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Design, Analysis and Optimization of front suspension wishbone of BAJA 2016 of All-terrain vehicle- A Review

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ABSTRACT

In view of the significant increase in the research activity on the front wishbone in last few years, the present article identify and highlight the various research that are most relevant to design, analysis and optimization of front wishbone suspension system. A present work is focused in the field of the material selection methods, impact load, deformation of material, stress, weight reduction for ATV vehicle for improving the stability and handling of vehicle to minimizing the un-sprung mass, better durability and less expensive also. The outcome of the discussed research is intended to give the reader a brief verity of the research carried out on the front wishbone suspension system.

Keywords: Double wishbone, suspension system, ANSYS, durability, Optimization, handling.

1.Introduction

In automobiles, a double wishbone (or upper and lower A-arm) suspension is an independent suspension design using two (occasionally parallel) wishbone-shaped arms to locate the wheel. Each wishbone or arm has two mounting points to the chassis and one joint at the knuckle. The shock absorber and coil spring mount to the wishbones to control vertical movement. Double wishbone designs allow the engineer to carefully control the motion of the wheel throughout suspension travel, controlling such parameters as camber angle, caster angle, toe pattern, roll center height, scrub radius, scuff and more. In automobiles, a double wishbone (or upper and lower A-arm) suspension is an independent suspension design using two (occasionally parallel) wishbone-shaped arms to locate the wheel. Each wishbone or arm has two mounting

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points to the chassis and one joint is pivot at the knuckle lower part other is mounted at upper of knuckle.

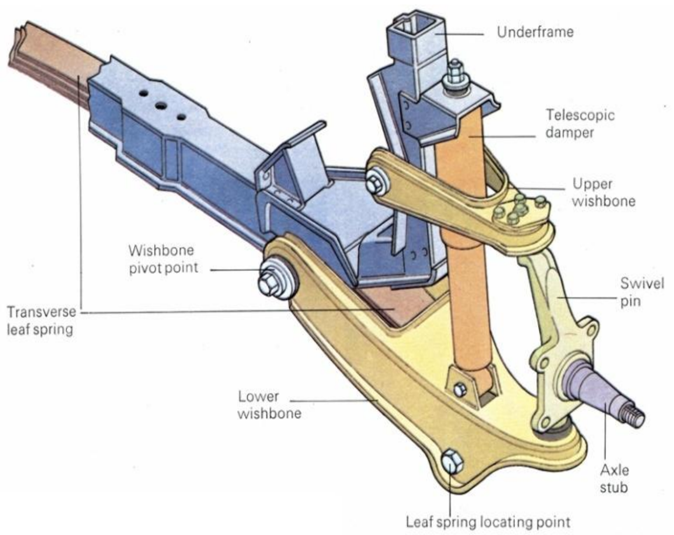

Fig. 1: front wishbone suspension system

2. BRIEF FRONT WISHBONE SUSPENSION SYSTEM

Double Wishbone Suspension System consists of two lateral control arms (upper arm and lower arm) usually of unequal length along with a coil over spring and shock absorber. It is popular as front suspension mostly used in rear wheel drive vehicles. Design of the geometry of double wishbone suspension system along with design of spring plays a very important role in maintaining the stability of the vehicle. [3] This type of suspension system provides increasing negative camber gain all the way to full jounce travel unlike Macpherson Strut. They also enable easy adjustment of wheel parameter such as camber. Double wishbone suspension system has got superior dynamic characteristics as well as load-handling capabilities. [4]

Material Selection of Wishbone :-

Satyajit S. Dhore1et al. In this paper a terrain vehicle with four wheels drive and four wheels steer intended to use for recreational purpose is presented. The main purpose is to design the suspension mechanism that fulfills requirements about stability, safety and maneuverability. Nowadays, as well as in the past, the development of the suspension systems of the vehicle has shown greater interest by designers and manufacturers of the vehicles. Research is focused to do a comprehensive study of different available independent suspension system (Mac Person, double wishbone, multi- link) and hence forth develop a methodology to design the suspension system for a terrain vehicle. Few chosen suspension systems are analyzed into the very details in order to find out the optimal design of it.

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Design of wishbones is the preliminary step to design the suspension system. Initially, the material is selected using Pugh's Concept of Optimization. Based on the properties of the selected material, the allowable stress is calculated using shear stress theory of failure. The roll-centre is determined in order to find the tie-rod length. The designed wishbones are modeled using software and then analyzed using Ansys analysis software to find the maximum stress and maximum deflection in the wishbone.

