Design and Development of Semi-Trailing Suspension System for an All-Terrain Vehicle

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Abstract - *The semi-trailing arm is an enhanced version of the trailing arm and swing axle suspension systems that balances their respective benefits and drawbacks. The semi-trailing arm suspension system's characteristic parameters are identified in order to maximize an all-terrain vehicle's handling and stability performances. There are two different kinds of objective functions defined: off-line and on-line. The off-line goal function takes into account variations in the tire track, toe angle, and camber caused by roll. The handling and stability characteristics of a moving vehicle during a typical J-turn maneuver are taken into account in the online goal function. A non-linear vehicle model with nine degrees of freedom, having semi-trailing arm and double wishbone suspensions in the rear and front axles, respectively, is investigated. The optimized suspension systems obtained from both off-line and on-line objective functions are utilized in making two accurate vehicle models in Lotus Software for experimental field test. A comparison between the behaviors of the two vehicles shows that despite the simplicity of optimization with off-line objective functions relative to on-line1, it returns the satisfactory results and improves both the handling and stability performances.*

Key Words*: Semi trailing arm, *tire track, toe angle, camber, roll, degrees of freedom, Lotus software, optimization.

1. INTRODUCTION

A multilink independent suspension system, such as the semi-trailing arm suspension, gives the car improved ride control and stability. The suspension system's design needs to be robust even in the worst of circumstances. Designing a suspension system with increased comfort, reduced weight, improved handling, increased shock absorption capability, increased vehicle stability, and reduced complexity is the major goal. By taking all of these factors into account, we are able to create suspension systems that are both more affordable and provide superior performance.

This report is based on the detailed design process that Team Torrid Racing follows in accordance with the BAJA SAE India rule book. The Baja sae India is an all-terrain vehicle event held at the national level, where teams of engineering colleges from all over India participate with custom-designed and manufactured ATVs. ATVs are designed and produced with competition in mind, meaning that they must be able to withstand the roughest road conditions. A vehicle's suspension system is crucial to its stability and control. Comparing semi-trailing arms to other types of rear suspension, there are numerous benefits.

1.1 OBJECTIVES OF SUSPENSION DESIGN

The main objectives of the design of the suspension system are:

- To minimize dynamic camber and toe changes in wheel travel to optimize the contact patch and thereby handling.
- To optimize rolling characteristics by increasing roll center height. This makes the car more responsive and this setting is ideal for tracks with quick direction changes.
- To synchronize the dynamic roll center variation for front and rear for better and predictable handling.
- To minimize trackwidth variations to reduce plunging of the shaft.
- To minimize unsprung mass to have more grip in irregular terrain and thereby improve performance.

2. NEED OF THE PROJECT

• Better Handling: Proper tire alignment and contact with the road surface are maintained with the aid of semi-trailing arms, which improves handling and stability of the car.
• Control of Camber and Toe Angles: During suspension travel, semi-trailing arms can regulate the wheels' camber and toe angles to keep them within permissible bounds.
• Rear Axle Location: Semi-trailing arms assist in maintaining the proper rear axle positioning in rear-wheel-drive and some all-wheel drive vehicles, guaranteeing appropriate weight distribution and traction.

3. DESIGN CONSIDERATIONS

3.1 Toe angle

The toe angle should be as close to zero as possible to maintain stability with the road surface. A slight toe gain Toe gain is permissible unless vehicle’s stability is not compromised.

3.2 Castor angle

Since the rear tires are not equipped with any sort of steering mechanism, the castor angle also is set to zero at static condition.

3.3.1 Vertical loading

The road wheel experiences tensile or compressive vertical forces—depending on the load irregularity—when it encounters a bump or pit in the pavement.
Calculations:
Consider a drop test where a buggy is unsuspended from a height of 6 feet.

