2010 Baja SAE Carolina
Ramrod Racing Design Report
Vehicle # 99

Vehicle Number 099

Lamar University 2010 Baja Design Report

Eric Halfmann
Team Captain

ABSTRACT

Cardinal IV, the vehicle submitted for the Baja SAE Carolina competition, is a vehicle that reflects the combined efforts of all Ramrod Racing team members. The Ramrod Racing team produced an off-road vehicle that meets all requirements set forth by SAE International. This is a single-person off-road vehicle powered by a 10 hp engine. This document provides details about every aspect of the design prototype including the decisions to use 1020 DOM for frame material, a CVT to gearbox power-train, independent rear trailing arms, double wishbone front suspension, rack and pinion steering, and many more.

INTRODUCTION

Ramrod Racing is the Lamar University 2010 Mini Baja team that will be competing in the SAE Baja Design Series. The SAE Baja Design Series is a collegiate design challenge that consists of six design competitions, three in the United States ("US") and three outside of the US. The purpose of this design competition is to simulate a real world engineering design project where a team of students have to design, fund, manufacture, and compete a rugged single-person off-road vehicle in multiple static and dynamic events. The Lamar 2010 Mini Baja Team will be competing April 8–11, 2010 in Greenville, South Carolina. Ramrod Racing began the task of designing by conducting extensive research of each main component of the vehicle. Our team did not want to design certain areas such as the frame, and then make the rest to fit. We considered each component to be significant, so we designed the vehicle as a whole trying to optimize each component while constantly considering how other components would be affected. We saw this as being beneficial because it forced us to think outside the box, research more thoroughly, and redesign components along the way in order for us to have a successful design. Combining this design methodology with the standard engineering design process enabled us to achieve a perfect match of aesthetics, performance, and ease of operation. One of the competition's events is the static design event. A key component of this event is the submission of a technical report that portrays the design methodology and analysis used to design and manufacture Cardinal IV. The following technical report is a result of this requirement.

CONSUMER INFLUENCES

Before any design could begin, we had to understand exactly who our customers are and their needs. To gain this understanding, we did extensive research that included attending the 2009 Alabama competition and interviewing both professional and nonprofessional local off-road enthusiasts. With this research, we determined that our customers are the SAE Baja Design Series and non-professional weekend off-road enthusiasts. We felt it necessary to distinguish between the two to ensure that we followed all rules set by SAE and to accommodate the weekend off-road enthusiasts in a safe manner within the SAE rules. With all necessary design parameters determined for each customer base, we were able to combine them for an overall list of design specifications that met all SAE requirements. We used these parameters to create a Qualitative Function Diagram (QFD) to determine which parameters were the most critical. These key parameters ranging from most critical to least critical are safety, reliability, low cost, ease of operation and maintenance, and overall performance.

FRAME DESIGN

DESIGN METHODOLOGY - The primary objective of the frame is to provide a 3-dimensional protected space around the driver that will keep the driver safe. Its secondary objectives are to provide reliable mounting locations for components, be appealing, low in cost, and low in weight. We met these objectives by choosing a frame material that exceeds the SAE strength requirements, but still gives us an advantage in weight reduction. We provided a low cost frame through material selection and incorporating more continuous members with bends rather than a collection of members welded together to reduce manufacturing costs. ProEngineer was used to model a frame that is aesthetically appealing and meets all requirements defined in Section 31 of the SAE 2010 Baja Rules.

MATERIAL SELECTION - We felt that one of the key design decisions of our frame that would greatly increase safety, reliability and performance is material selection. To ensure that we chose the optimal material, we did extensive research and compared materials in multiple categories. Our key categories for comparison were strength, weight, and cost. We first considered 1018 steel, 1020 DOM, and 4130 chromoly. Table 1 is a side by side comparison of these materials.

Table 1: Material Specification Comparison

	1018 1"x0.12"	**1020 DOM 1.25"x0.065"**	**4130 1.25"x0.065"**
Yield Strength	365 MPa	539 MPa	670 MPa
Bending Stiffness	2790 $N*m^2$	3640 $N*m^2$	3640 $N*m^2$
Bending Strength	391 N*m	602 N*m	747 N*m
Weight/100'	112 lbs	82 lbs	82 lbs
Cost/100'	n/a	$165.00	$455.00

SAE Rule 31.5 states that if the standard tube size of 1"x0.12" is not used, then the material has to have equivalent bending strength to that of 1018 steel in the standard tube size. Our initial research showed that 1020 DOM and 4130 chromoly exceeded the strength requirements set by SAE. This narrowed our decision down to 1020 DOM and 4130 chromoly. We contacted EMJ Metals in Houston, Texas to provide us with material data sheets and quotes for 1020 DOM and 4130 chromoly. This data allowed us to better compare these materials and set up an accurate decision matrix. In the decision matrix (Table 2), we took into account the manufacturing processes required by both 1020 DOM and 4130 chromoly. The 4130 chromoly has to be TIG welded which greatly increases the manufacturing time and cost while 1020 DOM can be MIG welded.

Table 2: Material Selection Decision Matrix

Parameter	**1018 Steel**	**1020 DOM**	**4130 Chromoly**	Legend
Weight	2	4	4	1=Worst 2=Poor 3=Okay 4=Best
Cost	4	3	1	
Manufacturability	4	4	2	
Strength	1	3	4	
Total	11	14	11	

The decision matrix in Table 2 led us to choose 1020 DOM as our frame material. We chose the 1.25"x0.65" 1020 DOM because the larger outside diameter allows us to use a thinner wall thickness which results in a lighter frame that still exceeds all strength requirements.

<u>1020 DOM FEA</u> - Since we didn't use the standard tube size set by SAE, we wanted to ensure that our 1.25"x0.065" tube would be satisfactory. This was initially done in the calculations seen in Table 1. We also ran an FEA analysis in Nastran of two different two foot pieces of tube. One tube had the standard dimensions of 1"x0.12" and the other had the 1.25"x0.065" dimensions. Here we wanted to make sure that the change in dimensions didn't drastically change the bending stress in the tube. We applied a force of 750 lbs to the center of each tube. In Nastran this was done using a half model of the piece of tube and applying the proper constraints. Analytical calculations were also performed and the results of this analysis are in Table 3. Both the stress and displacement values for the two tube geometries are extremely close. This shows that the dimension change will not have a drastic affect on the bending stress that is in the tube when a load is applied. Since 1020 DOM has a yield strength value of 78,200 psi, this tube will exceed SAE strength requirements and improve the safety and reliability of our vehicle by providing a higher margin of safety.

