ABSTRACT

BAJA SAE, the ATV design event provides a platform for the undergraduate students to apply the principles of engineering science to expose their proficiency in the automotive world. Contesting of the Team Roadies in this event always had the solo aim of reeling off the race by designing the best performing, rugged and economical vehicle. Terra-Incognita, the all-terrain vehicle powered by 10 HP engine, reflects the combined effort of all the team members who worked hard to come up with optimum design in accordance with the rule book. The design report focuses towards explaining the procedure and methodology used for designing the off road vehicle.

INTRODUCTION

The design process of this single-person vehicle is iterative and based on several engineering and reverse engineering processes. Following are the major points which were considered for designing the off road vehicle:

1. Endurance
2. Safety and Ergonomics
3. Market availability
4. Cost of the components
5. Standardization and Serviceability
6. Manoeuvrability
7. Safe engineering practices.

Team Roadies began the task of designing by conducting extensive research for main parts of the vehicle. Our team members did a global market search for the desired parts of the ATV. Including the market of Ranchi, we also went to Jamshedpur which is known as “Pittsburgh of India” and Adityapur (AIADA) - home to one of the India’s largest industrial zones and other automobile related areas for direct interaction to the. We contacted numerous auto part dealers in different parts of the country to know the availability of required parts. Then keeping the voluminous list of available parts in mind, the designing team initiated their work to achieve the best standardised as well as optimised design possible. Creo Parametric 1.0 (Pro Engineer) was the CAD software used for designing and ANSYS 13.0 was used to analyse the Impact test and all. Specifications laid down by the rulebook were the foremost concern while designing and selection of the parts. Besides performance, consumer needs of serviceability and affordability were also kept in concern which we got to know through the internet research and reviews for all terrain vehicles. In between we also met other experienced teams to get some ideas related to the event. Finally the design was presented in the Virtual event of BAJA SAE INDIA 2013 and we were through it. The first time participation and selection in that only increased the team’s enthusiasm drastically. Now we have started the fabrication part of the vehicle with all the blazing spirit and exhilaration.

ROLL CAGE DESIGN

Roll Cage can be called as skeleton of a vehicle, besides its purpose being seating the driver, providing safety and incorporating other sub-systems of the vehicle, the main purpose is to form a frame or so called Chassis.
DESIGN METHODOLOGY

We have designed the roll cage keeping in view the safety and aesthetics. These are the two factors which matters us the most, therefore they are given utmost consideration. The design complies with the rules mentioned in the BAJA SAE INDIA 2013 RULE BOOK.

MATERIAL OF THE ROLL CAGE

Material selection of the chassis plays crucial part in providing the desired strength, endurance, safety and reliability to the vehicle. To choose the optimal material we did an extensive study on the properties of different carbon steel. The procurement team was directed to get the quote of those steel pipes. We first considered AISI 1018 steel and 4130 chromoly. The strategy behind selecting the material for roll cage was to achieve maximum welding area, good bending stiffness, minimum weight and maximum strength for the pipes. So, after market analysis on cost, availability and properties of these two alloys, we finalized AISI 1018 of the following dimensions:

Outer Diameter : 25.4 mm
Wall Thickness : 3.05 mm

Then analyses of the roll cage considering AISI 1018 pipes of shown dimensions was done and we got the safe factor more than 2, which justified the selection.

VEHICLE DIMENSIONS

A wider track width at the front than at the rear will provide more stability in turning the car into corners decreasing the tendency of the car to trip over itself on corner entry and more resistance to diagonal load transfer. Wheel Base is 1600mm and Track Width is 1550mm. This has been chosen to ensure better balance and straight-line stability. This has also created ample space for the driver and other systems.

ROLL CAGE COMPONENTS

The components used to design the Roll Cage, their functions and designing procedure is mentioned below:

Rear Roll Hoop (RRH):
The RRH was the first section of the chassis to be designed. It is angled back at 100° angle to provide the driver with the most natural sitting position possible. It consists of four sections of tubing welded on the ends. The Rear Roll Hoop Lateral Diagonal Bracing (LDB) keeps the RRH from deforming and increases overall stiffness of the chassis. Two lateral members have been used for support and mounting points for seat belts and engine.

Roll Hoop Overhead (RHO):
The RHO is welded to the RRH. The RHO provides the appropriate head room for a 6 feet 3 inch driver with additional 6 inch clearance.

