team last year and applied a layer of packing tape to the male plug. We were pleased with the release results from these tests, except around areas of high curvature where the edges of the tape produced pronounced ridges in the composite mold. This issue was alleviated by applying a standard clothing iron at moderate temperature to the tape. This method very effectively smoothed out the fairing, producing an excellent mold surface. Wax and PVA were still used on the interior of the female molds when preparing for the fairing lay-ups.

Part II

Analysis

4 Rollover Protection System Analysis

A model of *The Plaid Panther's* rollover protection system (RPS) was simulated with the shell element analysis capabilities of Solidworks Simulation 2012. The model was created with surface elements, as described by *GoEngineer's online tutorial.* As Solidworks does not provide complete composite material properties, the composite sandwich strength was found experimentally as described in Section 8. The only geometric simplifications exist in the areas around the wheel box. Because these regions will be rigidly connected to the seat, which is held fixed during testing, we trust that this decision will not invalidate our results.

Two simulations were conducted. In the first, a 600lb load was applied to the top of the RPS at 12° from vertical towards the front of the vehicle. In the second, a 300lb load was applied at shoulder level. The measured deformation of the RPS is 1.25in for the top load case and 2in for the side load case. Although this value is greater than allowed by the HPVC rules, we believe that the simulational simplifications are affecting our results and expect the tested deformation to be much lower.

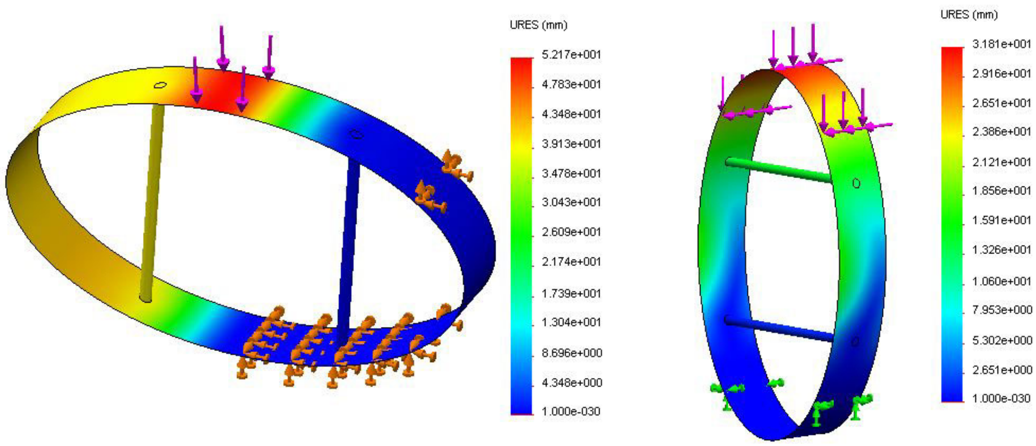


Figure 19: *Simulated displacement when the rollover protection system is subjected to a 600lb top load at* 12° *from vertical (left) and a 300lb side load at shoulder level (right).*

In both simulations, the RPS was held fixed at the seat. The results show that the greatest stresses occur where the steel support tubes meet the composite portion of the RPS. However, our flanged mounting system puts this stress into strong steel welds which we are confident will support the load.

5 Aerodynamic Analysis

Computational fluid dynamic (CFD) analysis was used to validate design decisions made in the fairing design process. Both the drag force on the vehicle and the crosswind ridability were analyzed.

5.1 Drag Force

The fairing was tested using CD-adapco's STAR-CCM+ CFD simulation software. As we iterated upon the design, analysis ensured that the design changes were improving the aerodynamics of the vehicle.

The simulations assumed a vehicle speed of 30mph and included the effects of the ground moving under the vehicle. Modeling the ground movement gives more accurate measurements by preventing inaccurate deflation of drag coefficients. The wheels were modeled as solid static bodies, an approximation to make the simulation easier.

Fairing performance depends on drag force, a function of drag coefficient, frontal area, air density and velocity. By factoring out the constants, we can compare our fairings on the metric of C_dA (drag coefficient times area). We derived C_dA values from the simulated drag forces and a known air density and fluid velocity (Figure 20).

The results indicate a significant improvement between the initial concept and the final vehicle design. Simulational analysis facilitated this jump and is responsible for the excellent aerodynamic properties of our vehicle. It is also important to note that this year's fairing has a higher drag coefficient than last year's. Although last year's vehicle was a more aerodynamic shape, *The Plaid Panther* has a smaller frontal area which allows its C_dA value to be the lowest of any vehicle the team has ever made. The fluid velocity profiles for the 2013 and 2012 competition vehicles are shown in Figure 21 and highlight the improvements made in the design of *The Plaid Panther*.

	F_D (N)	C_dA (m^2)	C_d
The Plaid Panther (2013)	3.6	0.033	0.094
Seabagel (2012)	3.94	0.036	0.087
Duck (Initial Concept)	4.59	-	-

Figure 20: *Drag Force Simulation Results.* The Plaid Panther *has the lowest drag force of any vehicle the team has ever built.*

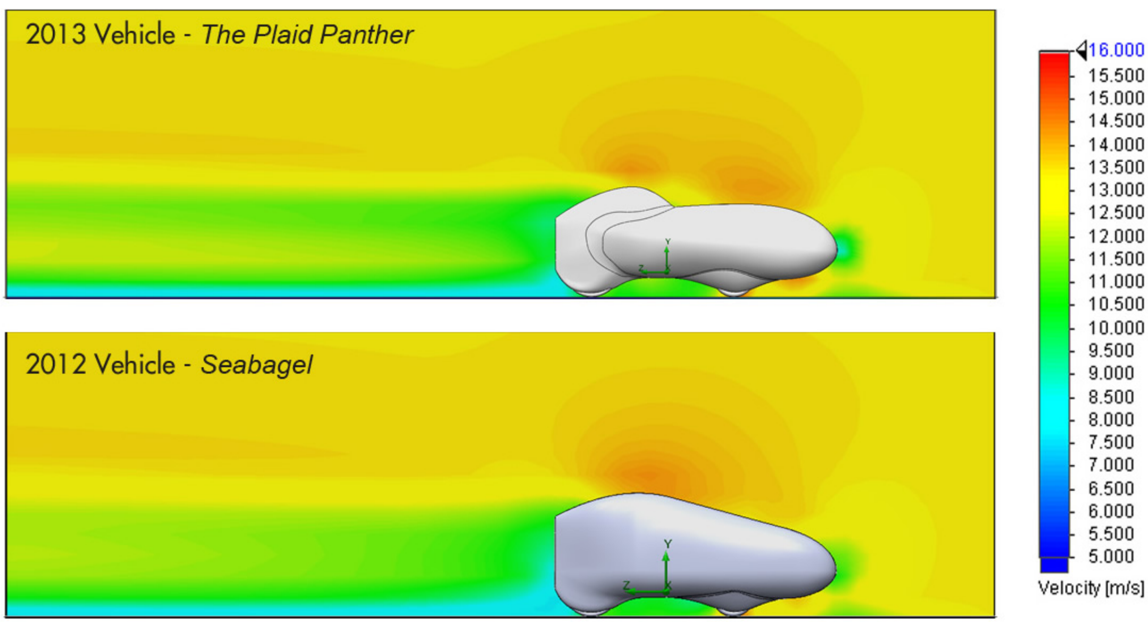


Figure 21: *Simulated fluid velocity profiles for the 2013 and 2012 competition vehicles. Although the vehicles have similar shapes, there is less stagnant air behind the 2013 race vehicle, decreasing its drag force. Note that these profiles were generated in SolidWorks Flow Simulation 2012 as access to STAR-CCM+ was not available when generating the figures.*

