

## Analysis of Rear Suspension Geometry of an ATV

Mayank Sanjay Gupta <sup>1</sup>, Yash Nitin Sharma <sup>2</sup>, Hari Vasudevan <sup>3</sup>, Vinayak H. Khatawate <sup>4,\*</sup>

### Abstract

*This research presents the design and optimization of a rear suspension system specifically developed for an All-Terrain Vehicle (ATV), with the primary goal of enhancing ride quality, handling, and overall dynamic performance across diverse terrains. A key objective is to improve damping characteristics while minimizing unwanted changes in track width and wheelbase during suspension articulation. The study carefully examines critical suspension parameters, including camber angle, toe angle, and wheel travel, to establish a geometry that maintains vehicle stability and control under varying load conditions. Special emphasis is placed on reducing the influence of roll angle on toe variation, which directly impacts handling precision and tire wear. Additionally, the research explores how suspension kinematics affect roll center height and its migration, as these factors play a significant role in determining lateral stability and comfort. A comparative evaluation was conducted between H-arm and trailing arm configurations to identify the most effective design. Findings indicate that a trailing arm layout, when equipped with two control links, delivers superior performance in terms of maneuverability, structural simplicity, and ride comfort. The initial suspension geometry was designed using solid modelling software and subsequently fine-tuned with Lotus Suspension Analysis software to meet both off-road and on-road performance requirements. Final validation using Lotus Shark simulation tools confirmed substantial improvements in cornering stability, shock absorption, and vehicle control. The optimized suspension system thus offers a balanced solution for performance, reliability, and driver comfort in rugged driving environments.*

**Keywords:** Suspension, optimization, all-terrain vehicle (ATV), vehicle stability, optimization

### INTRODUCTION

The suspension system of an ATV plays a crucial role in ensuring its performance and handling capabilities, particularly in off-road conditions [1]. A robust suspension system is essential for an off-road vehicle to ensure optimal performance, especially in bumpy and uneven terrain. It helps maintain wheel-to-ground contact and reduces the impact of shocks on the vehicle and driver [2]. Independent suspension systems allow each wheel to move independently in vertical directions, enhancing ride

#### \*Author for Correspondence

Vinayak H. Khatawate

<sup>1,2</sup>UG Student, Department of Mechanical Engineering, SVKM's Dwarkadas J. Sanghvi College of Engineering, Mumbai, Maharashtra, India

<sup>3</sup>Professor, Department of Mechanical Engineering, SVKM's Dwarkadas J. Sanghvi College of Engineering, Mumbai, Maharashtra, India

<sup>4</sup>Associate Professor, Department of Mechanical Engineering, SVKM's Dwarkadas J. Sanghvi College of Engineering, Mumbai, Maharashtra, India

Received Date: January 16, 2025

Accepted Date: March 04, 2025

Published Date: July 10, 2025

**Citation:** Mayank Sanjay Gupta, Yash Nitin Sharma, Hari Vasudevan, Vinayak H. Khatawate. Analysis of Rear Suspension Geometry of an ATV. Journal of Polymer & Composites. 2025; 13(Special Issue 5): S275–S286p.

comfort and handling stability by minimizing road disturbances. They also reduce steering vibrations, improve overall vehicle control, and maximize engine space. Examples of independent suspension systems include double wishbone, trailing arm, and MacPherson strut [3]. This study focuses on designing the rear suspension system of an all-terrain vehicle (ATV) in accordance with BAJA SAE rules, with the aim of optimizing suspension parameters to improve performance, safety, and driver comfort.

### DESIGN PARAMETERS

#### Geometry Selection

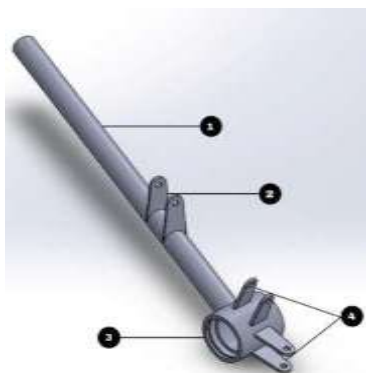
The trailing arm suspension (Figure 2) with two control links is a common rear suspension design

that provides a balance of simplicity, versatility, and performance. It offers good handling, reduces camber changes, and is suitable for various vehicle types. A trailing arm can be used in combination with one control link or even two control links in a rear suspension

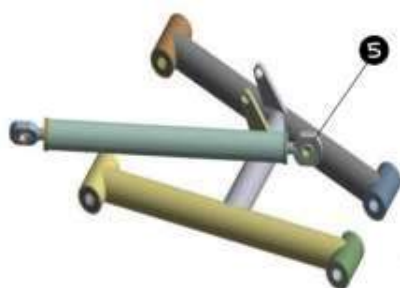
While comparing Trailing arm with two control links suspension with H-arm with upper control link suspension, it was found that Trailing arm with two control links has more advantages than the latter. The comparative analysis presented in Figures 4, 5, 6, and 7 offers a profound exploration of the contrasting performance characteristics of trailing arm and H-arm rear suspension systems. Figure 4 delves into the intricacies of cornering performance, highlighting the distinct advantages and disadvantages of each system. Figure 5 provides a comprehensive comparison of the design intricacies and complexities associated with trailing arm and H-arm suspensions. Moreover, Figure 6 offers a nuanced examination of the overall familiarity and ease of implementation for both systems. Finally, figure 7 presents a comparative analysis of the manufacturing complexities and challenges inherent in the production of trailing arm and H-arm rear suspension systems.



