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Suspension Design and testing of an All-Terrain Vehicle using Multi-body dynamics Approach.

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Abstract. The assignment presented below aims to understand the fundamentals of suspension design for a Baja trophy truck or an all-terrain vehicle. The essential parameters were identified to model the suspension system, both front and rear of a Baja Buggy. The designing was performed using a multi-body dynamics software, MSC. ADAMS. Theinterrogationswere made almost equivalent to real-time situations, which would enable the designer to benchmark.This will nurture the designer to redesign to meet the accuracy of the vehicles behaviour to actual response of the vehicle while performing off road negotiations, which would result in enhanced performance.

1. Introduction

A Baja buggy is an all-terrain vehicle which is designed to run on thrillingand extreme terrain environments. Developingthe suspension system for such a vehicle needs to be performed by addressing tothe fundamental functions which would ensure good ride and handling performance, directional stability and isolate high frequency vibrations caused by tire excitation [1]An appropriate and an ideal amount of equilibrium between the damping and stiffness of the suspension systemwill enable the driver to escape from sharp impact forces on his body.

2. Review of Suspension Systems

Many categories of front and rear suspension systems are usedwhilefabricating the front and rear suspension of a Baja Buggy. Unevenness of the terrain with lots of potholes, bumps and sudden impacts while driving Baja buggy, requires having a sturdy and responsive suspension system. Among the dependent, semi-dependent and independent categories of suspension system[1], it is preferredto use an independent suspension system. Using an independent suspension will provide an opportunity for anindividual wheel to be in perpetual contact with the road surface, even if any other tire encounters an obstacle. Suspension system of Baja Buggy is subjected to continuous cyclic loading encountering various sharps manoeuvres and rough roads throughout the travel[2].

2.1. Selection of Front Suspension System

The choices were double wishbone suspension (Figure 1) and Macpherson suspension system (Figure2).The important criteria for selecting the front suspension were.

- Geometry of the vehicle
- Ease of assembling and dismantling of the suspension system
- Simplicity of construction and manufacturing
- Material required to make the component

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- Cost of manufacturing

Figure 1- Macpherson Strut Suspension System

Figure 2- Double WishboneSuspension System

These suspension systems have their own merits and demerits. Macpherson struct suspension is simpler in construction, simple packaging, the weight of suspension system is lesser when compared with double wishbone suspension system. On the other hand, double wishbone suspension system has the strength to react to the transverse and longitudinal loads [1]. As knuckle is located at the centre of coupler link, its capable in providing straight line motion to the knuckle. Although cost of the manufacturing of a double wishbone suspension is comparatively higher than Macpherson strut, the ability to take loads under different conditions makes it suitable for the front suspension of a baja buggy.

2.2. Selection of Rear Suspension System

The rear suspension system of a Baja buggy is to be as crucial as the front one as the rear part takes the impact while the buggy negotiates a jump. The differential being in the rear of the buggy, suspension system should be designed in a manner such that the differential doesn't get damaged when buggy takes a jump

For rear suspension system designing, the trailing arm suspension system (Figure 3) and multi – link rear suspension system (Figure 4) were the types considered. Multi-Link rear suspension system had an advantage of performing specified function of the links attributed by the designer. Disadvantage of this type system was the complexity in packaging as there are numerous mounting points.

On the other hand, trailing arm rear suspension had a simple yet rigid construction. Mounting of this system delivers the freedom to use variety of springs for example, torsional bars, coil springs, rubber springs etc. This suspension system has relatively low cost of manufacturing and fits aptly with the geometry of the vehicle.

As Trailing arm suspension helps in reducing the packing constraints as well as the problems while mounting of suspension system to the body and the wheel, this was considered while designing the rear suspension system of the vehicle.

Figure 3- Trailing arm suspension system

Figure 4- Multi-Link Suspension System

3. Design Considerations

The wheelbase and the wheel track of the buggy was set to the value of 3.250m and 2.300m respectively. The front and rear wheel travel was 0.584m and 0.533m respectively. The dry weight of the Baja Buggy was considered to be 2177.4 Kg (4800 lbs), which included the weight of two passengers. The vehicle was to be considered with rear weight balance with 65%.

3.1. Assumptions

The total Unsprung mass was assumed to be 160Kg and the acceleration due to gravity was assumed to be 9.81m/s^2. The tire dimension was also assumed[3]which is mentioned in Table 3.