3. PREVIOUS RESEARCH

Previous work done on the methods of material selection

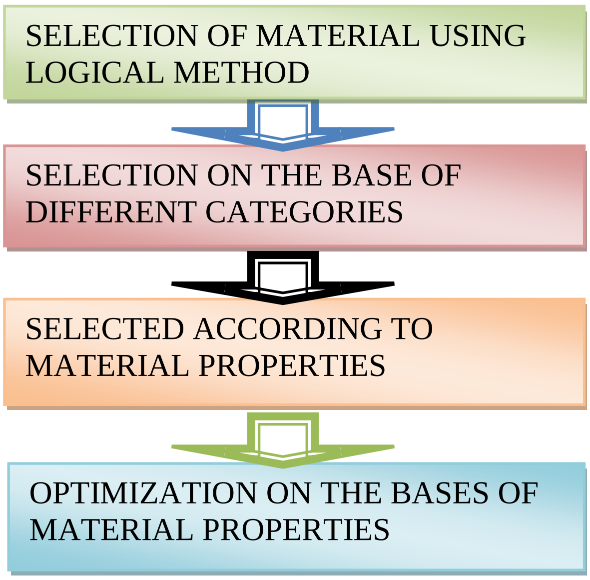

Fig. 2: Flow cart of material selection.

Pugh's Concept . This is a method for concept selection using a scoring matrix called the Pugh Matrix. It is implemented by establishing an evaluation team, and setting up a matrix of evaluation criteria versus alternative embodiments. This is the scoring matrix which is a form of prioritization matrix. Usually, the options are scored relative to criteria using a symbolic approach (one symbol for better than, another for neutral, and another for worse than baseline). These get converted into scores and combined in the matrix to yield scores for each option.

Material consideration for the wishbone becomes the most primary need for design and fabrication. The strength of the material should be well enough to withstand all the loads acting on it in dynamic conditions. The material

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selection also depends on number of factors such as carbon content, material properties, availability and the most important parameter is the cost. Initially, three materials are considered based on their availability in the market- AISI 1018, AISI 1040 and AISI 4130. By using Pugh's concept of optimization, we have chosen AISI 1040 for the wishbones. The main criteria were to have better material strength and lower weight along with optimum cost of the material.

Comparison of Materials. The properties of the above mentioned materials which were considered for wishbones are as follows,

Table.1: Pugh's concept selection chart

Description Criteria	AISI 1018	AISI 1040	AISI 4130
Total Weight	-2	0	+1
Yield Strength	-1	0	+1
Tensile Strength	-2	+2	0
Cost	+1	0	-2
Elongation at break	-2	+1	0
Net Score -	6	+3	0

Allowable stress is obtained by the following relationship: -

$$\sigma = \frac{S_y \pi}{f_s}$$

$$\sigma = \frac{415}{1.2}$$

Assume factor of safety, fs = 1.2 (as AISI 1040 is a ductile material).

$$\sigma = 345.83 \text{mpa}$$

Preview paper in 2014 for martial Multi tubular space frames, often referred to as roll-cage acts as a structural embody for various types of automotive vehicles. Material was selected after conducting an extensive market survey and on the basis of wetted point method. This sequential approach was adopted for the roll-cage design of BAJA vehicle and proved to be effective.

Torsional Stiffness

The maximum deformation was at the rear suspension mount

F = 2354 N

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L = Distance between diagonally opposite suspension mounts=490mm
D = Vertical deformation in suspension mounts
Θ = Angular deformation
$\tan(\theta) = D/(L/2)$
Torsional Stiffness = $(F \times L) / \theta$.
D=1.252mm
Torsional Stiffness= 3939.54 Nm/degree

Mr. P. Vinay Kumar1et al. The concept of the All-Terrain Vehicle is that has a capability to be driven on any kind of terrain (road). It is a type of vehicle which is accomplished of driving on and off paved or gravel surface. It is generally categorized by having bulky tires with profound, open treads and a stretchy suspension. This paper deals with the detailed description of designing a roll cage by taking inputs from SAE BAJA rule book 2016, suspension and steering of an All-Terrain Vehicle (ATV). Our primary focus is to design, analyze a single-sitter fun to drive, multipurpose, safe, strong, and high performance off road vehicle that will take the harshness of rough roads with maximum safety and driver comfort. The design consideration consists of material selection, design of chassis and suspension, simulations to test the ATV against failure

