Design and Analysis of Lower H-Frame Type Suspension for Rear Wheels of BAJA Vehicle

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***Abstract*- BAJA is an off road racing competition conduct by the SAE (Society of Automotive Engineers) every year. Team of 25 students have to design, build, test and race a high strength single seat All terrain vehicle as per the SAE guidelines. The dynamic events include endurance race, hill climbs, maneuverability events, and suspension & traction events. This paper covers the complete design of the non steerable lower H-Frame suspension system for rear wheel of a BAJA ATV (All Terrain Vehicles). The LSA (Lotus suspension Analysis) software is used for designing suspension geometry and after getting the hard points the CAD modeling is done on Creo 3.0. Hypermesh 13.0 is used for the stress and deformation analysis of the various components of suspension system.**

***Index Terms*- camber; roll gradient; motion ratio; finite element analysis;**

I. INTRODUCTION

The suspension system is one of the major parts for any vehicle, it not only provides comfort to the rider but also prevent the breaking of the other component by absorbing the unwanted forces from the road surface during the ride. The suspension system is the linkage mechanism which provides the relative motion between the wheels and the chassis [5].

Some other functions of a suspension system are:

- Provide support to the vehicle weight.
- It separates the vehicle Chassis from road disturbances and maintains the proper ride height.
- It maintains the contact between the road surface and the tires.
- It provides better Ride comfort and stability to the vehicle.
- It prevents the vehicle roll while cornering.

A. Lower H- Frame Suspension

H-Frame type suspension is a non steerable suspension system use for the rear wheel. It consist of a single Lower Wishbone of H shape having two pivot points on Chassis side and Two on the Wheel hub side with a single upper link to carry the lateral load and to set the proper camber.

Initially on static condition the Camber is set to be slightly negative because when the vehicle takes turn in speed due to centrifugal force the tire moves slightly outward. If there is negative camber then while cornering the tire becomes perpendicular to the ground which provide better stability to the vehicle and decrease the wear of the tire hence increase the tire life.

Objective of suspension system

1) Decrease unsprung mass.
2) Increase wheel travel.
3) Optimum ride height that balance between low CG height and high enough to pass large obstacles.
4) A more flexibility in terms of adjustments and high permissible lateral force attainment mechanism.
5) Minimize variation in wheel geometry during travel.
6) To minimize plunging of CV-joints in rear suspension. This minimizes chances of popping out of the half shafts from gearbox [5].
7) To provide better handling while cornering.

II. DESIGN METHODOLOGY

Before designing the suspension system we have to fix some of the basic parameters of the vehicle which we are going to use in during our entire design process.

TABLE I Basic Pameters

	Parameters	*Value*
1	Wheel base	1600 mm
2	Track width (rear)	1300 mm
3	Tire width	203.2 mm
4	Tire radius	292.1 mm
5	Suspension travel	134.62
6	Sprung mass	180 kg
7	Unsprung mass	45 kg
8	Ground clearance	279.4

Suspension calculation

1) Calculation of Desired frequency[2]

$$f = \sqrt{\frac{Kt}{m}}\,\text{Hz}$$

The static displacement can be calculated by,

SD= (total travel of wheel/2.5) mm

In our buggy the front frequency is 10% less than the rear suspension due to the static displacement constrain. To increase the frequency we need to decrease the static displacement which would decrease the total travel of the wheel to keep max load on the wheel at 3g.

2) Calculate the spring rate (SR)