5.2 Crosswind Performance

To ensure that the vehicle will ride well in a crosswind, additional simulations were performed for both the 2012 and 2013 race vehicle designs in SolidWorks Flow Simulation

2012. A 10mph crosswind was added to the 30mph frontal air speed of the previous simulation. Although the simulated flow profiles are very similar for both vehicles, the new vehicle has a smaller side area and less drag in a crosswind (Figure 23).

In order to ensure ridability, the fairing lean angle necessary to keep the vehicle upright in a crosswind is calculated from the drag force numbers. For the simulated conditions, the necessary angle is less than that of *Seabagel* (Figure 22). Because last year's vehicle has no ridability issues in crosswinds, we are confident that *The Plaid Panther* will be devoid of issues as well.

$$\theta = atan(\frac{F_d}{mg})$$

	F_D (N)	m (lb)	θ
The Plaid Panther (2013)	90.6	190	6.11º
Seabagel (2012)	123.2	200	7.88º

Figure 22: *The crosswind simulation results indicate that The Plaid Panther will need to lean less than Seabagel to stay upright in a crosswind.*

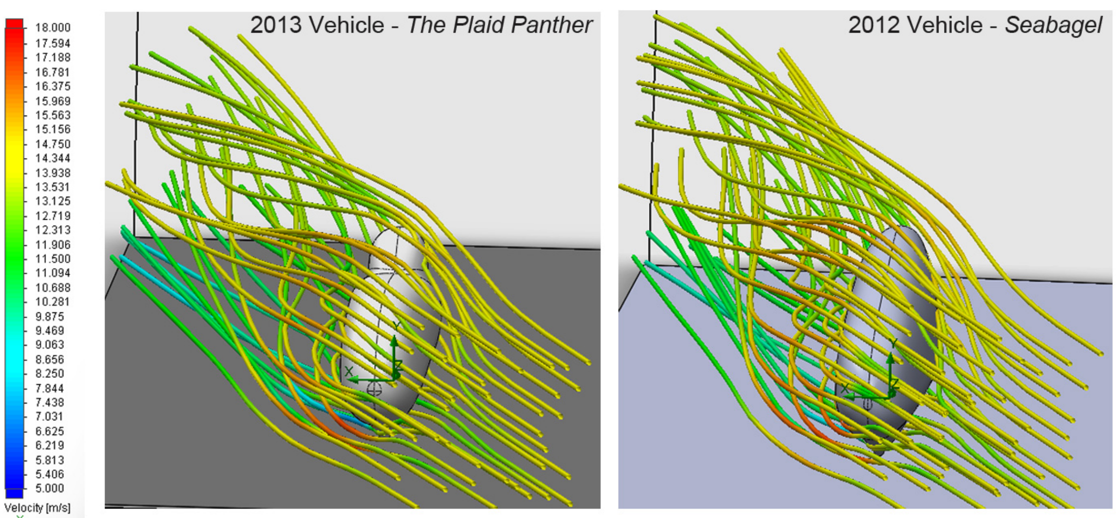


Figure 23: *As the crosswind flow profiles demonstrate, the 2013 vehicle has less area when viewed from the side and has significantly less drag force in a crosswind.*

5.3 Window Approximation Analysis

The final fairing's window will be an approximation of the designed shape to ease manufacturability. We decided to analyze the amount of deviation between this approximation and the original design. A comparison of the two shapes highlights that the shapes are very similar although the approximation hugs the riders helmet more closely. Moving forward, we believe that this approximated shape will work well, maintaining the structure in this critical area while also remaining reasonably aerodynamic.

6 Structural Analysis

6.1 Drivetrain Analysis

Analysis was performed for the components of this year's vehicle which were modified from last year. The analysis for the parts which have not changed significantly from last year's design will not be repeated in this year's report and can be found in our *2012 Design Report*.

6.1.1 Front Frame

We use finite element analysis (FEA) to investigate whether a cantilevered front frame supported between the rider's legs would be viable. The simulation indicated that a maximum deformation of just under 1/4" would occur on the weldment from simply the load of the front wheel pushing upward on the frame. Although the yield strength of the material was not reached, this deformation is high and we were not comfortable moving forward with this design.

A dually-supported frame was then investigated. The simulation indicated that the frame has a factor of safety of over 10 when all expected loads are applied. Furthermore, the lowest natural frequency the system is about 135 Hz, far above what is expected from either a pedaling rider (maximum 2-3 Hz) or bumps on the road. This analysis has given us the confidence to move forward with the vehicle's frame design. More information and pictures from the front frame analysis are available on our *team website*.

6.1.2 Rider Variation Compensation System Tuning

In designing our RVCS this year, our main goal was to reduce weight. The total weight of the system was reduced from 6.0lbs to 4.0lbs. Approximately 0.36lbs were taken from the horizontal members, and 0.88lbs from miscellaneous axles, bearings, and attachments. The single biggest weight saver was eliminating 0.80lbs from the crank arms. In removing so much weight from the cranks, we had to be sure that they were still structurally sound and performed FEA on each arm. Besides removing the clamp elements from the end of each arm, we also opened the pockets (Figure 24). The FEA was performed to assure us that the size of the pockets would not cause crank failure.

Because the front cranks of the system are attached to the horizontal component at axles on a sliding block (Figure 9), they will not be supporting significant loads. We therefore only analyzed the structure of the back crank arms. We assumed that the maximum force applied to a pedal is approximately 200lbs and that this force is applied 0.25" away from the face of the crank in contact with the horizontal pedal bar. This force is applied by the pedal bar to the inner hole face.

The back left crank is keyed to the shaft and back right crank, which attaches directly to the chain ring (Figure 6). In analyzing the back left crank arm, we modeled the hole for the keyed shaft as a fixed hinge and the face in the keyway at which force is applied with a sliding constraint. This assumes that the key is rigid and the keyway can move only parallel to the key's face. We also defined the segment of the main face in contact with the horizontal pedal bar as a sliding constraint as this portion will not be twisting relative to that face.