Lower Frame Side Members (LFS):
The LFS is welded at the bottom of the RRH as shown in Fig. 1. The width of LFS keeps on decreasing along the length. This provides maximum driver space and at the same time it reduces the size of the vehicle. The Lateral Cross (LC) Member joins the LFS in the front. The width of the LC member is selected so as to accommodate the three pedals comfortably.

Fig. 1 Roll Cage & Components
Side Impact Members (SIM):

The SIM increases chassis stiffness and is a major member that provides protection to the driver in a side-on collision. It is a single piece of tubing with two bends as shown in Fig. 1. The SIM extends straight up to the driver’s elbows and then converges in the front. The LC connecting the SIM in the front is a very important member because it is the first member of chassis to be hit in case of frontal impact. It not only protects the driver from frontal impacts but also increases the stiffness of the Roll Cage.

Rear Bracing:

The Rear Bracing encloses the engine, transmission, and rear drive assembly. The rear bracing also incorporates an independent rear suspension. The main properties of the rear chassis are all constrained by the driveline. Before the base of the rear was designed, the length of the drive axle was considered. Also the height of the lower rear roll cage is defined by the rear suspension mounting points. From this point the rest of the rear roll cage is designed.

To check the accommodation of driver in the roll cage design made, the team took two more days to make a dummy cockpit using Poly Vinyl Chloride pipes. It is shown in Fig. 2. The driver was seated to check out the comfortability and front visibility from the vehicle. After this test two major changes were done in the design:

i) Two front members were removed and its replacement were done by adding supports.

ii) The dimensions of the car were changed by a small ratio.

FINITE ELEMENT ANALYSIS OF ROLL CAGE:

After completing the design of the Roll Cage, Finite Element Analysis (FEA) was performed on the Roll Cage using ANSYS 13.0 to ensure expected loadings do not exceed material specifications.

Beam 188 element was selected with the cross section as the dimensions of pipe. The meshing was done globally with a size of 3mm and smooth transition in mesh. \( E = 3.65 \times 10^8 \text{ N/m}^2 \) and \( PRXY = 0.3 \) was used as per AISI 1018 properties. Standard loads as per Europe National Car Assessment Programme (EUNCAP) were applied on the key points and the results were obtained for Frontal Impact, Side Impact and Roll over. Results obtained were not so safe for the Impact so we added two more members to the roll cage. Finally, the maximum stress was found due to Frontal Impact on the truss members. It is around \( 1.74 \times 10^8 \text{ N/m}^2 \) which is within the limits. For other situations also results provided by the ANSYS are within limits. From the results of analysis we conclude that Von Mises stresses are within the limits and FoS is always greater than 2. Hence, the design is safe enough to proceed further for fabrication.
SUSPENSION

An ATV is supposed to have the best of the suspension systems than the other categories of vehicles. The unpredictable nature of off-road racing creates the need for a reliable and efficient suspension system. So the selection of suspension system was a tenacious task for the team, even the roll cage was designed keeping in concern the position of suspension mounting points.

Selection of suspensions was based on the criteria of their degree of freedom, roll-center adjustability, ease in wheel alignment parameters etc. The suspension system will be tuned according to the actual needs, keeping in mind the manufacturing aspects and the nature of loading it will have to suffer.

The design goals of the suspension system were:

1. Improve vehicle handling
2. Increase the ride height and total wheel travel
3. Improve durability of components

Because of inconsistencies in the track each of the four wheels need to act independently of each other. For this reason, an independent suspension was chosen over a dependent one. Among the independent suspensions MacPherson Strut, Double Wishbone and Semi-Trailing Arm were among our chief considerations.

DESIGN APPROACH

The advantages of the MacPherson strut include its simple design of fewer components, widely spaced anchor points that reduce loads. The disadvantage of this system is the comparatively high cost of servicing the shock absorber. The options now available with us were double wishbone and semi-trailing arm. However for the front the option of semi-trailing arm was ruled out due to problems in packaging and also for the rear with the trailing arms angled outwards on the frame, will increase the track width of the rear which is undesirable as it will decrease the manoeuvrability. Therefore it has been decided that we will use double wishbone suspension in the front and the rear with unequal and parallel A-arms.

<table>
<thead>
<tr>
<th>Length of A-arms</th>
<th>Parallel SLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>312 mm</td>
</tr>
<tr>
<td>Lower</td>
<td>338 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Roll Centre Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
</tr>
<tr>
<td>Rear</td>
</tr>
</tbody>
</table>
CONTROL ARMS:

Design for optimal geometry of the control arms is done to both support the race-weight of the vehicle as well as to provide optimal performance. Design of the control arms also includes maximum adjustability in order to tune the suspension for a given task at hand. Also kinematic analysis on the control arms was done as shown in the figure below to determine the dimensions of cross-section of control arms.