**Figure 1.** Vehicle and rear suspension assembly.



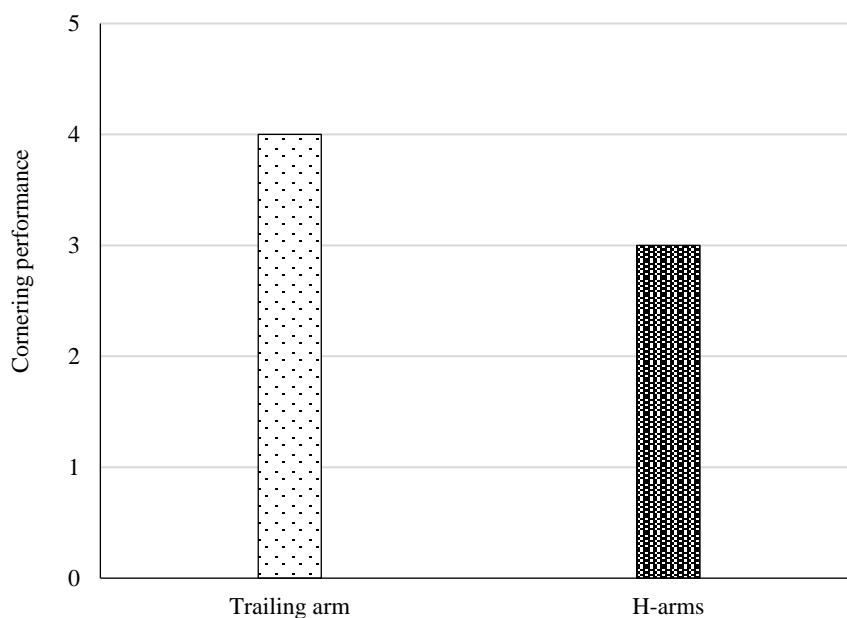
**Figure 2.** Trailing Arm Suspension Picture. (1 - Trailing arm, 2 - Damper lower end (outboard), 3 - Trailing arm upright, 4 - Upper and lower control link outboard, 5 - Heim joints).



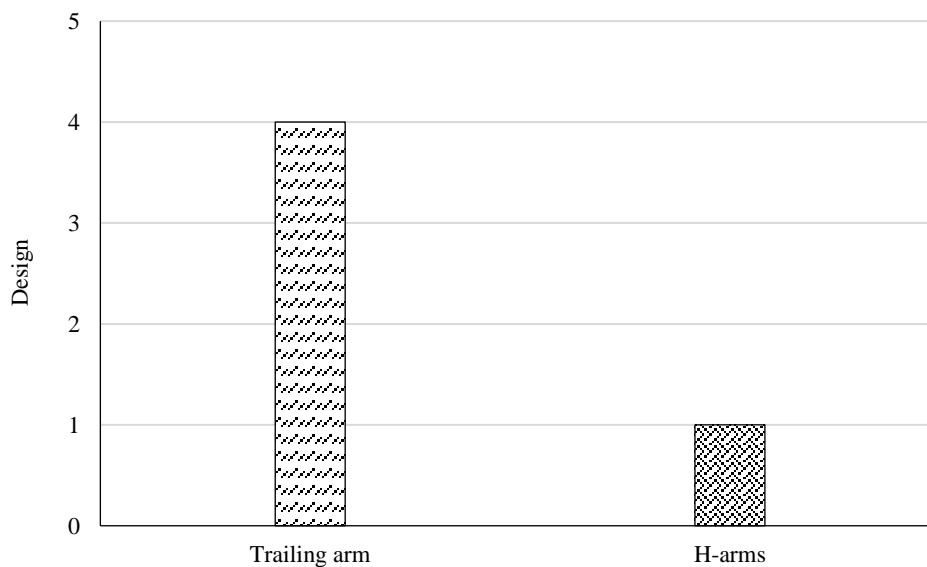
**Figure 3.** H and I arm suspension picture.

In an H and I arm suspension as shown in Figure 3, the lower control arm resembles the letter “H” with two vertical links connecting the wheel hub to the chassis. The upper control arm is typically a single link also resembles as the letter “I”. The positioning/mounting of “H” and “I” arm could even be vice-versa, i.e. “H” arm can be mounted as the upper link and likewise, “I” arm can be mounted as the lower link.

