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Fabrication and Design Process of Sae Baja Vehicle

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ABSTRACT

SAE, INDIA conducts a competition known as BAJA, which challenges aspiring engineers to create an off-road vehicle, called an ATV (All-Terrain Vehicle) or an off-road buggy. The competition‟s objective is to design and fabricate a prototype vehicle that could be manufactured for consumer sale. The original purpose of designing and manufacturing an ATV was to create a prototype of a recreational off-road vehicle that could provide a thrilling, but safe, and reliable experience for a weekend off-roading enthusiast. Moreover, this type of vehicle can find applications in defense and military, forest and mountain ranging or rescue operations, and as a cheaper and more refined alternative to tractors for use in small farms and fields.

The difficulties faced were many: selection and procurement of various parts being the major one. Also, we were constraint to use a BRIGGS AND STRATTON engine on an ATV, which required extensive designing and modification of the chassis, for it to be able to bear the harsh off-road conditions. A major challenge was to keep the center of gravity of the ATV as low as possible, because of the off-roading vehicle‟s tendency to topple, especially during turning, and at the same time, keeping the ground clearance high enough to ride easily on rough and rocky terrain.

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1. INTRODUCTION

In order to accomplish this task, different design aspects of an ATV vehicle were analyzed, and certain elements of the vehicle were chosen for specific focus. There are many facets to an off-road vehicle, such as the chassis, suspension, steering, drive-train, and braking, all of which require thorough design concentration. This vehicle is designed and manufactured according to rules provided by SAE, INDIA to compete in the event "SAE

BAJA" organized by SOCIETY OF AUTOMOTIVE ENGINEERS (SAE). The points of the vehicle that Dirt Rangers Club has decided to specifically focus on were the chassis, drive-train, and suspension. The most time and effort went into designing and implementing these components of the vehicle because it was felt that they most dramatically affect the off-road driving experience. During the entire design process, working towards consumer interest, through innovative, inexpensive, and effective methods, was always the primary goal.

For the purpose of the application on a high performance, off-roading course, the vehicle design has to meet the following criteria:

(1) Lightweight to maintain good performance to weight ratio of the race vehicle

(2) Optimum stiffness to ensure low system compliance and maintaining designed geometries.

(3) Ease of maintenance for enhancing serviceability and setup repeatability.

(4) Ability to have the components manufactured in-house, to reduce turnaround time and outside dependability.

By using Solidworks2013, for (CAD) Computer Aided Design, and Finite Element Analysis (FEA) for analysis of different parts to meet the requirements of SAE INDIA rulebook, different tests were done on the vehicle to make sure the vehicle will sustain in off road conditions.

2. BACKGROUND

The background for this thesis is based on design and manufacturing a off-road race vehicle for the annual SAE BAJA competition. The competition, as organized by the SAE INDIA is to allow University and collegiate students to exercise their engineering skills, and come up with a functioning prototype for the hypothetical business proposal of a budget race-oriented vehicle. The project consists of design, manufacturing, business, and for the bulk of the score available, the dynamic on-track aspect of the vehicle. For the first 3 parts of the competition, the students have to justify their design decisions, manufacturability in a mass production environment, and their project cost analysis to a panel of judges that were chosen from industry professionals. And for the dynamic events, these "prototypes" are put through their paces on a closed course and their performance measured by a stopwatch. The winner is determined by the cumulative scoring from all the events.

DESIGN

3.1 Design Considerations:

The BAJA Vehicle was designed with specific objectives in mind to provide an ultimate direction to guide the team through the design process. Some of the most important design objectives for this year„s team included the following:

• Ergonomics and driver comfort

Following points are take in consideration for Ergonomics of vehicle:

- ➢ Driver‟s comfort
- ➢ Driver‟s vision
- ➢ Seat height and Handle height
- ➢ All controls are in Handle bar for ease of driver

Fig 1: Ergonomics

• Manufacturability

SAE states that the goal of the competition is to design and manufacture a prototype of a small-scale production vehicle. In the interest of completing the vehicle for testing, all parts of the vehicle were designed with manufacturability and affordability in mind. Parts are positioned both for packaging and performance and easy access for tuning and replacement.

3.2 Manufacturing

Design for manufacturability was a main concern for the design of the vehicle. In the initial stages of component design, the manufacturability of the part was refined until the part could be made in a minimum amount of setups, and with a small number of tool changes. Throughout the design stages of the project, it was kept in mind that the team was designing a small-run production vehicle. Even though the vehicle, the team manufactured was made using single prototype manufacturing techniques, the components had to be designed so that the manufacturing processes could be easily scaled to larger production runs. A small savings in time or tool life in prototype manufacturing translate into large savings of time and money in a full scale production setting.

All components were manufactured in the college workshop with the exception of parts which were fabricated from outside manufacturer.

3.3 Design, Analysis and Fabrication

Keeping the design objectives developed early in the design process in mind, the team sought to design, manufacture, and analyse the vehicle with the idea that the vehicle would be competitive due to refined designs, thorough analysis and careful manufacturing. The vehicle was designed to not only perform competitively, but also to be cost effective. The team was mindful throughout the entire design phase that the vehicle was being designed and manufactured for the —weekend racer, an individual who demands top-notch racing performance from a reasonably priced and reliable vehicle. To accomplish these goals, the vehicle was designed to be as simple as possible. A simple design would allow ample time for manufacturing and testing of the vehicle. Reducing manufacturing time was not only important for the team in the prototype stage, but would be many times more important for a company producing these vehicles on a larger scale. Less time spent manufacturing saves funding and other resources. Even with careful design and manufacturing, testing the vehicle would expose it weaknesses. This would also allow the team to become accustomed to how the vehicle drove and to practice driving in a competitive environment. The following

sections detail the design, fabrication, and analysis processes for each of the vehicle„s

subsystems.

3.3.1 Suspension

For front suspension Independent, Double wishbone, unequal arm and non-parallel arm were selected to get good performance in off road conditions. And for rear swing arm, McPherson struts suspension was selected. For suspension Geometry of the vehicle

following points were considered:

1. Wheel Size Selection
2. Tire Selection
3. Track Width and Wheel Base Selection
4. Packaging Constraints
5. Wheel Size Selection
6. Tire Selection
7. Track Width and Wheel Base Selection
8. Packaging Constraints
9. Roll Centre Location and Movement Optimization
10. Camber Change Optimization

3.3.1.1 Suspension geometry

1. Front suspension

We have used double wishbone arrangement in the front end of the vehicle design typically uses two wishbone-shaped arms to locate the wheel. Each wishbone, which has two mounting positions to the frame and one at the wheel, bears a shock absorber and a coil spring to absorb vibrations. Double-wishbone suspensions allow for more control over the camber angle of the wheel, which describes the degree to which the wheels tilt in and out. They also help minimize roll or sway and provide for a more consistent steering feel.

a. Advantages

b. Its primary benefits is the increase of negative chamber as a result of the vertical suspension movement of the upper and lower arms. This translates to better stability properties for the car as the tires on the outside maintain more contact with the road surface. Handling performance also increases. The double suspension system is much more rigid and stable than other suspension systems, thus you would realize that your steering and wheel alignments are constant even when undergoing high amounts of stress.