It is given by,

SR= $MR^2 \times WR$ Where, MR= Motion ratio

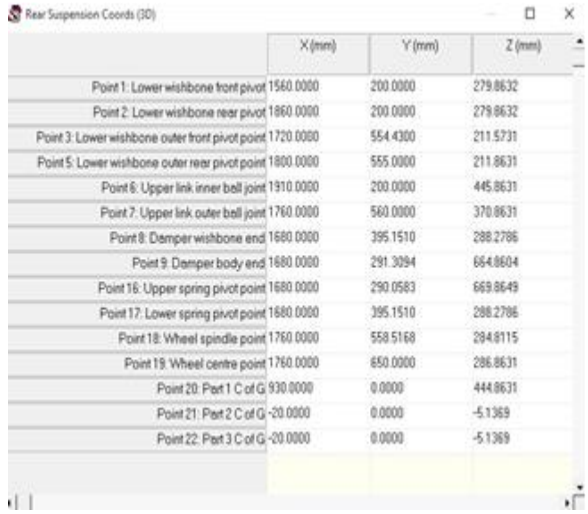
Wheel travel is decided to be 203.2mm at the rear due to variation in wheel geometry during travel and to keep 10% difference in frequency. The suspension we are using Fox Float 3 Evol R which has 134.62mm linear travel. The suspensions are mounted at 30 degree from vertical.

TABLE II output parameters

	Output Parameters	Value
1	Wheel rate (N/mm)	10.13
2	Frequency of unsprung mass	1.92
3	Motion ratio (vertical suspension travel/ vertical wheeel travel)	0.57
4	Spring rate (N/mm)	30.66
5	Roll gradient (deg/g)	0.4
6	Roll/camber deg (deg/deg)	3.15

B. Lotus Suspension

In order to analyze the kinematics of the suspension on the BAJA vehicle, Lotus Shark was use. This suspension software allowed the user to input suspension points for various geometries. When all points are inputted, software would display the result both graphically and visually how the suspension would move when the vehicle take turn or hit a bump. The final points were determined through the iteration.


Rear Suspension Coords (3D)

	X (mm)	Y (mm)	Z (mm)
Point 1: Lower wishbone front pivot	1560.0000	200.0000	279.8632
Point 2: Lower wishbone rear pivot	1860.0000	200.0000	279.8632
Point 3: Lower wishbone outer front pivot point	1720.0000	554.4300	211.5731
Point 5: Lower wishbone outer rear pivot point	1800.0000	555.0000	211.8631
Point 6: Upper link inner ball joint	1910.0000	200.0000	445.8631
Point 7: Upper link outer ball joint	1760.0000	560.0000	370.8631
Point 8: Damper wishbone end	1680.0000	395.1510	288.2786
Point 9: Damper body end	1680.0000	291.3094	664.8604
Point 16: Upper spring pivot point	1680.0000	290.0583	669.8649
Point 17: Lower spring pivot point	1680.0000	395.1510	288.2786
Point 18: Wheel spindle point	1760.0000	558.5168	284.8115
Point 19: Wheel centre point	1760.0000	650.0000	286.8631
Point 20: Part 1 C of G	930.0000	0.0000	444.8631
Point 21: Part 2 C of G	-20.0000	0.0000	-5.1369
Point 22: Part 3 C of G	-20.0000	0.0000	-5.1369