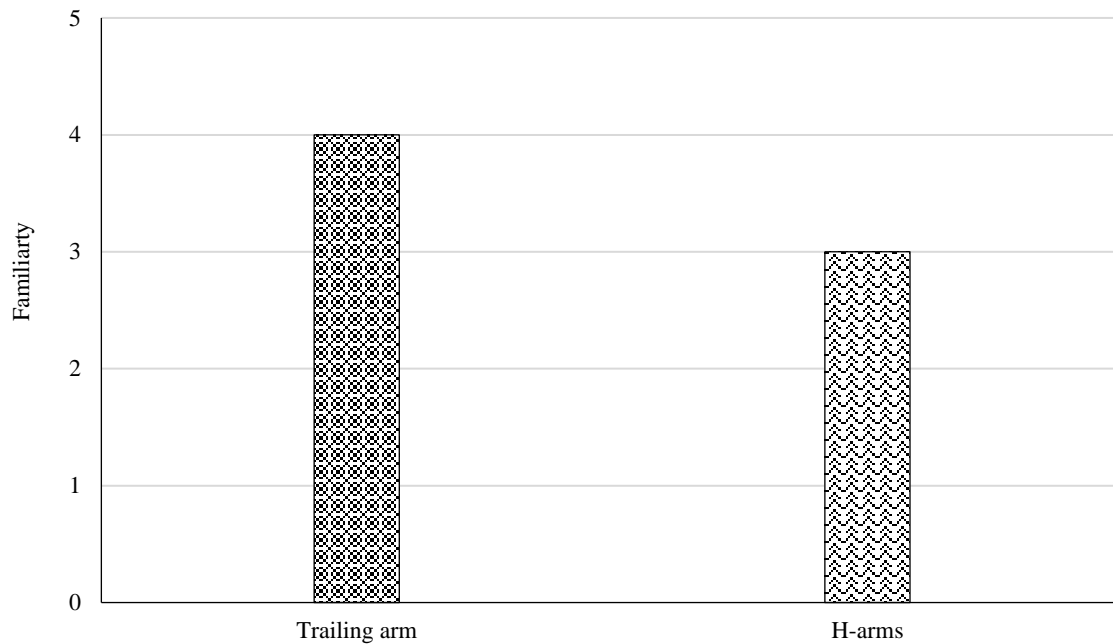
In the Figures 4, 5, 6 and 7, the y-axis indicates the ratings on a scale of 5 for different capabilities or requirements. Whereas, the x-axis depicts the comparison between trailing arm suspension and H arm suspension. The following graphs are generated by self-understanding from the various sources present on the internet and some literature available, reference [4] and more such other references have played a pivotal role in deciding the following rating scores for both, the trailing arm and the H arm suspension.



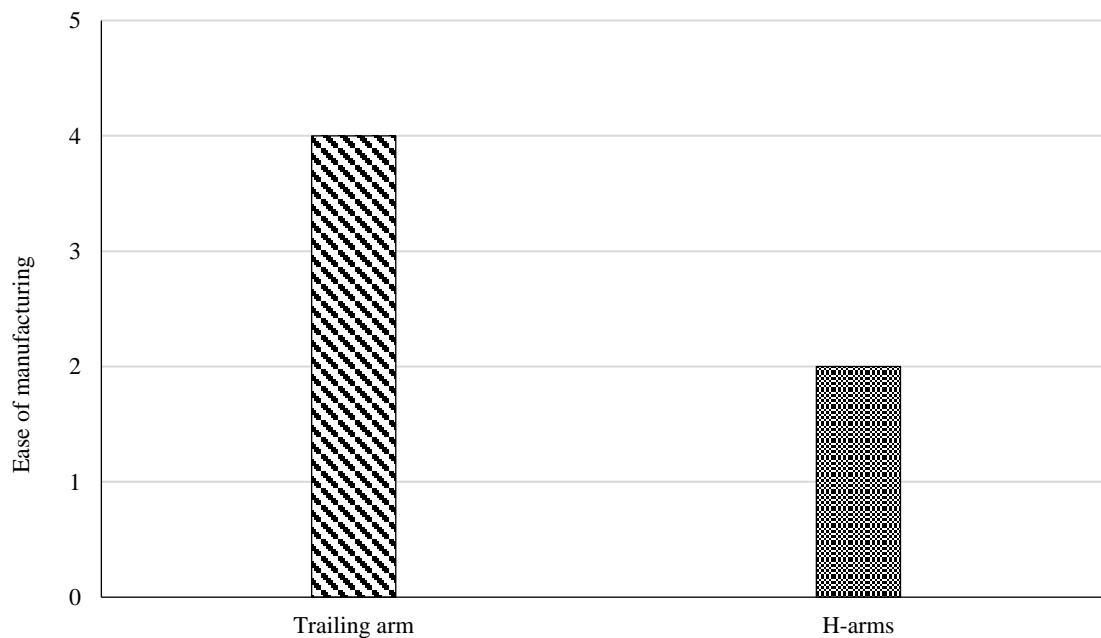
**Figure 4.** Cornering performance comparison.



**Figure 5.** Design comparison.



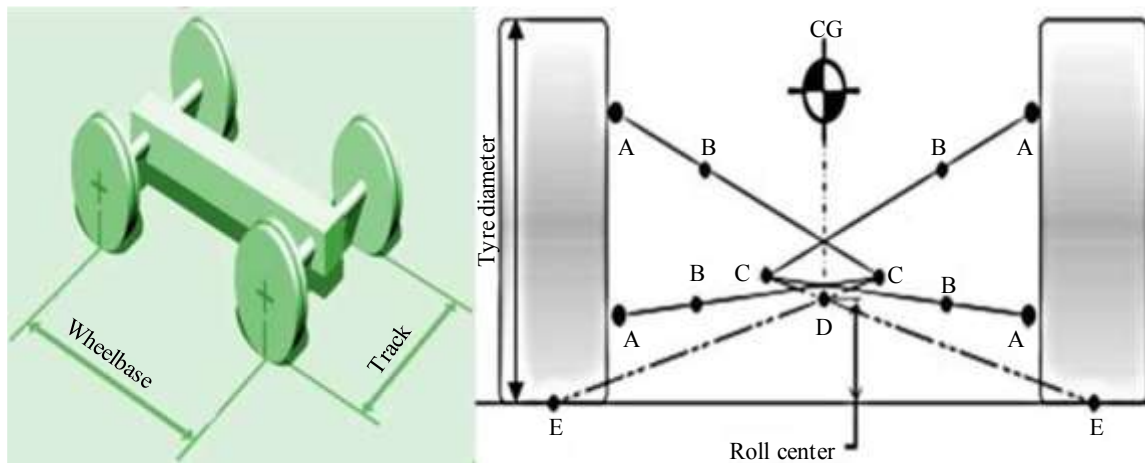
**Figure 6.** Overall Familiarity Comparison.



