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Suspension Kinematics and Unsprung Design

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Abstract – Suspension kinematics and design's primary function is to maximize the overall performance of a vehicle as it cruises down the road. Suspension system also helps to absorb bumps in the road and provide a safe and comfortable ride.

In the research paper we have analyzed the unsprung suspension design and calculated the dynamics and Kinematic forces on our Baja vehicle. An all-terrain vehicle (ATV) or a BAJA vehicle is defined as a motorized off-highway racing car designed to travel on four low-pressure or non-pneumatic tires, having a seat designed to be straddled by the operator and handlebars for steering control.

Our college tech team Deltechbaja manufactures a Baja car every year for various competitions and events throughout the year. The initiation of building the car starts with the analysis and calculations of the suspension dynamics and unsprung parts of the vehicle through software's like lotus, Ansys and solid works.

Key Words: *Suspension, unsprung, dynamics, Lotus, Ansys, solid works.*

1. INTRODUCTION

<u>Suspension significance</u>: When discussing automotive performance, many individuals focus on aspects such as horsepower, acceleration, and the engine's roar. Yet, the effectiveness of all these features hinges on the driver's ability to control the vehicle comfortably. This underscores the significance of the automotive suspension system, which plays a pivotal role in maximizing tire-road contact, ensuring steering stability and handling, evenly distributing the vehicle's weight, and enhancing passenger comfort by absorbing shocks.

The design phase kicked off with the optimization of various characteristics using the Shark Package of Lotus Suspension Analysis software. A double wishbone geometry was chosen for the front due to the ease of achieving static suspension properties, ease of manufacturing and cost effectiveness, the team's familiarity with the geometry and also its ubiquity in Baja and for the rear H-arm suspension geometry was chosen due to its low cost and compactness.

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2. LITERATURE REVIEW

Aditya Shahane, Manasi Kathale, Pratik Rathi and Ashank Gujar: Examined critical factors such as weight distribution, camber gain, instantaneous center of rotation (ICR), roll center height, and toe adjustment.

These parameters enable a vehicle equipped with a locking differential to navigate turns with a reduced turning radius, showcasing characteristics of oversteer. [1]

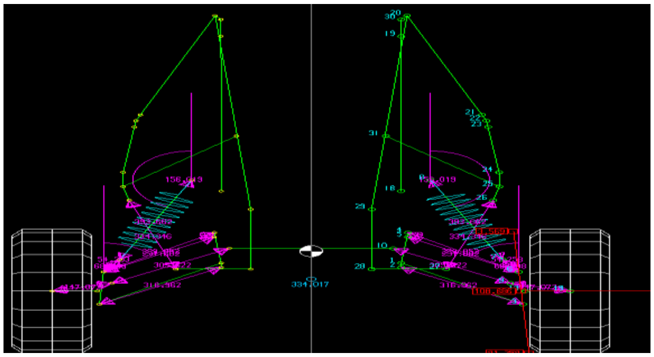
Sumit Sharma: Examined data regarding 4130 Chromoly indicates its capacity to endure various terrains, suggesting its suitability for cost-effective applications and weldability. Calculations encompassing front roll rate, wheel rate, coil rate, and wheel frequency values contribute to this conclusion [2]

Akshay G Bharadwaj, Sujay, Lohith, Karthik The executed implementation of the design within the vehicle successfully met the objectives of attaining peak performance through adaptable camber adjustment, minimal toeing, enhancing driver comfort, and maximizing travel distance, all achieved within a reasonable budget [3]

Reena Mishra, Anand Baghe: The analysis of the front wishbone arm for the BAJA SAE ATV revealed that a 3 mm thickness is suitable for the application. Compared to a 1 mm thickness, the stress concentration in the arm reduced by 76.24%. Additionally, the total deformation decreased by 63.9% with the thicker arm. Furthermore, using a 3 mm thickness increased the factor of safety of the suspension system by 68.56% compared to 1 mm thickness. This reduction in weight leads to lower fuel consumption for the ATV BAJA vehicle [4]