Table 1. Front Suspension Geometry Assumptions

Parameters	Values
Camber Angle	6 deg (negative)
Caster angle	8deg (negative)
Length of Knuckle	300mm
Length of Stub axle	250mm

Table 2. Rear Suspension Geometry Assumptions

Parameters	Values
Length of Knuckle	250mm
Length of Stub axle	227mm

Table 3. Tire Geometry Assumptions

Parameters	Values
Wheel Diameter	788mm
Wheel Width	266mm

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3.2. Weight Distribution

According to the design considerations, 65% of the weight is distributed to the rear part of the baja buggy. Rest 35% of the weight is distributed to the front part the buggy. The distributed mass was taken to be even on left and right sides of the buggy. The individual weight distribution is depicted in the Figure 5

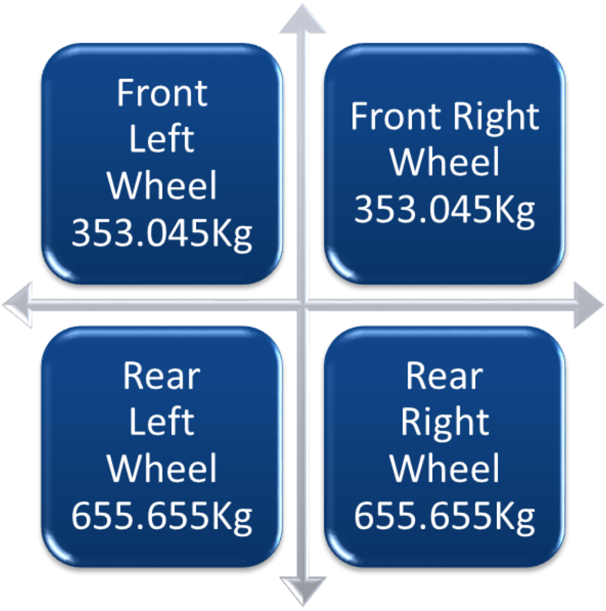
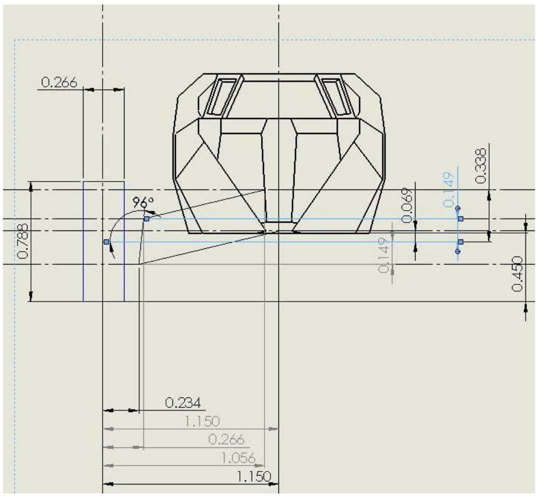


Figure 5- Weightdistribution according to the design considerations

4. Front and Rear Suspension Geometry

After theselection of the type of suspension system being used, the geometry of the suspension system was to be foresighted. Using a CAD tool, SOLIDWORKS, the camber and caster anglewere set, to achieve maximum precision.

4.1. Geometry of Front Suspension System



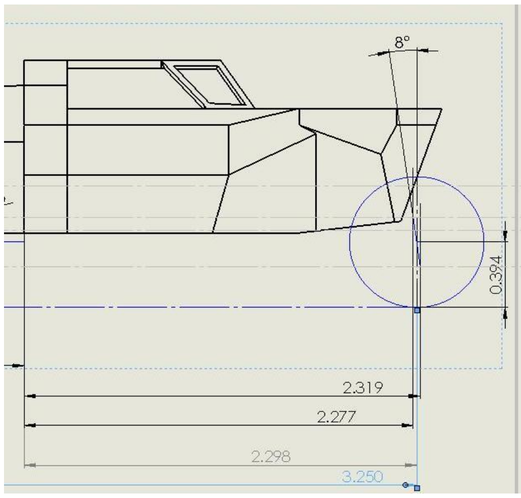


Figure 6- Front view of the front suspension geometry

Figure 7- Side view of the front suspension geometry

Table 4. Front Suspension Geometry Assumptions

Parameters	Values
Natural Frequency	1 Hz
Sprung Mass	354.045 Kg
Spring Rate	57.683 N/mm
Damping Co-efficient	14.689 Ns/mm
Preload	7045.82N