Table 3: FEA Analysis of Different Tube Dimensions

	1"x0.12" Tube		1.25"x0.065" Tube	
	Bending Stress (psi)	Deflection (in)	Bending Stress (psi)	Deflection (in)
Analytical	66,017	0.228	68,784	0.175
FEA Nastran	72,400	0.1778	76,240	0.1778

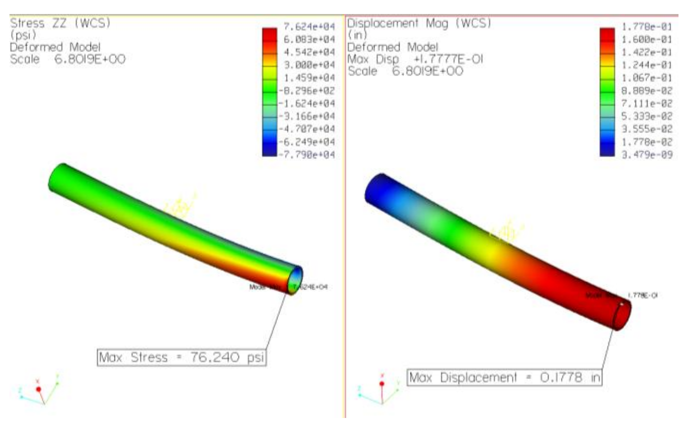

Figure 1: FEA Nastran Analysis of 1.25"x0.065" tube

Talking with local off-road enthusiasts and racers, it was found that 1020 DOM is a common material that has proven itself in action as being reliable and strong enough to handle rough terrain and easy to weld. With them supporting our decision, we are confident in the performance of 1020 DOM as our frame material.

FRAME DIMENSIONS - As we began to visualize and dimension our frame, we kept in mind strength, aesthetics, and low manufacturing cost. We adjusted the dimensions and placement of key members to make sure that they would fit well with other components. We also designed our frame members to incorporate many bends so that we would decrease the amount of welding that would need to be done. This helps to keep the strength and integrity of our frame members as well as decrease the manufacturing time and costs. Section 31 in the SAE rules has strict guidelines that must be followed for the dimensions of the roll cage. These guidelines along with the fact that our team members range in heights of 5' 8" to 6' 5" guaranteed that we designed a vehicle that will fit almost any size adult. To accommodate our drivers we made a cockpit that is 35" wide. This allows the tallest drivers to stick their legs to the side of the enclosed volume when driving and still be safely encompassed by the roll cage. At the same time the short drivers are able to keep their legs stretched straight and still comfortably reach the pedals. To accommodate the bender that we had available to us, we made all the bends with a 4.5 inch radius.

FRAME DESIGN ANALYSIS - To ensure that our frame design met all SAE requirements while still flowing well with all other components, we performed several evaluations of our roll cage and its dimensions. These evaluations include ProEngineer 3-D modeling, the construction of a mock-up frame, and fabrication tests.

<u>ProEngineer Modeling</u> - Our initial frame design was first modeled and dimensioned in ProEngineer. As other areas of the vehicle design evolved, the ProEngineer model of our frame changed several times until we had a design that integrated well with all other components. This model gave us a chance to go over the dimensions of our vehicle and to make sure that they met all SAE requirements. It provided us with a 3-D visualization of our frame which ensured that our frame would be aesthetically appealing. One of our goals was to incorporate bends where ever possible so we could minimize the number of welded joints. ProEngineer allowed us to correctly dimension these complicated bends which produced a strong frame with a very compelling look. Figure 2 is the final model of our roll cage and it shows how we were able to utilize bends instead of welds. The main members that we were able to keep continuous are the RRH, SIM, LFS, and rear hoop bracing members 1 and 2.

<u>Mock-Up Frame</u> - Before we started any fabrication, we decided to build a life size mock-up frame out of rebar. This gave us the opportunity to measure the frame dimensions with our tallest and shortest drivers sitting in the frame. With this data we were able to alter dimensions until our frame successfully met all SAE requirements.

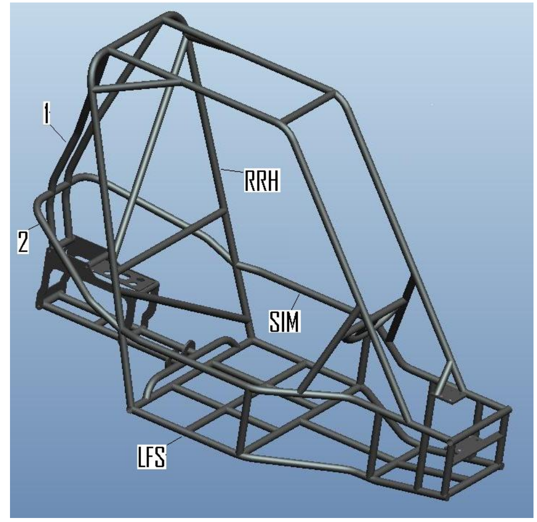

Figure 2: ProEngineer Model of Frame

<u>Frame Fabrication</u> - Before we started fabricating our frame, a series of tests were performed to make sure that our methods. A weld test required by SAE and defined in Section 31.2.11 of the SAE Baja rules was performed. This weld test was performed on our 1020 DOM using a 110 V Lincoln Weld Pack 100 MIG welder on setting C – 6.5. We used ER-70S-6 wire with a diameter of 0.023". The gas used is 7525 Argon CO_2 mix. This test was successfully performed and verified that our welding techniques were correct. To build an accurate frame, we constructed a small adjustable frame jig to ensure it is perfectly level. We also performed some bend tests to ensure that our bender would properly bend the tube without affecting its integrity. A JD2 Model 32 Hydraulic Bender was used. We utilized Bend Tech Pro software which greatly decreased our fabrication time and the amount of wasted material.