From impulse momentum equation

$$f\Delta t = m\Delta v$$

$$f = \frac{m\Delta v}{\Delta t}$$

$$= \frac{270 * \sqrt{2gh}}{0.6106}$$

$$= \frac{270 * \sqrt{2 * 9.81 * 1.8288}}{0.6106}$$

(h in meter)

$$\boldsymbol{f} = \mathbf{2653.13\ N}$$

3.3.2 Dynamic load transfer (Cornering force)

When vehicle goes through a turn, it faces centrifugal forces at the Hub end of the arm. When vehicle takes a turn this centrifugal force acts about the C.G. of the vehicle while the load opposition acts towards the wheel. This tends to create a turning couple acting about the longitudinal axis.

$$\mathbf{F_c = m * \frac{v^2}{r} * \frac{h}{t}}$$

$$=270 * \frac{11.11^2}{2} * \frac{0.5588}{1.2446}$$

F_c =7481.5N
F_c =7481.5*0.6 (rear side)
F_c =4488.9N
F_c =4488.9+(14*9.81)
F_c =4626.24N
Taking coefficient of friction of tyre into consideration ($\mu = 0.7$)
F_c =4626.4*0.7
F_c = 3238.37N

3.3.3 Dynamic Load transfer (longitudinal/ Squat)

Depending on the wheel base, various suspension parameters, and the position of the center of gravity in relation to the ground, the vehicle's nose drops when the brakes are applied. We refer to this phenomenon as a dip. The torque loads experienced during acceleration also have the tendency to elevate the front of the vehicle. This phenomenon is called as Squat.

$$R_{dyn} = \frac{h}{l} * W * a$$

$$R_{dyn} = \frac{0.5588}{1.4224} * 270 * 9.81 * 5.55$$

R_{dyn} =5775N

$R_{dyn} = 5775 * \frac{1}{2}$ (for each side)

R_{dyn} =2887.55N

R_{dyn} =2887.55N +(14*9.81)

R_{dyn} = 3024.89 N

Taking coefficient of friction of tyre into consideration ($\mu = 0.7$)

R_{dyn} =3024.89*0.7

R_{dyn} =2119.423 N

3.3.4 MOTION RATIO, SPRING AND WHEEL RATE

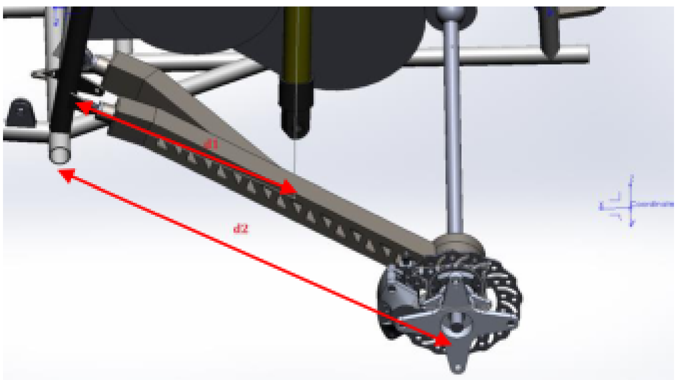

Fig -1: Motion Ratio

Motion Ratio

Motion ratio in suspension of a vehicle system describe the amount of shock travel for a given amount of wheel travel.

$$M.R = \frac{d1}{d2} = \frac{350.9}{589.8}$$

M.R.= 0.6

Spring rate

Spring rate refers to the amount of force that is needed to compress a spring by one millimeter. Denoted by K_s.

ENDURANCE
Rear=19.62 N/mm
(by manufacturer)

Wheel rate (K_w)

$K_w = K_S * M.R.^2 * A.C.F.$
$K_w = 19.62*0.6^2*1$ (A.C.F.= 1 for rear)
K_w =7.1N/mm

Sprung mass natural frequency (ω_n)

$$\omega_n = \frac{1}{2\pi}\sqrt{\frac{K_S}{m}}$$

Where K_S= spring rate
And m_f= front sprung mass

$$\omega_n = \frac{1}{2\pi}\sqrt{\frac{19620}{213.782*0.6}}$$

$$\omega_n = 1.97\text{Hz}$$

4. LOCATING THE SUSPENSION GEOMETRY IN LOTUS SHARK SOFTWARE

In this software, we need to fill up some pre-determined data like desired C.G. height, tyre specifications, damper travel, wheel base.
Then by selecting the desired suspension system for e.g. Semi-trailing Rear suspension system, we can start the procedure of locating the hard points (wheel side) and the soft points (chassis side).