3. RESEARCH WORK

Front Suspension geometry on Lotus



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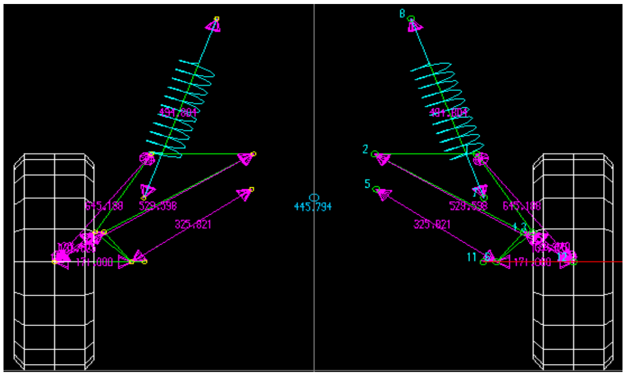
Rear Suspension geometry on Lotus



1. STATIC & GENERAL DATA VALUES

Camber Angle (deg): 0.00
Toe Angle {Plane} (deg): 0.00
Toe Angle {SAE} (deg): 0.00
Caster Angle (deg): 6.25
Caster Trail (hub) (mm): -14.02
Caster Offset (ground) (mm): 44.64
Kingpin Angle (deg): 3.57
Kingpin Offset (w/c) (mm): 108.69
Kingpin Offset (ground) (mm): 91.26
Mechanical Trail (ground) (mm): 44.38
Roll Center Height (mm): 334.02

Tire Rolling Radius (mm): 279.40
Wheelbase (mm): 1347.54
Center of Gravity Height (mm): 460.00

2. CALCULATION OF SUSPENSION DYNAMICS

Before designing unsprung components, we need to understand the forces acting on them. After Intensive research we came to a conclusion that for a sturdy design unsprung component must be Tested for:

1) Bump force.
2) Force due to reaction produced by shock.

3) Cornering force.
4) Barking force/ torque.
5) Steering force/torque.

1) Calculation of bump force.

The maximum bump force that can occur during an event is assumed to be when our car Undergoes a harsh landing from about 5 feet.
Thus, we obtain the following figures.
Mgh=mgs-fs
M= sprung mass of car (here for worst case instead of sprung mass we have taken the Weight of whole car)
g = acceleration due to gravity
h= height from which car falls
s= wheel travel
f = Reaction force produced by the ground
we had taken the mass of last year's car which was 230 kg with driver.
230*9.8*1.5=190*9.8*0.26-f*0.26
f=8880 N
since the car has 40-60 weight distribution so,
bump force on front tyre= (8880*0.4)/2=1776 N
bump force on rear tyre= (8880*0.6)/2=2664 N

2) Force absorbed by shock

- In front bump force in front/motion ratio=1776/0.6=2960N
- In rear bump force in rear/ motion ratio = 2664/0.6=4440N

3) Cornering force

We had validated the centrifugal force, Coefficient of friction and Centre of gravity on Our last year's car and using that data we have calculated the cornering force produced By the tyre.
Centrifugal acceleration=0.Sg
Coefficient of friction= 0.6
Height of Centre of gravity= 460mm

4) Calculation for lateral load transfer at front:

Let’s take trackwidth to bet, height of cg h, centrifugal acceleration a, mass of car m
Balancing moments about inner wheel Centre,
Lt=mg(t/2) +mah
Where Lis the normal force on the inner wheel.
We get Las 644N
During static conditions the load on outer wheels is (0.4 *230)/2=46kg=460N

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Therefore, load transferred= 644-460=184
Cornering force on outer wheel=friction coefficient x normal force

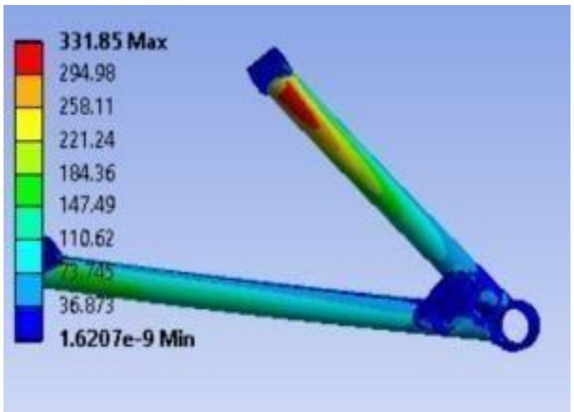
=0.6x644
=386.4N
Cornering force on inner wheel=0.6 x 276
=165.6N
Similarly, for rear we get Las 966N
Load transfer=966-690=276N
Cornering force on outer wheel=friction coefficient x normal force=579.6N
Cornering force on inner wheel=248.4N

5) Steering force:
Having studied various research papers, we found that the maximum torque one applies
On the steering wheel during driving= 60Nm
Also, since our pinion diameter is 30mm, we obtain the steering force
Steering Force = 60Nm/30mm = 2000N