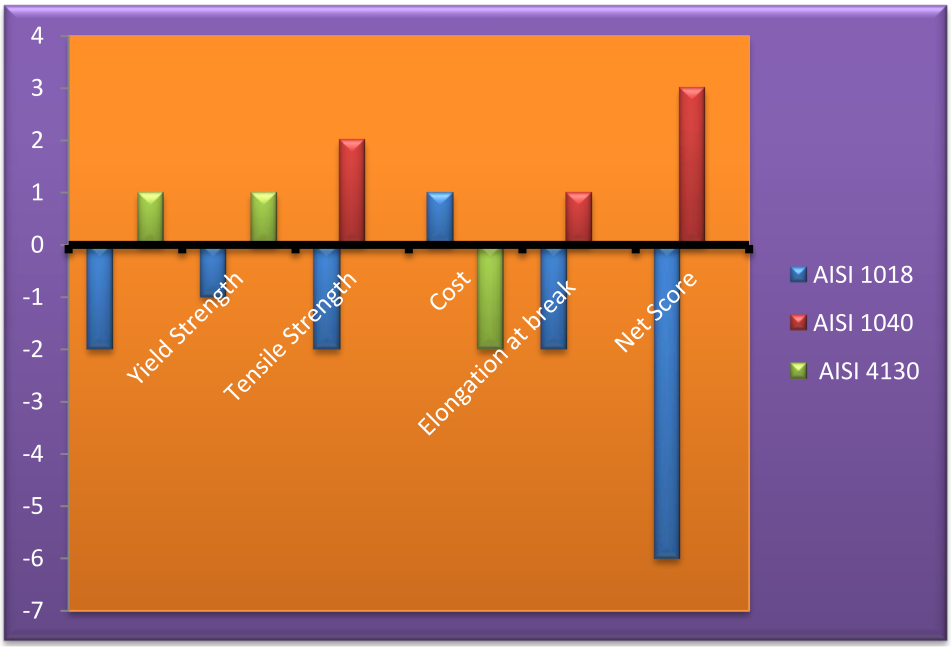

Fig.3:Plot graph Performance about selection of material

4. Previous work done of front suspension

Front Suspension Design: Front Suspension is very important and is designed first, in general, while designing off-road suspension. The front of the vehicle faces the obstacles or the jerks first and makes the base of the motion and loading characteristics. Thus, in an off-road vehicle it should provide ample wheel travel and damping effects to absorb the bumps and jerks. Moreover it should provide large amount of traction, as bearing the

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steering system, to maintain directional stability and reduce slip angles to prevent losses. The front of the vehicle should also have low amounts of un-sprung mass to keep optimum ride characteristics.

Table.2: specification front suspension

SPECFICATION	FRONT
Roll Centre (Static)	152.4 mm
Static Camber	2 degree
Static Caster	10 degree
King pin Inclination	10 degree
Scrub Radius	26.5 mm

P. Vinay Kumar et. al. Our primary focus is to design, analyze a single-sitter fun to drive, multipurpose, safe, strong, and high performance off road vehicle that will take the harshness of rough roads with maximum safety and driver comfort. The design consideration consists of front suspension, design of chassis and suspension, simulations to test the ATV against failure.

The overall dimension of the car was decided within constraints by considering B/L ratio for better performance of differential during cornering, and driver's comfort. From this decide track width as52" at front and 50" at rear and wheel Base as 57". According to the required travel for front suspension system of around 8" to go for Double wishbone system which gives maximum travel amongst all suspension systems. The double wishbone system is more flexible and provides better ride comfort on bumpy terrain; also it is easy to manufacture. Moreover get more control on parameters of suspension geometry.

Then decide the optimum length of wishbone keeping in mind the required leg space at front, the required ground clearance and the angles at which wishbones were positioned. The values of angles for wishbones were determined by required roll center height at front. To achieve that, fixed the feasible range for the height of roll center. Generally for the stability of vehicle it is required that the height of roll center at front is around 10.12" and at rear is9.44" for a ground clearance of 12" front and 11" rear. This roll center positioning provides better transmission of forces acting on the vehicle along the roll axis which yields good stability of vehicle and increased effect of roll/yaw damping. Then selected the horizontal distance between roll center and instantaneous center as 53.22".The position of instantaneous center which is more near to infinity is best suitable for a stable suspension design. To get a positive scrub radius of 2.6" we fixed kingpin inclination (steering axis inclination) as 10°.

