Off-Road Battle Championship

OFF-ROAD VEHICLE REPORT

Team XerXes

December 25, 2015

Table of Contents

1.0 Executive Summary

The Project on Off Road Battle at the Gautam Buddha University has been completed. This project is focused primary on the fabrication of the different subsystems of the kart including the frame, suspension, drive train, and various smaller subsystems. All of the initial designs that were done are provided very strong base for the team to build on. Having the design done before construction also allowed the team to adapt to any conceptual shortcomings that emerged and make iterations on their designs. The Piranha Buggy is currently a driving kart that will only need a few more components added until it is ready for competition.

Team XerXes selected to participate in the Off Road Battle competition organized by Gautam Buddha University. The competition Off Road requires each team to design and construct an off-road vehicle capable of competing in specialized events held in Gautam Buddha University on March. Many different aspects of the vehicle will be tested during the competition. Functionality and performance will be evaluated with respect to acceleration, traction, maneuverability, and endurance. The vehicle will also be subjected to a rock crawl event to test the diversity of the vehicle. Each team member was assigned a particular aspect of the vehicle to focus on. Team XerXes main objective for the off-road battle championship was to complete the vehicle early enough to allow testing. This goal has been partially accomplished. This has helped to ensure that most of the inevitable problems of the vehicle will be eliminated before the competition. Another objective of the XerXes was to construct a vehicle capable of completing the entire endurance race. This focus has led to an increase in attention on the suspension and drive train to ensure reliability. All of the design goals for the vehicle have been met or exceeded. Currently, the vehicle is driving which has allowed the team to work out small problems which potentially could have been devastating at the competition.

The drive train of the vehicle consists of the required 13 (250CC) horsepower Honda CBR 250R mated to a five speed transmission with a centrifugal clutch. The transmission will also have reverse because the vehicle must be prepared for any obstacle that it may encounter in competition. The front suspension has a single A-arm design. The rear suspension has a double swing arm. All of the shock absorbers are Spring Shocks. Steering consists of a bell crank system. This allows maximum steering of the

Vehicle without requiring the driver to go hand-over-hand. This steering design is also lightweight, less expensive, and has a built in positive Ackerman. Most of the fabrication has been completed at this time with only a few more safety components needing to be constructed. Testing has also begun on the vehicle to try to weed out all of the potential problems before the competition date.

Performing very extensive research in the first semester of this project has provided a very strong base for the team to build on. It has also made the construction of the vehicle very efficient with only minor problems occurring. All of the separate components of the vehicle have come together into a driving vehicle that the team feels will be very successful in competition.

2.0 INTRODUCTION

The goals for the Off-Road Battle Championship is to gain valuable engineering experience and obtain crucial analytical skills applicable to the job place. These skills combined with fundamental workplace skills like project management and teamwork will provide the base for a successful engineer. The XerXes has been working on the design and fabrication of an Infesta vehicle for the competition to be held in Gautam Buddha University. The overall design of vehicle has been broken up into the following subsystems: drive train, front and rear suspension, brakes, steering, frame design, and ergonomics. This report contains an overview of the design and redesign work for each of the subsystems.

3.0 BACKGROUND

The Infesta vehicle is a single-seated all-terrain vehicle capable of taking abuse from rugged, off-road driving conditions. This year the Off Road Battle competitions is being held in GBU. Universities from around the country come to participate in these competitions. The challenge for the engineering students is to design and fabricate an Off Road Vehicle. Safety features on the vehicle must be followed as set by the rule book provided by Organizer. Teams are then scored based on the vehicle's performance in dynamic events (acceleration, a pulling event, maneuverability, rock crawl, and endurance) and static events (design report, cost report, and presentation). A breakdown of points for the competition is given in Table 1 & 2.

Pre-Final Round

S.NO.	CATEGORY POINTS	
1.	Design Report	150
2.	FMEA	100
3.	DVP	100
4.	Cost Report	100
5.	Gantt Chart	50
	Total Marks	500

. **Table 1: Breakdown of Competition Points**

Final Round

S.NO.	CATEGORY	POINTS
1.	Endurance	400
2.	Showdown	300
3.	Cones Down	150
4.	Pull the Bull	150
5.	Acceleration	100
6.	Flag Off	100
7.	Tug of War	100
8.	Innovation	100
9.	Aesthetics and Ergonomics	100
	Total Marks	1500

Table 2: Breakdown of Competition Points

The XerXes has made significant progress towards the completion of their Infesta vehicle. Infesta is our first project significantly the team is trying to put its best earned knowledge and endeavor in the above mentioned project. Although, the team faced many challenges during the progression of the project and the also overcame all the challenges successfully. Some of the major problem was related with the frame design and rear end housing. First off all the design which we have develop is able to hold a higher Cubic Capacity engines, even an inline three cylinders of 800-1000 CC. So, we encountered our first challenge of developing it according to the rulebook, provided by the organizing committee which was limited to 310CC. The major problem was with the housing. As discussed we have housing which consist the driving sprocket and the braking disc of 280mm the alignment of the sprocket and braking disc in the housing was a challenging job which we came past by some supervision help from our faculties.

And finally, team came out with a design as given below in figure 1.