FIG 1 Final hard points

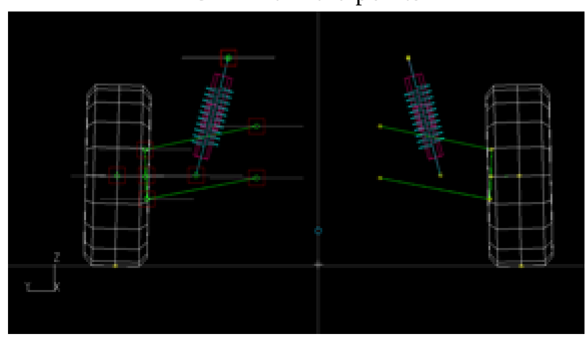


FIG 2 Lotus Front View

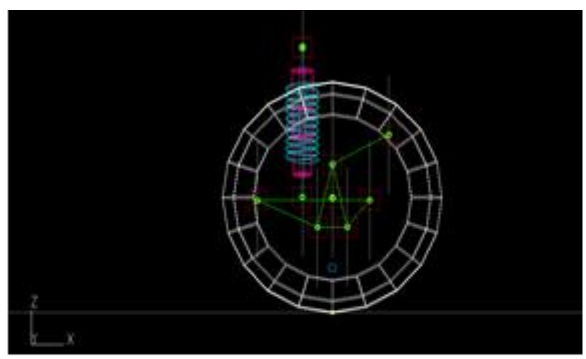


FIG 3 Lotus Side View

The iteration process is done until we did not get the minimum variation in the value of the camber, toe and the half Track change during the entire wheel travel to reduce the condition of roll and maintain the stability of the vehicle. We have taken the bounce to rebound ratio of 60:40. If there is lager variation in the half Track change during the travel it will leads to the pooping out or breaking of the half shaft during the testing of vehicle.

1) Numerical Result

INCREMENTAL GEOMETRY VALUES

BUMP TRAVEL (mm)	CAMBER ANGLE (deg)	TOE ANGLE (deg)	CASTOR ANGLE (deg)	KINGPIN ANGLE (deg)	DAMPER RATIO [-]	SPRING RATIO [-]
-80.00	-1.6839	0.0355			1.834	1.834
-70.00	-1.6367	0.0324			1.838	1.838
-60.00	-1.5888	0.0289			1.841	1.841
-50.00	-1.5403	0.0249			1.844	1.844
-40.00	-1.4910	0.0206			1.845	1.845
-30.00	-1.4409	0.0160			1.846	1.846
-20.00	-1.3899	0.0110			1.847	1.847
-10.00	-1.3378	0.0057			1.846	1.846
0.00	-1.2847	0.0000			1.846	1.846
10.00	-1.2305	-0.0060			1.845	1.844
20.00	-1.1749	-0.0123			1.843	1.843
30.00	-1.1180	-0.0190			1.841	1.841
40.00	-1.0597	-0.0260			1.839	1.838
50.00	-0.9997	-0.0333			1.836	1.836
60.00	-0.9380	-0.0409			1.833	1.833
70.00	-0.8744	-0.0488			1.830	1.830
80.00	-0.8087	-0.0571			1.827	1.827
90.00	-0.7409	-0.0656			1.824	1.824
100.00	-0.6706	-0.0746			1.820	1.820
110.00	-0.5978	-0.0838			1.817	1.817
120.00	-0.5221	-0.0934			1.814	1.814

FIG 4 Camber & Toe Variation

INCREMENTAL SUSPENSION PARAMETER VALUES

BUMP TRAVEL (mm)	ANTI DIVE (%)	ANTI SQUAT (%)	ROLL CENTRE HEIGHT TO BODY (mm)	ROLL CENTRE HEIGHT TO GRND (mm)	HALF TRACK CHANGE (mm)	WHEELBASE CHANGE (mm)	DAMPER TRAVEL (mm)	SPRING TRAVEL (mm)
-80.00	0.71	-0.39	197.36	277.36	-24.11	0.07	43.39	43.40
-70.00	0.72	-0.37	185.85	255.85	-19.91	0.06	37.95	37.95
-60.00	0.73	-0.34	174.74	234.74	-16.07	0.05	32.51	32.51
-50.00	0.74	-0.32	163.99	213.99	-12.57	0.04	27.09	27.09
-40.00	0.75	-0.30	153.55	193.55	-9.42	0.03	21.66	21.67
-30.00	0.76	-0.27	143.37	173.37	-6.59	0.02	16.25	16.25
-20.00	0.77	-0.25	133.41	153.41	-4.08	0.01	10.83	10.83
-10.00	0.79	-0.22	123.65	133.65	-1.89	0.01	5.42	5.42
0.00	0.80	-0.20	114.05	114.05	0.00	0.00	0.00	0.00
10.00	0.81	-0.17	104.58	94.58	1.59	0.00	-5.42	-5.42
20.00	0.83	-0.15	95.21	75.21	2.87	-0.01	-10.84	-10.84
30.00	0.84	-0.12	85.93	55.93	3.87	-0.01	-16.27	-16.27
40.00	0.86	-0.09	76.69	36.69	4.57	-0.01	-21.71	-21.71
50.00	0.88	-0.06	67.48	17.48	4.98	-0.01	-27.15	-27.15
60.00	0.89	-0.03	58.28	-1.72	5.09	-0.02	-32.60	-32.60
70.00	0.91	0.01	49.05	-20.95	4.92	-0.01	-38.06	-38.06
80.00	0.93	0.04	39.78	-40.22	4.46	-0.01	-43.53	-43.53
90.00	0.95	0.08	30.45	-59.55	3.70	-0.01	-49.01	-49.01
100.00	0.98	0.12	21.01	-78.99	2.65	-0.01	-54.50	-54.50
110.00	1.00	0.17	11.46	-98.54	1.30	-0.01	-59.99	-60.00
120.00	1.02	0.21	1.75	-118.25	-0.35	0.00	-65.50	-65.50