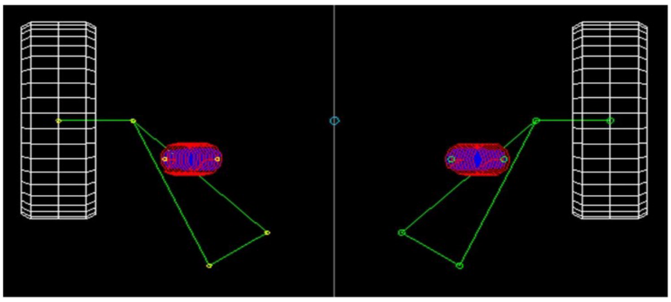

Fig -2: Top view of rear suspension (in Lotus Shark)

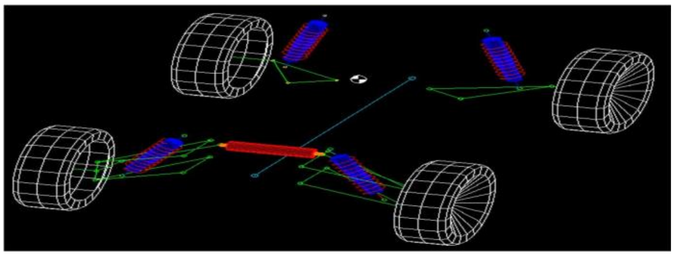

Fig -3: Front and rear suspension (in Lotus Shark)

5. CAD MODELLING

After obtaining all the chassis and knuckle points these points are to be traced at a CAD software in our case, we used Solid-works by Dassault system.
By tracing the points, a 3D model is made with respect to the interference with the Brake calliper and the hub disc through assembly feature.
Several iterations are done and some few are selected for further Analysis part.

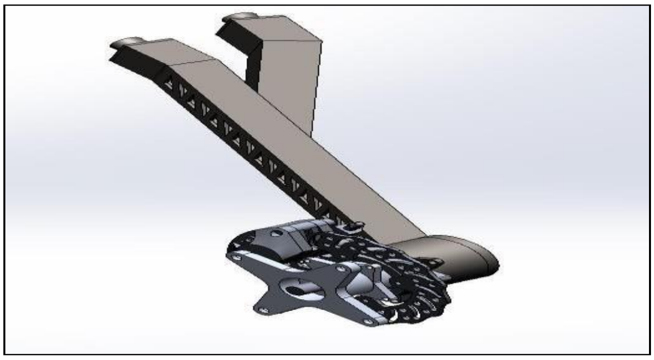

Fig -4: CAD Model of Semi Trailing Suspension System

6. MATERIAL SELECTION

Al 7075 T6 was selected as the material of our hubs and upright after comparison with other alloys. It was further anodized to reduce the crack propagation. square pipe of AISI 4130 with side 30 mm and wall thickness of 3mm for semi-trailing arm.

Components	Materials	Yield St. (MPa)	Ultimate Strength (MPa)	Young's Modulus (GPa)
Rear Upright	Al7075-T6	460	530	71.7
Wheel Hub	Al7075-T6	460	530	71.7
Semi Trailing arm	AISI 4130 Square pipe	460	560	205

Table-1: Material Properties of Suspension Components

7. ANALYSIS

The G-force range selected is from 2G to 5G for various conditions

- **Static structural and fatigue analysis:**

  These analyses were performed on A-arms, semi trailing arm,tie rod, mounts, both uprights, hubs.
- **Random vibration analysis**: This analysis gave us a frequency response spectrum which helped us in deciding the stiffness of the shocks. We have therefore found that the AFCO shocks perfectly fit our requirement.
- **Topology optimization:** Hubs, uprights and mounts were analysed and material was removed from low stress concentration region. This also helpedin reducing the weight.