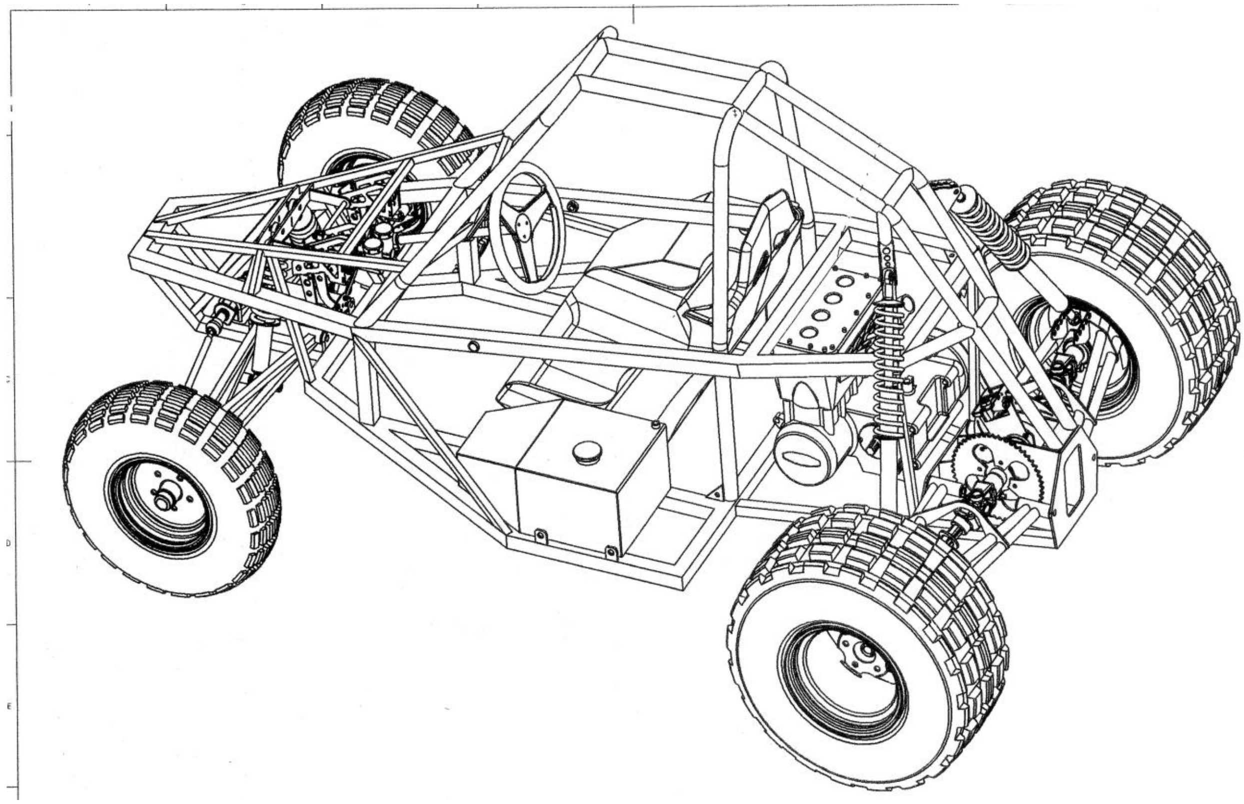


Fig 1: The Infesta

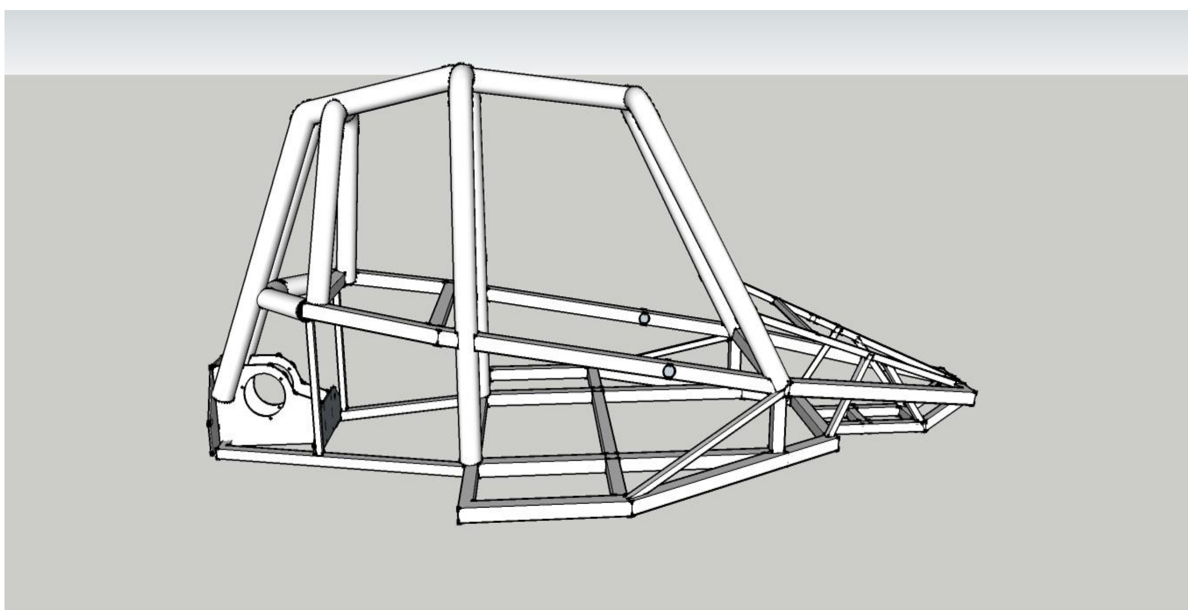


Fig 2: 3-dimensional model of proposed design

Table 3: Design Consideration Table

Design Consideration	Significantly Affects Design	Where Discussed
Performance	Yes	4.0
Serviceability	Yes	4.1
Economic	Yes	4.9
Environmental	No	-
Sustainability	No	-
Manufacturability	Yes	4.1
Ethical	No	-
Health and Safety	Yes	4.2
Social	No	-
Political	No	-

4.0 DISCUSSION

4.1 Design Objective

For the Off-Road Battle championship, XerXes planned to completely redesign the vehicle. The team compiled four main goals. The first goal was a lighter design in its category so, we tried to bind the weight limited to 450 pounds. The second goal was simple manufacturability and servicing of the vehicle. From the mistakes and errors learned from previous competitions and our analysis, another goal this year was to keep the design simple and easy to assemble. If a part was to fail such as the A-arm, the team would ideally have extra part manufactured to replace the failed part quickly.

The fourth objective of the vehicle was the overall performance of the vehicle. Therefore, a lightweight design, which was our main goal, will improve the overall performance of the vehicle by increasing the power-to-weight ratio. The design criteria for the vehicle can be found below in Table 4. All of these goals have been met by the end of the 2015 school year. By setting these goals from day one, the team feels that they will be very competitive in the 2015 Off-Road Battle. The concept design for the 2015 vehicle can be found in Figure 2&3.

Table 4: Design Criteria of the Vehicle

No.	Criterion	Priority
1	Reliability	Essential
2	Ease of Design	Essential
3	Performance	High
4	Serviceability	High
5	Manufacturability	High
6	Health and Safety	High
7	Lightweight	High
8	Economic/Low Cost	Desired
9	Easy Operation	Desired
10	Aesthetically Pleasing	Desired