SHOCK ABSORBERS:

We have decided to procure the shock absorbers available in the market rather than fabricating them as it would not only reduce the cost and time but also it will be more reliable. We will be using shockers of Polaris ATV for both the front and the rear. In the front shock absorbers will be mounted on the lower arm, this will decrease the vehicle height, which in turn will increase the driver’s visibility. The parameters affected by the lower mounting point are the speed and the steering ability of the vehicle. Both of them are equally important for us therefore lower mounting points of the shocks will be more or less in the middle of the A-arm. In the rear the shockers are mounted on the upper arms as it can’t be mounted on the lower arm as the axle runs between the upper and the lower arms. Therefore the shocks will be mounted in the center of the upper A-arms.

Main features of our suspension design are

1. We have positioned our roll centers at 81.66 mm and 114.82 mm above the ground in the front and rear respectively. These values allow us to minimize jacking forces while maintaining acceptable values for roll.

2. The ratio of Rear to Front Roll center is 1.44, close to 1.5 which is considered ideal.

3. We have provided Nose dive type roll axis (higher roll center in rear than front) to minimize vehicle roll.

4. The control arms have been kept of optimum length, so as to attain desirable wheel travel and also to minimize the tendency of body to roll and stabilize the vehicle during cornering.

When designing the double wishbone suspension the resulting moment effects have been calculated to make sure that the control arms are not going to experience plastic deformation in a range of foreseeable events that may occur. To conclude, the suspensions have been designed to ensure a ride that is as smooth as possible when driving on the rough terrain.

STEERING

The essentials still remaining the same, the importance of the steering mechanism cannot be compromised with. The BAJA track consisting of sharp turns and bumpy roads, the stability of the system and the response time (Feedback) are vital factors in deciding the vehicles’ run. The Worm and Sector
mechanism, Rack and pinion and the Re-circulating ball mechanism were among our options to go with. But on consideration of mounting ease, simplicity in design and considering that our vehicle is of the compact category; rack and pinion was chosen over the others. The rack and pinion being a simple system; can be easily maneuverer and the defect, if any, can be spotted and taken care of. Moreover the steering wheel and other relevant apparatus are so placed in the design, for easy entering and exit of the driver.

**DESIGN METHODOLOGY**

**Steering Geometry:**

The Ackermann geometry is the easiest to implement and has been tested for BAJA vehicles all over the globe and hence it was a unanimous choice for the steering geometry. With Ackermann Steering all four wheels of the vehicle pivot around the same point making sharp turns relatively easy to accomplish. This ensures that the vehicle tires do not slip during turns that are sudden.

**Steering Gearbox:**

We shall be manufacturing a customized centred steering mechanism, the basis of which shall be derived from the rack and pinion of MARUTI 800. Direct usage of the Maruti 800 gear system is not done, mainly because of its eccentric placement of the gearbox that disrupts the C.G. balance of the vehicle.

**SPECIFICATIONS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Caster</td>
<td>$5^\circ$ Positive</td>
</tr>
<tr>
<td>Camber (static)</td>
<td>$2^\circ$ Negative</td>
</tr>
<tr>
<td>Toe In</td>
<td>10 mm</td>
</tr>
<tr>
<td>King-pin inclination</td>
<td>$12^\circ$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scrub radius</th>
<th>44 mm</th>
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</thead>
<tbody>
<tr>
<td>Lock Angle</td>
<td>$40^\circ$ (approximately)</td>
</tr>
<tr>
<td>No. of turns to steer from Extreme Left to Extreme Right</td>
<td>2.66 turns</td>
</tr>
</tbody>
</table>

The major parameters in steering design are,

1. The Caster angle has been adjusted to $5^\circ$ as it increases directional stability and handling of the vehicle in bumpy sections.
2. The Camber is kept negative to ensure maximum contact of tire with ground during cornering and to reduce chances of flipping over.
3. Ackermann type of steering geometry ensures consistent and smoother ride and prevents the slipping of tires during cornering.
4. We have a scrub radius of 44 mm approximately. This is acceptable as it is neither a negative value nor too large of a positive value. Such a small value will leave the car slightly harder to steer at very low speeds. It is important for this value to be equal on both tires to avoid the car “pulling” to one side.