Semi-Trailing Arm

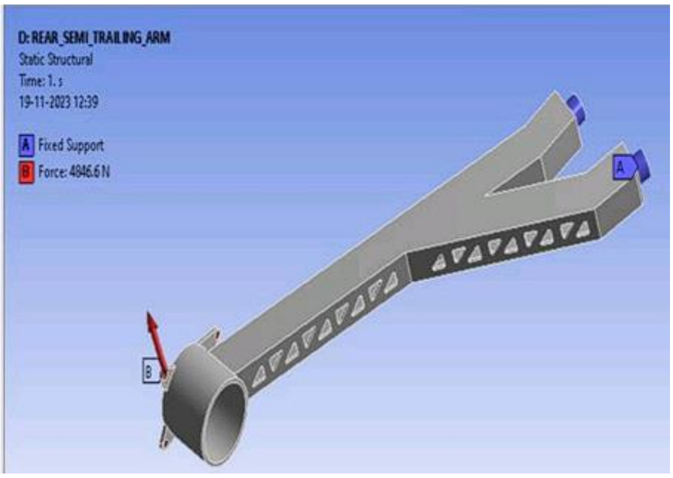

Fig -5: Semi Trailing Arm Boundary Conditions

The analysis is done in Ansys Workbench, where the boundary conditions set are Fixed at the chassis pivot point and the component of forces of all dynamic load transfer are provided at the wheel side.

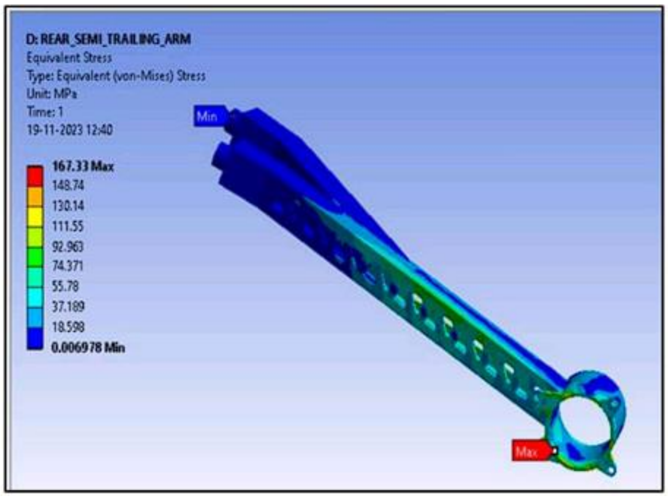

Fig -6: Semi Trailing Arm Equivalent Stress

The element type is 3D and Hex dominant type of mesh is used. The element size is of 3mm. We have performed various iterations with relatively higher and lower size element but we found this size as next to accurate.

Rear Upright

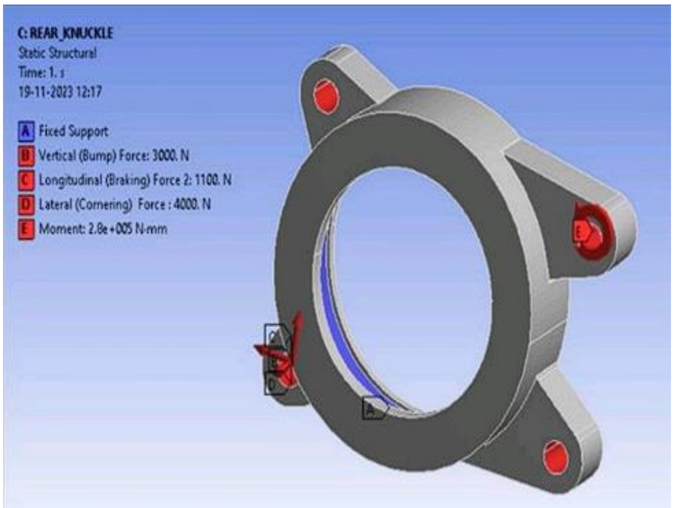

Fig -7: Upright Boundary Conditions

The face where the bearing will be fitted is kept fixed and forces and moment are applied at the ears of the knuckle where the brake disc and arm will be mounted.