**Figure 7.** Ease of Manufacturing Comparison.

While diving deep into the details of the two suspension systems separately and while comparing both of them, the two very common factors we came across is, performance and compatibility. Trailing arm suspension system can provide us a very good performance and a very decent compatibility for our conditions and requirements. Hence choosing the trailing arm suspension for the rear suspension system focusing on maneuverability is a good option to move forward with [4].

Trailing arm with two control link suspension is a simple yet effective system having simple design, minimal components, is easy to assemble, provides desired cornering effect and hence, Trailing arm with two control link suspension is adopted over H-arm with upper control link [4].



**Figure 8.** Static parameters of the vehicle.

**Table 1.** Static parameters.

Parameters	Data
Centre of Gravity	21 inches
Wheelbase	56 inches
Track width	47 inches
Sprung Mass	195 kg
Tyre Diameter	23 inches
Ride Height	12.55 inches

Parameters for the design are based on mock chassis measurements and drivetrain considerations, with the rear track width intentionally smaller for improved maneuverability. Ground clearance optimization considers terrain obstacles like rocks, bumps, and logs. The research evaluates suspension types in mini-Baja vehicles, compliance with SAE regulations, dynamic behavior analysis using CAD modelling, and simulation software like ANSYS. The design aims to enhance handling, absorb terrain irregularities, and meet SAE parameters, utilizing compression springs for stability and passenger comfort. Table 1 tabulates the static parameters of the suspension system shown in Figure 8, that were considered after performing iterations and making rough sketches on SolidWorks to get an estimation of the positioning of the entire sub-system of the car including the driver and a data extracting from the standard sizes like the tyre diameter.

An independent suspension system was selected due to its superior performance in comparison to a dependent suspension system, independent system allows for greater wheel articulation without affecting the opposite wheel. When traversing rugged terrain with numerous obstacles, an independent suspension system is generally considered the most suitable option for maintaining traction and handling [5]. Conversely, a dependent system can suffer from changes in camber that are synchronized between the wheels [6]. An independently acting two control link and a trailing arm suspension system is used and the system is kept stiff so a good amount of geometric load transfer is achieved than that of elastic load transfer to ensure that the vehicle has a good maneuverability at the curves or turns [7].

### Geometry Features

Hard points are selected keeping in mind appropriate spacing for rear bucket dimensions, required ride height, motion ratio, roll center height, minimum bending of trailing arm, required track width and to ensure adequate ground clearance and prevent interference with other components.

The provided graph (Figure 9) depicts the relationship between rear toe angle and roll angle for a vehicle. The x-axis represents roll angle, while the y-axis represents rear toe angle. The blue and orange

lines illustrate the toe angle changes for the right and left wheels, respectively. The graph reveals that as the vehicle rolls, the toe angle of both wheels adjusts to maintain stability and control. The specific relationship between toe angle and roll angle is influenced by the suspension geometry and tuning parameters. By carefully designing the suspension to achieve the desired toe angle changes with roll, engineers can optimize vehicle handling, tire wear, and overall performance.

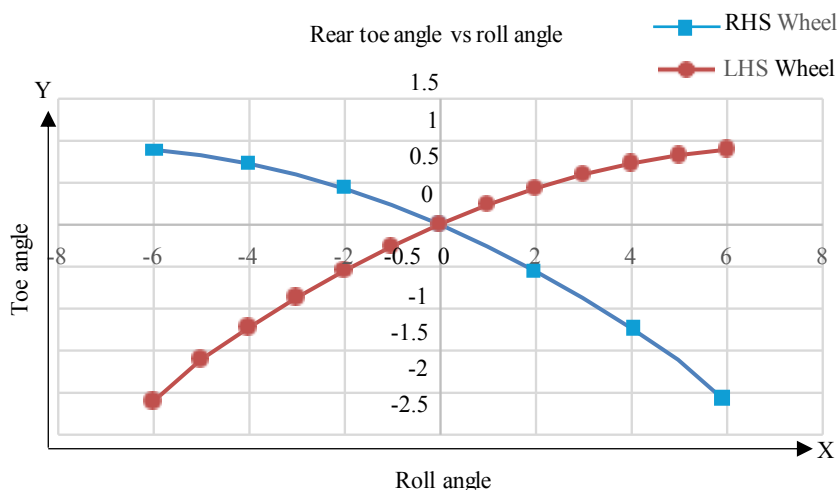
Rear roll and toe angle are two critical geometric parameters that significantly influence a vehicle's handling and performance. Rear roll angle affects vehicle stability, tire load distribution, and ride comfort, while toe angle influences tire wear, steering feel, stability.

Talking about oversteer and roll steer, roll center height in rear is kept higher than in front so that the roll axis is inclined towards the front causing oversteer. Roll steer is also induced such that the outside tire toes out and the inside tire toes in such that it aids oversteer. Above, figure 5 shows a comparison graph of rear toe angle and roll angle.

The trailing arm suspension with two links offers a practical, efficient, and cost-effective solution for rear-wheel-drive vehicles. By optimizing design, reducing weight, maintaining cost-efficiency, this system improves vehicle handling while ensuring a high safety factor. The suspension system exhibited satisfactory performance in both static and dynamic testing, making it suitable for use in ATVs [8].