FIG 5 Half Track Change

2) Graphical Result

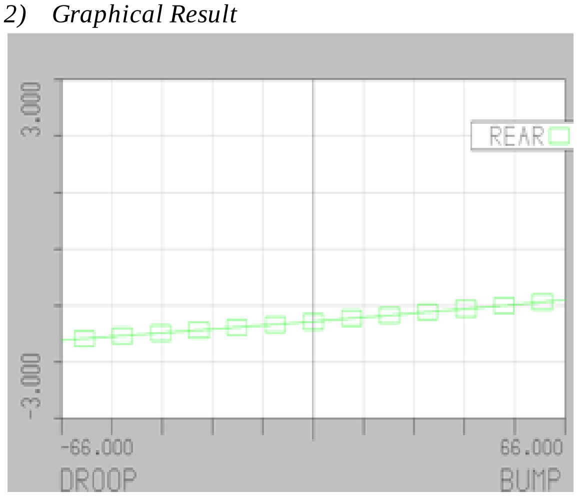


FIG 6 Camber Vs Wheel Travel

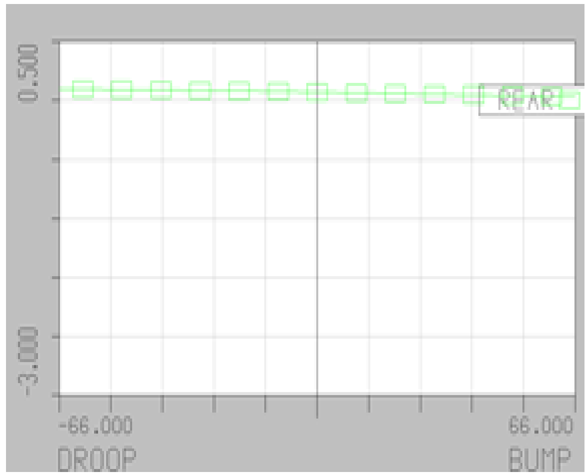


FIG 7 Toe change Vs Wheel Travel

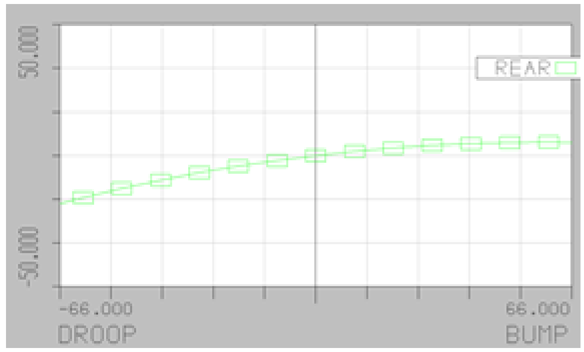


FIG 8 Half Track Change Vs Wheel Travel

C. CAD(Computer Aided Designing) Modeling

After getting the hard points through Lotus Suspension Analysis Software the following components are to be design on CAD software:

1) Lower wishbone
2) Knuckle
3) Wheel Hub

All the components are design using Creo 3.0 Software. Before designing the Knuckle and Wheel hub we have to concentrate on the size of the half shaft which we are going to use, Rim offset and Bearing type and size. Here we are design the Knuckle and Hub for the positive offset Rim compatible to Maruti 800 Half shaft. The bearings we use are cylindrical Roller Bearing of outer diameter 62mm and 47 mm.