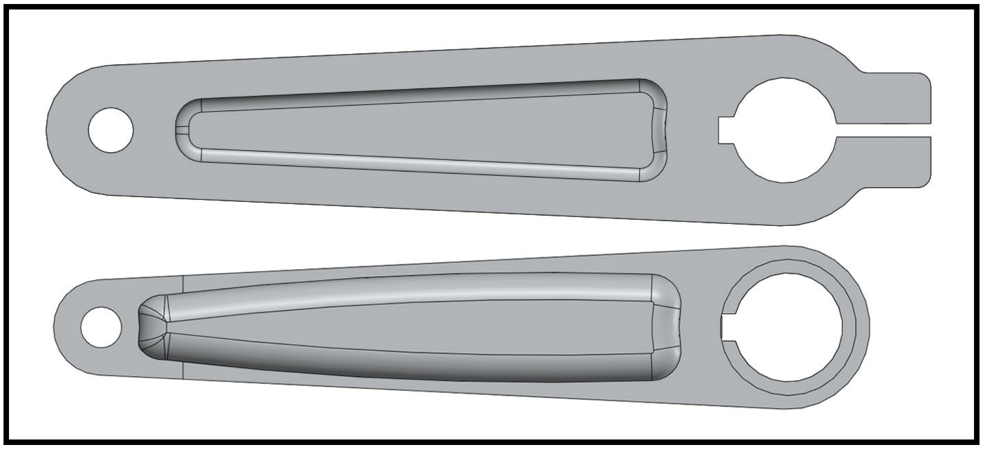


Figure 24: *2012 Vehicle Crank Arm (top) and 2013 Vehicle Crank Arm (bottom)*

The FEA model of the left rear crank can be seen in Figure 25. In this figure, the maximum visible stress is approximately 50MPa, giving us a factor of safety of 5.5. If we look more closely at the keyway in Figure 26 however, the maximum stress here is about 243MPa, giving a factor of safety of 1.13. We are not concerned with this stress because the excess material behind this location takes minimal stresses.

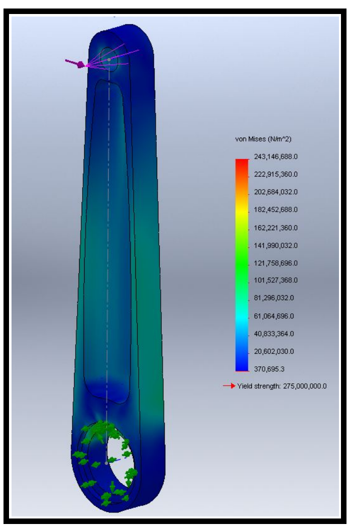


Figure 25: *FEA model of left rear crank arm*

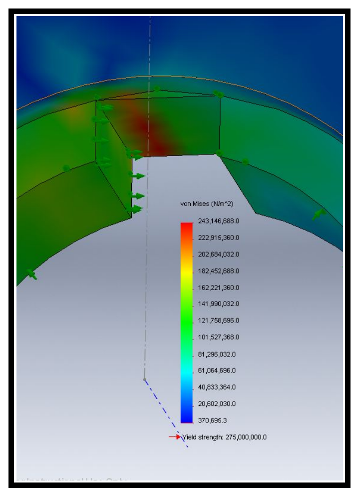


Figure 26: *FEA model of left rear crank keyway*

The back right crank is keyed to the shaft and bolted to a chain ring. The same sliding condition has been placed on the segment of the main face in contact with the horizontal pedal bar, restricting rotation of the arm at that point. The shaft as well as the five bolt holes have been constrained with hinge constraints. The same 200lbf load is applied at 0.25in from the face in contact with the horizontal pedal bar. An additional force of 2520lbf is applied on a face of the keyway, representing the force applied by the opposite pedal on the key. These forces and constraints can be seen in Figure 27. The maximum stress in the crank arm is about 65MPa giving a factor of safety in the arm of 4.2. The maximum stress in the crank is again seen in the keyway in Figure 28. This maximum stress of 73MPa still gives a factor of safety of 3.79.

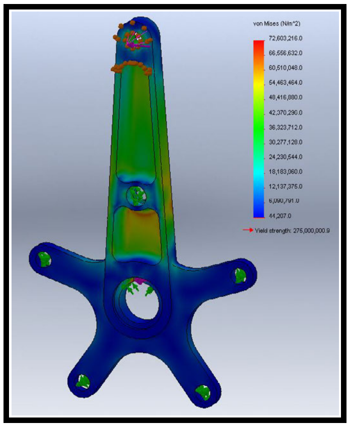


Figure 27: *FEA model of right rear crank arm*

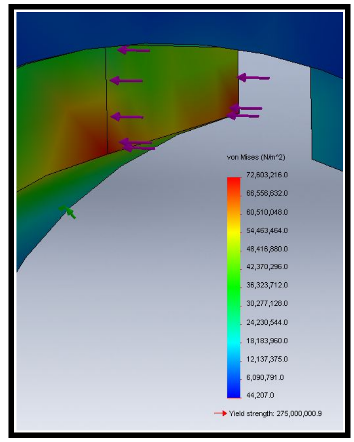


Figure 28: *FEA model of right rear crank keyway*

After removing more material from the pocket area of each crank, we successfully reduced weight while maintaining structural integrity. The factors of safety on each load-bearing crank are high enough to satisfy our requirements. Although the factor of safety is lower in the keyway of the left load-bearing crank, we are confident that the excess material backing the keyway will provide ample support.

6.2 Slow Speed Stability System

One of the limiting factors of the SSSS is the strength of the anti-backdrive ratchet. The first prototype built had teeth so coarse that the SSSS could not fully deploy. The support wheels need to be as close to the ground as possible to prevent vehicle wobble. Ratchets of a constant pitch diameter with tooth counts between 12 and 28 were analyzed with FEA.

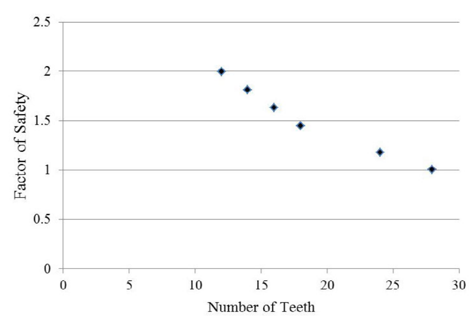


Figure 29: *Factors of safety for various ratchet geometries. The final system will utilize a 24T ratchet.*

As a worst case scenario, the simulation assumes that 35% of the vehicle and rider's mass is carried solely by one SSSS leg while the other 65% is carried by the front wheel. This scenario applies 107lbf to the ratchet tooth face. The simulated factors of safety for the various ratchets are shown in Figure 29. Because a 24-tooth ratchet provides the desired resolution and strength, it is implemented in the final SSSS. Even-toothed ratchets also have the benefit that they are easier to hold in mill vice jaws, cementing the decision to implement a 24-tooth ratchet.

7 Cost Analysis

The costs for *The Plaid Panther* are assessed with the following estimates. These assume free labor, no major capital investment, and no bulk purchase savings.