### Geometry Modelling

A sketch model was prepared on solid works software 2023 that shows the side view of a car in a loaded condition including the driver's weight by plotting the transmission layout which resulted in calculation of center of gravity (CG). Here, the type of suspension system used is independent suspension system that employs to control link and one training arm. All the three views i.e. the front view, the side view, and the top view were plotted as a line diagram on solid works. Damper plotting was done separately after the completion of front view, side view, and the top view of the car which was done prior along with other components and assembly of the entire system. Once the suspension hard points were finalized, the next step involves designing the suspension arms and mounts. This design phase considers components from the chassis and powertrain to ensure the control arms and pivot mounts are integrated effectively. The design process was carried out using SolidWorks 2023 software, where meticulous attention was given to the details of the suspension components to optimize performance and functionality. The interplay between the suspension system, chassis, and powertrain components is crucial in achieving a well-integrated & efficient design for the control arms & pivot mounts [9]. The static parameters along with some defined or considered parameters were listed. Table 2 shows the dynamic parameters of the rear suspension.



**Figure 9.** Visual depiction of rear toe angle vs roll angle.

The theoretical point of convergence for the axes of the suspension links of each control links when viewed head-on is the theoretical pivot point for the suspension known as Instantaneous Centre of Rotation (ICR) [3]. Hence, the instantaneous center of rotation is identified by the intersection of the two-control links intersection and the assumed (initially) Roll Centre (RC) height intersecting line [2].

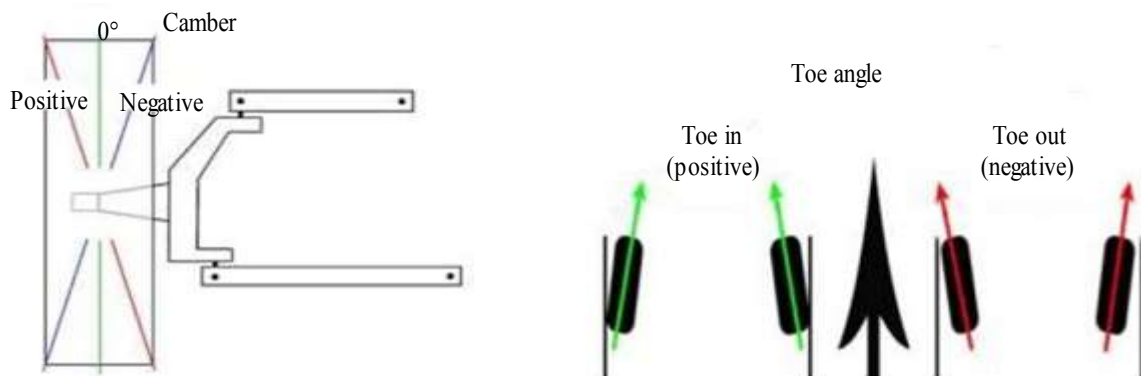
The camber curve, a measure of wheel angle relative to the vertical, is highly dependent on the suspension linkage and instantaneous centers. The wheel's movement affects the camber curve, which in turn influences vehicle stability during bump and droop conditions [10]. The roll center, a key factor in vehicle stability, can be derived from the instantaneous center [11]. Since the rear wheels lack steering capability, they exhibit toe-in and toe-out tendencies. These characteristics can contribute to oversteer or understeer, but for us, oversteer is preferred as we focus on maneuverability and hence the system is kept stiff with an optimal track width [12]. While optimizing the overall geometry inboard and outboard points of the suspension, the role center height changes, but finally when we come to a conclusion the role center height is fixed.

The upper and lower links are Intentionally designed with varying lengths to optimize performance and achieve the desired suspension geometry. This design enables optimal camber travel during cornering and bump travel. To compensate for minor length discrepancies, Heim joints are used, as they offer flexibility in fabrication and alignment [13]. The roll center is the intersection point of the line joining the instantaneous center and the wheel contact patch with the front chassis member. The lateral location of the roll center is generally considered to be on the vehicle's centerline [3].

Figure 10 show Camber and Toe description. Negative camber improves cornering grip and stability, but excessive camber can increase tire wear and reduce straight-line stability. A slight toe-in can enhance cornering stability by providing additional grip on the inside wheel. Proper toe-in can help minimize uneven tire wear.

**Table 2.** Dynamic parameters.

Parameters	Data
Motion Ratio	0.62
Bump Travel	7 inches
Droop Travel	3 inches
Rolling Radius	10.9 inches
Spring rate	35 N/mm
Roll center height	7.2 inches



**Figure 10.** Camber and toe depiction.

## Geometry Analysis

To ensure optimal performance and tire life, we seek to minimize changes in wheel alignment angles. By maintaining track width & wheelbase within a narrow range, we can effectively manage load transfer [14]. Optimizing suspension parameters in an all-terrain vehicle (ATV) is essential for ensuring they fall within the desired range, considering the interrelated geometry where changes in one parameter can affect others. LOTUS Shark software is utilized to iterate suspension points and achieve an optimized geometry and suspension parameters. The software provides derived results used in suspension calculations, contributing to the overall design process and performance optimization of the ATV's suspension system.

To attain optimal suspension performance, iterative refinements were conducted in Lotus software following the initial input of fundamental suspension geometry and hard points. Following are some points, altering which iterations to optimize the geometry coordinates may be obtained:

- Camber change can be controlled by manipulating the inboard points of the trailing arm.
- Adjusting the control link points allows for precise camber control.
- The toe is kept zero but for controlling the toe, we can manipulate the control link points.
- The four connection points of the upper and lower control arms provide ample flexibility for iterative adjustments.

Shock absorber selection: Afco 63 series [15] monotube shocks shown in Figure 11 was used for following reasons,

- It provides 7 inches of damper travel.
- It has option for adjustment according to our needs.
- These hydraulic dampers have better performance characteristics than pneumatic dampers.
- It is cost effective.
- It does not cause foaming when subjected to high frequency oscillations due to separate chamber for liquid and gas.