We have kept a small Toe-in in the front. This will stabilize the car while moving straight and while coming out of turns. It will smooth out the steering response, making the car very easy to drive.

**BRAKING SYSTEM**

An excellent braking system is the most important safety feature of any land vehicle. Competition regulations require at least two separate hydraulic braking systems, so that in the event of a failure of one, the other will continue to provide adequate braking power to the wheels. The main requirement of the vehicle’s braking system is that it must be capable of locking all four wheels on a dry surface. Ease of manufacturability, performance and simplicity are a few important criteria considered for the selection of the braking system.
OBJECTIVES

The goals for the braking system were:
1. Reduce weight in the overall system.
2. Increased reliability
3. Improved performance.

DESIGN APPROACH

The two main types of braking systems under consideration were Drum and Disc brakes. But in case of drum braking there is a high possibility of mud and debris to gather in the space between the shoe and the drum. Same problem is faced in mechanical disc brakes, but not in hydraulic disc brakes. Hydraulic brakes are found to be suitable for all type of terrain across worldwide. So we have decided to use hydraulic disc brakes in the front and the rear. We will be using two master cylinders, one for the front and the other for the rear. The master cylinders will be mounted in parallel such that both the master cylinders are connected to a same linkage which connects them to brake pedals and actuates braking in all the four wheels when foot pedal is pressed. The internal diameter of our rim is 8 inches, so we need a small disc and calliper assembly. We will be using discs and callipers of Maruti 800. The diameter of the disc is 180mm which is optimum as per our need. And also will help us easily mount the disc and the calliper on Maruti 800 knuckle.

In general brakes are used to control the speed of the vehicle; they are seldom used for sudden braking which may cause the vehicle to nose-dive. We have decided to increase the CG height by around 5-6 inches to increase ground clearance and improve driver comfort, hence greater pitching tendency is expected in our design, and therefore we have taken pro-active measures by using anti-dive geometry in suspensions.

TYRES AND RIMS

In an All-terrain vehicle, traction is one of the most important aspects of both steering and getting the power to the ground. Tire configuration treads depth, weight, and rotational of inertia are critical factors when choosing proper tires. The ideal tire has low weight and low internal forces. In addition, it must have strong traction on various surfaces and be capable of providing power while in puddles.

TYRES

Keeping in mind all the above mentioned aspects we studied about the various types of tires available in market. After enough market research and guidance from our faculty advisor we have decided to use 4-ply rating, tubeless tires and that have got specific tread pattern so as to provide a very strong and firm grip on all kinds of surfaces as well as sturdy enough to absorb various bumps and depressions on track. After going through the engine, transmission and some basic torque and angular velocity calculations we have finalized the diameter of tires to 22 inches which would help us to transmit maximum power. This calculation is also in accord with the requirements of Acceleration, Hill climb, Maneuverability and Endurance events. The dimension of all four tires is finalized as 22 x 8 inches where diameter is 22 inches and width is 8 inches.

RIMS

The Rims shall be made up of Aluminum to minimize unsprung weight. By reducing the width of the rim the inertia will be directly decreased and subsequently this will also reduce the overall weight. The dimension of all four rims will be 10 x 6 inches.

WHEEL END

The wheel end is made up of the following parts- Rim, Hub, Disc, Milled bearing, and knuckle in sequence. Their compatibility with each other is a major design issue as these parts have been taken from different sources.

KNUCKLE

The dampers, A-arms and steering tie rod are connected to this part. Every car needs a separate design to have the required Caster and Kingpin angles set for the particular car. It is also to be noted that the entire load of the vehicle will be transferred to the tires through the knuckle only. So, this part’s design is very critical for any cars performance. Knuckle is
mounted to the hub with a bearing with the help of a hydraulic press and bolts are screwed to keep the stud and disc together. The inner part of bearing is milled which acts as a spline to transmit power from the axle.

**Approach I:**

Fabricate the knuckle out of plates of M.S by welding and mount it to a stud with a fabricated matching plate to fix with the rim. This would give us independence in selecting the geometry control the dimensions would be compact.

But this would take more time and cost.

**Approach II:**

Use the knuckle of an on-road vehicle and modify it accordingly. This would involve converting the MacPherson type mountings to double wishbone type and no change in geometry possible. This approach would be cheap and reliable and also aid in better packaging with our rim.