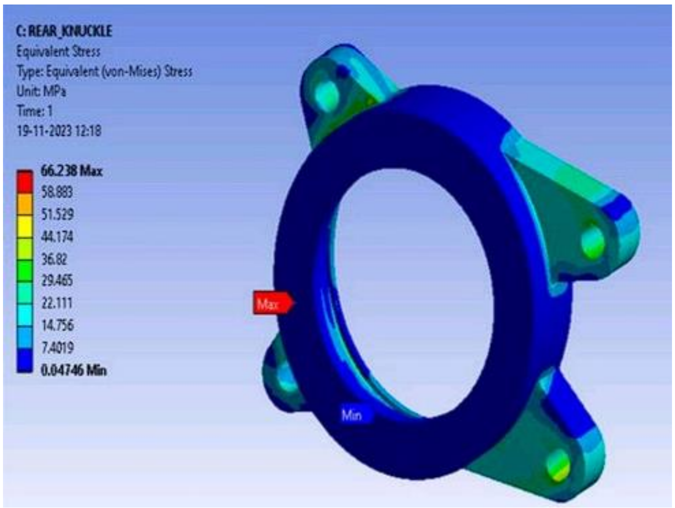

Fig -8: Upright Equivalent Stress

The element type is 3D linear and Hex dominant type of mesh is used. The element size is of 2mm. We have performed various iterations with Boundary conditions with respect to various driving conditions.

Wheel Hub

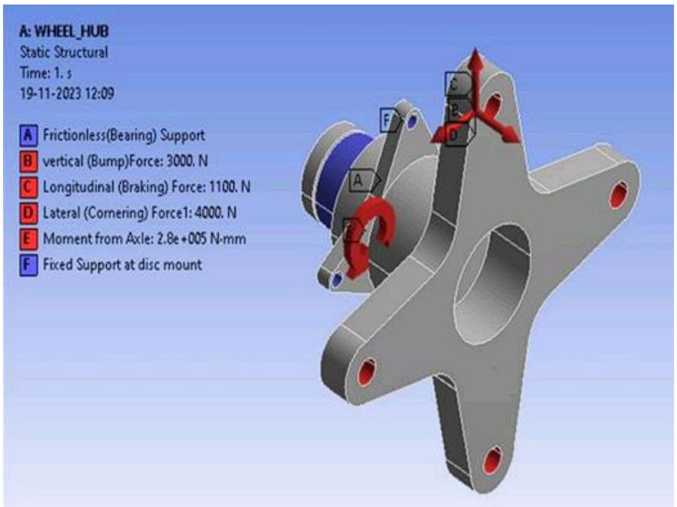

Fig -9: Wheel Hub Boundary Conditions

The face on which the Upright bearing will be fitted is kept as Frictionless support, the wheel mounting points are applied with the Dynamic forces. The Disc mounting spokes are opposed by the longitudinal load transfer and Braking torque.

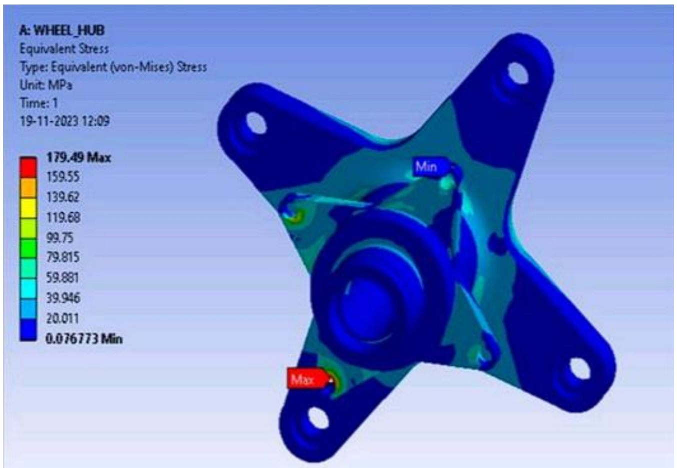

Fig -10: Wheel Hub Equivalent Stress

As you can see that the maximum stress is been shown at the brake disc mounts, this is due to stress singularity which means that where there is less resisting area the magnitude of stress is more. But in actual condition there is no harm at that mount at all, it is strong enough to sustain braking moment and Dive force.