SUSPENSION DESIGN

DESIGN METHODOLOGY - The overall purpose of a suspension system is to absorb impacts from course irregularities, such as bumps, and distribute that force with the least amount of discomfort to the driver; while providing the best handling. We completed this objective by doing extensive research on the front suspension arm's geometry to help reduce as much body roll as possible. Proper camber and caster angles were applied to the front wheels as well. An independent rear suspension will be achieved with rear trailing arms. The shocks will be set to provide the proper dampening and spring coefficients to provide a smooth and well performing ride.

FRONT SUSPENSION DESIGN - For our front suspension, we chose one with a double A-arm style. This style allows the designer to adjust the geometry of the arms and their mounting locations to fine tune the performance characteristics of the arms. One of these design parameters is to position the roll center of the vehicle. By shortening the distance between the center of mass (COM) of the vehicle and the roll center, the amount of body roll that occurs when cornering will be reduced. This allows us to run softer shock absorbers since we will not be relying on them to completely control body roll. This analysis was done by setting up a four bar linkage representation of the system and locating its instantaneous centers. This can be seen in Figure 3.

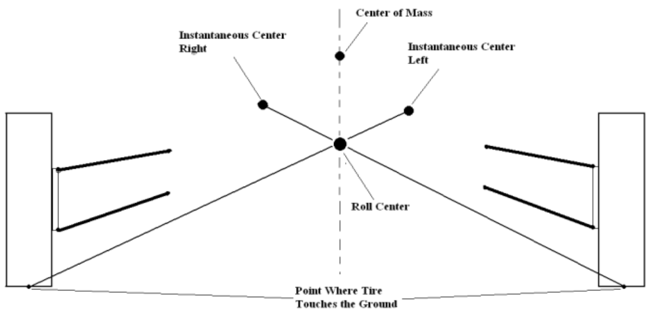

Figure 3: Locating the roll center

Our tires have a -2 degree camber at static ride height to help with steering and cornering. We also designed our camber angle to decrease when the shock absorber is compressed during turns. This allows our tires to stay in better contact with the ground while cornering which greatly improves the steering response. This is done by making the upper arm shorter than the lower arm and bringing their mounting locations closer together. We also had to make sure that the motion of our arms would not interfere with the motion of our steering rod. This limited the amount of optimization we could do. A 10 degree caster was applied to our front tires through the design of our frame nose by putting a 10 degree angle to the nose end of the LFS members. The final specifications of our front suspension arms that meet these criteria can be seen in Table 4.

Table 4: Front Suspension Specifications

A-arm	Length	Performance Criteria	Value
Top	12.5”	Caster	10 degrees
Bottom	13.5”	Camber	-2 degrees
Top Material	1”x0.082” 4130 Chromoly	Rate of Camber Change	0.3125º of camber/1º of bottom arm rotation
Bottom Material	1”x0.12” 4130 Chromoly	Distance from Roll Center to COM	8”

We ensured the reliability of our suspension systems by making them out of 4130 chromoly. We used the thicker walled material for the bottom arms since they will experience most of the forces, and we used thinner walled material for the upper arms to reduce weight. For our suspension arms to successfully mount to our frame design, we had to make the top arm much wider than the bottom arm. This is unique to common designs seen on the market. This allows us to mount the upper control arm without adding extra frame members. It also ensures that our steering rod will be thoroughly protected and will not interfere with the rotation of our arms. The suspension arms can be observed in Figure 4.

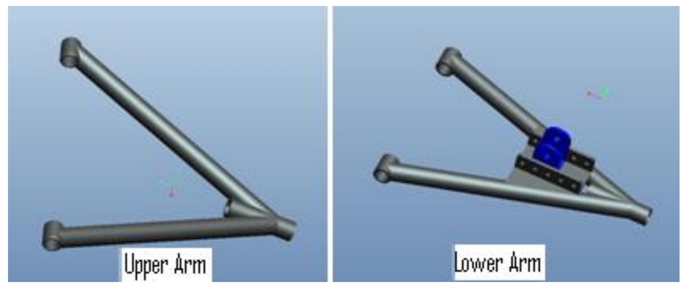

Figure 4: ProEngineer model of control arms

We added a unique design feature to our front suspension system that will give the operator easy adjustability of the shock mounting locations. This will allow the customer to tune the shock performance to better fit different environment. The ProEngineer model of this design feature can be seen in Figure 4. The blue adapter is what will attach directly to the shock and can be bolted in different locations. There are four different locations for the shock to be mounted. Each location is 0.75” apart and will give the tire a range of travel between 19” and 14”. Tabs are used to bolt the control arms to the frame. To do this we utilized plastic bushings machined out of Delrin. Delrin is a high strength self lubricating plastic that is not commonly used in the suspension industry, but it offers all the material properties we need for a reliable high performance bushing. Grade (8) 3/8” bolts are used to bolt the control arms to the frame. To connect the suspension arms to the 2009 Polaris Outlaw front knuckles, we used 5/8” chromoly heim joints with misalignment spacers. These high strength heim joints along with the misalignment spacers will ensure a strong connection with a complete range of motion for our suspension arms. We also had to drill out the bolt hole on the Polaris knuckles to accommodate Grade (8) ½” bolts and a steel sleeve.