Weight transfer to the rear of the vehicle during cornering significantly influences vehicle stability. Centrifugal forces acting on the vehicle's center of gravity cause weight to be transferred from the inner wheels to the outer wheels. If the normal reaction at any wheel becomes zero or negative, that wheel will lift off the ground, initiating vehicle roll.

The visual representations in Figure 12 and table 3 offer a glimpse into the sophisticated mechanism of data entry and analysis within the Lotus software.



**Figure 11.** Afco hydraulic damper [15].

**Table 3.** 3D Parameter values.

Parameters	Values
Bump Travel	177.80 mm
Rebound Travel	76.20 mm
Bump/Rebound Increment	5.00 mm
Wheelbase	1422.40 mm
C of G Height	533.40 mm
Braking on front	60.00 %
Weight on front	42.00 %
Front brake type (1/2 inboard/outboard)	2
Rear brake type (1/2 inboard/outboard)	1
Total Sprung Weight	195.00 kg
Front suspension type (1/2 independent/rigid)	1
Rear suspension type (1/2 independent/rigid)	1

Before input of the geometry points, rear tyre properties were defined and was given as input on an interface shown with the help of Figure 12. Width of the tyre chosen was 180 mm. Due to the vehicle weight, rolling radius of the tyre will be lesser than that of tyre radius, vertical stiffness was considered to be 400 N/mm. The rolling radius of the tyre is 277 mm in loaded condition. After defining the tyre properties, 3D Parameter values were inserted further details are as shown in Table 3. These values are going to be same for the entire iteration process for optimizing the suspension geometry.

When designing ATV suspension components like trailing arms and control links, material selection is crucial. Traditionally, AISI 4130 steel is favored for its strength and toughness. However, advancements in polymer composites, particularly fiber-reinforced polymers (FRPs), offer a lightweight and corrosion-resistant alternative. While steel (AISI 4130) boasts high tensile strength and proven durability, FRPs offer significant weight reduction, potentially improving vehicle handling and fuel efficiency. Although composites can have higher initial costs, their benefits in performance, design flexibility, and corrosion resistance make them increasingly attractive. Ultimately, the choice depends on specific performance needs, environmental conditions, and budget constraints.

#### Metals (e.g., AISI 4130 Steel)

- *Strengths:* High strength and stiffness; well-established manufacturing processes; proven track record with extensive fatigue and durability data.
- *Weaknesses:* High density, increasing un-sprung mass; susceptible to corrosion; limited design flexibility.

#### Polymer Composites (e.g., FRPs)

- *Strengths:* High strength-to-weight ratio; excellent corrosion resistance; design flexibility for complex shapes and tailored stiffness.
- *Weaknesses:* Higher initial cost; complex material behaviour requiring careful design; impact resistance can be a concern; limited long-term durability data in off-road applications.

While AISI 4130 steel remains a reliable choice for ATV suspension components, the advancements in polymer composites, particularly FRPs, offer a compelling alternative with advantages in weight reduction, corrosion resistance, and design flexibility. Future research focusing on optimizing composite materials and manufacturing processes holds the potential to further enhance their performance and cost-effectiveness, paving the way for wider adoption in ATV and other demanding vehicle applications [16].

## RESULTS AND DISCUSSIONS

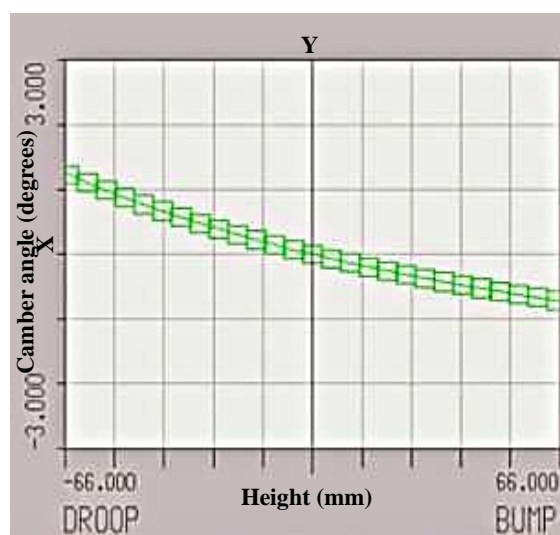
After inserting all the values that are mentioned above, the hard point coordinates of the designed geometry were inserted, all the coordinates were taken from a reference line that was initially defined. Table 4 shows final geometry points that were considered.

After following the iterative steps repetitively mention above i.e. making changes in the geometry points again and again and inserting it into the lotus suspension software and monitoring the results, we arrived to a final conclusion of hard points, i.e. the finalized rear suspension geometry. An optimum range of camber and toe angles are negative camber (-1 to -2) degrees and toe in (1 to 2.5) degrees respectively [2]. The camber value we achieved was in between the range of 1.5 degrees in droop to -1.6 degrees in bump. Talking about the toe angles that was achieved, it ranges in between the value of -2.4 degrees in droop to -0.8 degrees in bump. Droop is kept to be 3 inches and bump is set to be 7 inches. Figures 12 and 13 show the camber & toe graphs respectively those are plotted on Lotus Software.