Here we use cylindrical Gun metal bushes at the wishbone pivot point for giving the smooth movement to the wishbone with respect to the frame. The suspension bracket should be placed in such a way that it is at least 50mm offset from the wheel centre line.

FIG 9 Wishbone

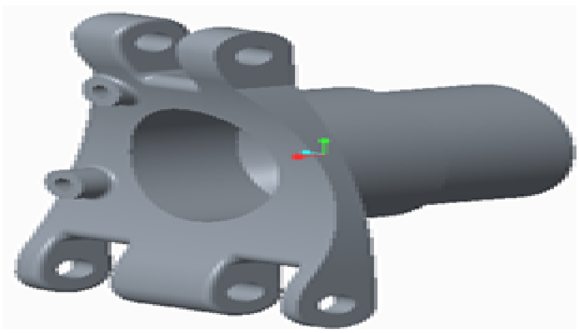


FIG 10 Rear Knuckle

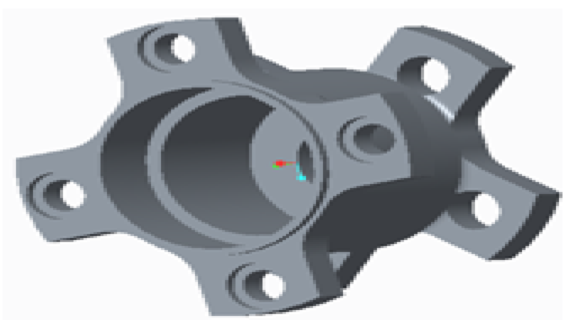


FIG 11 Rear Hub

D. Material Selection

After the cad modeling of all components we had done material selection by looking into various parameters such as ultimate strength, yield strength, elongation etc. For the wishbone circular cross section hollow pipes of different thickness are available in both AISI 1018 and AISI 4130 material and for knuckle and Hub EN-8, EN-24 and EN-32 are available .The properties of AISI 1018 and AISI 4130 are [7]:

TABLE III Material properties

	AISI 1018	*AISI 4130*
Density	7.87	7.85
Carbon %	0.14-0.20	0.27-0.30
Yield Strength (MPa)	370	460
Ultimate Strength (MPa)	440	560
Elongation at Break (50mm)	15%	21.5%

Similarly the properties of EN-8, EN-24, and EN-32 are as follows [6]:

TABLE IV EN - Material properties

	EN-8	*EN-24*	*EN-32*
Carbon %	0.36-0.44	0.36-0.44	0.10-0.18
Yield Strength (MPa)	465	650	300
Ultimate Strength (MPa)	700	850	430
Elongation at Break (50mm)	16	13	18

We have selected AISI 4130 of 31.75 mm Outer Diameter and 2mm thickness for Wishbone and EN24 for the Knuckle and Hub.

E. Analysis

After the designing in Creo 3.0 components are imported to Hypermesh software (Computer Aided Engineering). FEA (Finite element analysis) of the suspension is carried out in Hypermesh 13.0 Software. Several types of thermal analysis, Dynamic and static structural analysis can be made possible using Hypermesh Software. But here we are conducting structural analysis to define the boundary conditions and to determine the maximum deformation and maximum stress develop by applying various Loads.

Let us consider the weight of the vehicle including the driver is 350 kg.

1) Wishbone Analysis

The maximum vertical 3g Force is acting on the wishbone during the bump condition.