We have selected approach II, the primary reason being the increased reliability of the system, since they have been tried and tested. We checked out the upright of various cars like WagonR, Maruti 800 etc. Eventually after doing enough market research we found out that the smallest and cheapest knuckle available in the market was that of Maruti 800. We will modify the knuckle which is used for MacPherson strut to mount our A-arms. The mounting points of the A-arms will be fabricated in such a way so as to have a King-pin inclination of 12° as desired. The wheel end assembly will be mated in the rim with the help of plate matching which will be bolted to the hub and the rim.

The salient features of our wheel end include increased reliability, ease of serviceability and availability of replacement parts.

**DRIVE TRAIN**

The drive train includes the engine, transmission and the axles for transmitting the power to the wheels. We will be having a Rear wheel drive and the engine and the transmission both will be placed such that centre of gravity of both of them lie more or less in the centre.

All the teams participating in Baja SAE-Asia 2013 have been generously sponsored with a 305 cc, 10 HP Briggs and Stratton Engine. The detailed specifications of the Engine are shown below:

**ENGINE SPECIFICATIONS**

<table>
<thead>
<tr>
<th>Torque* (ft-lbs, gross)</th>
<th>14.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Displacement (cc)</td>
<td>305</td>
</tr>
<tr>
<td>Number of Cylinders</td>
<td>Single</td>
</tr>
<tr>
<td>Engine Configuration</td>
<td>Horizontal Shaft</td>
</tr>
<tr>
<td>Engine Technology</td>
<td>OHV</td>
</tr>
<tr>
<td>Length (in)</td>
<td>12.3</td>
</tr>
<tr>
<td>Width (in)</td>
<td>15.4</td>
</tr>
<tr>
<td>Height (in)</td>
<td>16.4</td>
</tr>
<tr>
<td>Weight (lbs)</td>
<td>50.4</td>
</tr>
<tr>
<td>Bore (in)</td>
<td>3.12</td>
</tr>
<tr>
<td>Stroke (in)</td>
<td>2.44</td>
</tr>
<tr>
<td>Engine Fuel</td>
<td>Gasoline</td>
</tr>
<tr>
<td>Spark Plug</td>
<td>RC12YC</td>
</tr>
</tbody>
</table>
We are not allowed to modify the engine but we have been given the choice of choosing our Transmission.

The transmission under considerations for our vehicle included shifter transmission and CVT (Constant Variable Transmission). The CVT is a heavy transmission, but no shifting mechanism required. It has a high power output, however manufacture of this transmission is difficult and the cost of the CVT adds a disadvantage to this option. Also while using a CVT is makes it very difficult to introduce a reverse a gear. The shifter transmission has high output and power transfer. The power is more easily controlled on with the gear shifter and desired gear can be chosen at any time. The disadvantage of the shifter transmission is that it requires a shifter mechanism and a clutch therefore increasing the number of components. But the main advantage of the shifter transmission is that it is tried and tested in many previous vehicles besides it has a high output also.

Therefore we have decided to use the shifter transmission. We have studied the transmissions of various 3-wheelers and other small vehicles but none of them meets our requirements as much as the Mahindra Alfa transmission does. Therefore we have decided to use the Mahindra Alfa transmission.

SAFETY, ERGONOMICS & ELECTRICAL:

Driver’s safety is the most important concern for our ATV. For the comfort and safety of the driver in the rugged, up and down track the vehicle will be provided with 5 point harness seat belt system along with neck restraint and arm restraint. A pivoted bumper with spring support in the front of the vehicle will be installed on the front of the off road vehicle to absorb energy from collision. Fire extinguisher and kill switches specified in the rulebook will also be used for the case of emergency.

Ergonomics include the belly pan structure running over the entire length of the cockpit, foam padding of the roll cage, gear shifting indicators and such other things.

SAE grade brake lights and back alarms will be installed in the ATV with proper insulations. 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.

CONCLUSION

When undertaking any design project there are several factors to be considered that are common to all engineering projects. A project must have a proper scope with clearly defined goal. Our team is participating for the first time in this event, so a comparative study of various automotive systems is taken as our approach. With such an approach, engineers can come up with the best possible product for the society. We are also planning to conduct a customer needs survey to improve the vehicle further more. Anything being done for the first time, few difficulties are sure to come. Further improvements and a detail design of all other systems of the vehicle will lead to competitive vehicle. We hope to come with the best possible final product so that we will be one of the noticeable competitors in this year’s competition.

ACKNOWLEDGMENTS

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3. www.howstuffworks.com

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The FINAL view of our vehicle