3. DESIGN OF UNSPRUNG SUSPENSION

Control Arms:

Upper and lower arms were manufactured from chromoly pipe (AISI 4130) used in the chassis with outer diameter of 25.4 mm and thickness of 1mm. We designed upper arm mounted shocks to overcome clearance issues between tie rod and shocks. Also, instead of using bent arms we plan on using straight arms to simplify the manufacturing process. Rear arms are designed from a single secondary member pipe hence eliminating the cost as well as weight due to welding. The H-arms are constructed from chromoly pipe (AISI 4130) tubing's.



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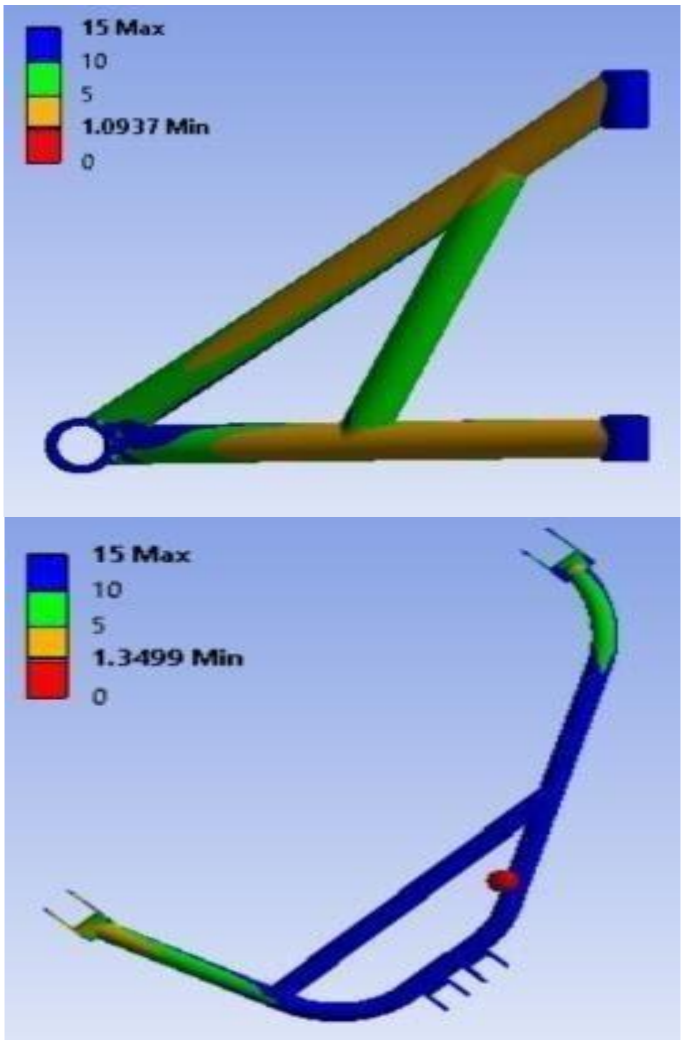

Upper control arm, Lower control arm, Rear arm (ANSYS)

Uprights and hubs:

The front uprights are to be CNC milled from Aluminium 7075 T6 billets and will contain a press-fitted spindle machined from Aluminium 7075 T6. This year we will use spherical bearings instead of ball joints to shed some weight without losing strength. Al 7075-T6 will also be used to machine the four-lobed hubs which are supported on the spindle by two ball bearings.

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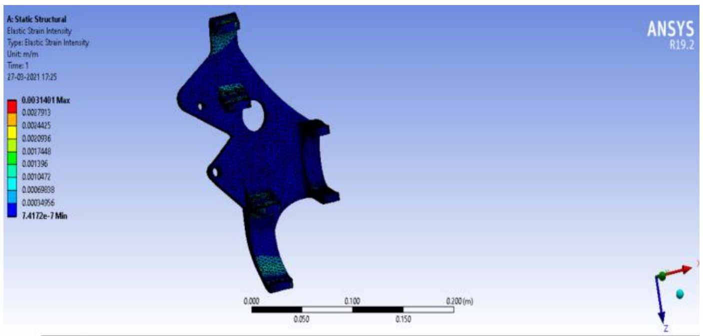
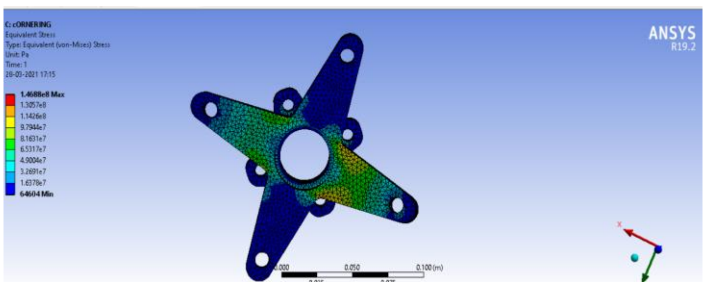
The rear hub as well as upright were machined from aluminium 7075-T6 and were analysed for bump, braking and cornering force.