The parameter which is initially fixed for drawing front suspension geometry for obtaining the optimum length of wishbone are given below.

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Table.3: Input values for front suspension geometry

Track width(b_f)	52''
Wheel base	57”
Scrub radius	2.60”
Toe in	0°
Caster angle	5 °
Camber angle	-2 °
King pin Inclination	10 °
Roll Center Height	10.12''

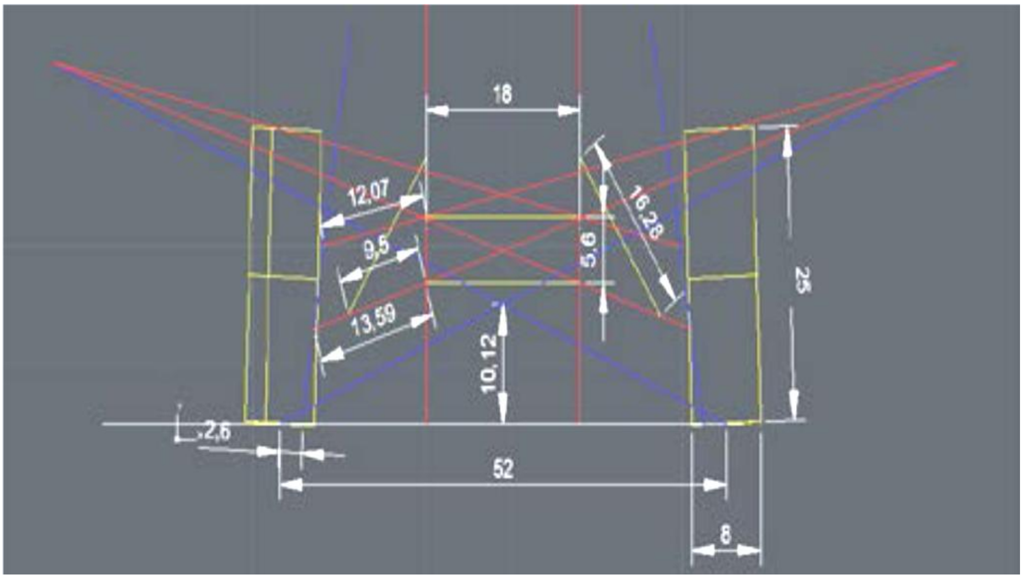

Fig.4: Front view of front suspension geometry

Table.4: Final values obtained for designing front wishbone

Length of upper wish bones	12.07''
Length of lower wish bones	13.59''
Inclination of wishbone with upper horizondal(α)	12°
Inclination of wishbone with lower horizontal(β)	17°

Tripp Schlereth Suspension design is one of the most complex systems on a Baja SAE vehicle. The terrain that must be covered is extreme and the horsepower is limited. Suspension design for this competition is one of the most varied items seen at race. As many people have not seen a Baja SAE vehicle, below is an image of the 2010 car during testing.

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Graphical Results Of Suspension Geometry