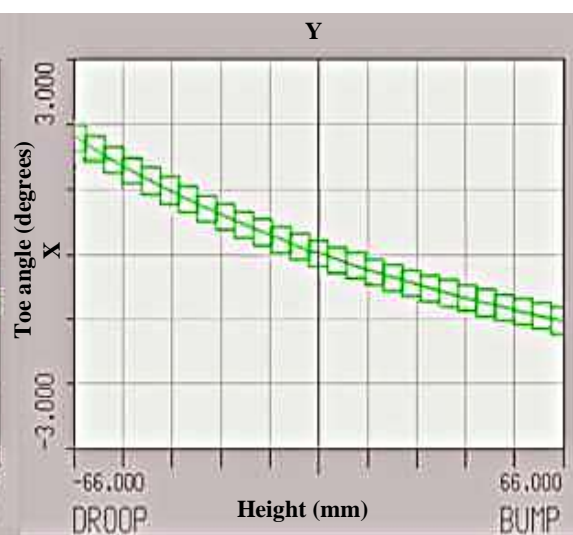
We can see the variation in the camber angle in Figure 12, when the tyre goes in the droop and in the bump condition. On the y-axis there is the angle at which the droop or the bump that take place. While on the x-axis the amount of wheel travel is mentioned minus indicates droop and plus indicates bump. We can see the variation in the toe angle in Figure 13, when the tyre goes in the droop and in the bump condition. On the y-axis there is the angle at which the droop or the bump that take place. While on the x-axis the amount of wheel travel is mentioned minus indicates droop and plus indicates bump. Although the considered value of droop is 3 inches and bump is 7 inches, and both the graphs show variations in between the range of -66 mm to +66 mm. The visual output of the process as a result on lotus suspension software [17] are shown by the Figures 14, 15 and 16.

**Table 4.** Geometry Co-ordinates.

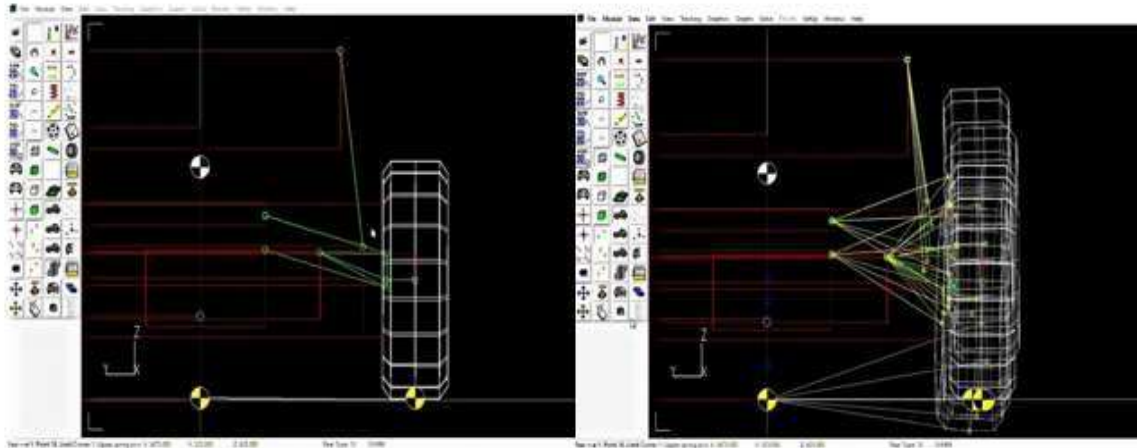
Co-ordinate Points	X (mm)	Y (mm)	Z (mm)
Trailing arm front pivot	049.27	-310.97	335.92
Lower link inner ball joint	710.00	-179.70	341.95
Lower link outer ball joint	669.73	-516.90	260.60
Upper link inner ball joint	710.00	-179.70	421.54
Upper link outer ball joint	639.59	-516.90	338.84
Damper lower trailing arm end	410.86	-451.62	352.35
Damper body end	408.25	-388.42	801.48
Wheel spindle point	596.63	-516.90	277.37
Wheel center point	596.63	-596.90	277.37



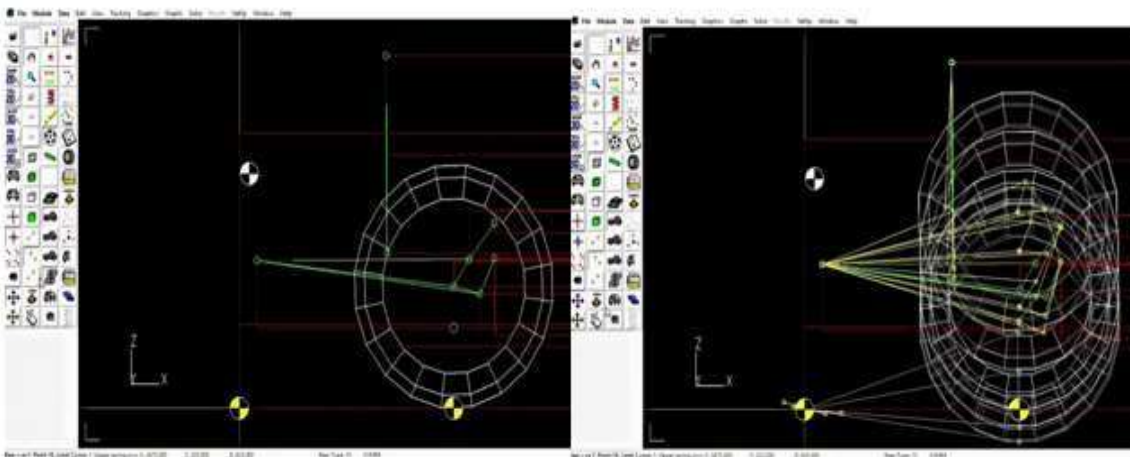
**Figure 12.** Variation of camber (degree).