REAR SUSPENSION DESIGN - Our rear suspension began with the decision to design an independent system. Independent suspension allows both the right and left suspension systems to operate independently of each other. This improves driver comfort by allowing only one of the rear suspension systems to be affected by a small obstacle such as a rock while the other system can keep the tire in contact with the ground. We compared the following systems: a rear double wishbone, a semi-trailing arm, and a trailing arm. Because of our rear detachable sub frame, the trailing arm system was the only system that could be incorporated with our frame design. However, the trailing arm provides many advantages. The trailing arm is a simple and reliable design that has few areas for failure. Its axis of rotation is the same as the tires, so it enhances the ability for the tire to roll over obstacles. The shock can be mounted anywhere on the arm which allows us to completely utilize our shocks in the rear. Due to its axis of rotation, the mounting location for the trailing arm is going to need to withstand all lateral forces. Each arm is designed with two mounting locations and incorporates Delrin bushings along with 3/8” Grade 8 bolts to keep the mounting locations strong. Trailing arms also experience extreme abuse when going over obstacles. The trailing arms are constructed out of 4130 chromoly because its high strength will help to enhance the reliability of the trailing arm and its mounting locations. Figure 5 is a ProEngineer model of our trailing arms. To connect the trailing arm to the 2009 Polaris Sportsman 300 rear hubs, the trailing arm has a plate with tabs on it that will bolt to the Polaris hubs. Delrin bushings will be utilized in this connection to make it tight and secure.

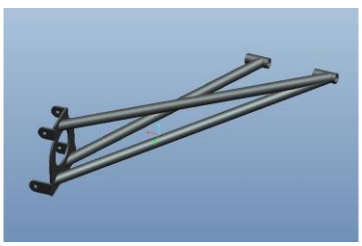

Figure 5: ProEngineer Model of Rear Trailing Arms

SHOCK ABSORBER DESIGN - For our shock selection we compared gas shocks and coil over shocks. Research led us to choose the Fox Racing Float 2 Shock Absorber based on its weight and adjustability. These shocks are lightweight and can save approximately 40 lbs compared to traditional coil over designs. They also provide a progressive spring rate. This means that during the second half of shock travel, the spring force increases rapidly. This virtually eliminates harsh bottoming of the shock. Also the adjustment of the air spring changes both the preload and spring rate, making it a much more effective adjustment than preloading a coil-over spring. The shocks are 19.5 in. long when fully extended and have a travel of 6.8 in.

<u>Simulink Analysis</u> - Simulink in Matlab was utilized to determine what the optimal spring constant for our shocks needs to be. We used a front to rear weight bias of 40:60. This gave us 120 lbs on each front shock and 180 lbs on each rear shock. This analysis was performed with a velocity of 25 MPH. The input used was three different rock profiles that were 9” tall, 5.8” tall and 4” tall. The optimal spring constants for the front and rear shocks are 110 lb/in and 170 lb/in. One analysis can be seen in Figure 6.

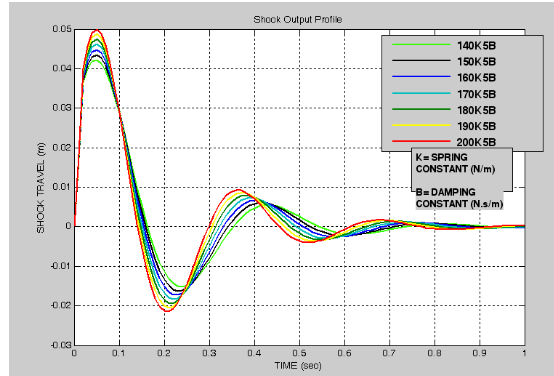

Figure 6: Rear Shock Analysis with 4 in rock input

POWER TRAIN DESIGN

DESIGN METHODOLOGY - The power train is designed to transmit the power of the engine to the wheels and tires. As a team we wanted to do this as efficiently and reliable as possible. We did this in a manner that would allow the power train system to be easy to operate, and reduce maintenance and maintenance cost.

ENGINE - The engine provided by SAE is a 10 hp Briggs and Stratton that produces 14 ft*lbs of torque. The SAE Baja rules state that the maximum rpm of the motor for the competition has to be set at 3800 rpm and the idle speed has to be 1750 rpm.

POWER TRAIN DESIGN - To begin the power train design process we had to determine if we were going to use a manual or automatic transmission. For an automatic transmission we would have to utilize a Continuously Variable Transmission (CVT). We did extensive research to compare the manual transmission (MT) and the CVT.

Table 5: Transmission Decision Matrix

Parameter	CVT	MT
Weight	1	0
Performance	1	1
Drivability	0	1
Reliability	0	1
Tuning	1	0
Simplicity	1	0
Ease of Installation	1	0
Total	5	3

In our decision matrix in Table 5, we ignored the cost of each transmission. This was done because the cost of a pre-manufactured CVT and assisting components would cost more than the MT and its components. However, the MT would require extensive machine work to make it adapt which would increase its cost and make it comparable to the CVT. Most MTs that would fit our application are found on motorcycles and four wheelers. These vehicles have a very high rpm range. A MT on these vehicles is beneficial because the operator can shift into a higher gear with the rpm at a high value. Since our engine has such a small range between 1750 and 3800 rpm, the performance gain by incorporating a MT is minimal. We felt that since the CVT allows our engine to constantly run near its maximum torque, it would give us the ability to get max power from the engine in both the high and low ranges. Also, operating the CVT is easier for the driver since the driver doesn't have to constantly shift gears. The performance gain of the MT happens only if the operator shifts gears at the optimal RPM, but if the operator does not then there is a significant loss of performance. By using the CVT we eliminate this possibility of error which greatly improves the performance and reliability of the vehicle especially when it comes to endurance events. Also, this ease of operation will attract consumers to buy our product. The CVT is designed to have infinite gear ratios between its high and low range. A strong rubber belt is used to connect the drive pulley and the driven pulley. We chose the Polaris P-90 CVT. This CVT consists of the primary spring, cam weights, secondary springs, and secondary cam. These four parameters control nearly every aspect of the transmission such as engagement rpm, shift speed, acceleration rpm, belt grip, up shifting, back shifting, and many others. The ability to fine tune these parameters will allow our team to make the CVT as efficient as possible. This CVT provides us with gear ratios of 3.83:1 in the low range and 0.76:1 in the high range. To connect the CVT to the engine and to our chosen gearbox, there was machining that had to be done. This included the boring out of the drive pulley to fit the engine shaft, and the splining of the gearbox input shaft to connect to the driven pulley of the CVT. To connect the CVT to the axles we had the option of using a chain driven system or using a gear box. We wanted to keep the efficiency and reliability of our power-train system high. Gears are the most efficient way of transmitting power. Having a chain in the system provides another area for failure with the possibility of the chain being knocked off of the sprockets. It also increases the maintenance of the system by having to constantly maintain the tightness of the chain as it stretches and having to replace the chain after extensive use. We chose to use the H-N-R gearbox from Stak 4x4. This gear box provides us with a forward and reverse gear and a gear reduction of 9:1 in forward and 11.5:1 in reverse. The specifications of this power train design can be seen in Table 6. The max torque of 338 ft*lbs is calculated assuming a 70% power-train efficiency at the lowest possible gearing of the vehicle. Based on the efficiency of our CVT, it was found that our power-train will be most efficient between speeds of 13-27 mph which is what we consider to be the typical range of speed for the endurance event.