8Fig. 2 : Double wishbone suspension

Fig. 3: Front Suspension Arrangement

2. Rear suspension

We have used McPherson struts in the rear end of the vehicle. The MacPherson strut combines a shock absorber and a coil spring into a single unit. This provides a more compact and lighter suspension system that can be used. A MacPherson strut uses a wishbone, or a substantial compression link stabilized by a secondary link, which provides a bottom mounting point for the hub carrier or axle of the wheel. This lower arm system provides both lateral and longitudinal location of the wheel. The upper part of the hub carrier is rigidly fixed to the bottom of the outer part of the strut proper; this slides up and down the inner part of it, which extends upwards directly to a mounting in the body shell of the vehicle.

a. Advantages

The struts are designed with more simplicity, and thus takes up less space horizontally. They also display low un-sprung weight, an advantage

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that reduces the overall weight of the vehicle as well as increases the car's acceleration.

Lower un-sprung weight also makes your ride more comfortable. Another major advantage of this system is its ease of manufacturing as well as low cost of

manufacture compared to other stand-alone suspension systems. Without an upper arm, the suspension system designers can directly block vibration from reaching the driver compartment.

Fig. 4: McPherson strut suspension

Fig. 5:Rear Suspension Arrangement

Fig. 6: Front Dampers

Fig. 7: Rear Dampers

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3.3.2 Wheel Size Selection

After consideration the following factors, the selected front wheel size is **25 x 8** – **10** and rear wheel size is **25x8-12**.

1. Tire Data – Using information from the Tire Consortium is critical to selecting the optimal tire.
2. Tire Availability – As we are limited to using what is available for purchase, the selection matters.
3. Knuckle hub Packaging – Different size wheels dictate how much room there is to place components such as Knuckle, Hub and brake rotors inside of them.
4. Chassis Impact – The tire size ultimately affects the positioning and packaging of the rest of the chassis.
5. Wheel Availability – Less important than tire availability since making a wheel is much easier than making a tire, but this is still a consideration.

Fig.8: Front and Rear Tires

3.3.3 Initial Kinematic Design

Design began with a 2D design in SolidWorks outlining chassis dimensions.
Here, constraints could be incorporated from the beginning and ensure that all later designs would comply with rules.

Next, representations of the remaining components of the front suspension were added, including wheels, tires, and control arms. At this point, the iterative tuning process began. With this simple 2D model, changes can be made to track width, control

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arm lengths, ride height, instant centres, roll centre, wheel camber, and kingpin inclination easily.

With this model there is complete control over making adjustments to optimize roll center location, migration, and camber curves as well as their effects on roll rate and lateral load distribution. When making changes to different dimensions, it was important to keep in mind compromises that take place. For example, increasing track width can help reduce lateral load transfer; however it will also make navigation through the narrow autocross course more difficult. Raising the roll centre location can decrease the lever arm that the rolling moment applies to the vehicle; however, raising the roll centre will also increase jacking forces. A calculated medium needs to be found for everything.

We started the front suspension design by determining the desired vehicle roll rate.

The equation for vehicle roll rate is shown below:

$$K_\phi = \frac{\pi(t_f^{\,2})(K_w^{\,2})}{180(2*K_w)}$$

K_ϕ =Roll Rate (Nm/Deg)

K_w = Wheel Rate (N/m)

t_f = Track Width (m)

Given this equation, it can be seen that roll rate can be manipulated through changing the roll centre to centre of gravity (CG) distance. This can be influenced by changing the stationary angle of the control arms to change the vertical location of the instant centres and thus the roll centre height.

With the desired roll rate determined, and dimensions iterated to meet these specifications, the springs and dampers were then considered. The important factor

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to keep in mind when determining the kinematics of the damper assembly is the motion
ratio. This is the ratio of vertical wheel travel to damper compression, i.e. if the wheel bumps up 0.5 inches and this causes the damper to compress 0.375 inches then the motion ratio is 0.75. The motion ratio does not need to be linear. Rising rate motion ratios are commonly designed since the increasing rate will help prevent the suspension from bottoming out. The equation for motion ratio is given below:

$$M_r = \Delta H / \Delta S$$

M_r =Motion Ratio

ΔH –Change in Wheel height

ΔS =Change in Spring Length

Original designs incorporated an outboard mounted damper tied directly inline between the lower controls arm and chassis. This design was considered due it its simplicity, reduction in number of parts that needed to be made, and conceptual similarity to many common consumer production vehicles. This design also incorporated a custom shock with 1 inch of total travel.

3.3.4 Kinematic Design Optimization and Packaging

Using SolidWorks, transitioning from a 2D model to 3D is not difficult. With the 2D model previously discussed nearing an optimized state, it was now time to convert this to a 3D model. This is necessary not only to start designing the actual parts for manufacturing, but also to make sure that there are no packaging issues between any components. For example, in the 2D model, the tie rod and damper push rod essentially pass through each other. When developing the 3D model it is important to make sure there is no interference between these parts while still maintaining the optimized geometry that had already been developed. Sometimes, this may not be possible and compromises may need to be made.

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Development of the 3D model allows for many aspects of the final design to be tackled; first being methods of interaction. In the 2D model, every time one component coupled with another, it simply consisted of a point. With the 3D model, a joint type needs to be determined. Although there are many different methodologies that can be used to determine how components to, an axiomatic design process was used for the team's application. For the front suspension, emphasis was put on independence and decoupling, since adjustment is needed in the suspension for factors such as camber, caster and toe.

Adjustment for camber is controlled by a knuckle ball joint. The upper wishbone has adjustable ball joint while the lower wishbone has fixed ball joint. Shown below, in Figure

Fig. 9: Ball joint

A slight positive camber is adjusted through upper ball joint for better steer in off roading. While caster angle and toe are adjusted at 0 degree. Lastly ride height can be changed independently. Due to the fact that an extension was needed for the damper, this allowed for the length of the damper shaft after the spring perch to be changed, thereby raising or lowering ride height.

3.3.5 Load Calculations

In order to determine appropriate dimensions and materials for components to be used, we first needed to determine the forces they would be loaded under. Milliken's Race Vehicle Dynamics book contains both equations and methods to aid in calculating these loads. This provided the information necessary to perform

FEA of all suspension components. Stresses and buckling loads could then be calculated.

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.3.6 Structural Design

As this is a design competition and not an assembly competition, everything that goes into the vehicle should be properly tested and analyzed before it is ever manufactured into a tangible form. To aid in this, the SolidWorks program comes with an FEA add-on, CosmosWorks. CosmosWorks makes FEA analysis of parts and assemblies extremely simple. The main components being dealt with in the front end are the control arms. Since these are the parts that connect the wheel to the chassis, they are critical to performance and safety. Beyond that, flexing 23 of the control arms will change the intended geometry of the suspension and cause it to act differently from intended. Therefore, both Factor of Safety (FOS) and deflection were of concern.