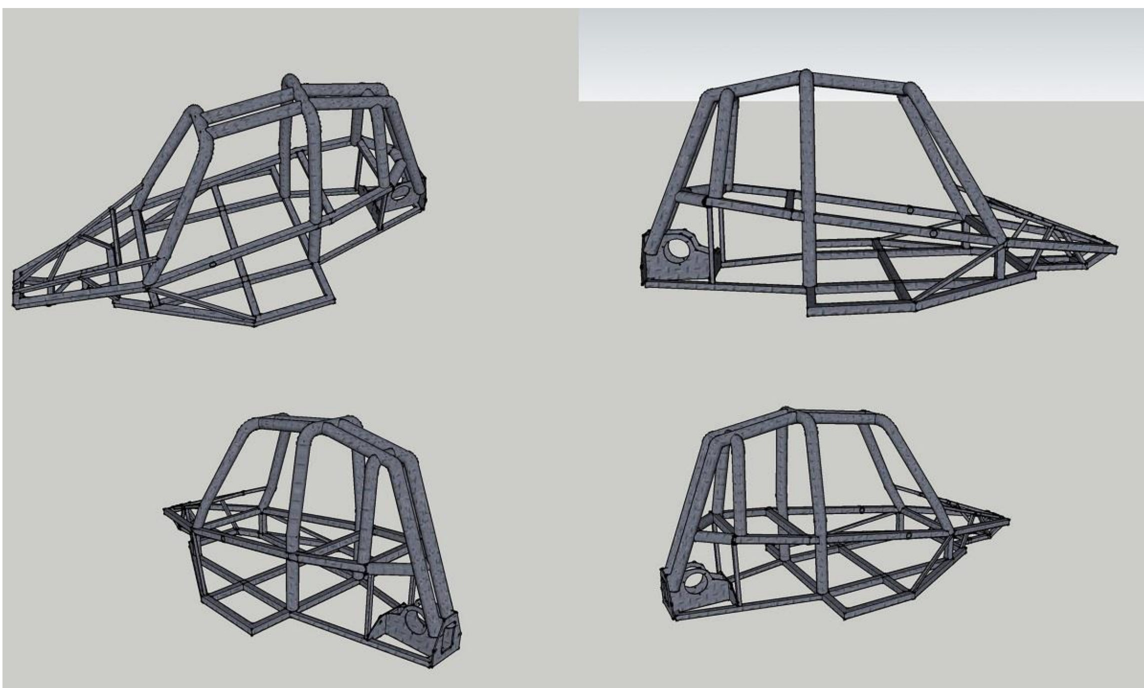


Fig 4: Infesta 4-sded view

4.2 Frame

The design of the vehicle is structured around the safety rules established by Organizing Committee [1]. The rules constrain the design of the frame in two. First, the rules specify a minimum strength and thickness of the material used in the creation of the crucial support members of the frame. The rules also restrict the geometry of the shape of the frame in many ways. These rules were referenced many times in the material selection process, the overall design geometry, and all additional modifications to the original designs. The bottom base of the frame was created by the leaders of the suspension subsystems. The frame was then designed around this base frame in order to accommodate both the front and rear suspension. This is not the traditional method of designing a frame, but was necessary due to the ranging heights and weights of team members while still ensuring capability in the suspension. The materials used in the cage must meet certain requirements of geometry and minimum strength requirements found in Organizing Committee rules. Since, the frame is being used in a racing vehicle rather than a recreation vehicle, weight is a very large factor in the shape and size of the frame. The proper balance of strength and weight is crucial for the team.

Overall success. The rules define the roll cage must be made out of a material with properties at least as equivalent to the following specifications:

(A) Circular steel tube with an outside diameter of 2.5 cm (1 inch) and a wall thickness of 3.05 mm (.120 inch) and a vehicle on content of at least .18.

OR

(B) Steel members with at least equal bending stiffness and bending strength to 1018 steel having a circular cross-section with a 2.5cm (1 inch) outer diameter and a wall thickness of 3.05 mm (.120inch)

The rules go on further to define bending strength and stiffness as:

Bending stiffness is proportional by the EI product and bending strength is given by the value of SyI/c, (for 1018 steel the values are; S_y= 370 Mpa (53.7 ksi) E=205 GPa (29,700 ksi).

E = the modulus of elasticity

I = the second moment of area for the cross section about the axis giving the lowest value

Sy = the yield strength of material in units of force per unit area

c = the distance from the neutral axis to the extreme fiber (Appendix II)

Using these specifications and the ability to choose the alloy of the steel, 4130 Chromoly Steel was selected. This material was chosen over 1018 Steel because 4130 Steel has a greater strength to weight ratio. Along with material selection, tube diameter was also taken into consideration. Three different sizes of tube were considered for the frame. It was decided to create the Roll Cage using 1.125 in OD, 0.083 in wall thickness, 4130 Steel tubing. This tube was chosen because it met the minimum requirements set by the organizing committee, it was lighter than a 1” tube, and is thought to be more structurally sound than a larger diameter tube. This tube size can be seen in the final design of the frame colored in in Figure 4.

Alternative requirements for other members of the frame are also provided by organizing committee. These criterion allow for less stringent strength requirements, the team decided that it would be beneficial to utilize this opportunity to use lighter material. Additional support members were made of 1.125 in OD, 0.065 in wall thickness, 4130 Steel tubing, shown in green in Figure 4. This tube was chosen to provide additional weight reduction without sacrificing structural stability.

The frame in Figure 3 shows the frame design was chosen by the early September semester. Fabrication of this design started in mid-November 2015. After the completion of this frame a few problems arose. The first problem was one of dimensions. The distance between the driver’s helmet and the bends in the forward roll hoop did not meet the specified distance, making this frame not suitable for competition. This frame is currently being used to dynamically test for areas of weakness. This way if the frame is broken in testing then the competition frame remains undamaged. Thus far no weak points have been located, and the final competition frame is currently being fabricated.

One design aspect that changed from the testing frame to the competition frame is located at the front of the) needed to be bent as seen in the bottom of Figure 4. Two other new additions to the competition frame can be found in yellow in Figure 4. These sections will be made from 4130 steel tube with an outer diameter of 1” and a wall thickness of 0.065”. The front tubes will act as a bumper and frontal tow bar specified in the rules. The rear tubes will provide a place to mount a skid plate for protection for the drive train. If any additional problems arise during the testing of the vehicle the necessary changes will be made to the competition frame in order to ensure proper performance.

Table 4: Frame Design Considerations

Consideration	**Priority**	**Reason**
Light-Weight	Essential	A light race vehicle is a fast race vehicle
Durable	Essential	Must not deform during rugged driving
Meet Requirements	Essential	Must meet requirements to compete
Simple Frame	High	Majority of frame fabrication done in house
Attractive Design	Desired	Easier to sell an aesthetically pleasing vehicle
Cost	Low	Vehicle needs to be within budget