4.2. Geometry of Rear Suspension System

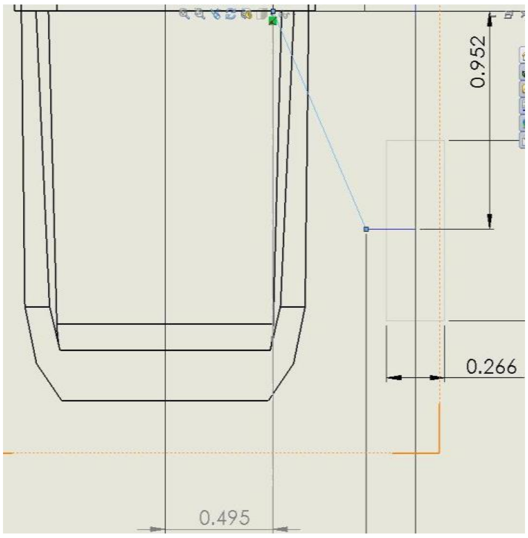


Figure 8 – Top View of the Semi – trailing arm rear suspension

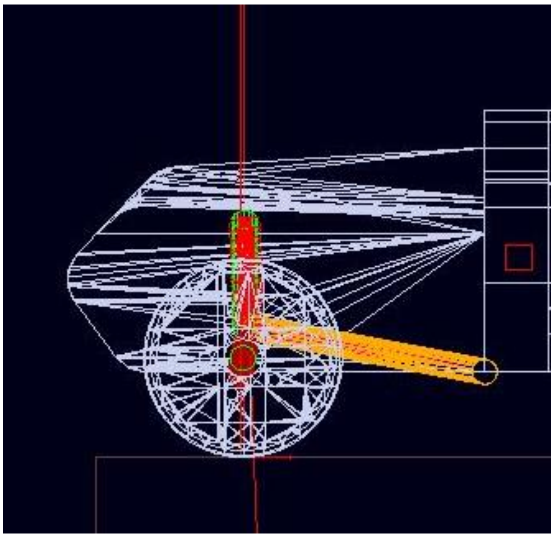


Figure 9 – Side View of the Semi – trailing arm rear suspension

Table 5. Rear Suspension Geometry Assumptions

Parameters	Values
Natural Frequency	1.1 Hz
Sprung Mass	655.655Kg
Spring Rate	35.551N/mm
Damping Co-efficient	8.230Ns/mm
Preload	6852.73N

5. Calculations

A set of sample calculation was performed to get the practical values of various suspension parameters like spring rate, damping co-efficient, preload etc[4]. Figure 10 will depict the flow of design calculations which was performed to attain the above-mentioned parameters. From the given mass of the vehicle, sprung mass of the vehicle is calculated by removing the Unsprung mass of the All-Terrain Vehicle. The basic natural frequency of the Baja Buggy was considered to 1 Hz at the front and 1.1 Hz at the rear, which will enable to reduce the pitching action by catching-upthe undulations[5][6].