Single Vehicle

Parts and Materials	**Quantity**	**Price**	**Unit**	**Total**
Drivetrain				
6061 T6511 Aluminum 0.5" x 6" Bar	3	$15.84	Per Foot	$47.52
Thin Walled 4130 Steel Tubing 1.75'	6	$6.00	Per Foot	$36.00
Derailleur	1	$50.00	Per Unit	$50.00
Wheels	2	$100.00	Per Wheel	$200.00
Chains	2	$20.00	Per Unit	$40.00
Pedals	1	$35.00	Per Set	$35.00
Various Hardware	1	$50.00	Lump Sum	$50.00
Welding Supplies	1	$5.00	Lump Sum	$5.00
Crankshaft Aluminum	11	$15.00	Per Unit	$165.00
Crankshaft Bearing	2	$25.00	Per Unit	$50.00
Disk Brakes	1	$50.00	Per Unit	$50.00
Pedals	1	$35.00	Per Unit	$35.00
			Total	$763.52
Frame				
Thin Walled 4130 Steel Tubing 7/8"	10	$3.50	Per Foot	$35.00
Thin Walled 4130 Steel Tubing 1.25'	4	$3.70	Per Foot	$14.80
Welding Supplies	1	$5.00	Lump Sum	$5.00
Assorted Mounting Hardware	1	$10.00	Lump Sum	$10.00
			Total	$64.80
Fairing				
Carbon Fiber BiWeave Fabric	15	$20.00	Per Yard	$300.00
Carbon Fiber QuadWeave Fabric	1	$35.00	Per Yard	$35.00
Kevlar Fabric	1	$19.00	Per Yard	$19.00
Epoxy Hardener	0.5	$30.00	Per Gallon	$15.00
Epoxy Resin	1.5	$60.00	Per Gallon	$90.00
Vacuum Bagging Supplies	1	$280.00	Lump Sum	$280.00
PETG (2' x 2' x 1/16")	1	$21.00	Per Sheet	$21.00
			Total	$760.00
			Parts and Materials Total	$1,588.32
Tooling				
Fairing Mold				
Fiberglass Fabric	10	$9.00	4' Yard	$90.00
Fiberglass Basalt	20	$8.00	4' Yard	$160.00
Epoxy Hardener	0.5	$30.00	Per Gallon	$15.00
Epoxy Resin	1.5	$60.00	Per Gallon	$90.00
Vacuum Bagging Supplies	1	$50.00	Lump Sum	$50.00
			Total	$405.00
Frame Jig				
Thin Walled 4130 Steel Tubing 7/8"	6	$3.50	Per Foot	$21.00
Thin Walled 4130 Steel Tubing 1.25'	3	$3.70	Per Foot	$11.10
			Total	$32.10
			Tooling Total	$437.10
			Total Cost (Single Vehicle)	**$2,025.42**

The cost estimates for a limited-scale production run are outlined below. Estimates are made assuming a three-year production run of ten vehicles per month, including labor costs and equiptment capital investment. We are also assuming bulk purchase savings of 40% on parts and raw materials.

Production Run

Parts and Materials	Quantity	Price	Unit	Total
Bulk Purchase Discount		40%	Percent Saved	
Production Run Materials	10	$952.99	Per Vehicle	$9,529.92
			Parts and Materials Total	$9,529.92
Tooling				
Frame Jig	1	$32.10	Per Month	$32.10
Fairing Molds	1	$405.00	Per Month	$405.00
			Tooling Total	$437.10
Overhead				
Building Rent	1	$1,500.00	Per Month	$1,500.00
Utilities	1	$400.00	Per Month	$400.00
Welder Operating Costs	1	$20.00	Per Month	$20.00
Machine Maintenance	1	$20.00	Per Month	$20.00
			Overhead Total	$1,940.00
Labor				
Machinist/Welder	3	$3,200.00	Per Month	$9,600.00
Composite Technician	3	$2,080.00	Per Month	$6,240.00
Floor Worker	4	$1,600.00	Per Month	$6,400.00
Manager	1	$4,800.00	Per Month	$4,800.00
			Labor Total	$27,040.00
			Monthly Total	**$38,947.02**
Capital Investment				
CNC Router	1	$15,000.00	Initial Purchase	$15,000.00
CNC Mill	1	$22,000.00	Initial Purchase	$22,000.00
Lathe	1	$20,000.00	Initial Purchase	$20,000.00
Water Jet Machine	1	$30,000.00	Initial Purchase	$30,000.00
Welder	1	$3,500.00	Initial Purchase	$3,500.00
Grinder	1	$150.00	Initial Purchase	$150.00
Band Saw	1	$2,000.00	Initial Purchase	$2,000.00
Vacuum Pump	1	$350.00	Initial Purchase	$350.00
			Capital Investment Total	**$93,000.00**

Production Cost Prediction by Month

Months	Total Cost	Cost Per Vehicle
1	$131,947.02	$13,194.70
3	$209,841.06	$6,994.70
6	$326,682.12	$5,444.70
12	$560,364.24	$4,669.70
24	$1,027,728.48	$4,282.20
36	$1,495,092.72	$4,153.04

These estimates show the cost of producing a vehicle on a small consumer scale, demonstrating the possibility of it as an alternative to traditional means of transportation.

Part III
Testing

Many of the components of our vehicle were tested either to validate the results of our analysis or to ensure proper functionality of the designed mechanisms.

8 Rollover Protection System Testing

As fabrication on *The Plaid Panther* is not complete, we are not able to test the final system. Though the following tests provide confidence that the vehicle will meet all ASME specifications, we will perform requisite testing on the system prior to use. This testing will be featured in our Design Report Update.

As composite material properties depend on a wide range of variables, we found testing necessary to define the parameters used in RPS analysis. To this end, we performed three-point bend testing on roll hoop cross sections. We then replicated this testing in simulation, creating a custom material with the stiffness matching that of our roll hoop samples. This custom material was then used in analysis of the rollover protection system (Section 4). Note that this method simplifies the carbon sandwich described in Section 3.1.3 to a linear, homogeneous, isotropic material. Though none of these adjectives describe carbon matrices, load-cell testing showed these are safe assumptions for the loads we expect to undertake.

Supporting our analysis is the fact that this year's rollover protection system is a one-piece version of that of our 2012 vehicle, *Seabagel*. *Seabagel*'s system passed necessary testing, deforming less than 15% of the maximum amount permitted by ASME regulation. We predict that *The Plaid Panther*'s RPS will be even stronger as it is one-piece and will have no problems passing requisite testing.

8.1 Splintering

In the event of catastrophic failure, carbon fiber can splinter and potentially injure the rider. To alleviate this issue, the team tested samples of a plain carbon twill weave, like that of the monocoque, with and without a Kevlar lining. The Kevlar-lined samples were not only stronger but also exhibited no splintering whatsoever, even when the sample was bent back on itself (Figure 30). The results of these tests have inspired us to line the rollover protection system with a layer of Kevlar to keep the rider safe in the event of catastrophic failure.