Aluminium alloy AL7075-T6 alloy with a theoretically high yield strength of 504MPa and comparatively low density.

By assuming the worst-case scenario of a 5ft fall, we can calculate the maximum bump force on individual wheels as **1776 N** for front tyres and **2664 N** for rear tyres.



Front upright in simultaneous Bump, Corner and Braking conditions



Front hub in simultaneous Bump, Corner and Braking conditions

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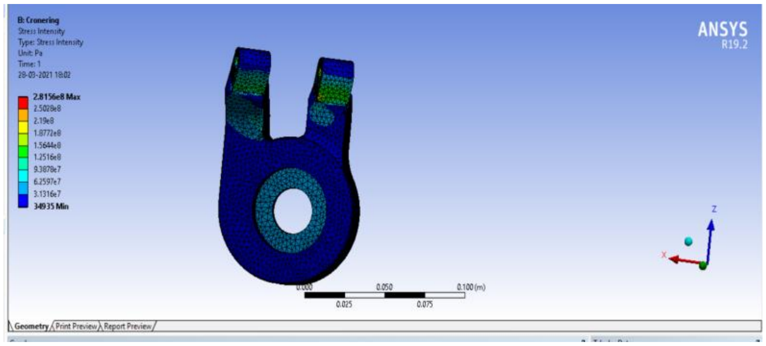
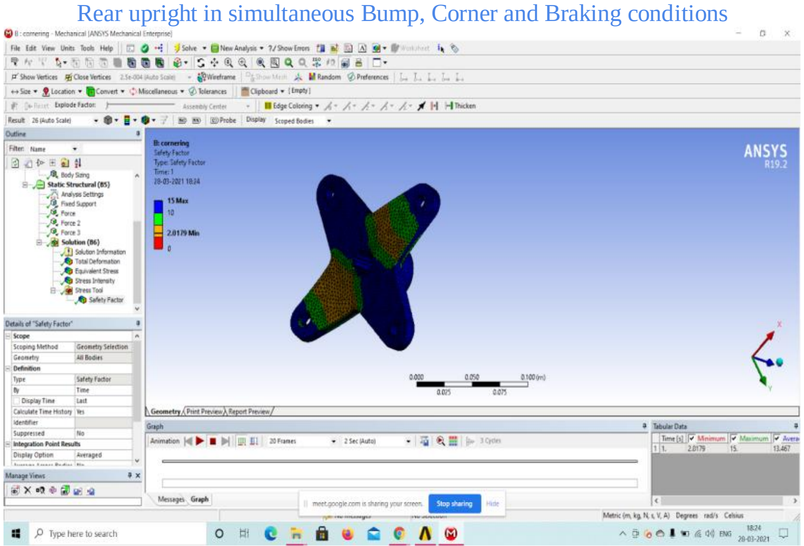


Rear upright in simultaneous Bump, Corner and Braking conditions



Rear hub in simultaneous Bump, Corner and Braking conditions

Shocks:

Afco 16 series coil overs at the front and the rear with custom made springs are suitable choices to be used in our car. Spring stiffness at the front is 12N/mm and at the rear is 15N/mm. The damping ratio for the front spring is 0.41 at compression and 0.34 at rebound. While at the rear it's 0.35 at compression and 0.3 at rebound.