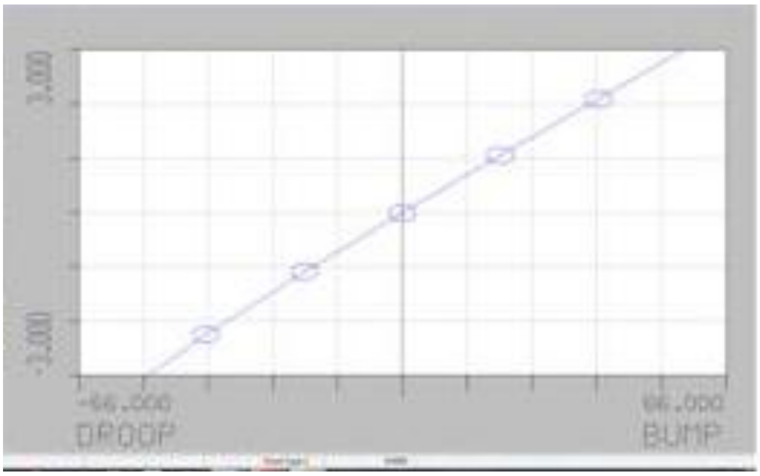

Fig.5: Camber Angles at BUMP

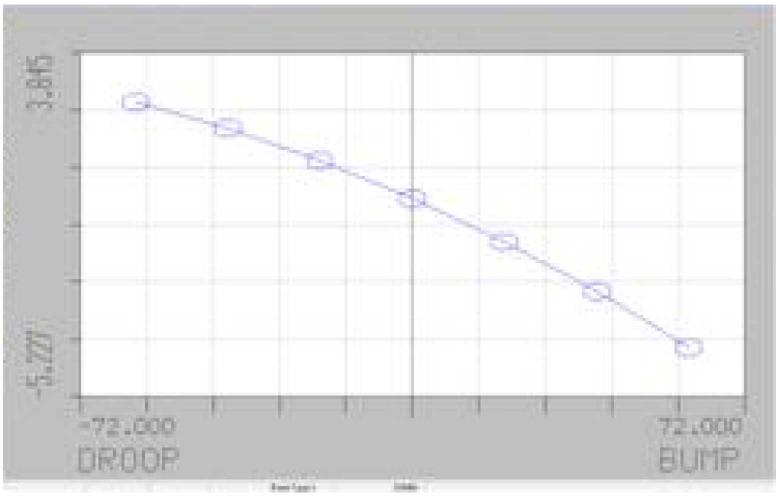

Fig.6: Toe Angles at BUMP

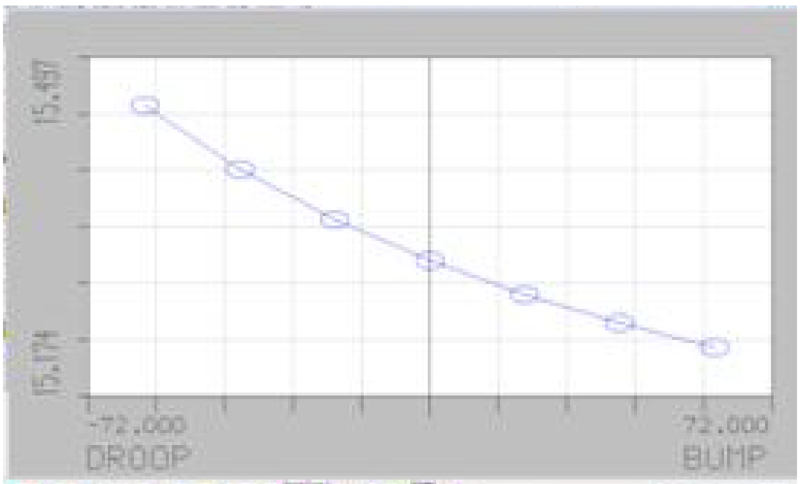

Fig.7: Caster Angles at BUMP

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Table.5: Incremental geometry values

BUMP TRAVEL(mm)	CAMBER ANGLE (deg)	TOE ANGLE (deg)	CASTOR ANGLE (deg)	KINGPING ANGLE (deg)
-60.00	-3.5177	2.5540	15.4506	12.9552
-40.00	-2.2539	1.8563	15.3897	11.8766
-20.00	-1.0936	1.0005	15.3417	10.9462
0.00	0.0000	0.0000	15.3028	10.1247
20.00	1.0547	-1.1464	15.2705	9.3859
40.00	2.0939	-2.4510	15.2432	8.7115
60.00	3.1402	-3.9369	15.2199	8.0878

5. PREVIOUS WORKDONE

Previous work on weight analysis:-

The suspension was designed to isolate the motion of the road from the vehicle chassis and hence improve ride comfort, vehicle handling, and traction and minimize wear in tyres. Hence it was decided to equip the vehicle with a four-wheel independent double A-arm type suspension.