Fig. 10: Rear wishbone rendered image

Fig. 11: Front wishbone rendered image

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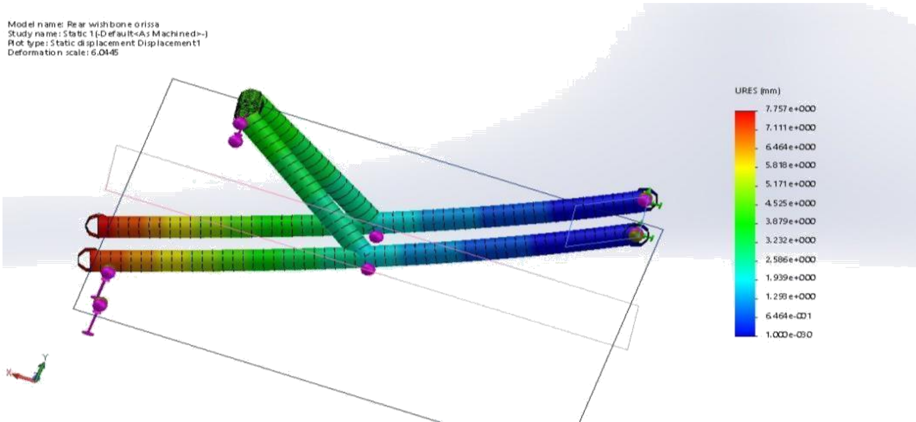

Fig. 12: Rear wishbone stress distribution

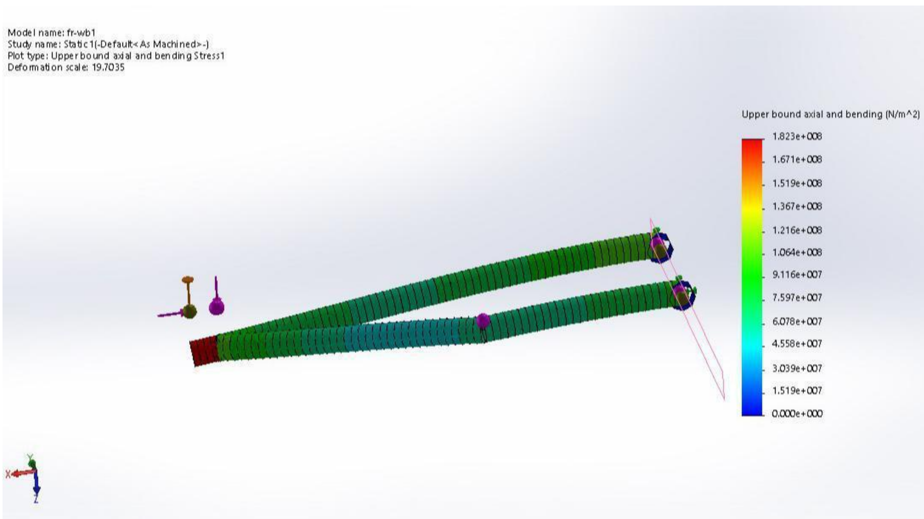

Fig. 13: Front-lower wishbone stress distribution

Pick-ups for the control arms for the suspension were somewhat more complicated than many other teams due to the means of adjustments that were incorporated in to them. Here, fixturing and welding were just as important as factor of safety (FOS) for weight reduction. For this reason, simple box tubing was used. This can be easily machined for the desired hole locations and then notched to fit the chassis. Just as important though is the accuracy with which it is attached to the chassis. A means of fixturing is needed to insure that the pickups for each of the control arms have their pivots on the same axis. If this is not done, the control arm may not be able to travel through the full range of motion needed.

With all parts optimized in FEA, it is important to make sure that there are still no packaging issues. Ideally, a full model should be maintained in

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order to allow easy replacement with updated parts to make sure interference and range of motion are not affected.

Fig. 14: Front wishbone

Fig. 15: Rear Wishbone

3.3.7 Knuckle and Hub:

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For simplicity, we import the front and rear hub and knuckle from Polaris, Gurgaon, which are suitable for off roading.

ig. 16: Front Knuckle

Fig. 17: Rear Knuckle

3.3.8 Rear End

In the designing the rear suspension, there were several different types that played into the decision process. Initial design ideas stated that the vehicle needed to

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be lightweight and simple. The rear suspension of the vehicle could have been a traditional double A-arm set-up which, although proven to work well, had several drawbacks. Double A-arm suspensions require six points of pivot to be fixed to the chassis, per side. One point of pivot for each leg of each A-arm, a pivot for the toe link, and pivot for the shock; a total of twelve for both sides. To add to the complexity, two constant velocity joints mounted to each half-shaft must allow for vertical displacement between the fixed centre section and the wheel. All of these components combine to create a heavy, complex, and potentially expensive suspension.

A unique solution to this is a Mcpherson Strut Geometry. A MacPherson strut uses a wishbone, or a substantial compression link stabilized by a secondary link, which provides a bottom mounting point for the hub carrier or axle of the wheel. This lower arm system provides both lateral and longitudinal location of the wheel. The upper part of the hub carrier is rigidly fixed to the bottom of the outer part of the strut proper; this slides up and down the inner part of it, which extends upwards directly to a mounting in the body shell of the vehicle.

Fig 18: Rear axle arrangement

3.4 Chassis

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3.4.1 Chassis Design Considerations

Design of the BAJA Vehicle began with the frame. There are several factors that must be considered when designing the frame:

Stiffness

Normally, an off-road vehicle chassis should be as stiff as possible torsionally. This is to facilitate easier suspension tuning. When determining the handling qualities of a vehicle, one of the most effective methods of adjusting the amount of oversteer and understeer is the adjustment of roll stiffness front-to-rear. By increasing front roll stiffness while decreasing rear roll stiffness, both rear tires are more equally weighted than the front tires. The force on the outside front tire quickly overwhelms the traction available to it, and the vehicle understeers. Conversely, with

a large amount of rear roll stiffness and a small amount of front roll stiffness, the inside rear tire is lifted during a turn, the amount of available rear traction is reduced, and the vehicle oversteers. By tuning the stiffness of the anti-roll bars, it is possible to affect the balance of the vehicle. However, torsional flex in the frame adds another spring to this two-spring system. This makes tuning much more difficult, and in extreme cases, impossible.

Weight

As discussed earlier, wherever possible, weight should be minimized. All tubing sizes not dictated by the rules were chosen to be as light as possible while remaining structurally sound and suitably stiff. Just as important as weight is mass moment of inertia. A vehicle with a lower mass, moment of inertia will be able to turn more quickly. In order to reduce mass moment of inertia, all weight on the chassis is pushed as far as possible towards the centre of the vehicle.

Fitment and Packaging

Possibly the most difficult criterion to satisfy is fitment. This criterion determines the functionality of the chassis. The chassis must accommodate the

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engine, suspension components, and templates while remaining as light and small as possible. While a problem with structural integrity or stiffness can usually be solved by simply varying the wall thickness or diameter of a tube, the challenge of fitting all components into the smallest space possible rarely has clear or straightforward solutions. Multiple iterations and brainstorming sessions are usually required for fitment problem.