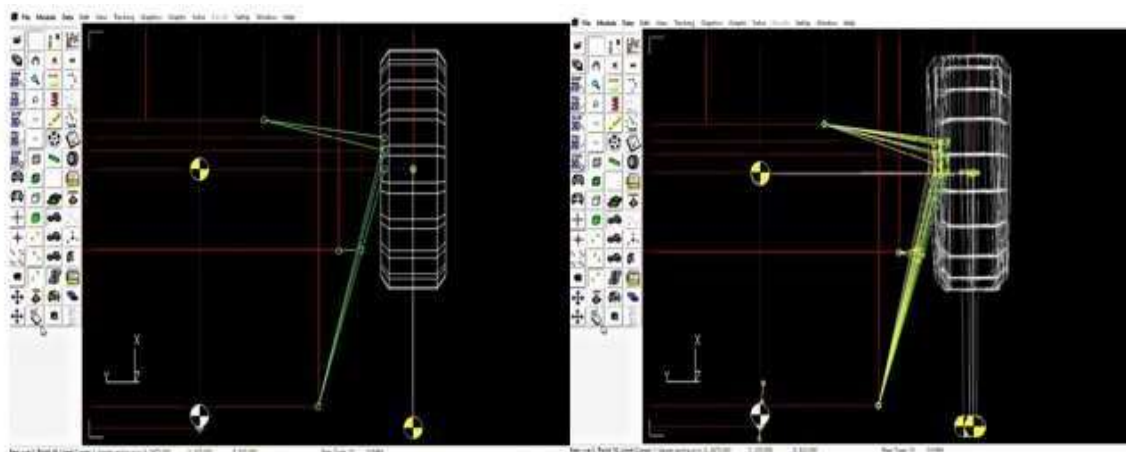
**Figure 13.** Variation of toe (degree).



**Figure 14.** Front View of rear suspension system.



**Figure 15.** Side View of rear suspension system.



**Figure 16.** Top View of rear suspension system.

## CONCLUSION

The rear suspension geometry of an ATV with a trailing arm and two control links is crucial for optimizing its performance, handling, and ride comfort. The geometry directly influences wheel control, stability, ride comfort, handling characteristics, tire wear, and vehicle balance. By carefully designing and optimizing the suspension geometry, engineers can ensure that the ATV delivers a safe,

comfortable, and enjoyable driving experience, even in challenging off-road conditions. The suspension system of an All-Terrain vehicle undergoes simulation and analysis using SolidWorks 2023 and Lotus Shark software. The finalized suspension design successfully met the initial objectives, resulting in optimal suspension angles, improved Lotus graphs, enhancing dynamic performance and driver comfort. Hence, the suspension system, focusing on providing “comfort,” “contact,” and “control,” effectively fulfills its purpose.

Other than pure metals, the use of polymer-based composites reinforced with particles for the suspension arm of all-terrain vehicles offers significant advantages in terms of weight reduction, durability, corrosion resistance, and vibration damping. Empirical data and comparative analyses suggest that these materials can outperform traditional metals in certain performance metrics, such as fatigue resistance and environmental & adaptability. With further advancements in material science and processing techniques, reinforced polymers represent a promising alternative for optimizing ATV suspension components, contributing to both enhanced vehicle performance and sustainability.

## REFERENCES

1. Gertz LC, Martelo L, Laranja RA, Rech C, Balbinot A, Brusamarello VJ. An Off-Road Suspension Design. SAE Technical Paper; 2005 Nov 22.
2. Gillespie T, editor. Fundamentals of vehicle dynamics. SAE international; 2021 Apr 29.
3. Milliken WF, Milliken DL, Metz LD. Race car vehicle dynamics. Warrendale: SAE international; 1995 Dec 15.
4. Gandhi O, Nagar T. Detailed Concept Selection Strategy for Rear Suspension Design Entailing Comparison Between H-Arm and Trailing-Arm Geometries for ATV Application. SAE Technical Paper; 2021 Oct 1.
5. Baja SAEINDIA 2022 rulebook, *Society of Automotive Engineers*, 2022.
6. Bhandari V.B. Design of Machine Elements, *McGraw Hill Education (India)*, 2014.
7. Dixon JC. Suspension geometry and computation. John Wiley & Sons; 2009 Oct 27.
8. Shlok K. Laddha, Hritik S. Jain, Design, Analysis and Optimization of Trailing Arm with Two Link Suspension System, *IJRAR*, Volume 8, Issue 2, 2021.
9. Fred P. How To Make Your Car Handle.
10. Vashist A, Kumar R. Design and analysis of suspension system for an all-terrain vehicle. *Materials Today: Proceedings*. 2021 Jan 1;47:3331-9.
11. Malik N, Agarwal P. Fine-Tuning Of the Suspension System of Baja ATV. vol. 2017;7:6.
12. Smith C. Tune to win. Fallbrook: Aero Publishers; 1978.
13. Rithvick MS, Reddy BS. Improved Vehicle Dynamics with Development in Suspension Geometry.
14. Sangave A, Aurangabadkar C. Design and Analysis of an ATV Suspension System. *International Journal of Current Engineering and Technology* E-ISSN. 2017:2277-4106.
15. 63 series 1-4 rebound adjustment guide, Afco product catalogue 2017.
16. Hussain F, Manikanta KS, Ahmed NW, Vinoth A, Roy S, Datta S. Design optimization of polymer composites for lower suspension arms of automotive vehicles. *International Journal on Interactive Design and Manufacturing (IJIDeM)*. 2025 Feb;19(2):1013-23.
17. Lotus Cars Ltd., “Getting Started with Lotus Suspension Analysis” Version 3.11.