Table 6: Power Train Specifications

Engine Speed	3800	RPM
CVT High Ratio	0.76:1	-
Tire Diameter	23	in.
Final Gear Reduction	9:1	-
Gearbox input speed	4736.84	RPM
RPM of Tires	526.32	RPM
Theoretical Top Speed	36.01	MPH
Max Torque at Axles	338	ft*lbs

Aside from the high efficiency of the gearbox, there is another advantage that is important to our customer base. Some teams decide to eliminate the reverse gear to allow for another forward gear or a lighter transmission. This is seen as improving the performance of the vehicle. We felt that having a reverse gear makes it a lot easier for the driver to maneuver the vehicle in tight spots such as garages, trailers, and off-road situations. This prevents the driver from having to exit the vehicle to push it out. This added convenience will really increase the marketability of our product because after interviewing nonprofessional off-road enthusiasts it was found that the added convenience that a reverse gear provides greatly outweighs performance.

REAR SUB-ASSEMBLY - To ensure easy maintenance of our power-train, we provided the customer with a detachable sub-frame. This sub-frame is implemented in a way that allows the entire power-train to be disconnected by removing seven bolts, the axles, the electrical lines, and the brake lines. This is a unique design feature that offers many benefits such as making maintenance of the vehicle easier, constructing a lighter engine mount assembly, and providing an appealing look and unique selling point to the customer. Figure 7 shows the rear sub-assembly connected to the frame and disconnected from the frame.

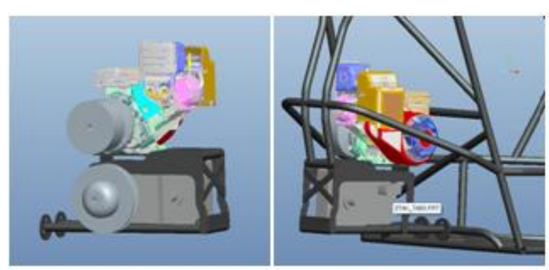

Figure 7: Rear engine sub-assembly

AXLES - Axles are used to transfer power from the gearbox to the tires. The gearbox we are using utilizes VW Type 2 Flanged CV connections. We had the option of getting custom built axles or buying Polaris axles and designing a custom flange to match. The custom built axles are very expensive because of the machining that has to be done while the Polaris axles cost a lot less. The stock Polaris axles are too short for our application so we would have to extend their length. This is a concern because the extended axles could become off balance. Since the rpm of our application is so low, then the risk of having off balance axles isn't great enough to justify the high cost custom axles. When designing our custom flange, it was determined that they were an extremely critical part that we could not afford to have fabricated off balance and not properly aligned. Since a VW Type 2 CV shaft has a similar diameter to our Polaris axles, we chose to purchase a VW Type 2 CV shaft and use it to lengthen our Polaris shaft. This provided us with the correct VW inner CV flange, a Polaris outer CV, and a very reliable axle.

WHEEL AND TIRE SELECTION - The final components of the power-train are the wheels and tires. The wheels and tires play an important role in performance as well as reliability and aesthetics. We wanted to choose tires and wheels that would give our vehicle an aggressive off-road look. We also wanted to make changing the tires easy and convenient for our customers. Our research found that when riding rough terrain, tire problems are common and many riders bring spare tires along with them so they can overcome these challenges in the field. We made this convenient on our customers by using the same bolt pattern all the way around our vehicle. This is unique to what is found in the industry where the front and rear tires and wheels are commonly different. We chose to use Polaris hubs with matching bolt patterns of 4/156 on all four wheels. This bolt pattern allows us to use 12x6 Douglas 0.190 Aluminum Racing Wheels. These wheels were chosen because they are light and strong. For our tires we chose Maxxis Bighorn 2.0 23x7x12 tires because of their appearance and radial design. The radial tires will be more reliable for maintaining air pressure and longevity. These tires are also lighter than their bias ply competitors, weighing only 15.3 lbs compared to19.4 lbs. We chose our tires to be an inch wider than our wheels so that track obstacles will come into contact with our tires before our wheels which will reduce damage to our wheels.

BRAKING SYSTEM DESIGN

DESIGN METHODOLOGY - The braking system for the vehicle is responsible for stopping the vehicle at all times and is integral for the driver's safety. SAE rules state that the brakes must be capable of locking all four wheels when applied. We will incorporate a disk and caliper brake on all four spindles to accomplish this.

BRAKING DESIGN - For the front and rear braking systems, we chose to use the stock Polaris disk and calipers that are designed to mount up to the Polaris 2009 Outlaw front hubs and the Polaris 2009 Sportsman rear hubs. Both the front and rear braking systems were chosen because of the ease of compatibility between the spindles, disks and calipers, the availability of Polaris replacement parts, the overall effectiveness that the systems provide, and because it satisfies SAE requirements. Also, the reliability of our braking system is improved by having separate disk and calipers on each wheel. Our hydraulic brake system is controlled by a single pedal in line with two separate master cylinders. One cylinder will control the front braking system and the other will control the rear system. The use of two separate master cylinders is a safety interlock, in case one fails, the other will still be operable. Another advantage of using dual master cylinders is the ability to adjust brake bias. That means the front wheels can brake harder than the rear wheels. This is necessary to slow the vehicle down while making a turn without the rear tires locking up giving added maneuverability to the vehicle. The dual master cylinder chosen is from Desert Karts. It has two 0.75 in. diameter cylinders. With one of our design goals being to ensure easy maintenance of the vehicle, we had to make sure that the master cylinders were mounted in a convenient location. This was accomplished by mounting the master cylinders on the top of the nose. To do this we had to unbolt the pedal that is on the assembly and flip it upside down. The pedal was found to be too long so we had to cut and shorten the pedal. This system allows for easy operation and maintenance. Analysis of the brake system was performed on the vehicle with a velocity of 30 MPH. We found that an input force of 100 lbs on the pedal will achieve an overall stopping force of 272 lbs at the front wheels and 310 lbs at the rear wheels. The resulting deceleration was 0.89 g's. At this deceleration it would take Cardinal IV 1.5 s to stop. The parameters for the analysis are shown in Table 7.