3.4.2 Chassis Construction Methods

As this is a design competition and not an assembly competition, everything that goes into the vehicle should be properly tested and analysed before it is ever manufactured into a tangible form. To aid in this, the SolidWorks program comes with an FEA add-on, CosmosWorks. CosmosWorks makes FEA analysis of parts and assemblies extremely simple. The main components being dealt with in the front end are the control arms. Since these are the parts that connect the wheel to the chassis, they are critical to performance and safety. Both Factor of Safety (FOS) and deflection were of concern.

Fig. 19: Chassis Final Design

3.4.3 Chassis Material Considerations

The team decided to use a tubular spaceframe due to cost, ease of construction, and facilities available. Because the chassis is a tubular spaceframe design, the materials used in its construction were limited to readily available, easily weldable materials. In the interest of simplicity, it was decided that all tube members would be made from the same type of material. The following materials were considered:

1. AISI 1020 Steel
2. AISI 4130 Steel
3. AISI 1018 Steel

Each material possesses shared attributes:

1. Manufacturing Process
2. Yield Strength (MPa)
3. Ultimate Strength (MPa)
4. Brinell / Rockwell Hardness
5. Carbon Content (%)
6. Cost per Unit Length
7. Elongation (%)

By designating a numerical value to each attribute, and ranking each attribute by importance, such as weighing yield strength as the most important attribute, the values are evaluated against each material through a mathematical process.

Equation 1 determines ranking of attribute values against the minimum and maximum

values. Equation 2 determines the ranking of each attribute by the user‟s evaluation of most important to least important. Lastly, equation 3 calculates the sum of each

attribute multiplied by the importance of the attribute. The highest value is the logically ideal material for selection.

.

$$Rij = (Aij - Ajmin) \div (A\,jmax - Ajmin) \quad \ldots.(1)$$

$$Ij = Pj \div \Sigma\, Pj \quad \ldots.(2)$$

$$Mi = \Sigma\, RijIj \quad \ldots.(3)$$

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Material	***1020 steel***	***4130 steel***	***1018 steel***
Manganese	0.3-0.6%	0.4-0.6%	0.6-0.9%
Carbon	0.18-0.23%	0.28-0.33%	0.15-0.2%
Sulphur	0.05%	0.04%	0.05%
Phosphorus	0.04%	0.035%	0.04%
Density (g/cc)	7.87	7.85	7.87
Tensile Strength (MPa)	420	560	440
Yield Strength (MPa)	350	435	370
Elongation at failure	20.25%	21.5%	15%
Thermal Expansion (µm/mK)	11	12	10
Thermal Conductivity (W/mK)	43	50	51.9
Inference	Preferred choice.	Welding problems, due to very high carbon content.	Low carbon content, thus, less strength than 1020 steel.

Table 1 : Comparison of properties of the shortlisted materials

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Considering light weight, cost effectiveness, availability and weldability team selected AISI 1020. As a result the ideal material for our space frame is the 1020 Cold Rolled Drawn over Mandrel Mild-Carbon Steel, possessing the following attributes:

1. ManufacturingProcess:ColdRolled (Accurate Tolerances Due to No Expansion)
2. Yield Strength : 350 MPa
3. Ultimate Strength : 420MPa
4. Brinell/Rockwell Hardness : 137
5. Carbon Content : 0.18-0.23%
6. Cost per unit length : Rs 115- Rs 150/foot
7. Elongation : 20.25%

3.4.4 Structural Analysis

CosmosWorks was used to validate the structural integrity of the frame. The beam mesh technique was used for analysis. In a beam mesh, all structural members of a tubular structure are approximated as a series of small beams, rather than a mesh of triangles or tetrahedrons. This is much less processor-intensive and much faster than a solid mesh or shell mesh, though obviously not suited for parts that are not composed of beam-like elements (for example, a machined part could be analysed with solid mesh, a sheet metal part could be analysed with a shell mesh, and a tubular spaceframe such as this one could be analysed with a beam mesh). It is important to note, however, that a beam mesh is incapable of analysing the effects of welding on tube. Additionally, it only gives results for axial stress, not shear or Von Mises stres

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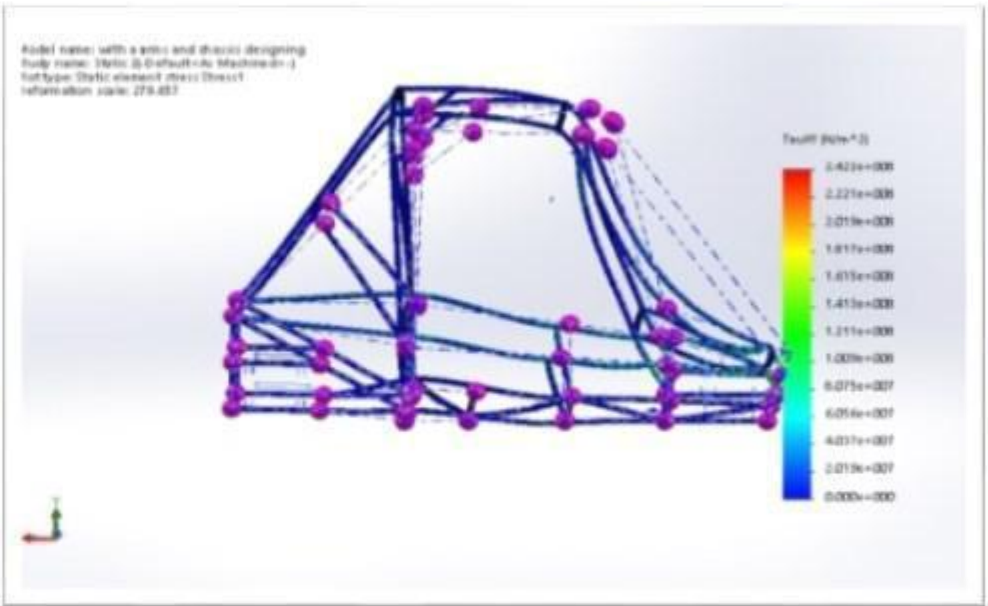
- IMPACT

SCENARIO	LOAD (N)	FOS
1.Front Impact	10500	1.3
2.Side Impact	9000	2
3.Roll over	9000	1.2
4.Rear Impact	10500	0.7

Table 2 :Load Data

Fig. 20: Front impact analysis



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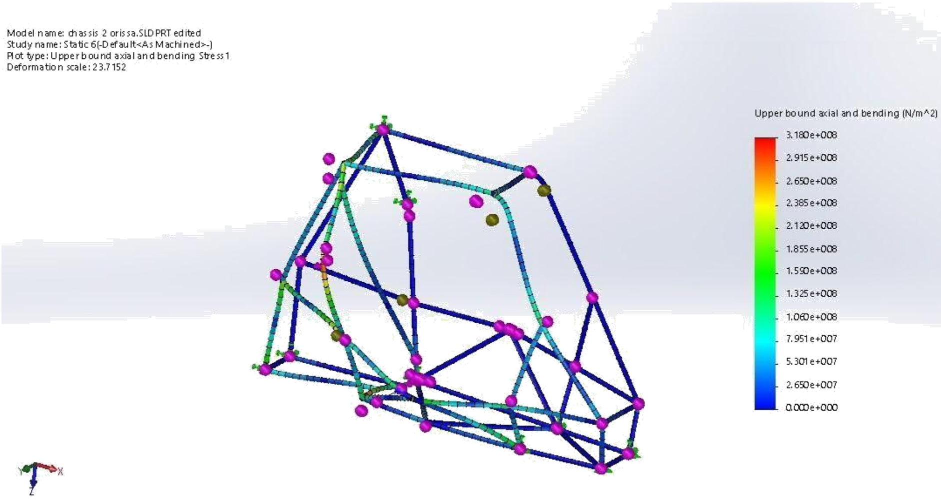