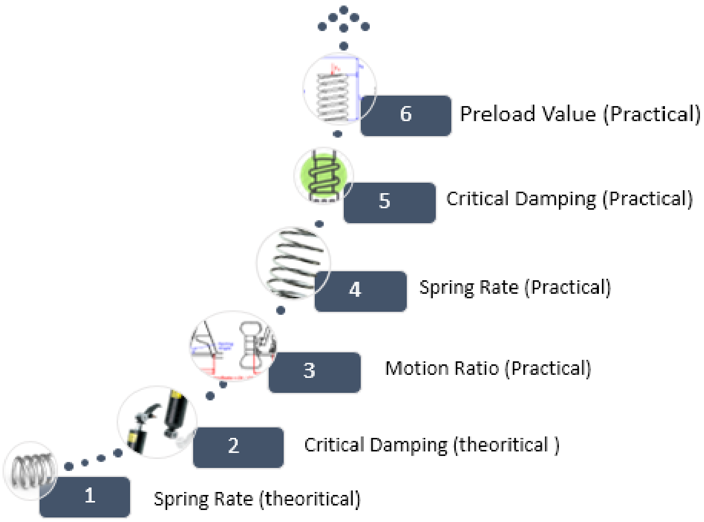


Figure 10– Flow of design Calculations

5.1. Sample Calculation

1. Spring Rate, $K_t = (2\pi f_n)^2 m \ (N/m)$
2. Critical Damping $C_{ct} = 2\sqrt{mk_t} \ (Ns/m)$
3. Motion Ratio (MR) = Wheel Movement/ Damper Movement
4. Practical Spring Rate = Spring Rate $(K_t)\times$ (Motion ratio)^2 (N/m)
5. Practical Critical = Critical Damping $(C_{ct})\times 0.8\times$ (Motion ratio)^2
6. Preload = mg

   Where,

   m = Sprung Mass of the vehicle (Kg)

   f_n = Natural Frequency of the corresponding spring (Hz)

6. Testing of the Suspension by Drop Testing

The interrogation of the vehicle was done in different stages. The vehicle was made to drop freely from a distance of 0.5m, 1m and 1.5m[7].

6.1. Drop Testing

With the given inputs, the buggy seemed to sit properly on the ground. But the front of the vehicle was still lower than the rear part of the vehicle. The spring on the front side was incapable of expanding, after the compression of spring due to the preload applied by the vehicle to it.

When the motion ratio was multiplied to the existing preload of front and rear spring, the cushioning effect was seen to be as real as possible to the real-world scenario.