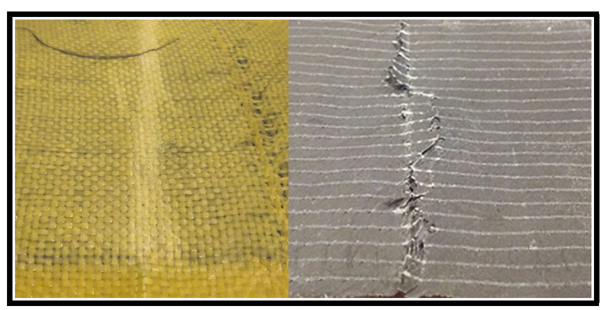


Figure 30: *A layer of Kevlar (left) prevents carbon splintering (right) in the event of catastrophic failure.*

9 Developmental Testing

In the development of the vehicle's subsystems, tests were performed to confirm assumptions made during component design and to develop manufacturing techniques. The most useful tests are detailed in this section.

9.1 Superman Rider Position

At the beginning of the year, the team investigated the possibility of a prone rather than recumbent rider position. We implemented a series of tests where a rider laid on her stomach on a support 2ft above the ground and pedaled a generator. We found that the position was uncomfortable and were concerned by the risk of headfirst collisions and so abandoned the idea.

9.2 Fairing Size Reduction

Last year's vehicle, *Seabagel*, had a large amount of unnecessary space around the rider. In order to determine the areas in which space reduction could occur, tests were performed in Fall 2012 where progressively larger blocks of foam were inserted into areas around the rider's shoulders and head until they could no longer comfortably ride the vehicle. We found that about 3" of space could be taken away from the top of the vehicle and the area on either side of the rider's head could be reduced significantly. Furthermore, the total width of the fairing could be reduced by up to 1". These results guided the process as the team designed *The Plaid Panther*.

Figure 31: *Fairing size validation*

9.3 Fairing Size Validation

The team strives to build a vehicle that all members can easily ride. To determine whether the fairing would fit all riders, fairing cross sections were cut out of cardboard and assembled for the tallest team members to sit in. The riders wore a helmet, mocked pedaling and practiced entry and egress in order to ensure proper fit.

9.4 Slow Speed Stability System

This year, the team built two iterations of the SSSS. After building the initial design, thorough testing indicated that the deployment winch was severely flawed. Significantly higher friction than expected was experienced in the brake cable used to actuate the landing gear. Because the winch relied on power from the brake handle, a large number of pulls were needed to deploy the system. Although the winch failed, testing of the carriage system indicated that it would successfully give *The*

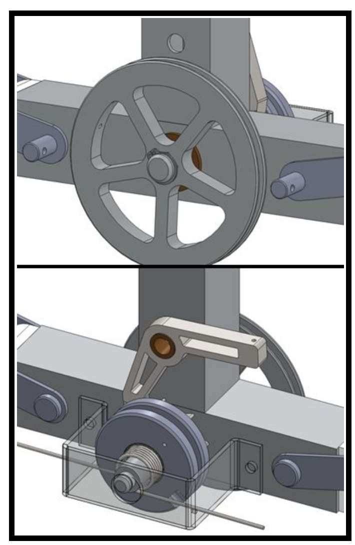


Figure 32: *Initial landing gear prototype winch*

Plaid Panther the desired deployment motion.

When building the second iteration of the SSSS winch, testing indicated that the sliding actuation plate was over-constrained leading to binding (Figure 33). The issue was corrected by removing the three pins holding the plate in place and replacing them with a single properly-constrained slider (Figure 34). Otherwise, the new winch system worked as designed and was implemented on the final vehicle.

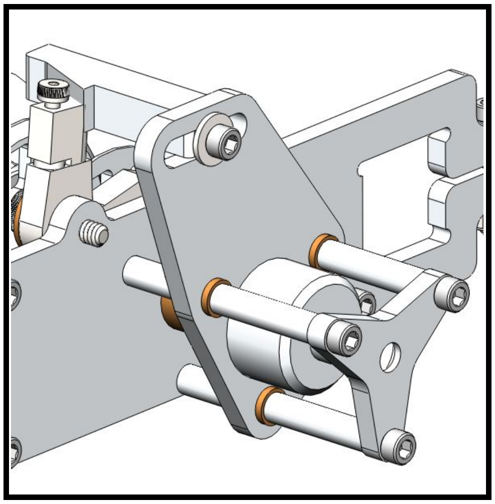


Figure 33: *Overconstrained SSSS Design*

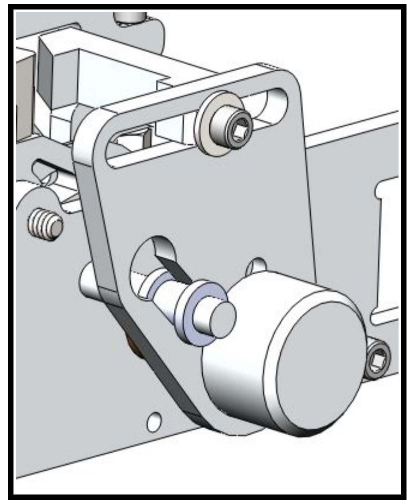


Figure 34: *Improved SSSS Design*

Besides the winch, testing was also done on the sheet metal brackets which provide a reaction force on the landing gear legs. It was found that the brackets were very strong along their length but suffered from bending when side loads were experienced. Because the landing gear is oriented at an angle in the vehicle, these brackets experienced significant side loads and deformation. To alleviate this issue, the brackets were replaced by a stronger milled part which better resists flexure.

9.4.1 Ratchet Resolution

Testing showed that our SSSS deployment winch struggled to lock the system's support wheels within 1/2" of the ground. Though the vehicle was still stable during testing, riders lacked confidence in the system. Also, the closer the support wheels are to the ground, the less they must be relied on for stabilization, thus subjecting the entire system to lighter loading.

Through testing, we judged that locating our wheels within 1/4" of the ground would provide sufficient stability. To this end, we will double the number of teeth on the SSSS winch's ratchet. Although this creates smaller ratchet teeth and thus a more concentrated load, we are confident in the component's strength, as detailed in Section 6.2.

9.5 Fairing Manufacture Technique Development

Several new fairing manufacture techniques were tested in an effort to improve the quality of *The Plaid Panther*'s fairing. First, a test lay-up was performed on an already constructed miniature fairing plug with packing tape as a mold release. The packing tape worked very well and the team moved forward with this on the full-scale fairing.

In addition to packing tape, a test lay-up was performed with a new composite joining technique. Previously, the team has connected multiple carbon structures with layers of thick carbon fiber spanning the gap between them. A test lay-up was done where an amount of carbon was hung over the edge and not epoxied during the first lay-up. When performing the mating lay-up, the pieces were connected with the previously dry carbon from the initial structure. This test worked well and allowed us to vacuum bag the joining lay-up, resulting in a stronger, smoother and lighter connection.

10 Performance Testing

10.1 Slow Speed Stability System Deployment

Based on our year of experience with landing gear fabrication and use, the team has become keenly aware that consistent and trustworthy SSSS deployment is key to safe vehicle operation and high performance in the ASME endurance event.

To this end, the team tested the SSSS deployment mechanism, the system's most complex component, via brake cable actuation as it will exist in the final vehicle. Each trial was deemed successful if the system actuated through its full range of motion and reset itself for the next trial. The system experienced a failure rate of 5% over 100 trials. Failures were primarily due to friction between the mating aluminum surfaces of the actuating shaft and hex shaft.