Fig. 21: Side impact analysis

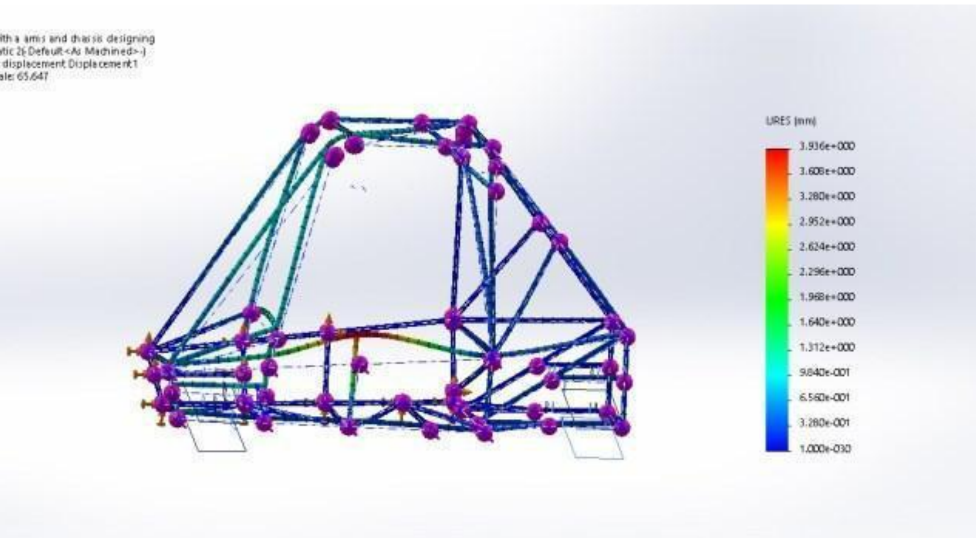

Fig. 22: Roll Over Analysis

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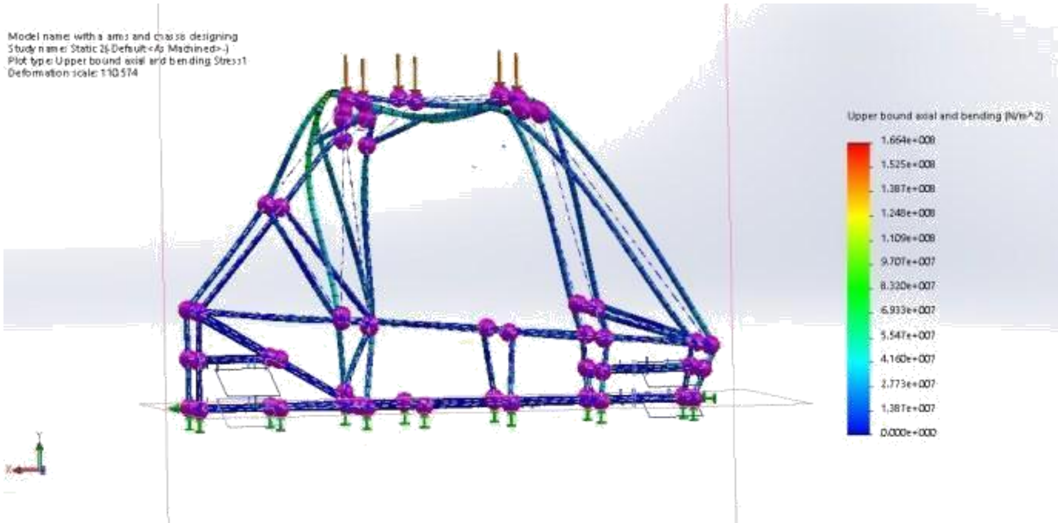

Fig. 23: Rear impact analysis

3.4.5 Tube Bending

To increase manufacturability, many bends were used as opposed to miters. By implementing bends into the design of the frame, the number of cuts and welds were decreased. Decreasing the number of cuts and welds lowers the production cost and increases overall chassis strength, as opposed to hand welded miter joints, reducing man-hours and production costs. All bends were designed to be made using a tube bender fitted with a 9-inch diameter die, which would eliminate costly tooling changes from the manufacturing process.

3.4.6 Chassis Fabrication

The 1020 tubular steel space-frame chassis was manufactured using jigs and fixtures. The outer diameter of the chassis material employed is 1 inch while the thickness being 3mm.

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Fig. 24: Fabricated Chassis

Fig. 25: Complete painted chassis

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3.5 Steering System

The purpose of the steering system is to provide directional control of the vehicle to the driver with minimum input. While designing the steering system the constraints that we possessed were centre alignment of steering system, track width, human effort at the steering wheel and the desired response of the steering system. Team decided to use rack and pinion mechanism steering followed by Ackerman geometry.

3.6 Braking

3.6.1 Objectives

The purpose of the brakes is to stop the vehicle safely and effectively. In order to achieve maximum performance from the braking system, the brakes have been designed to lock up all four wheels. To reduce the amount of heat production during braking, Polaris manufactured ventilated disc brakes were used. The light weight of the entire brake assembly fulfils our overall intention to keep the vehicle weight as low as possible.

3.6.2 Design

The braking system is composed of components from Polaris. Due to their light weight, efficient braking and effective heat loss capabilities, the suited the purpose to be met. The outer diameter of front disc is 9.5”, inner diameter is 6.5” and the thickness is 5mm. For the rear disc, the outer diameter is 9”, inner diameter is 4.2” and the thickness is 5mm. Brake lines run the length of the bike, and flexible braided lines are used at the A-arms in the front for suspension travel and calliper pivoting. It was determined that the selected components would perform to the expectations needed. The ventilations throughout the disc rotor ensure proper heat loss and efficient ventilation.