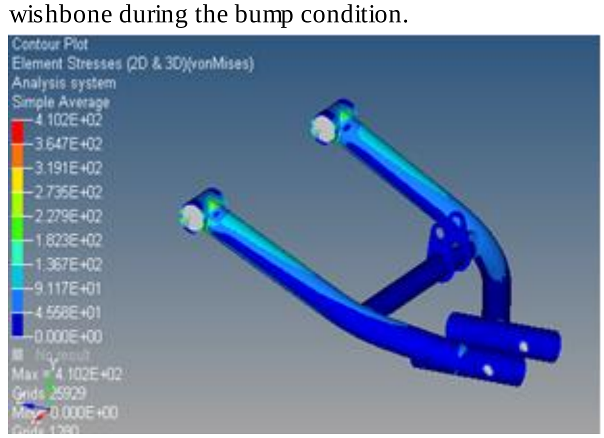


FIG 12 Wishbone Analysis

2) Rear Knuckle and Hub Analysis

The forces acting on the Knuckle are:

Cornering Force: - Cornering forces arises when the vehicle take turn at its maximum speed due to centrifugal force and also due to some lateral dynamic load transfer [5]. We take maximum 1.5g cornering Force.

Vertical Forces: - These forces arise due to the self weight of the vehicle during the bump condition. Usually 3g loads are acting on the components in case of Bumps.

TABLE V Forces

	Knuckle	*Hub*
Maximum Force	Bump - 3g Cornering-1.5g	Bump - 3g Cornering - 1.5g Motor torque – 456 Nm
Force applied	Bearing Position	Wheel Mount
Fixed	Wishbone Mount	Spline Housing

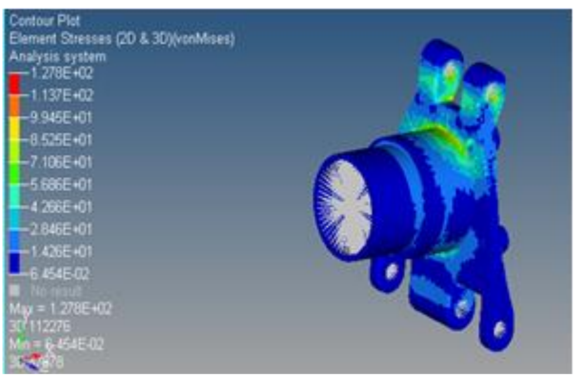
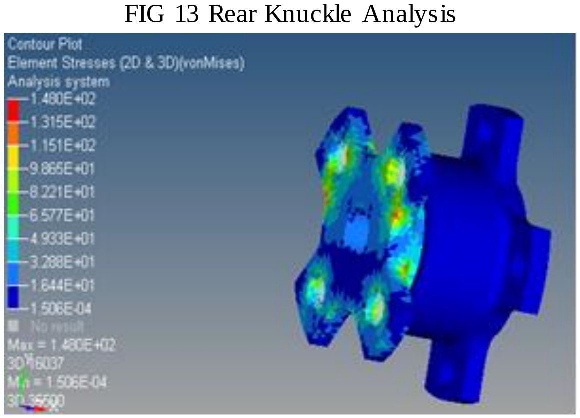


FIG 13 Rear Knuckle Analysis



FOG 14 Rear Hub Analysis

TABLE VII RESULT

	Wishbone	Knuckle	Hub
Maximum Stress	410 MPa	127.8 MPa	140.0 MPa
Deformation	4.06 mm	0.194 mm	0.039 mm

III. CONCLUSION

All the components are analysis in Hypermesh 13.0 software. The elements meshes are tria and tetra elements of optimum size for accurate results.

The results of the Hypermesh software provides that the stress generated due to all the combine forces is less than the yield stress of the material which proves the component will be safe during the extreme conditions.

All the components design are very light in weight which decrease the unsprung mass and thus, increase the sensitivity of the suspension system. The weight of wishbone, rear knuckle and rear hub are 1.83 kg, 2.5 kg, 2.6 kg respectively.

The entire suspension geometry was simulated in Lotus Shark software which provides us the verification of the suspension hard points. The result obtain from the Lotus software proves the there is minimum change in the value of the camber, toe and track change during the entire wheel travel.

This geometry of the suspension system provide maximum wheel travel, minimize the condition of pooping out of the half shaft, minimize the bump steer condition and always keep the tire perpendicular to the ground while cornering. Thus maintain the stability of the vehicle.

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