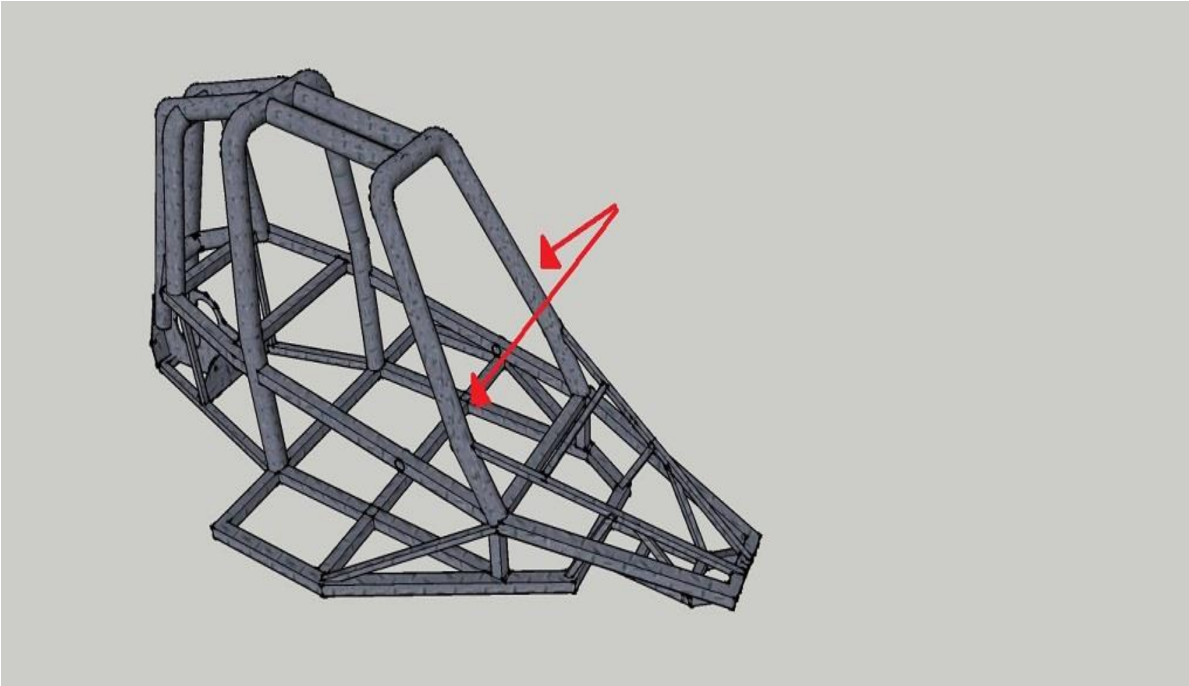


Fig 5: Front tubes will act as a Bumper

4.3 Front Suspension

The problem that was encountered was to design a competitive front suspension for the Competition. To do this the operating conditions of the competition had to be researched, and from that design considerations had to be decided.

Table 5: Front Suspension Design Considerations

Consideration	Priority	Reason
Simplicity	Essential	This is a main goal of the team overall
Lightweight	Essential	Weight is the number one enemy of a race vehicle, especially sprung weight
More than 14” of Travel	High	Turning and stopping both require re contact between the tire and the ground, which is achieved through travel
Durability	High	While it is essential to the vehicle, it could be achieved with any of the considered designs
Shock Absorbing	Desired	Frontal impacts cause a heavy amount of damage to the vehicle
Extremely Adjustable	Desired	A major factor in overall handling is the front suspension setup
Compatibility with Steering	Desired	The suspension geometry determines the geometry of the steering, which has its own set of limitations
Unique	Low	Being noticed during the design competition is desirable

Three designs met the above criteria for the front suspension. Out of these designs a double A-arm was chosen for the vehicle. This design achieved 16” of suspension travel while only using a Shocks 2.0 Spring Shock with 8.5 inches of travel. This shock is not only lightweight, but is completely adjustable by the user, which fit the tunability requirement. On the inside, two heim joints will be used to hold the arm to the chassis and allow proper alignment of the arms. On the outer side John Deere hubs and spindles were selected because they used a kingpin bushing design for mounting. To ensure durability of the arms, gusseting for the kingpin tube was design to distribute loads created by the wheel. One major concern with this design was the large degree of camber change. However, upon further examination it was determined that the tire, under normal travel conditions, would always contact the ground on its curved contact surface and never the edge of the tire. To create a shock absorbing front suspension the arms are set at 26 degrees laid back with relation to the ground. To assist with the steering design a caster of positive 10.5 degrees was set. Through solid modeling the suspensions interaction with the other subsystems has been evaluated. Finite element analysis has also been conducted on the front arms and showed that the suspension can handle up to 2500 pounds of static loading. The stresses created in the part can be seen in Figure 6 and Figure 7. The biggest reason for choosing this design is that it only requires one piece, using a simple jig, to be fabricated. Further, the suspension only requires five fasteners per side for complete installation.

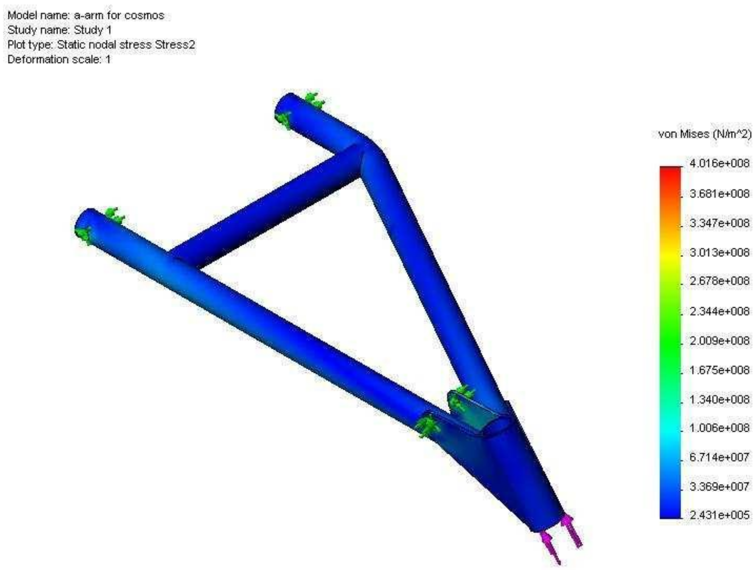


Figure 6: 2500lb Load along the Kingpin Axis

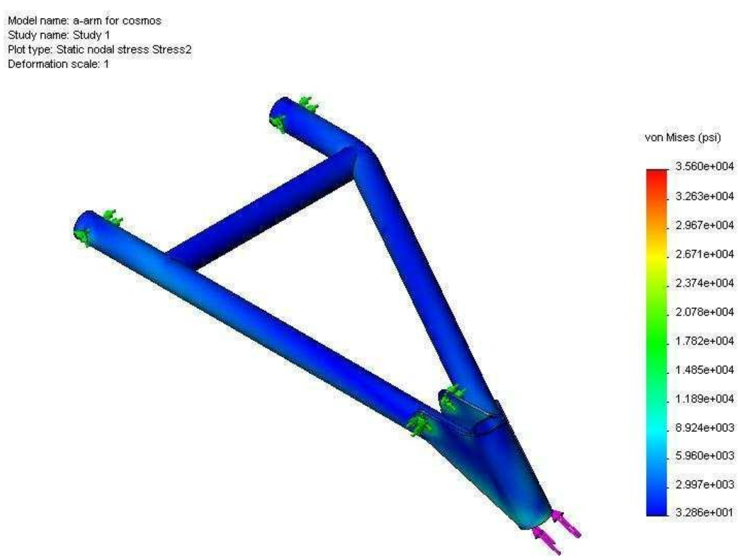


Figure 7: 2500lb Load as side load

It has been determined that the tubing used for the suspension arms will be 4130 steel. It will be 1.25" diameter with .049" wall thickness. This was determined after comparing the weight and material properties for several sizes of tubing, which can be seen in Table 6. Table 7 was used to determine the size of heim joints to use for the front a-arms. For the kingpin on the outer edge there is two bushings. The lower bushing is a flanged brass bushing. This is designed to allow easy steering yet be durable enough to handle repeated impacts from the spindle. The upper bushing is made of delrin because of its extremely low coefficient of friction, and high resistance to wear.