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Fig. 26: Disc Rotor

Fig. 27: Calliper

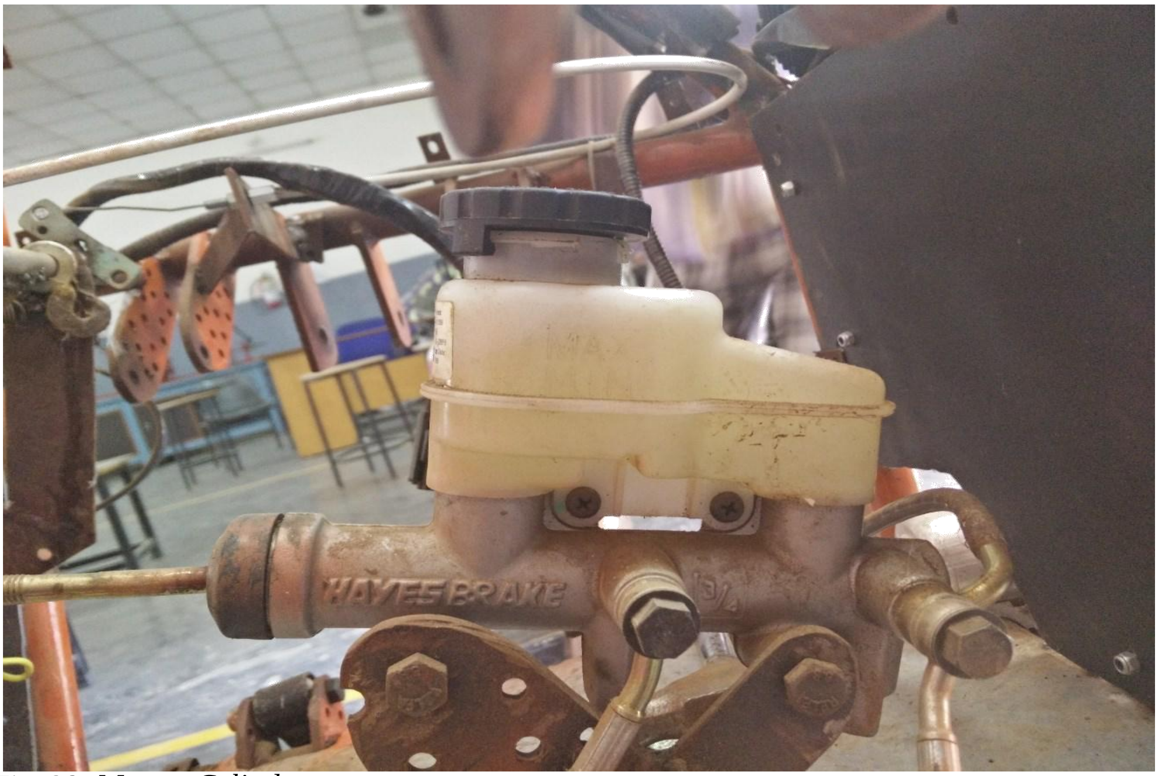

Fig. 28: Master Cylinder

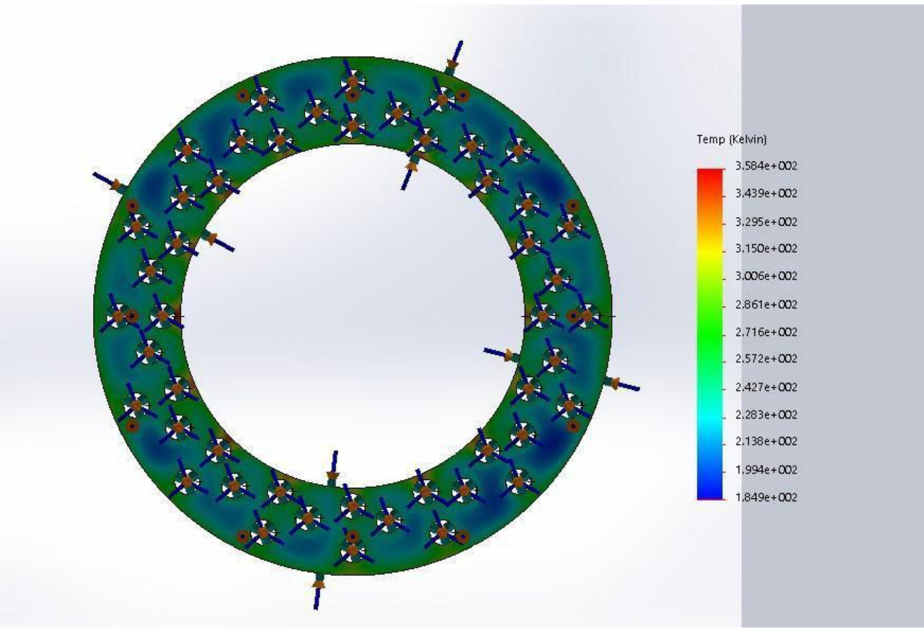

Fig. 29: Thermal analysis as performed on rear disc rotors in SolidWorks Cosmos

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3.7 Body Works

There are many options for construction of the body, each depending upon the approach of the designers and the goals for the vehicle. There are many options like fibreglass, carbon fibre, sheet metal, etc. But team decided to use steel sheet bodyworks by keeping following goals in mind:

1. Ease of manufacturing
2. Affordability
3. Light weight

3.8 Seat

FIA certified Sparco seats were used. The bucket seats provide more support and control. There is no inbuilt reclining or tilting mechanisms, this reduces any weak points and movement in the seat when being used for off-road conditions. Hence, these provide a great alternative to the standard seats.

Fig. 30: Seat

3.9 Engine and Transmission

Engine was taken from a Briggs & Stratton as per the SAE BAJA rulebook. Mahindra Alfa 4-speed transmission is used.

Fig. 31: Briggs and Stratton Engine

Torque	14.50
Engine Displacement(cc)	306
Number of Cylinders	Single
Engine Configuration	Horizontal Shaft
Engine Technology	OHV
Length(in)	12.3
Width(in)	17.0
Height(in)	16.4
Weight(lbs)	58.20
Bore(in)	2.28
Stroke(in)	2.04
Engine Fuel	Gasoline
Fuel Tank Capacity(gallons)	0.8
Lubrication System	Dura-Lube Splash

	Lubrication
Oil Capacity(oz)	20
Starter	Manual Choke
Air Filter	Dual Element Cartridge
Muffler	Lo-Tone

Table 3: Engine Specifications

Due to its easy compatibility and coupling with the Briggs and Stratton Engine, Mahindra Alfa 4 speed, 1 Reverse Manual Transmission system was used. The gear ratios of the transmission system are as follows:

Gear	Gear Ratio
1	31.45:1
2	18.70:1
3	11.40:1
4	7.35:1
Reverse	55.08:1

Table 4: Transmission Gear Ratios

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Fig. 32: Side View of Transmission

Fig. 33: Side View of Transmission

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One of the major drawbacks of using the Mahindra Alfa Transmission System is the limited travel of the wishbone arms due to restrictive housing within the transmission system.

However, for off-roading conditions, there should be a travel of atleast & inches. Henceforth, a new innovation was incorporated into the vehicle in the form a self and a newly designed housing and axles.

First of all, the initial travel provided by the transmission housing was restricted, and then a new housing was designed to maximise the travel.

The axles consist of two splines with male and female splines allowed to slide over one another. In order to keep the movement of the two meshed splines smooth and jolt free, German made Bosch Grease is used to provide adequate lubrication, hence enhancing the sliding motion. The axles were hardened efficiently to avoid fractures or fatigue failures.