Specifications	**Front**	**Rear**
Spring Rate	12 N/mm	15 N/mm
Motion Ratio	0.6	0.68
Ride frequency	1 Hz	1.2 Hz

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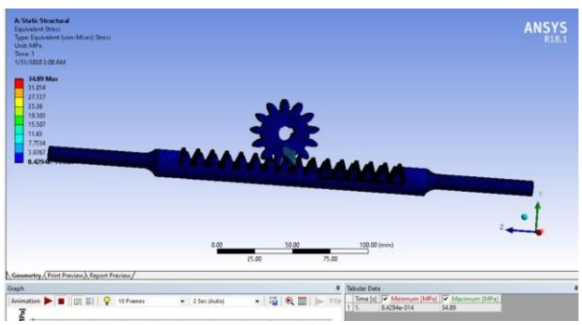
These damping ratios were calculated for high speed damping. The travel of our shocks is 6 inches at the front and 7 inches at the rear. The non-adjustable damper is made of light-weight aluminium weighing 1.2 kg per shock.

Rack and Pinion:

The fatigue limit stress of gear teeth, also known as bending strength, is typically around one-third of the material's ultimate tensile strength. Another potential failure mode is wear, which occurs when material erodes from the surface due to interaction with another surface. To mitigate these failure modes and account for material selection criteria, the chosen material for the gear is Aluminum T6 7075, which has a yield strength of 468 MPa and an ultimate tensile strength of 540 MPa. With a maximum applied torque of 60 N-m and a minimum factor of safety (FOS) of 1.5, the Rack and Pinion successfully passes static structural analysis in Ansys.



Structural Analysis of Rack and Pinion

4. CONCLUSION

Suspension dynamics calculations

a) bump force on front tyre=1776 N
bump force on rear tyre= 2664 N
b) In front bump force absorbed by shock=2960N
In rear bump force absorbed by shock=4440N
c) lateral load transferred=184
d) Cornering force on inner front wheel=165.6N
Cornering force on outer front wheel=386.4N
e) Cornering force on outer rear wheel=579.6N
Cornering force on inner rear wheel=248.4N
f) Steering Force = 2000N

The utilization of the Lotus Shark software and Ansys software in the modeling process proved indispensable and significantly contributed to reaffirming and attaining favorable outcomes. The research findings culminate in proposing secure, ergonomic, and well-balanced wheel assembly configurations for BAJA ATV. Through meticulous calculations, the study facilitated the enhancement of an all-terrain vehicle with improved understeer capabilities, ensuring adept handling in challenging terrains.

5. ACKNOWLEDGMENT

We extend our gratitude to our institution for its unwavering support and motivation in engaging us in challenging competitions. We acknowledge the invaluable assistance offered by our esteemed Faculty advisor, Prof. Qasim Murtuza. Finally, we express our heartfelt appreciation to every member of our team for their significant contributions to the project.

6. REFERENCES

[1] The official website of Milliken provides detailed information about the company’s products, services, and innovations in various industries.

[2] SAE International offers a comprehensive book titled "R-146," which delves into the technical aspects of automotive engineering and related fields.

[3] The Milliken Research Center's webpage on the RCV&D platform details their research, development, and innovative projects.

[4] Lotus Engineering features an array of engineering software solutions designed to enhance automotive design and performance on their official site.

[5] ANSYS's India-specific website highlights their advanced engineering simulation software used across diverse industries for product development and optimization.

[6] Reena Mishra and Anand Baghe present a study in the International Research Journal in Global Engineering and Sciences, analyzing and optimizing the front suspension wishbone for the BAJA 2016 all-terrain vehicle, found in volume 2, issue 1 (March-May 2017), pages 1-13.

[7] The research by Akshay G Bharadwaj, Sujay M, Lohith E, and Karthik S in the International Journal of Innovative Research in Science, Engineering and Technology (Vol. 5, Issue 12, December 2016) explores the design, analysis, simulation, and validation of a suspension system for an electric all-terrain vehicle.

[8] Sumit Sharma's paper in the International Research Journal of Engineering and Technology (IRJET), volume 7, issue 5 (May 2020), provides a design review of the suspension assembly for a BAJA ATV, with e-ISSN 2395-0056 and p-ISSN 2395-0072.

[9] Udhav U. Gawandalkar, Ranjith M., and Anshej Habin's work, published in the International Journal of Engineering Research & Technology (IJERT), volume 3, issue 9 (September 2014), investigates the design, analysis, and optimization of an off-road vehicle's suspension system under a Creative Commons Attribution 4.0 International License.

[10] Aditya Shahane, Manasi Kathale, Pratik Rathi, and Ashank Gujar discuss the kinematics of a rear suspension system for a BAJA all-terrain vehicle in the International Journal of Mechanical Engineering and Technology (IJMET), volume 8, issue 8 (August 2017), pages 164–171, article ID: IJMET_08_08_019.