Figure 35: *Stationary lean test of the SSSS*

To reduce the friction, a dry graphite lubricant was applied at the interface of the components. This reduced our failure rate to 2% after 100 trials, though it was clear that this temporary improvement would fade through use. To that end, the shaft will be lined with a teflon sleeve which, based on previous experience, will provide near-lossless actuation.

In addition to testing deployment on the workbench, the system was tested in real-world conditions to determine the strength and durability of the assembly. Stationary lean tests were performed to test the strength of the system (Figure 35) and rolling tests confirmed the durability of the custom wheels.

Part IV
Safety

11 Design for Safety

Safety is key in producing a successful product, especially a human powered vehicle. In the safety analysis of *The Plaid Panther*, we considered occupant safety, bystander safety, and labor safety during manufacturing.

11.1 Vehicle Occupant Safety

Keeping riders safe is one of the primary areas of concern with any vehicle. We've accomplished this goal by designing a number of safety features into the vehicle's monocoque fairing. These include the primary line of defense: the RPS. This includes a rollover preventing shape, protective ribbing and an integrated safety harness.

The RPS protects the rider from two major hazards in the event of a crash: crash impacts and skin abrasion from rider contact with the ground. The RPS consists of a foam hoop lining the vehicle's aerodynamic fairing covered on the inside with a layer of carbon fiber weave followed by a layer of Kevlar closest to the rider. It is strong enough to deal with impacts without infringing on the rider's space or allowing external objects to do so.

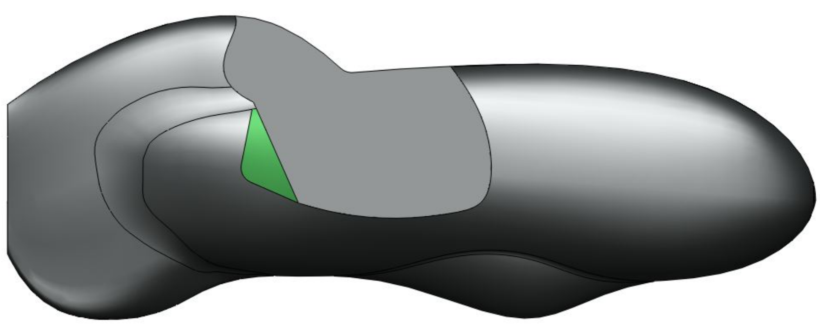


Figure 36: *Shoulder protection area & door cutout*

The chosen fairing shape has an additional beneficial property beyond being aerodynamic and providing good visibility: it won't roll easily. The low center of mass and relatively flat sides will keep it from flipping in a crash. It will instead slide to a stop. Additionally, the carbon fiber exterior is smooth enough to not catch on the ground and thus discourage rolling.

One major concern present when deciding to put a door into the fairing was the possible loss of structural support on all sides of the rider. Of particular concern is an impact to the top of the fairing in front of the RPS which, if not reinforced, could cause the fairing to cave in on the rider. This issue is resolved by a reinforcing rib along the top of the fairing. The door also securely mounts to this rib.

Similar to in previous years, a four-point safety harness in the vehicle restrains the rider in the case of an impact. This harness is be securely mounted to points within the structural monocoque.

Two additional safety concerns addressed this year were the risks of having a one-sided door and stability issues during slow-speed uphill motion. Immediately obvious upon considering a single-sided door is the possibility that the rider might fall onto it and be unable to exit the vehicle. We have addressed this dangerous possibility by including door hinges with removable pins accessible to the rider. In the event of a topple, the rider can remove the pins and escape.

The hill climb during last year's endurance race put undue stress on the riders due to a lack of low range gearing, unbalancing them and increasing their likelihood of crashing. We've taken steps to ensure that the selection of gear ratios covers a greater range, particularly at the low end for slow speed operation.

11.2 Bystander Safety

After a high speed crash last year, we have taken bystander safety into concern in the design of *The Plaid Panther*.

The vehicle's lower weight makes the it safer for bystanders in two ways. First, a lighter vehicle will be more agile than a heavier one, allowing it to stop quickly and more effectively maneuver to miss bystanders. Second, in the unfortunate case of a collision with a bystander, lowering the weight of the vehicle will decrease the impact energy and the likelihood of either party experiencing injury.

Fairing shape has a large impact on bystander safety, both in reducing the likelihood of a collision and the likelihood of injury. The chosen fairing design incorporates a head bubble which gives the rider unprecedented visibility compared to previous designs. The fairing also fully encloses all moving or sharp parts, specifically chains and sprockets.

The planned gearing changes also improve bystander safety. Gearing changes will help stabilize the vehicle and will reduce the likelihood of an uncontrolled crash. We will also train all of our sprint riders as to increase confidence and reduce crash probability.

Figure 37: *Team members wearing personal protective equiptment during composite lay-ups.*

11.3 Vehicle Builder Safety

While it is important that riders remain safe during the operation of the vehicle, it is of utmost importance that we as a team remain safe during the construction of the vehicle. The team's accident-free record is due to our adherence to the safety procedures outlined by our school, as well as the use of intelligent decision making and proper safety procedures when performing tasks not explicitly covered under our school's safety protocols. This primarily involves following a buddy system, wearing appropriate personal protective equipment at all times and ensuring team members are appropriately trained. In addition to these standard safety procedures, certain fabrication methods are favored because of their increased safety benefits. One example is the vacuum bagging technique used for lay-up which both decreases the amount of time spent handling uncured epoxy and the amount of time spent sanding composite materials.

12 Hazard Analysis

Understanding danger is crucial for rider safety but also for performance. As such, we have identified many of the major hazards that our riders may encounter while competing and have developed systems, redundancies and procedures to alleviate these dangers. These are outlined in Figure 38.

Hazard	**Likelihood**	**Solution**
Vehicle crashes	High	Extra-sturdy RPS, carbon fiber fairing, extra ribbing in weak spots
Rider cannot fit in vehicle comfortably	High	Rider variation compensation system allows riders of many sizes to ride comfortably
Rider needs to stop suddenly	High	Slow-speed stability system can deploy quickly and easily for unexpected stops
Window fogs up or riders overheat	Moderate	Door is completely removable to allow for increased airflow
Landing gear does not deploy	Moderate	LED indicators inform the rider of the situation, allowing the rider to take appropriate action
Chain breaks, tire goes flat, or other maintenance is needed	Moderate	Vehicle is equipped with slow-speed stability system
Vehicle tips with no assistance nearby	Moderate	Door is removable so rider can escape
Choppy road conditions or high traffic area	Moderate	Window has large field of view and riders are experienced
Wet or icy conditions on track	Low	Riders are well-trained in Boston weather and vehicle is very stiff, giving good road feel
Rider incapacitated inside vehicle	Low	Door can be opened from outside to access rider
Stinging insect in vehicle	Low	Rider will be equipped with bug spray in summer months

Figure 38: Hazard analysis chart. *The Plaid Panther* is well equipped to handle these hazards.