Table 6: Tubing Selection

Wall Thickness (in)	Outer diameter (in)	E (psi)	σys (psi)	Bending Stiffness (lbs-in^2)	Bending Strength (psi)	Tensile strength (Psi)	Volume for one foot (in^3)	Density (lb/in^3)	Weight (lb)	Approximate weight (lb/arm)
0.095	1.25	2.97E+07	6.31E+04	1.7E+06	5.8E+03	2.2E+04	4.14	0.28	1.17	5.85
0.065	1.25	2.97E+07	6.31E+04	1.3E+06	4.3E+03	1.5E+04	2.90	0.28	0.82	4.11
0.049	1.25	2.97E+07	6.31E+04	9.9E+05	3.4E+03	1.2E+04	2.22	0.28	0.63	3.14

Table 7: Heim Joint Capacity

					Allowable Acceleration (g's)			
Fasteners	Tensile Area (in^2)	Radial Load Capacity (lbs.)	Tensile Strength (psi)	Ultimate Tensile	Tensile Load	Infinite Fatigue Life in Tension	Shear Load	Infinite Fatigue life in Shear
1/2 20	0.1599	8338	92000	120000	18.4	3.3	13.1	4.2
5/8 18	0.256	9713	92000	120000	29.4	5.3	20.5	6.8
3/4 16	0.373	14207	92000	120000	42.9	7.7	29.5	9.9

During the past few months the front suspension has been completely designed which can be seen in Figure 8. A jig has been created so that fabrication time could be cut down significantly and repeatability of geometry is ensured. After fabrication was completed it was statically tested to see how much travel and camber change it would produce. The overall travel achieved is 13.5" which is restrained by a limiting strap to keep the shocks from over extending and damaging them. The camber ranges from -12^{o} at full droop to 16^{o} at full bump. To test the overall suspension articulation on the vehicle a single front wheel was lifted until one of the other tires on the vehicle lost contact with the ground, at this point the front tire was 29" from the ground. The o overall track width at static ride height is just under the required 64" [1]. Testing has begun for the entire vehicle and so far the front suspension has proven itself to have very good overall performance. Under normal driving conditions it rides very smooth and soaks up bumps with ease. The tires also remain extremely vertical within the range of motion seen on relatively smooth surfaces. On bumpy surfaces the camber angles have not proven themselves to be detrimental to the handling characteristics of the vehicle.

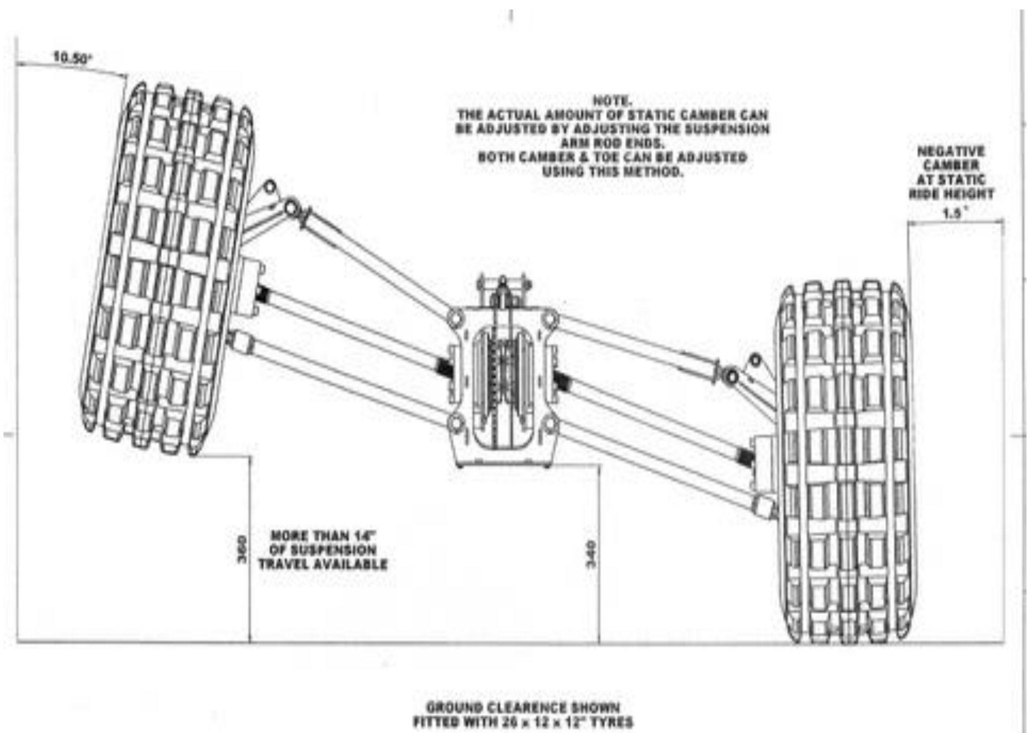


Fig 8: Completely Designed rear suspension

In an effort to accomplish the goal of being lightweight a replacement hub and brake rotor has been designed. It would replace the heavy cast steel John Deere part with a much lighter aluminum hub. Not only would this hub be lighter but it will also eliminate the need for an adapter plate to be used to allow fitment of the ATV wheels. The new part has also been altered so that the brake rotor is no longer integral to the hub but instead bolts on using three 5/16” fasteners. To ensure pro per fitment of both the wheel and the rotor both were created as hub-centric pieces. Static FEA was conducted on the replacement hubs in an effort to make them durable enough to withstand the loads seen during driving. At the moment the team is in the process of getting an outside vendor to

Machine these parts, which cost provided will happen in time for testing before the competition. The parts can be seen in Figure 9&10 and the FEA image of the hub can be seen in Figure 12.