Fig. 34: Axle to the Wheels

Fig. 35: Axle from the Transmission

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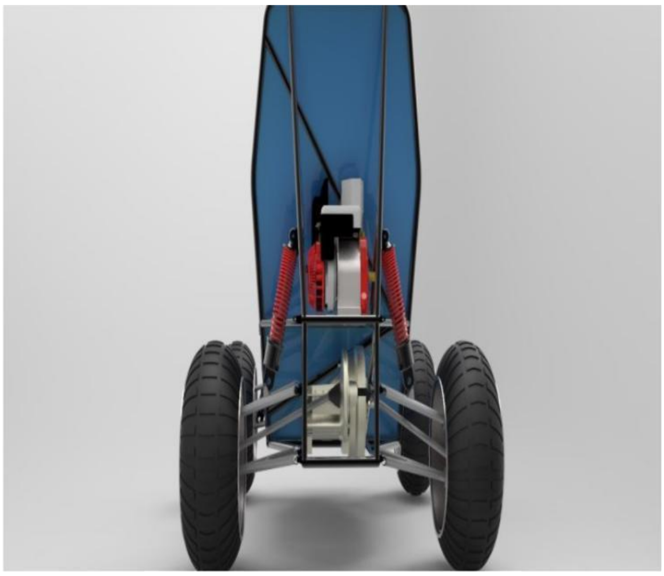
Fig. 36: Complete Axle Assembly

APPENDIX – A : VEHICLE DRAWINGS

FRONT VIEW

TOP VIEW

SIDE VIEW



REAR VIEW

ACTUAL VEHICLE PHOTOGRAPH

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VEHICLE SPECIFICATIONS

Overall length- 65 inches

Overall width- 60 inches

Ground clearance-13 inches

Wheelbase- 42 inches

Track Width- 50 inches

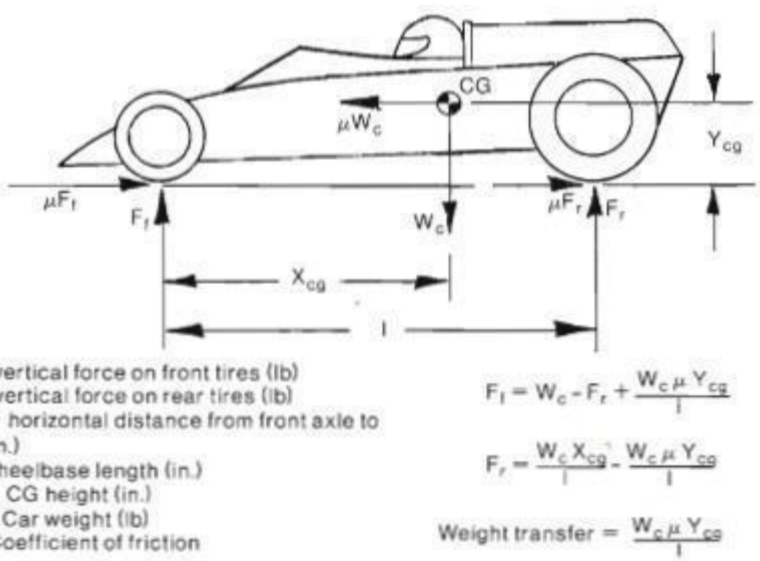
Roll Cage Material- AISI 1020

Pipe Outer Diameter-1 inch

Pipe thickness- 3 mm

Overall Weight- 220 kg

Load Transfers-



APPENDIX-B

VEHICLE DYNAMICS

FOR MAXIMUM INCLINATION THE VEHICLE CAN CLIMB IN STATIC CONDITION:

Assume no speed condition at rear wheel; vehicle will topple when reaction at front axle will become zero.

When $R \rightarrow 0$

$\tan\theta = b/h$ = distance of C.G from rear axle ÷ height of C.G = 0.530/0.533 =0.99

$\boldsymbol{\theta} = 44.8°$

LIMITING VALUE OF INCLINATION FOR ACCELERATION AT $\theta = 44.8°$

$a_{max} = g \sin\theta$

$$1.38 + 9.8\sin\theta = 9.81 \times 0.530\,(1 - \sin^2\theta)^{0.5} / 0.533$$

$\sin\theta = 0.70$

$\theta = 44.5°$

Hence the vehicle can safely climb a hill of more than 44.5° degrees with maximum acceleration. However the actual inclination that could be climbed (with less than maximum acceleration) will be much more than the given value.

STATIC AXLE LOAD DISTRIBUTION

$$\frac{M_r}{M} = \Psi$$

where:

M_r	=	static rear axle load (kg)
M	=	total vehicle mass (kg)
Ψ	=	static axle load distribution

Mr = 127 kg

M = 220 kg

Ψ = 0.52

RELATIVE CENTRE OF GRAVITY HEIGHT

$$\frac{h}{w_b} = X$$

where:

h	=	vertical distance from C of G to ground on the level (m)
w_b	=	wheelbase (m)
X	=	relative centre of gravity height

h = 533.4 wb=

1.105 X = 0.4827

ACCELARATION

For a final speed of v = 45 km/hr (12.5 m/s) and time t = 10 sec

By laws of motion, v = u +at a = 1.25 m/s^2

DECELARTION

Here, final speed u = 12.5
m/s and time t = 2.5sec v =
u + dt

d = 4.16 m/s^2

DYNAMIC AXLE LOADS

The changes in axle loads during braking bears no relationship to which axles are

braked. They only depend on the static laden conditions and the deceleration.

$((1-\Psi)+(X.a)).M = M_{fdyn}$

where :

a	=	deceleration (g units)
M	=	total vehicle mass (kg)
M_{fdyn}	=	dynamic front axle load (kg)

a = 0.55 g units M =

220 kg M_{fdyn}=85.2 kg

Dynamic front axle load = 205.2 kg

Dynamic rear axle load = 115.8 kg

PERCENTAGE WEIGHT TRANSFER

Due to braking, weight transfer occurs and this depends on the deceleration of the vehicle. During maximum deceleration, weight on the front wheels is more compared to rear wheels.

$$= (d\times h) \div (g\times W\ b)$$

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=(5.55×53
3.4) ÷
(9.81×1105
)
=27%**PIPING MATERIAL CALCULATIONS**

For 1inch outer diameter and 3mm thickness

Sy= yield strength (350 MPa)

E = modulus of elasticity (205 GPa for all steel) I = second moment of inertia = 10116

C = distance from neutral axis to extreme fiber (12.7 mm) Bending strength

= SYI/C

= (350 x 10116) / (12.7 x 1000)

= 278.787 N/m

Bending stiffness=ExI

= (205x10116)/1000

= 2073.780 Nm^2

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BRAKES

Brake system- Splitter system

Brake disc and assembly used-
Polaris **Front calliper bore-**1.88”

Rear calliper bore-dual bore 1”

Rear disc brake outer diameter-8.625”

Rear disc brake inner diameter-4.2””

Front disc brake outer diameter-9.5”

Front disc brake inner diameter-6.5”

Front Disc Thickness- 5mm

Rear Disc Thickness-5mm

Brake fluid- DOT 4

Calliper type-floating
type **Pedal force**=2000N

Brake force

$$B_F = Mag$$

where:

B_F = total braking force (N)
M = total vehicle mass (kg)
a = deceleration (g units)
g = acceleration due to gravity (m/sec^2)

B_F= 32.34kN

Stopping Distance

$S = V^2 \div 2ag$
V = 45km/hr

a = 0.15 g units

g = 9.81 m/s^2

Therefore, **Stopping distance** = 7.963 m

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Stopping time=3 seconds

Deceleration=14m/s^2

Pedal ratio=

Disc Effective Radius

$$r_e = \frac{D+d}{4}$$

where:

r_e = effective radius (m)

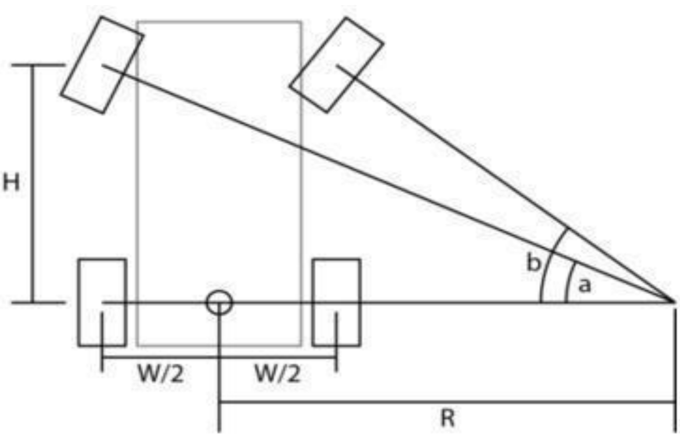
D = disc useable outside diameter (m)

d = disc useable inside diameter (m)

For rear disc rotor, **Disc effective radius=**3.206”

For front disc rotor, **Disc effective radius=**4”

STEERING



$$b = \arctan\left(\frac{H}{R - W/2}\right)$$

$$a = \arctan\left(\frac{H}{R + W/2}\right)$$

Therefore,

b=37.2 degree

a= 24.1 degree

$$Ackerman = \tan^{-1}\left(\frac{wheelbase}{\frac{wheelbase}{\tan \delta_{outside}} - track_{front}}\right)$$

$$Ackerman_{percent} = \frac{\delta_{inside}}{Ackerman} \times 100$$

Ackerman$_{\mathbf{percentage}}$ =27%

Length of tie rod= 480cm

Steering angle*:*

Inside wheel angle, A = 37.2 degrees

Outside wheel angle, B = 24.1 degrees

$$x = Ltan(90 - A) + d/2 \frac{A - B}{\tan^{-1}(\frac{1}{\tan(B) - 1}) - B}$$

Where,

x is the turning radius,
L is the length of the vehicle,

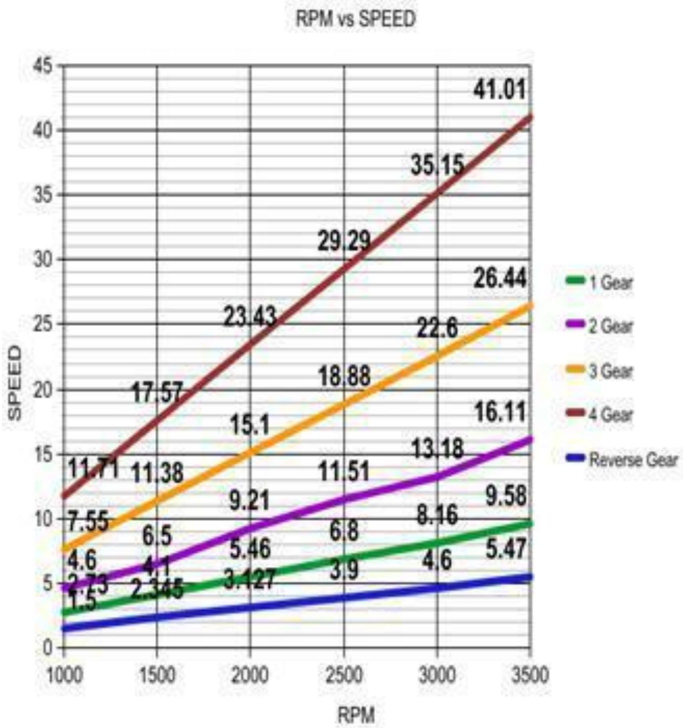
A is the angle of the inside angle of the wheel
B is the angle of the outside wheel
d is the width of the vehicle.

To determine the Ackerman percentage,

Turning Radius by *Ackermann Principle* = 2.9m

TRANSMISSION & ENGINE

Gear	Gear Ratio	Power train ratio	Traction (N)	Maximum speed(kmph) @3600rpm	Acceleration(m/s^{2})	Gradability (degree)
1	31.45:1	44.03:1	2047.395	9.76	7.3	48.19
2	18.70:1	26.18:1	1217.37	16.42	4.34	26.3
3	11.40:1	15.96:1	742.14	26.94	2.65	15.6
4	7.35:1	10.29:1	478.48	41.78	1.707	10.03
Rev.	55.08:1	77.11:1	3585.70	5.57	12.8	52.54



RPM vs Speed Graph

SUSPENSION

Mean coil diameter=8mm

No. Of active coils=14

$$\text{Spring stiffness} = \frac{Gd^4}{8nD^3}$$

G = shear modulus of material
d = wire diameter
D = spring diameter
n = number of coils.

Spring stiffness=535.93N/m

Inner spring diameter=80mm

Outer spring diameter=64mm

Free length=17”

Motion ratio=0.9

Camber=.2 degree

Sprung mass=40kg(approx.)

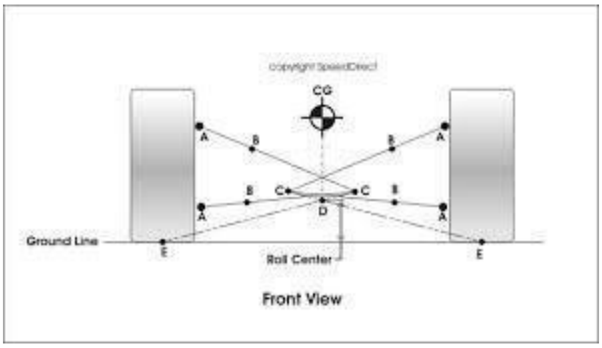
Unsprung mass=180kg

Ride rate=18”

Suspension travel front=7.5”

Suspension travel rear=7.5”

Roll center height =



Wheel rate = (motion ratio)^2 x(spring stiffness)=434.10 N/m

REFERENCES

1. Milliken, Douglas, and Milliken, William, *Race Car Vehicle Dynamics*, SAE International, 1995.
2. Smith, Carroll, *Tune to Win*, Aero Publishers, Inc., 1978
3. SAE, *BAJA Rulebook*, 2015
4. bajatutor.org
5. en.wikipedia.org
6. Automotive Engineering Fundamentals, by Richard Stone and Jeffery K. Ball
7. Fundamental of Vehicle Dynamics by Thomas D. Gillespie
8. Vehicle Dynamics- Theory and Applications by Reza N. Jazar
9. Brake Handbook by Fred Puhn