Table 7: Braking Parameters

Parameter	**Value**
Front Disk O.D. (in.)	7.00
Rear Disk O.D. (in.)	8.00
Front/ Rear Radial Pad Width (in.)	1.2
Front/ Rear Master Cylinder Diameter (in.)	.750
Pedal Ratio	3:1
Weight of Vehicle plus Driver (lb)	≈650
Front Weight Bias Percentage (%)	40
Coefficient of Friction	.700

STEERING SYSTEM DESIGN

DESIGN METHODOLOGY - The steering system for the vehicle has to be designed to provide maximum control of the vehicle. Along with controlling the vehicle, the steering system has to provide good ergonomics and be easy to operate.

STEERING DESIGN - We researched and compared multiple steering systems. We wanted a steering system that would provide easy operation, would be low in maintenance, provide excellent feedback, and be cost efficient. Table 8 is the decision matrix used to compare the different steering systems.

Table 8: Steering System Decision Matrix

	Hydraulic System	Rotary Cable	Rack and Pinion	Flag and Shaft
Feedback	5	4	3	1
Lock-Lock Ratio	5	2	5	3
Ease of Operation	5	3	4	3
Maintenance	1	3	4	5
Cost	1	2	5	5
Total	17	14	21	17

Based off of our decision matrix, we chose to use the rack and pinion system. The rack and pinion system chosen is a 14" rack and pinion from Desert Karts. It has a 1.5:1 gear ratio which provides a good compromise between control and ease of use. If the ratio is high, the driver would have to turn the wheel several rotations to reach full lock. In the tight space of the vehicle, this is undesirable. If the ratio is too low, a slight movement will cause the wheel to turn. This is undesirable because a bump in the trail could cause loss of control. The rack and pinion will be connected to the knuckles using the rod ends that are designed for the Polaris 2009 Outlaw front knuckles.

BODY PANELS

DESIGN METHODOLOGY - The body panels are designed to protect the driver from objects entering the vehicle and to provide an appealing shell for our frame. We provided the customer with a shell that is strong and durable while still being attractive and cost efficient. We also made sure that our shell provided easy access for vehicle components.

BODY PANEL DESIGN - We researched carbon fiber, fiberglass, and aluminum sheet for our design. Carbon fiber was found to cost approximately 30% more than both fiberglass and aluminum sheet. That narrowed our decision to fiberglass and aluminum sheet. Fiberglass has the advantage of being able to be shaped into unique curves and designs that would give a vehicle an appealing look. A disadvantage of fiberglass is the fabrication time. It takes a lot of time to successfully mold fiberglass panels, to make them presentable, and to repair. On the other hand, aluminum sheet is easy to work but is limited in the number of curves and shapes that can be incorporated. When comparing the weight of each material, it was found that the use of aluminum sheet will save 4 pounds. Since fiberglass composites didn't save us any weight, we decided that the increased fabrication time of fiberglass wasn't justified. We chose to use 18 Gauge 5052 Aluminum sheet for all body panels. We used quarter turn disconnects on certain panels to allow for easy access to critical components such as the brake cylinders. The rest of the panels will be riveted to the frame to provide a tough and secure connection. A firewall is necessary keep the driver safe from any power-train fires and failures. This firewall is going to be constructed out of 23 gauge Aluminum sheet. This exceeds the SAE requirements of having 0.02 in thick metal. A skid plate on the bottom of the cockpit is needed as well. This plate protects the driver from course obstacles that could protrude through the bottom of the frame. Fourteen gauge aluminum sheet was chosen for the skid plate because of its strength and light weight.

<u>Aluminum Fracture Analysis</u> – A fracture analysis of our chosen aluminum was performed to ensure that our panels can withstand an off-road environment. The test for the 14 gauge aluminum was performed on a 600 lb baja falling at a distance of 1 meter onto a rock. The values for the analysis can be seen in Table 9.

Table 9: Aluminum Fracture Analysis

	14 gauge	**18 gauge**
Yield Strength	213.7 MPa	213.7 MPa
Fracture Toughness	36 MPa*√m	36 MPa*√m
Withstanding Stress	225 MPa	225 MPa
Withstanding Force	663202 N	418579 N
Force Applied from 1m Fall	410092 N	n/a

The aluminum sheet is assumed to have a very small crack that is too small to be detected by visual inspection and simple instrumentation. This data shows that the yield strength of 213.7 MPa is less than the withstanding stress of 225 MPa for the 18 gauge aluminum. This means the 18 gauge aluminum will yield before a crack starts, and the withstanding force of 418,579 N should never be reached so these panels are strong enough to withstand an off-road environment. The 14 gauge skid plate will see a force of 410,092 N when Cardinal IV is exposed to the extreme conditions detailed above. This is less than the 663,202 N that the 14 gauge aluminum can withstand before the crack grows, so the 14 gauge aluminum is sufficient for use as our skid plate and should not tear when exposed to a rough off-road environment.

ELECTRICAL

ELECTRICAL SYSTEM - We installed certain electrical components that will greatly improve the safety of our vehicle. Two easily accessible kill switches are installed on our vehicle to provide an easy and safe way to kill the motor by both the driver and somebody assisting the driver. A brake/reverse light and Caterpillar back-up alarm are installed to warn people when the brakes and reverse gear are engaged. The signal to the brake light will be provided by a pressure switch in the brake line. The reverse light will be engaged by a mechanical switch on the shifter. A transponder will also be mounted on the vehicle which allows us to successfully compete in the SAE Design competition. All electrical components will be powered by a completely sealed 12 V DC dry cell battery that cannot leak in the event of a roll over.