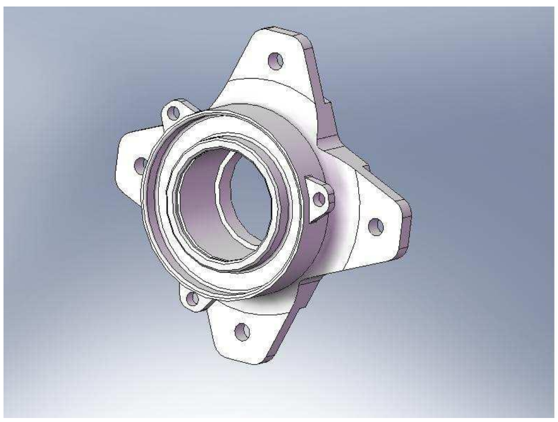


Figure 9: Replacement Aluminum Front Hub

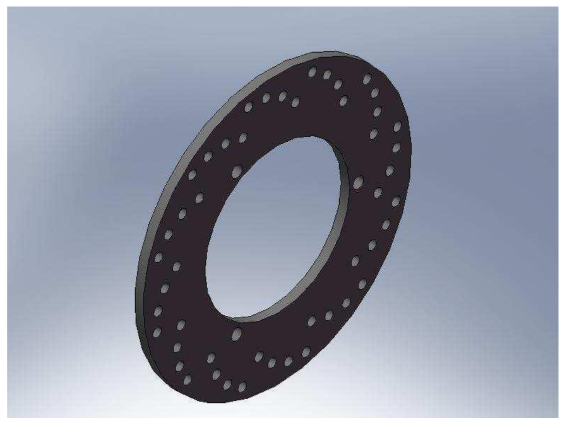


Figure 10: Replacement Front Brake Rotor

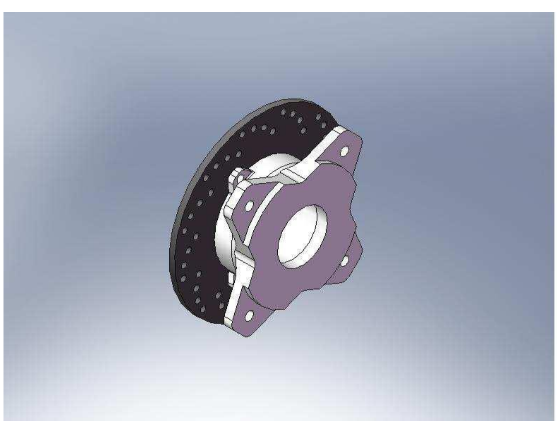


Figure 11: Replacement Front Hub Assembly

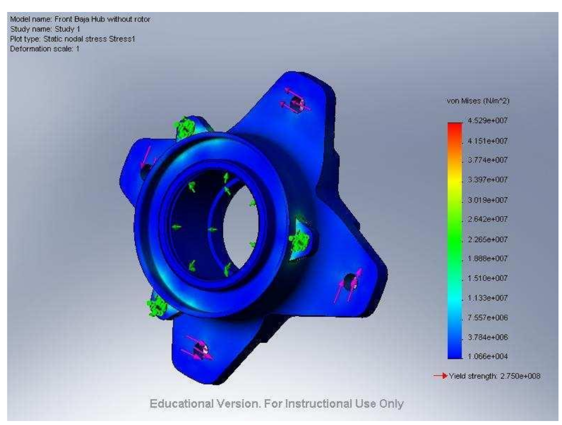


Figure 12: FEA Testing of Replacement Front Hub

4.4 Rear Suspension

The goal was to design and build a rear suspension for the Infesta vehicle, which has been completed successfully. There were many objectives and considerations to look at during the process of designing and building the rear suspension. One main objective was to build a simple reliable vehicle that will compete in all the areas of the competition. The rear suspension is a full double floating arm design with only one arm per side. The Fox 2.0 Spring Shocks have more than 14 inches of travel, and are mounted right above the bearing vehicle rear, near the end of the arm, and about half way up the rear main roll hoop. This allows for maximum suspension travel while staying within the range of the rear axle CV joint travel. Another reason that trailing arms were used was that the drive train design was to be modular. The trailing arms allow for the full drive train assembly to be removed without interference by the suspension. This enables the drive train to be pulled from the vehicle for maintenance, and keeps the overall design of the rear of the vehicle simple. There was only one small design modification which had to be made to the design. The problem was that the engine cover stuck out further than anticipated, so one member of the right side trailing arm had to have a bend put in it so that during travel the arm clears the cover.

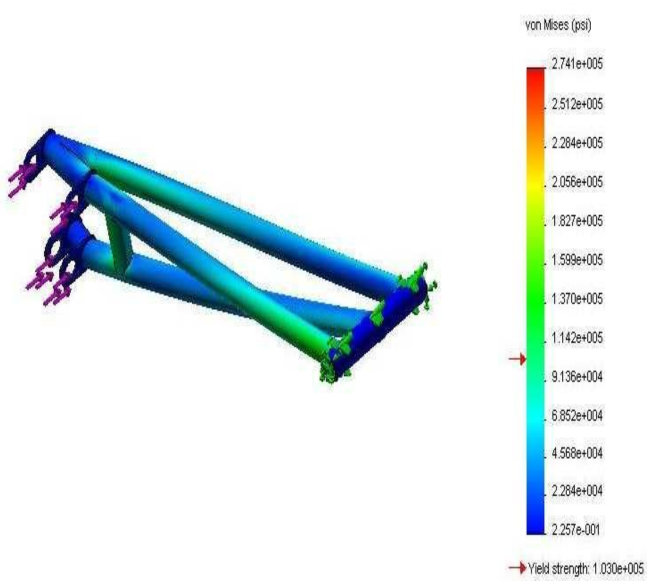
The full trailing arm design was selected and built for many reasons. One reason is that it is very simple; there is only one arm with a simple mounting structure. Another reason is that the drive train will be able to be integral because the rear suspension is not dependent on any part of the rear support hoop, and/or anywhere else along the drive train. The tire along with the arm moves in pure rotation on an arc about the pivot point on the frame.

This characteristic will make adjustment of the rear shocks easier, as well as give the rear suspension a progressive rate that will help the handling. The full trailing arm does not allow for adjustment of camber; however this was decided to be a minor issue as the surface will not be flat during driving. This design is also lighter since there is less steel involved in the fabrication of the arm, but is inherently strong by design. The rear suspension will also be simple to rebuild, repair, and disassemble because of the single trailing arm per side. The choice to use factor length rear axles forced the rear suspension to have a track width of 54”.

Table 8: Rear Suspension Design Considerations.

Considerations	Priority	Reason
Simplicity	Essential	Easier to fix, build, design, analyze
Light Weight	Essential	Less weight is essential to be competitive
More than 14” Travel	High	Allows for tires to be on the ground d during off camber situations and still have traction
Side Impact	High	Must be able to handle uneven impacts from all directions
Durability	High	Withstand abusive driving during the endurance race
Adjustable Suspension	Desired	Nice to have but not necessary for design
Unique	Low	To stand out from the competition and try something new

There has been 3D modeling and FEA testing on the part to see the reactions under different loading conditions, see Figure 10. The material chosen to construct the arms is 4130 Steel of 1.25 inch outer diameter, with 0.049 and 0.065 inch wall thickness tubing. The tube strengths can be found in Table 6. There were two sizes of wall thicknesses-



Used because of the bend in one member. We were not able to make COSMOS Works work for this arm design, but since it was the only member being modified, the decision to use thicker tubing was for additional strength. Since the weight addition is very small by using a slightly thicker tube, it was decided to make the pivoting member which the arm swings on and the lower tube out of the thicker tubing as well.

Since the vehicle has been driving for two weeks, there has been testing done to see if the suspension reacts the way intended by design. It turns out that the design of the rear suspension is working as well or better than expected. The goal of 12 inches of travel was met. Along with that travel, the articulation of the rear suspension was tested by

Lifting on tire until another tire off the ground. The height measured to be 24”. This was done to check the amount of articulation of the suspension which could be helpful in events such as the Rock Crawl. This allows the vehicle to remain stable and to keep traction with all tires while encountering complex terrain. The rear suspension, under normal driving conditions, reacts as planned and the camber changes with the roll of the vehicle. Also, at race speed the rear inside tire lifts slightly lowering the traction of tire which allows for better turning since the rear axle is locked, as this lower traction allows for some differential effect do to a slipping tire. Testing and tuning of the rear suspension will continue as stated in the Appendix IX. Overall the rear suspension was a success, and definitely helps the vehicle be a possible competitor. The rear suspension can be seen in Figure 8.