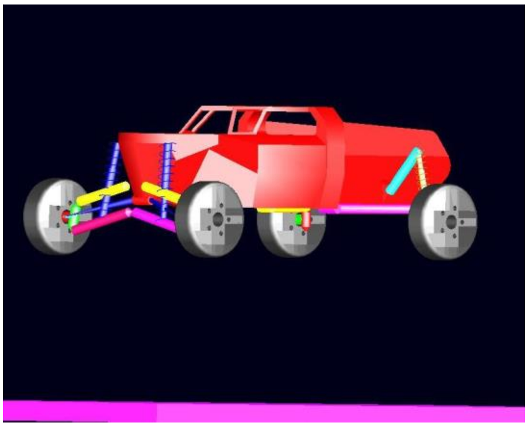


Figure 11 – Buggy at 1.5m at the ground

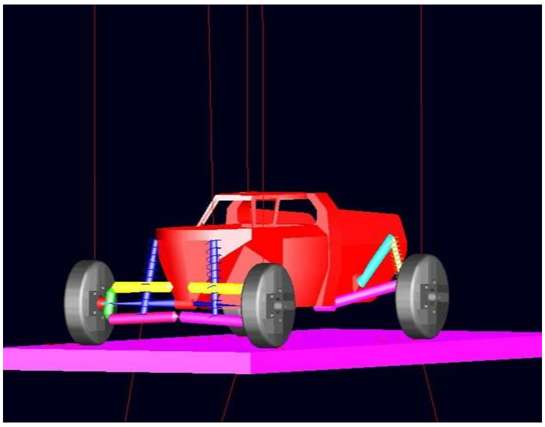


Figure 12 – Buggy after the fall from 1.5m from the ground

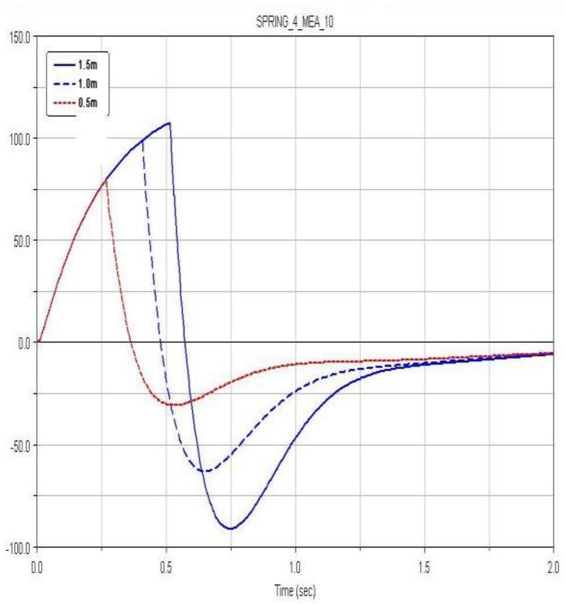


Figure 13 – Graph showing the damping of front suspension from various heights

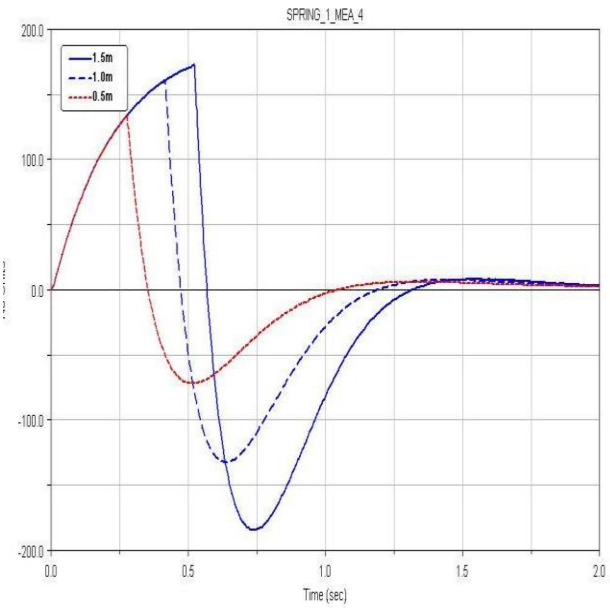


Figure 14 – Graph showing the damping of rear suspension from various heights

The graphs above indicate the increment of the amplitude of the coil as the height of the fall increases. In Figure 13, the suspension system is underdamped which is evident from the graph as the undulations are yet to settle down after 2 sec.

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6.2. Jump Testing

A 2-meter ramp at 35 degrees elevation was designed to perform the jump test.The vehicle starts toppling after the jump, if the translational factor is given as 8000. The vehicle topples and goes harshly if the same factor is given as 10000. The vehicle negotiates the jump in good manner when the translational factor was given as 7000. So, the maximum velocity of the vehicle to take the jump is 25.20 Km/hr or 15.64 miles/hr.

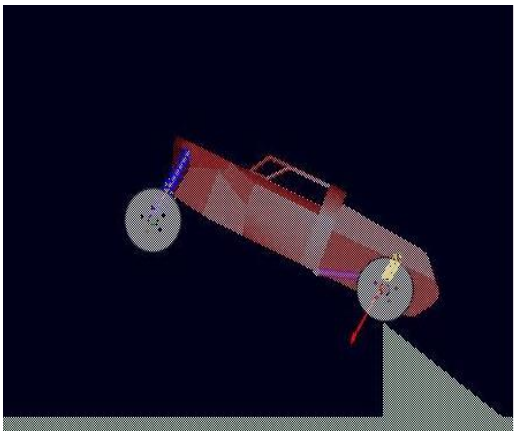

Figure 15 – Buggy taking off the jump

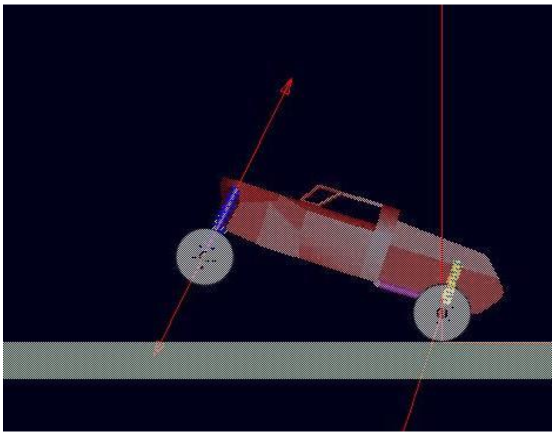

Figure 16 – Buggy landing on the ground after the jump test

7. Results & Conclusion

The Baja track is generally a rough and rugged surface with lots of frequent difficulties. The damping of the vehicle must be quick enough to come into equilibrium without hurting the driver. A compromise had to be performed within the stiffness and damping of the spring to achieve it.

The vehicle does come into equilibrium when it is dropped from a height of 1.5m as the suspension is designed in critically damped manner. In jump test, vehicle seems to land properly until a velocity of 15.64 miles/hr. After which the buggy starts toppling and moves in an undesirable way.

8. References

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