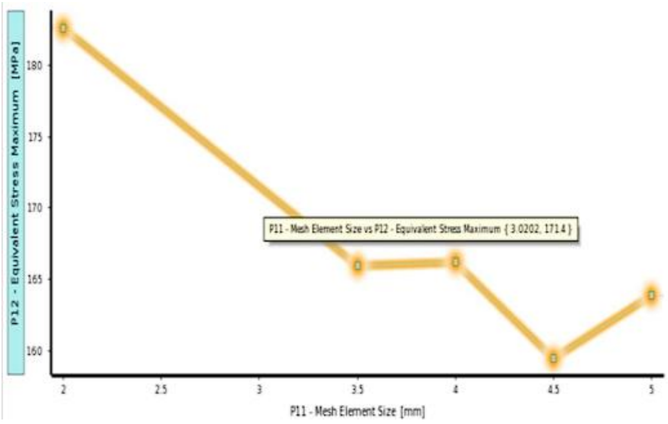

Chart -1: Element size v/s Equivalent stress

Mesh properties

Component	Element Type	Meshing type	Element size(mm)
Rear Upright	3D	Hex Dominant	2
Wheel Hub	3D	Hex Dominant	2
Semi-Trailing Arm	3D	Hex Dominant	5

Table-2: Mesh properties (Ansys software)

8. RESULTS

Suspension Geometry Results

Sr. NO.	Parameters	Values
		Rear
1	Wheel Travel Jounce/Bounce	140 mm (5.5") jounce, 63.5 mm (2.5") rebound
2	Roll Centre Height	-3.6mm mm
3	Camber variation	0.8 deg
4	Castor	None
5	KPI	None
6	Scrub Radius	0
7	Toe Variation	0.8 deg
8	Sprung Mass	137.4 kg
9	Unsprung Mass	28 Kg

Table-3: Suspension Geometry Results

Table-4: Structural Analysis Results (Ansys software)

Component	Deformation (mm)	Von-mises stress (MPa)	Stress FOS	Fatigue FOS
Rear Upright	0.0231	66.24	7.59	2.44
Wheel Hub	0.2157	179.49	2.8	1.13
Semi-Trailing Arm	1.23	167.33	2.74	1.1

9. CONCLUSIONS

The design, analysis, and integration of the semi-trailing type suspension system of an all-terrain vehicle (ATV) are covered in this study. This paper's main goal was to determine a vehicle's design parameters by a thorough analysis of vehicle dynamics. Software such as Lotus Shark, Solid Works, and Ansys were utilized to obtain more precise and clear results of the parameters that were created to meet high accuracy and minimize any kind of unusual circumstances. For off-road conditions, the suspension system design mentioned above is the most dependable and safest. After 200 hours of rigorous testing, we have not yet observed any vehicle breakdowns. With such an approach, engineers can come up with the best possible product for the society.

REFERENCES

[1] William F. Milliken, Douglas L. Milliken, "Race Car Vehicle Dynamics", SAE International, 1994. Miliken and Miliken

[2] Kirpal Singh, "Automobile Engineering", Vol 1, Seventh Edition, Standard Publishers, New Delhi, 15th Edition 2017

[3] Thomas D. Gillespie, "Fundamentals of vehicle dynamics", SAE International, 1992.

[4] Ishan Hiremath, Avanti Nalawade, Jai Patil, Swarup Patil, Riteshkumar Patil, Swapnil Ugalmugale *"Design and Development of Semi Trailing Arm Suspension System for an Off-Road Vehicle"* International Journal of Research in Engineering, Science and Management Volume-3, Issue-7, July-2020

[5] BAJA SAEINDIA 2024: 2024 Collegiate Design Series Baja SAEINDIA®Rules

[6] Reimpell J, Stoll H, Betzler W. *The automotive chassis-engineering principles*, 2nd edn. Oxford: Butterworth Heinemann, Elsevier, 2001.

[7] Attia HA. Dynamic simulation of a vehicle with semi-trailing A-arm suspension. *Trans CSME* 1996; 20(2): 175–186.

[8] Dixon J. *Suspension geometry and computation*. Hoboken, NY: John Wiley and Sons, 2009

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