4.5 Drive Train

The goal of the drive train is to transfer power from the engine of the vehicle to the wheels. The power transferred must be able to move the vehicle up steep grades and propel it at high speeds on level terrain. Acceleration is also an important characteristic controlled by the drive train. For this vehicle, it was desired to be able to climb a 45 degree slope while vehicle carrying the heaviest of the team’s drivers. It was also decided that the vehicle should be able to achieve a velocity of approximately 60 kilometer per hour on level terrain. The next most important design goal was to minimize weight of the assembly in order to improve acceleration and decrease rolling resistance. A tertiary, but still important goal was to maximize serviceability by modularizing the drive-train. This has been attempted several times in the past with limited success.

There are several different methods of power transmission that have been used in the past. One very common method which has been used in the past is a manual transmission.

The common means of power transmittal is a manually shifted gear box. They are available with up to five forward speeds, which provide a large range of gear ratios. In addition, existing ATV transmissions have been designed to fit a similar role to what is desired in our off road vehicle. The disadvantage is that they must be shifted by the driver. In order to minimize this distraction, the transmissions are available with automatic clutches. They engage the drive plates above idle RPM, and disengage below this RPM. So, in order use CVT, the driver only has to reduce the throttle and press a shift up or down button. Other less common methods of power transmission include automatic planetary transmission and hydrostatic transmission. These transmission types are very uncommon for this type of vehicle, and as such they would have to be mostly manufactured from scratch.

Several different five speed transmissions with auto clutch and reverse were compared for packaging, weight, and gear ratio range. The HONDA provided a transmission which was superior in all three of the categories. In order to determine the final gear ratios for the input and output sides of the transmission, approximations for air resistance, rolling resistance, and weight were made using the maximum values allowed by our design goals. This provided a desired overall gear ratio to be created by the combination of input and output sprockets on the transmission. The input side of the transmission had a readily determined ratio because the idle speed of the engine had to be converted to a speed which was below the engagement of the automatic clutch. The output gear ratio was determined by comparing the desired overall gear ratio to those provided by readily available ATV sprockets. In order to attach the sprockets to the input and output shaft, modifications were made to the transmission. The input shaft previously consisted of a splined section, a crank, and a section for the starter gear to drive. By removing the crank and starter gear, significant inertia was removed from the shaft. A new shaft was then keyed into the existing shaft, and provided bearing support and a keyed shaft for the input sprocket to drive. The completed shaft is shown below in Figure 13. Refitting the output side of the transmission consisted of removing a cast boss around the output bevel gears, removal of the bevel gears, and construction of a simple threaded adaptor to drive the output sprocket.

Figure 13: Completed Machined Crankshaft

In order to package the transmission, a cradle was constructed of several water-jet cut plates. The plates were bent to provide the proper offset between the components. Bulkheads made the assembly rigid in torsion in order to resist the torque generated by a seized drive train. Numerous stress analyses were performed in order to remove excess material and ensure that the cradle would withstand the expected loading. The bulkheads and other cross-members were tabbed for a semi self-fixturing assembly. Welds were made along the joints of the bulkheads and side plates, and the large weld length provides for a very stiff assembly. All components are capable of being easily removed from the cradle, and the cradle itself can be removed from the vehicle with an ATV jack after removing three bolts. The bolts go through hollow steel tubes which have been filled with rubber isolators, and attach the assembly to tabs on the frame. The rubber isolators increase ride comfort and allow for manufacturing deviation due to their compliance. The final drive uses an articulated common driveline. A solid model of the completed drive train assembly can be seen in Figure 14. This consists of a center hub assembly with both a sprocket and brake rotor. Two constant velocity joints connect to drive axles. This gives essentially a locked diff, but is much lighter and more compact.

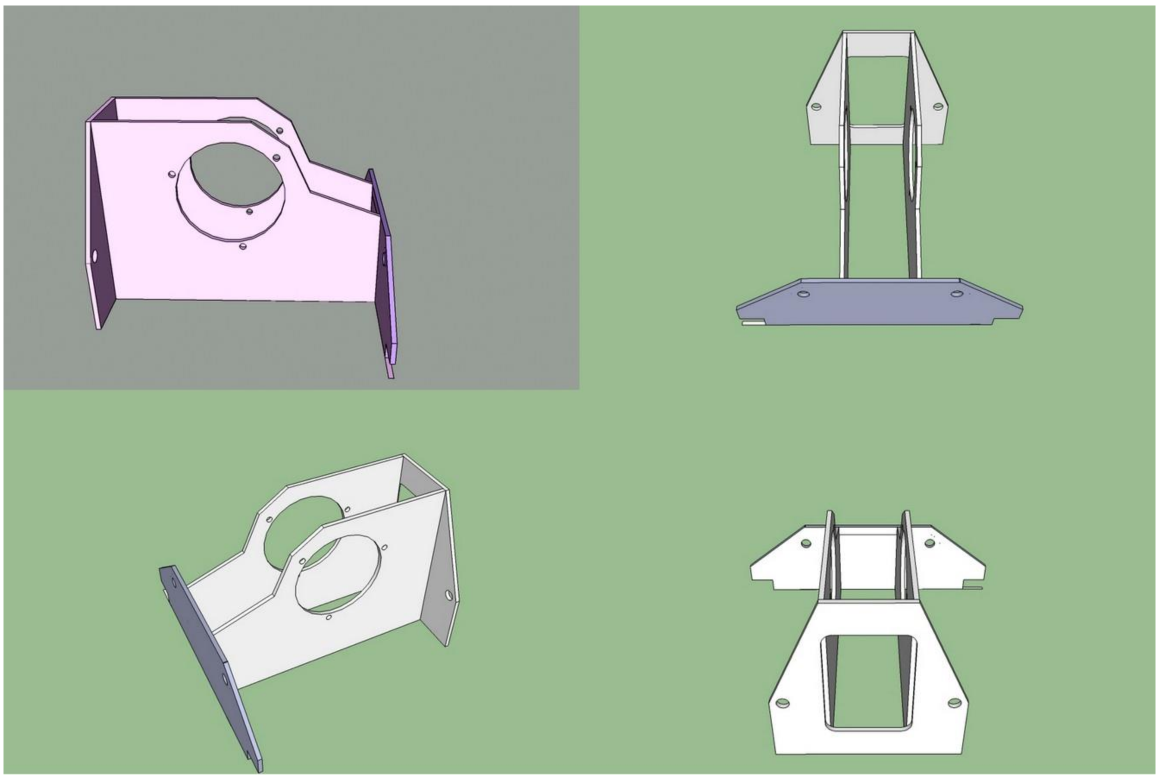


Figure 14: Four Views of Rear Drive Train Assembly

4.6 Braking System

Table 9: Braking Design Consideration

Consideration	Priority	Reason
Simplicity	High	Overall goal of vehicle
Performance	High	Capable of decelerating a 500lb vehicle
Lightweight	High	Prevent air bubble within the brake lines
Reliability	Essential	Lightweight parts to minimize total weight
Ergonomics	Essential	Optimal pedal assembly fitment to suit every driver

The objective of the braking system is to provide a reliable and prompt deceleration for the vehicle. Moreover, the driver must have complete control of the vehicle while the brakes are activated. More importantly, the brakes must be capable of locking up all four wheels while on the pavement, which is one of the requirements stated by the OFF ROAD BATTLE 2k16 rules. Considerations for the brakes can be found in Table. Through research and applications from previous years, disc brakes have been selected as the optimal choice for the braking system. The vehicle is equipped with a hydraulic braking system. All major components have also been installed.