Part V

Aesthetics

The Plaid Panther was designed with aesthetics in mind with the full knowledge that aesthetics can have a real, measurable impact on vehicle performance.

13 Vehicle Aesthetics

The Plaid Panther's fairing is designed knowing that clean lines, smooth curves, a polished finish, and a tight fit around the rider lead to increased performance and a visually appealing vehicle. The fairing is sculpted around the rider and has a smooth bottom curve which nicely integrates the wheels into the overall shape. The window of the vehicle has a smooth three-dimensional curve which looks futuristic and better integrates the rider into the shape of the vehicle. On the manufacturing front, new fairing manufacture techniques have made our fairing smoother than ever before. Specifically, the packing tape mold release has helped our mold's surface finish and smoothed the exterior of the fairing.

Figure 39: The Plaid Panther *is sculpted to the rider's shape in order to look clean and narrow.*

Breaking from tradition, we decided to leave the fairing mostly unpainted this year. The sleek black color and distinctive texture of the carbon fiber will hide scratches and dirt, which has been a problem for our blue painted fairings in the past. We have also decided, tentatively, to give our fairing a little personality by adding a plaid stripe, which will give a unique look and identity to *The Plaid Panther*. Finally, the team's sponsors are recognized on the side of the vehicle with decals cut out of high-adherence white vinyl for a professional and highly legible appearance.

Although the exterior of the vehicle is the public-facing side of the project, effort was also put into the interior, particularly in making the interior clean, comfortable, and free of clutter. Our SSSS, for example, uses a dual trigger such that we only need one wire and one lever to send the landing gear up and down. We also plan to powder-coat *The Plaid Panther's* steel frame, protecting the raw metal from rust while adding professionalism and polish.

14 Team Image Unification

In the past year and a half, the team has worked to revitalize our branding in order to create a cohesive and professional image. We believe that frequent and consistent use of key identity elements strengthens and helps build a successful team brand.

New modern identity elements include the penny farthing logo (in header) and the cog & phoenix logo (on cover page). Furthermore, the team website (Figure 40) has been redesigned to be more modern and mobile-friendly and we have also embraced social media, creating a Facebook page to help our team connect with fans.

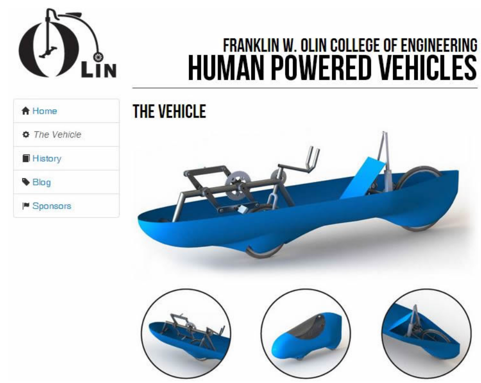


Figure 40: *The new team website was created from scratch to be modern and unique while cleanly and effectively communicating our team.*

On the physical side of things, we have moved from having randomly colored shirts each year to having shirts which match our vehicle. Furthermore, our shirts have been redesigned to professionally incorporate our new identity elements. We believe that this new attention to our team image better and more professionally communicates our team to the outside world.

15 Design Report

In addition to the vehicle, the aesthetic of this document was taken very seriously. In the past, we used Microsoft Word for our design reports. Although Word is easy to pick up, it struggles with accurate typesetting and formatting consistency and is hard to edit collaboratively. This year, we developed a system such that we could collaboratively write the design report in LaTeX, giving us better typesetting and formatting consistency while allowing us to focus on content.

Part VI

Conclusions

The team is happy and proud of *The Plaid Panther* and the concepts and techniques we have learned over the course of the year.

16 Comparison

The Plaid Panther stands up very well when compared to our stated design goals and to prior vehicles of the Olin College HPV team.

Vehicle Design Specifications	Analytical Performance Predictions	Experimental Results
Vehicle has high quality subsystems, particularly the SSSS and RVCS.	We can improve our performance in the endurance event by reducing the number of falls and vastly increasing rider confidence with our SSSS. Our RVCS can reduce transistion times in the endurance event.	Our SSSS is more reliable than that on *Seabagel*. Our rider variation compensation system will be easier to adjust than that of last year.
Vehicle is lighter than our previous vehicle, *Seabagel*, by around ten pounds.	We can reduce around ten pounds from our prior vehicles via a lighter fairing and reducing subsystem weight. This will improve our sprint and endurance times.	We reduced the weight of the RVCS by more than two pounds and are on track for a significantly lighter fairing.
Vehicle has small, light fairing with an improved surface and improved visibility.	We expect a low C_dA, small frontal area, widening the field of view to close to 180°, improved airflow via a smoother surface, and low weight via smaller size and improved manufacturing.	Due to a reduction in frontal area from 0.41 to 0.35 m^2 we reduced our C_dA at 30 mph, the field of view is close to 180°, the fairing's surface will be smoother due to our packing-tape process, and we will have a lighter fairing than last year's vehicle.

17 Evaluation

While difficult to evaluate an unfinished vehicle, it is fair to evaluate *The Plaid Panther* against the team's design goals.

The first design goal was to attain a high level of quality in all subsystems, particularly in the slow-speed stability system. The thorough design and analysis of the SSSS, combined with the working prototype, indicate that the goal has been achieved. Additionally, we are pleased with our refinements of our rider variation compensation system.

The second design goal was to reduce weight from the previous vehicle. While many subsystems have lower weight than their previous counterparts - such as the fairing and the slow-speed stability system - this is a goal that we may have achieved to a lesser extent than we had anticipated. A modest weight reduction of around 15% is expected, which may or may not be the large performance boost we were hoping for.

The third and final design goal was to design and build a vastly improved fairing. We believe this is where our team has excelled. We took a radically different direction from previous years and made a *Duck* fairing with a small window. This gives our riders significantly improved visibility and translates directly into increased rider confidence. Furthermore, this improvement comes without increased drag and allows all team members to ride the vehicle. On the fabrication side, thorough experimentation has allowed us to develop new techniques and vastly improve our process.

18 Recommendations

Looking back, the team has many recommendations to make to future teams. Fairing fabrication is an incredibly time-intensive process and we have found that getting started early allows us to focus on excellence. In that vein, however, changing our schedule to start the fairing earlier also gave us less time to work on subsystems, so we needed to be very judicious about which subsystems to spend significant design time on (such as the slow-speed stability system) and which to focus less on (such as the seat). We recommend that teams give themselves ample time for fairing fabrication and stick to their design goals when making decisions on where else to expend resources.

19 Conclusions

In conclusion, the team is confident that we will be bringing the best vehicle in Olin College's eight-year history to the HPVC East competition this year. Our combination of reduced weight, improved fairing design and superior subsystems will enable us to perform well in both the speed and endurance parts of the competition,l while allowing each and every member of our team to enjoy riding *The Plaid Panther*.