ACCESSORIES AND OTHER CONSIDERATIONS

Safety is the most important factor to consider when designing a product. With this in mind, there were additional features added to our vehicle that will help ensure the safety of the driver. These include the installation of a 5 point harness, a fire extinguisher mounted in the cockpit, and a gas tank splash shield. The splash shield is fabricated to capture any leaking or spilled fuel that might occur during the re-fueling process. We also chose to use a steering wheel that is easily removed by pulling a release switch, then pulling outward on the steering wheel. This will allow the driver to exit the vehicle rapidly in the case of an emergency. Ergonomics and reliability are other considerations to keep in mind when designing a marketable product. To ensure the comfort of the driver we aligned the steering wheel to be comfortably used by all drivers. For all fasteners we chose to use Grade 8 bolts because of their high strength and Grade 8 nylon lock nuts to ensure the reliability of all connections.

MARKETABILITY

Cardinal IV is the latest mini baja produced by Lamar University's Mini Baja Team, Ramrod Racing. This off-road vehicle incorporates many unique design features that you cannot find anywhere else. The Stak 4x4 gearbox provides a durable and maintenance free power-train. Our automatic transmission has a forward and reverse gear that provides hours of easy and fun riding for drivers of all skill levels. Are you tired of tire issues while riding? Well, Cardinal IV has the same bolt pattern on all four wheels, so only one extra wheel and tire will solve all of your issues in the field. Do you get frustrated by components that are difficult to reach and fix? Cardinal IV has multiple design features that make maintenance easy. These include an easily detached rear sub-frame which provides unlimited access to all power-train components. The brake master cylinders are mounted on the top of the nose for easy access, and key body panels are connected by quarter turn disconnects. You won't be able to find another mini baja that is this easy to work on. Ever get the desire to adjust the performance of your off-road vehicle? Cardinal IV has completely adjustable shock absorbers and front shock mounts that allow you to adjust the suspension to fit your needs.

CONCLUSION

The Lamar University 2010 Mini Baja Team, Ramrod Racing, is proud to present its latest mini baja design, Cardinal IV. Our chosen design method of designing the vehicle as a whole, forced us to constantly research, redraw, and think outside the box in order to have a successful and unique design. We are confident in the performance, safety, and reliability of Cardinal IV. Cardinal IV's power-train offers easy operation and maintenance that will satisfy the customer's needs. Multiple unique design features on Cardinal IV provide easy maintenance and adjustability that give the owner more control over the vehicle. Ramrod Racing will be presenting and competing Cardinal IV in the Greenville, South Carolina competition. We would like to thank SAE International, Polaris, Briggs and Stratton, and all volunteers and sponsors that make this competition possible.

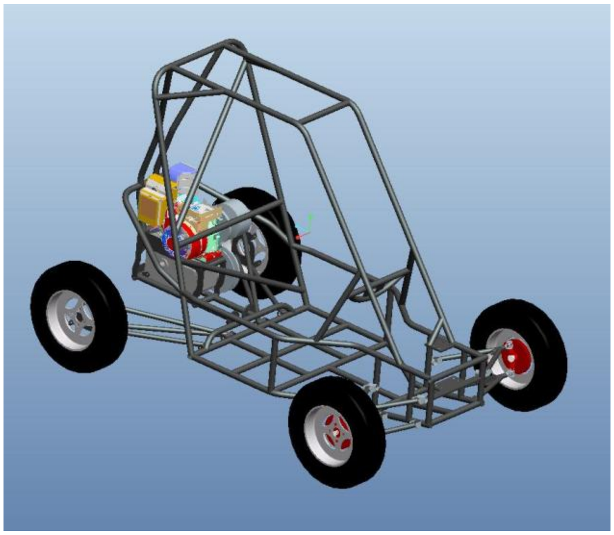

Figure 8: ProEngineer isometric view of Cardinal IV

VEHICLE SPECIFICATIONS

Engine	
Type	4-Stroke, OHV, Briggs and Stratton, 305 cc, CR of 8:1
Power	10 hp
Torque	14 ft-lb
Drive Train	
Transmission/Reduction	H-N-R Stak 4x4 Gearbox / 9:1
CVT/Reduction	P-90 Polaris CVT / High .76:1, Minimum 3.83:1
Chassis/ Suspension	
Chassis Type	1020 DOM Steel
Overall Length	~88 in
Wheel Base	69 in
Overall Width	63 in
Front Suspension	Double Wishbone
Rear Suspension	Trailing Arm
Ground Clearance	11 in.
Front/ Rear Shocks	Fox Racing Float 2
Vehicle Weight (w/Driver)	600 lb (approximately)
Wheels/Tires	
Front/Rear Wheels	12x6 Douglas 0.19 Aluminum
Front/ Rear Tires	Maxxis Bighorn 2.0 23x7x12
Performance	
Top Speed (estimated)	≈36 MPH
Max Axle Torque	483 ft*lbs

ACKNOWLEDGMENTS

The 2010 LU Mini Baja Team, Ramrod Racing, would like to thank all of our sponsors: Foster Wheeler, AGC Southeast Texas Chapter, Lamar University, SAE, ASME Sabine Section, Chevron, BASF Fina Petrochemicals, Thermacon, Sabina Petrochemicals, Total, Chevron Phillips, Laurie Kader, Corbell Masonry, Gulf Coast Fabricators, Ray & Carol Davis, American Valve and Hydrant, Timberline Mfg., Everett Phelps, Tammy Hefner, Vince Rinando, and Gulfco. Without your support this would not have been possible.