A CNC Dual Cylinder Brake Pedal Assembly was used as the pedal assembly of the vehicle. The unit composed of dual circuit master cylinders. Thus the implementation of this feature is easily accomplished.

To ensure proper fit of the pedal assembly into the frame, the brake pedal leverage has been shortened. Although shortening the lever arm requires an increase in foot force, the vehicle is still capable of decelerating safely and efficiently.

4.7 Steering

The objective of the steering system is to control lateral motion while the vehicle is in longitudinal motion. The objective of the steering geometry was to provide Ackerman geometry. This geometry ensures that all wheels roll freely without slip because the wheels are steered to track a common turn center. Without Ackerman geometry in the steering design, the front tires tend to slip instead of roll causing the car to decelerate. This is energy loss is very undesirable especially when considering the limited horse power available.

Some objectives established for the steering system were to use a simple design, easily controlled Ackerman, and limit steering wheel rotation from lock to lock. Two different steering designs were considered for this vehicle. The first design that was considered was a rack and pinion. However this steering configuration would restrict and complicate the primary design considerations. It was determined that using a bell crank would allow all design considerations to be achieved for a fairly low cost with ease of maintenance. All design considerations for the steering system can be seen in Table.

Due to the suspension geometry and placement of the bell crank pivot, minimal bump steer could be achieved in full suspension travel. Minor alterations to the frame had to be made to accommodate for clearance of the tie rods in order for full suspension travel. This design has performed well for the configuration it was designed for. The low steering ratio works well with the rear semi solid axle and single front A-arms.

The current design is limited to having the desired positive Ackerman geometry. To solve this problem the bell crank will be shortened as much as possible keeping the current Ackerman geometry in addition to adding a gas shock to decrease feed back to the driver.

Figure 15: Bell Crank Assembly

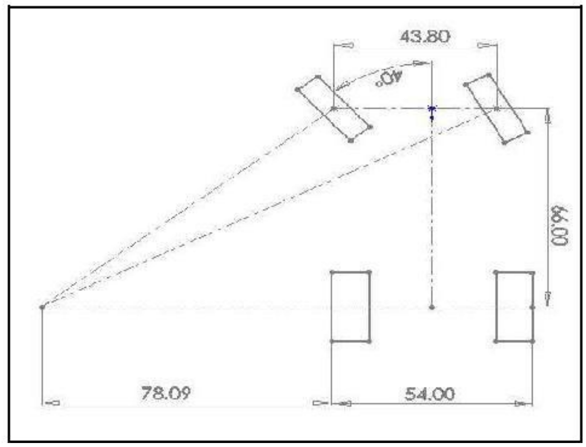


Figure 16: Steering Ackerman Geometry

Table 10: Steering Design Considerations

Consideration	Priority	Reason
Simple Design	Essential	Easy to repair during competition
Light Weight	Essential	Minimize weight to maximize power to weight ratio of car.
Low Steering Ratio	Essential	Quick steering response
Ackerman geometry	High	Minimize billed labor time will increase points awarded
Billed time of fabrication	High	Conserve forward momentum throughout suspension travel
Minimize Bump steer	Desired	Conserve momentum while steering

4.8 Ergonomics

Ergonomics is the science of equipment design intended to maximize productivity by reducing driver fatigue and discomfort. The ergonomics aspect of the off road battle is crucial in ensuring that the car will both meet all of the rules stated in the rule book as well ensuring that all of the components of the car will function properly when assembled together. The team consists of members who are of a wide range of heights and weights. It is an essential part of the car that each member of the team is able to safely and comfortably operate.

Each member of the team sat in the seat prior to purchasing it to make sure that they would fit properly and make certain that it provided the necessary support. Holes were drilled using a hole saw in the seat from the 2015 car. This was done to determine the benefit of weight loss without jeopardizing the structural integrity of the seat. Other design considerations inside car included the placement of the steering wheel in relation to the various drivers.

This was done in order to allow the optimal placement with respect to the different members of the team the vehicle. The transmission will also have reverse that can be engaged when the vehicle is in first gear. The first plan for shifting the car was to use a pneumatic shifting system consisting of separate air pistons linked two an air tank to shift the car. After this system was created it was determined that it would not be possible to drive the car for the amount of time required without using a heavy air tank that would be very impractical for such a small car.

As a replacement to the pneumatic system, manual linkage has been installed in the car. This is a very simple system that has proven to be very reliable. The system allows the driver to shift the car via a paddle located on the steering wheel which allows the driver to shift without having to let go of the steering wheel. A large display tachometer along with an hour meter has been mounted in direct view of the driver. This will allow the driver to know when they must shift the car. The hour meter will be important in testing the car to help determine how long certain components will last so that the team can decide whether or not they will be sufficient for the competition or not.

All of the required electronic systems on the car will be run to a single, central location on the back of the car. At this location there will be a single, sealed box that will also house the reverse light and alarm as well as the battery and all of the required switches and relays for the car. This will allow for easy access as well as a safe location for all of the electrical components. Other ergonomic designs on the Baja will include reverse mirrors and removable lights to allow the team to test the car at night prior to the competition.

4.9 Budget

For the competition, the Society of Automotive Engineers requires each team to submit a prototype cost report, which can be seen in Appendix VII. For this report the team had to acquire manufacturer's suggested retail price for each item used on this car. This cost report is worth 100 points of the total 1000 available as seen in TABLE ## FROM INTRO. 15 of these points come from formatting, and the remaining 85 come from a comparison of the teams cost to the least and most expensive prototypes at the competition.

A budget of the money actually spent is also included in Appendix VII. To date everything needed to complete the car has been purchased except the body panel material.

5.0 CONCLUSION

The team has been made great progress on the vehicle. As of now it is a completed driving vehicle with only safety components being needed to comply with the specified ORGANIZING COMMITTE rules. There have been a lot of minor design changes that have surfaced during fabrication, but all have easily been overcome. After initial testing it can be seen that our design should be a strong competitor in this year's competition. There will be extensive testing done to prove the design and durability of all the systems on the vehicle and make any necessary changes up until the leaves for the competition.