Appendices

A Design Innovation

A.1 Justification

The objective of the Slow Speed Stability System (SSSS) innovation was to easily and reliably allow the rider to stop and start without assistance. In previous years, we observed that many vehicles lost valuable time due to their inability to stop and start without assistance. Most landing gear systems were unreliable, in that they either did not deploy or did not provide enough support to keep the vehicle upright. Previous sprint events have provided evidence that two wheeled vehicles are faster than those with three wheels, which justifies our choice of a faster, though inherently less stable, two wheeled vehicle. Because our vehicle is fully enclosed by an aerodynamic and structural fairing, the rider cannot lower a leg for stabilization as one would on a traditional bicycle. We need a dependable SSSS which acts in place of our legs to stabilize the vehicle at slow speeds.

The SSSS's importance transcends the scope of the HPVC. The advantages of any fully-faired recumbent bicycle are countered by the inability of the rider to balance while not in motion. Developing a robust, reliable system for quickly and easily retracting and extending a landing gear could provide a monumental step forward for widespread adoption of recumbent technology as it removes that weakness from the vehicle. We were inspired by this idea, and aimed to bring into existence a technology that is intuitive, reliable, and requires no electronics. We firmly believe that technologies like these could lead to the greater utilization of fully-faired cycling as a viable transportation method.

A.2 Description

In this design, a free-spinning sprocket is connected to the rear wheel by a chain. When the brake lever is fully pulled, a friction disc engages a slip clutch and lowers the SSSS mechanism by drawing power from the back wheel. The SSSS mechanism consists of two small custom made wheels that stabilize the bike on both sides. When the brake lever is pulled halfway, the SSSS mechanism retracts, using constant force springs to pull it up to its neutral position.

This innovation not only advances technology formerly used to design landing gear systems, but also provides an opportunity to think outside the box in terms of obtaining power from the back wheel of a bicycle and the usage of chains in power delivery. This innovation could easily deliver power to any other part of the bike, and provides a mechanism that could control the timing of power delivery. It would be easy to apply this system to power other devices, such as lights or door actuation.

A.3 Improvements from Previous Year

The landing gear implemented in *The Plaid Panther* is an improvement of the system that we used in last year's vehicle. This year's user interaction with the SSSS actuation is the same as last year's system, and is highly accessible and intuitive to the rider. The A-frame geometry has fewer moving parts than last year's telescoping tubes. The sprocket and chain system that we have devised is more reliable than the system that we used last year, which was directly powered by a small, knurled wheel that came into contact with the rear wheel of the bike.

These improvements represent a great leap from the landing gear that we fabricated for last year's vehicle, *Seabagel*. At the last competition, we were unable to ride in the utility event with the top of our fairing on, since our landing gear was not dependable. We ended up using our feet to hold the vehicle upright while stopped. This had obvious disadvantages: speed was compromised due to the loss of our aerodynamic shape and the rider was not as protected from irregular objects during high speed falls.

A.4 Related Work

In past competitions, we have seen a variety of ways to stabilize a stopped vehicle. These include small stabilizing wheels that deploy on one[3] or both[2] sides of the bike, a rider's feet, or building naturally stable three-wheeled vehicles[4]. In the vehicles that have small stabilizing wheels, there are various methods in which they are deployed. Previous systems include swinging arms[5], sliding tubes[9], and telescoping tubes[5]. Lastly, there has been a wide range of actuation methods, including the use of electricity generated by the vehicle, push-pull cables[5], pulley cables[6], and power derived from the rear wheel[2]. To our knowledge, we are the only team which has derived power from the rear wheel by a chain, used a slip clutch mechanism, and has actuated the landing gear with the brake lever.

No patents exist for landing gear for recumbent bicycles, and the majority of landing gear patents are for aircrafts and large trailers. These include electrically activated systems[8], a combination of a pivotal arm and telescoping parts[1], and crankshaft driven systems that are able to rotate in either direction[7]. Based off this patent search, this innovation is patentable in that using power is taken from the rear wheel, the slip clutch mechanism, and the actuation from the brake handle are all unique.

A.5 Testing and Evaluation

The SSSS was rigorously tested and evaluated to ensure that it functioned properly. After the initial design, a computer aided design was created in SolidWorks. The motion of the device was simulated to ensure that the geometry would not interfere with any other moving parts. The SSSS was then fabricated and went through a second revision after it was discovered that the initial idea of a hand crank system did not provide enough power to quickly actuate the landing gear. Therefore, the sprocket design was devised. This new motion was tested and simulated, and the new system was fabricated. The revised SSSS was rigorously tested by attaching it to the back of a test recumbent bicycle so that we could ensure that it deployed quickly and reliably.

A.6 Market Analysis

This innovation is extremely marketable, as consumers are familiar with many of the components used in this design, and many of these parts are widely available. The chain and sprocket that are used to obtain power from the back wheel are common bicycle parts which are available for purchase at any bike store. The slip clutch mechanism is familiar to consumers as well, as a similar system is implemented in common bicycle disc brakes. The simple and intuitive deployment of the SSSS is appealing to consumers because they will have to spend minimal time learning how to use it. The main cost is that many of the pieces would have to be custom made, as currently there is no mass production of similar A-frame landing gear systems. However, the benefits of the system outweigh the costs, as the system uses many mass-produced parts, and is simple and intuitive.

A.7 Conclusions

The SSSS that we have designed and fabricated is simultaneously novel and familiar. It uses common bike parts in a way that they have never been used before. Through this combination, the landing gear is able to provide new function to the user in a way that is intuitive and simple to use. It effectively provides its intended function, and is easily applicable to other power generation technologies. Widespread use of this novel and effective technology in fully-faired recumbent vehicles could help lead to their realization as a viable transportation method.

References

[1] Bennett, Ian, et al. ”Landing Gear.” Patent 2,248,720. 16 November 2011.

[2] Olin College Human Powered Vehicle Team, 2012, ” Design Report: 2012 Human Powered Vehicle Seabagel,” Olin College, Needham, MA.

[3] Rose-Hulman Human Powered Vehicle Team, 2007, ”2007 ASME East Coast HPV Competition,” Rose-Hulman Institute of Technology, Terre Haute, IN.

[4] Rose-Hulman Human Powered Vehicle Team, 2009, ”2009 ASME West Coast HPV Competition,” Rose-Hulman Institute of Technology, Terre Haute, IN.

[5] Rose-Hulman Human Powered Vehicle Team, 2011, ”2011 ASME East Coast HPV Challenge,” Rose-Hulman Institute of Technology, Terre Haute, IN.

[6] Rose-Hulman Human Powered Vehicle Team, 2012, ”2012 ASME East Coast HPV Challenge,” Rose-Hulman Institute of Technology, Terre Haute, IN.

[7] Swanson, David and Lyons, Dale. ”Landing Gear Actuator.” Patent 4,400,989. 22 January 1981.

[8] Trotterm Steven, et al. ”Electrically activated aircraft landing gear control system and method.” Patent 2,082,956. 26 December 2012.

[9] University of Toronto Human Powered Vehicle Team, 2011, ”Vortex: Unlimited-Class Human-Powered Vehicle,” University of Toronto, Indianapolis, IN.