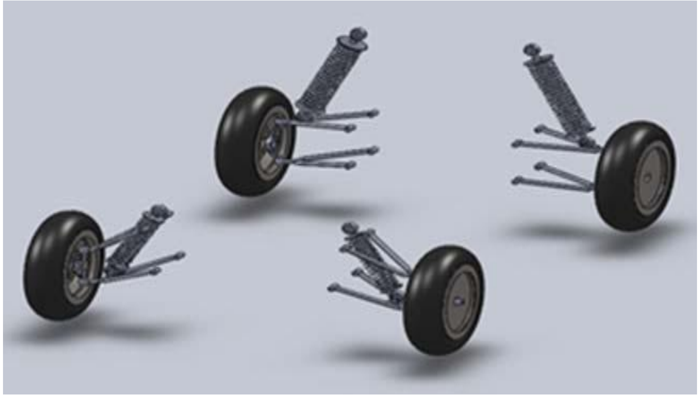

Fig.8: Suspension system

The suspension system consists of the conventional helical coil spring. A damper or shock absorber has been added to improve the comfort and safety of the vehicle. The wire diameter, mean diameter were calculated as per the load of the roll cage, driver weight, engine weight and other miscellaneous extra weights.

The front suspension consisting of double wishbone coil spring with damper is designed by evaluating the ideal ride height to easily steer through unsmooth tract. Double a-arm allows for good control over wheel angles and produces minimal camber gain over large amounts of wheel travel.

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The rear to front distribution of weight in the vehicle was calculated to be 35: 65. The total load of the vehicle (which includes roll cage, engine, driver and other weights) was estimated to be 220 kg (approx.) and the load acting on the front suspensions were calculated as 77.82 kg (762.636 N). Load on each spring = 381.318 N (assuming equal distribution of weight on each spring.)

Table.6: The various calculated dimensions and other variables calculated are tabulated below

	Diameter of wire (in mm)	Mean diameter (in mm)	Pitch (in mm)	Load (N)	Coils (n)
Front	7.778	66.113	21.819	381.318	14

Rahul Sharma et al The aim of in this paper the vehicle must be able to sustain all the loads that are generally encountered in an off-road scenario both static and dynamic. These loads are generally Impact loads which occur either due to a crash or jump. The designed vehicle is analyzed to ensure its durability under these circumstances.

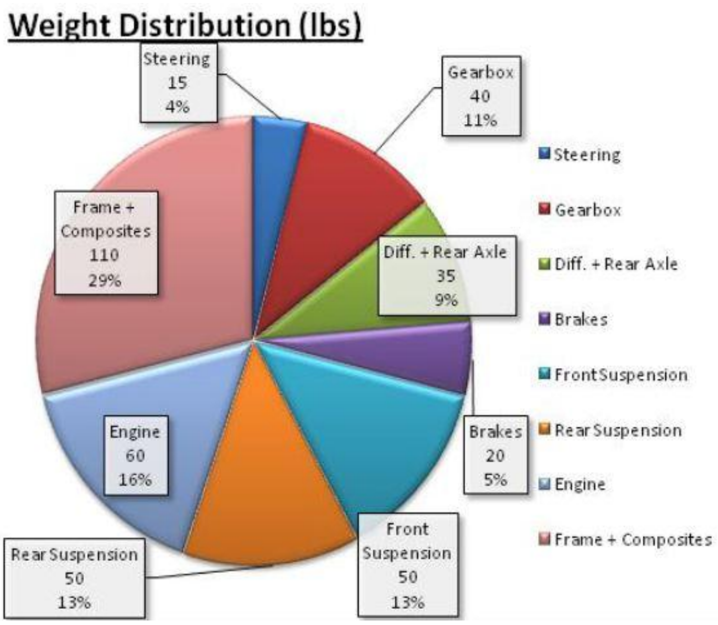

Fig.9: Weight distribution

Prof. A. M. et al In this paper a Under the static load conditions deflection and stresses of steel lower wishbone arm and composite lower wishbone arm are found with the great difference. Carbon fiber suspension control arms that meet the same static requirements of the steel ones they replace. Deflection of Composite lower wishbone arm is high as compared to steel

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lower wishbone arm with the same loading condition. The redesigned suspension arms achieve an average weight saving of 27% with respect to the baseline steel arms. The natural frequency of composite material lower wishbone arm is higher than steel wishbone arm.

6. Previous work done on forces analysis:-

The overall purpose of a suspension system is to absorb impacts from coarse irregularities such as bumps and distribute that force with least amount of discomfort to the driver. We completed this objective by doing extensive research on the front and rear suspension arm's geometry to help reduce as much body roll as possible. Proper camber and caster angles were provided to the front wheels. The shocks will be set to provide the proper dampening and spring coefficients to provide a smooth and well performing ride. Double A Wishbone was selected for it's simple design and ability to provide a good travel.