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CONTACTS

Eric Halfmann, Project Manager (M.E. Undergraduate)

Email: halfmann4@hotmail.com

Dr. Ken Aung, Faculty Advisor (Associate Professor)

Email: ken.aung@lamar.edu

DEFINITIONS, ACRONYMS, ABBREVIATIONS

‘: Foot
“: Inch
%: Percent
AGC: The Associated General Contractors of America
DOM: Drawn Over Mandrel
CR: Compression Ratio
CVT: Continuously Variable Transmission
DC: Direct Current
FEA: Finite Element Analysis
ft: Feet
hp: Horse Power
lbs: Pounds force
m: Meter
MT: Manual Transmission
MIG: Metal Inert Gas
MPH: Miles per hour
N: Newton
TIG: Tungsten Inert Gas
LU: Lamar University
LFS: Lower Frame Side
Pa: Pascals
PSI: Pounds per square inch
RPM: Revolutions per minute
RRH: Rear Roll Hoop
SIM: Side Impact Member
V: Volt

APPENDIX: DESIGN PICTURES

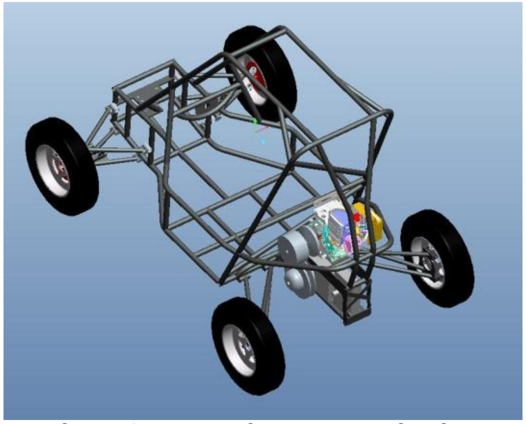

Figure 9: ProEngineer Isometric View

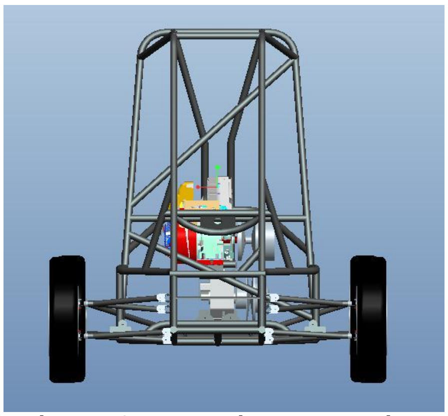

Figure 10: ProEngineer Front View

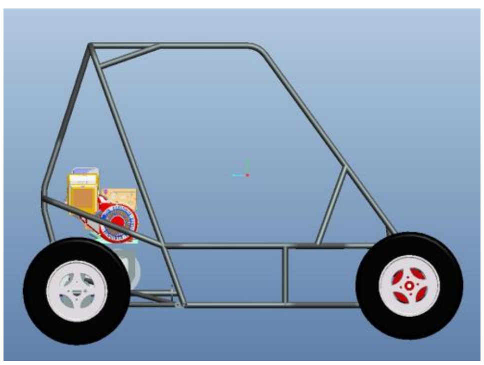

Figure 11: ProEngineer Right View

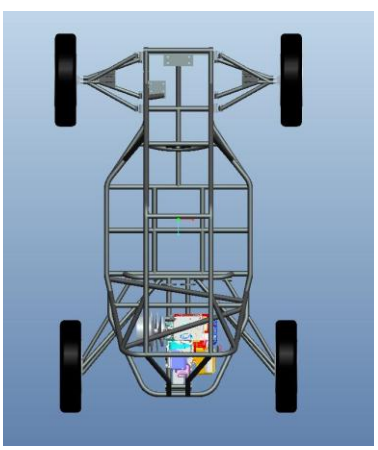

Figure 12: ProEngineer top View

Figure 13: Bree Babin measured in mock-up frame

Figure 14: Final mock-up frame

Figure 15: Weld test

Figure 16: Hydraulic Bender used for fabrication

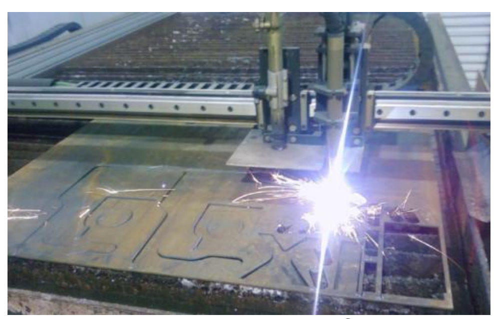

Figure 17: Plasma cutting of 3/16" plate

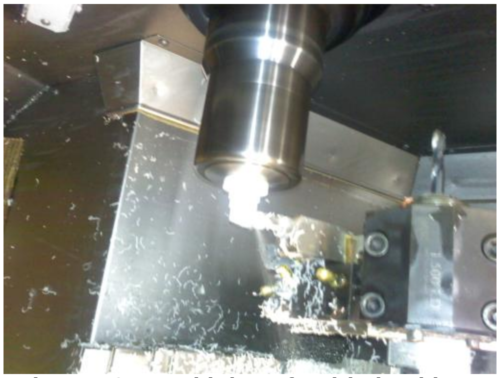
Figure 18: Machining of Delrin bushings


Figure 19: Delrin Bushings


Figure 20: Frame during fabrication


Figure 21: Front lower suspension arms


Figure 22: Aligning of front suspension arms


Figure 23: Frame with sub-assembly bolted up


Figure 24: Stak 4x4 Gearbox in sub-assembly


Figure 25: Sub-assembly and its mounting location

Figure 26: Side view of Cardinal IV

Figure 27: Isometric view of Cardinal IV

Figure 28: Left Front Suspension Assembly

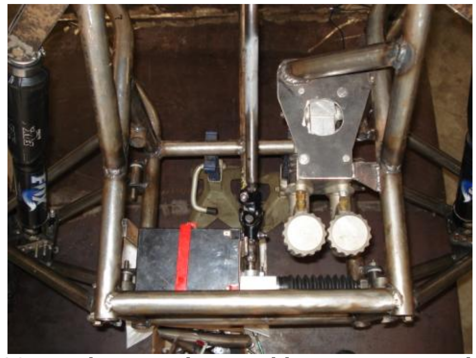

Figure 29: Brake, steering, and battery mounted in nose

Figure 30: Left view of Cardinal IV

Figure 31: View from driver's seat