Vinayak Kulkarni1, Anil Jadhav2, P. Basker3 [7] This paper deals with calculating the forces acting on lower wishbone arm while vehicle subjected to critical loading conditions (Braking, Cornering and Descending though slope). From result obtained it was found that current .They conclude that On strength basis, aluminum alloy is good material than Mild Steel whereas on strain basis, Mild Steel is good material than aluminum alloy. Modes and mode

Table.7: Technical Specification of suspension system

PARTICULARS	VALUES
Motion Ratio Front	0.86
Motion Ratio Gear	0.6
Front Spring Constant	12.86N/mm
Rear Spring Constant	39.6/mm
Camber	-1
Caster	3.6
Toe	0
Sprung mass	185
Un-sprung Mass	90
Wheel Travel Front Left	6 “
Wheel Travel Front right	6 “
Wheel Travel rear Left	5 “
Wheel Travel rear right	5 “

Sagar Darge*, et al In this paper it has been seen that the maximum value of force transmitted by tyre to the body of vehicle through lower suspension arm. During braking and cornering lower suspension arm is subjected to high stresses because of that Failure of lower suspension arm of vehicle was reported. Plastic deformation and cracks were observed frequently during on road running of vehicle. Stress analysis was performed using finite element method. Reinforced models were

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proposed on the basis of result data..they used specific size of bead to subdivide the area into a large number of separate variables whose influence on the structure is calculated and optimized over a series of iterations.

According to the constraint in the rulebook, the maximum speed of the vehicle is assumed to be 60 km/h or 16.66m/s. Calculations below were calculated in order to design the roll cage in best possible way.
Let Wnet = Net work done,
f = Force and
d = Distance travelled
Now,
Wnet = ½ mv2 final - ½ mv2 initial (1)
Wnet = - ½ mv2 initial (2)
But, Wnet = Impact force × d (3)
It was considered that for static analysis, the vehicle comes at rest within 0.1 seconds after impact (Sania and Karan et al, 2013). Therefore, for a vehicle which moves at 16.66 m/s, the travel of the vehicle after impact is 1.66 m (Sania and Karan et al, 2013).
From equations (1), (2) and (3)
Impact force = ½ mv2 initial × 1/d (4)
Impact force = ½ × 235 × (16.66)2 × 1/1.66
Impact force = 19,632.85

The Baja vehicle will have a maximum of 7.9 G's of force during impact, G = Mass of the vehicle × Gravitational force acting
on the vehicle (Sania and Karan et al, 2013).
F = m × a = 235 × 7.9 × 9.81 = 18,212.265 N
Impact force by acceleration limit = 18,212 N
The above calculated values are practically comparable.

FRONT IMPACT ANALYSIS
Deceleration of 10 G's was assumed for the loading which is equivalent to a static force of 26,698 N (equivalent to6000 lbf) load on the vehicle, assuming the weight of the vehicle is 270.16 Kg (600 lbs.).Load applied: 26698N/m2 on front corner Constraints: ALL DOF's=0 on Rear corner points Note: Here applied load of 10G. The research found that the human body will pass out at loads much higher than 9 times the force of gravity or 9 G's. A value of 10kG's was set as the goal point for an extreme worst case collision.

Table.8: Analysis impact force

Technical Parameter	Front impact	Side Impact	Rear Impact
Velocity (Km/h)	50	40	40
Time of impact (s)	0.2	0.3	0.2
Force (kN)	24.305	12.96	19.44
In terms of G's	7.09	3.78	5.66

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7. Conclusion

This was followed by analysis of the system in the ANSYS. The stipulated objectives namely providing greater suspension travel, reducing the un-sprung mass of the vehicle, maximizing the performance of the suspension system of the vehicle and better handling of vehicle while cornering; have been achieved.

1. According to material selection in above analysis is Hence proof , AISI 1040 is selected for wishbones because the net score is highest for AISI 1040.

2. According front suspension to analysis the Length of upper wishbones 12.07" Length of lower wish bones 13.59'' Inclination of wishbone with upper horizontal (α) 12^0 Inclination of wishbone with lower horizontal(β) 17^0

3. According to weight analysis the front suspension consisting of double wishbone coil spring with damper is designed by evaluating the ideal ride height to easily steer through unsmooth tract. Double a-arm allows for good control over wheel angles and produces minimal camber gain over large amounts of wheel travel

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