Journal of Harbin Engineering University
ISSN: 1006-7043
Vol 47 No. 05
May 2026

Comparing the Ride Comfort of Electric Vehicle Using Leaf Spring and Air Suspension Systems

Nguyen Thi Kim Ngoc[1], Luong Van Van[1], Tran Thi Ngoc Truc[1*], Nguyen Thanh Dong[1], Dang Hai Dang[1]
[1]Vinh Long University of Technology Education

Abstract
This paper uses a 7-degree-of-freedom dynamic model to study electric vehicle ride comfort with leaf spring and air suspension systems. We simulate road surface excitation with sinusoidal ripples at 10–60 km/h. The evaluation focuses on mean displacement and vehicle acceleration. The vehicle body shakes more as speed increases for both suspension systems. The air suspension system performs much better. It reduces vehicle acceleration by 5–17% and displacement by 3–5% compared to leaf spring suspension. At higher speeds, the air suspension dampens oscillations better, improving stability and ride comfort. This study found that air suspension improves electric vehicle driving.

Keywords: air suspension system, leaf spring suspension system, ride comfort, electric vehicle.

1. Introduction

The suspension system plays a crucial role in ensuring a smooth ride, traction, and reducing impact on the road surface. According to research by [1-6], dynamic loads caused by vehicles can be significantly greater than static loads, especially when vehicles are moving on rough roads. This increases damage to the road structure and affects the lifespan of transportation infrastructure. Multi-degree-of-freedom vehicle dynamics models have been developed to describe the interaction accurately between the vehicle and the road surface.

Le Van Quynh [7] built a 3D nonlinear model for multi-axle trucks, thereby determining the dynamic load coefficients and the threshold of influence on the road surface. Similarly, Luong Van Van et al. [8, 9] used a stochastic method to evaluate the dynamic load of trucks, showing that the random nature of road surface excitation plays an important role in vehicle oscillation. Compared with traditional suspension systems (leaf springs), pneumatic suspension systems are increasingly widely used thanks to their ability to adjust stiffness, improve ride comfort, and reduce dynamic load.

Zhang et al. [10] showed that pneumatic suspension significantly reduces vehicle body acceleration compared to leaf spring suspension; specifically, RMS vehicle body acceleration is reduced from 10 to 40%. Air spring elastic element models are the foundation of air suspension research. According to Nguyen Thanh Tung et al. [11], the characteristics of air springs depend on thermodynamic factors such as pressure, volume, and temperature, which influence their performance and efficiency in various operating conditions.

The GENSYS model [12] is recognized as one of the most comprehensive models for analyzing elastic stiffness, nonlinear viscous damping, and friction simultaneously. This model serves as a foundation for comparative studies of suspension performance. In the field of automotive dynamics research, models with seven or more degrees of freedom are utilized to characterize the oscillatory motion of vehicles.

According to [11, 12], increasing the number of degrees of freedom helps the model more accurately reflect the interaction between system assemblies such as the body, axles, and wheels. In addition, study [13] analyzed the oscillation characteristics of the pneumatic suspension seat. The results indicated that the pneumatic suspension system not only improved the overall ride comfort but also significantly reduced vibrations transmitted to the driver and passengers, especially in the low frequency range (1–10 Hz), which is sensitive to the human body.

Abid et al. [14] developed an equivalent model for the pneumatic suspension system in a quarter-car model. This model simplifies the nonlinear characteristics of the air springs while still ensuring the necessary accuracy in dynamic simulation. This makes the analysis and design of the suspension system more efficient and provides a foundation for the development of advanced control algorithms. The study also showed that using the equivalent model significantly reduces computational complexity without losing the physical nature of the system.

Meanwhile, Sun et al. [15] focused on the problem of controlling the vehicle height of an electronic air suspension (EAS) system. The study used the Mixed Logical Dynamical (MLD) modeling method to describe the system, allowing simultaneous processing of continuous and discrete factors. The results showed that this method helps to accurately control the vehicle height under different load conditions while improving the stability and performance of the suspension system. This is an effective approach for complex control systems with nonlinearity and logic constraints, as it enables better adaptability to varying conditions and enhances overall system reliability.

Tan et al. [16] investigated the design of an electronically controlled pneumatic suspension system tailored for commercial vehicles. Their study detailed the overall structure of the system, which includes sensors, controllers, and actuators, and assessed its performance through experimental testing. The findings revealed that the system could significantly enhance ride comfort and stability across various types of terrain. Specifically, the EAS system enables flexible adjustments to the vehicle's ride height, thereby contributing to greater operational efficiency and safety.

The studies mentioned indicate that pneumatic suspension systems offer significant advantages in terms of smoothness and dynamic load reduction. However, given the characteristics of electric vehicles, which have a considerable mass due to the weight of high-voltage batteries, there has been a lack of research comparing and evaluating the benefits of pneumatic suspension systems against leaf spring suspension systems specifically for electric vehicles. This study aims to assess the smoothness of pneumatic suspension systems in comparison to leaf spring suspensions on electric vehicles, focusing on conformal unevenness of the road surface as the primary factor in the evaluation [17].

A single slope is used in surveys because its simple structure makes it easy to predict the pattern of results, as well as easy to conduct experiments to verify the model. The height of the bumpy is calculated using the formula:

$$h(x) = \begin{cases} \frac{1}{2} H\left(1-\cos\left(2\pi \frac{x}{L}\right)\right) \text{ when } 0 < x < L \\ 0 \text{ when } x \le 0, x \ge L \end{cases} \quad (1)$$

inthere: *H* - maximum bumpy height [*m*];

L - bumpy length [*m*];

v - the speed of the vehicle [*m/s*];

t - The past period has been bumpy[s].

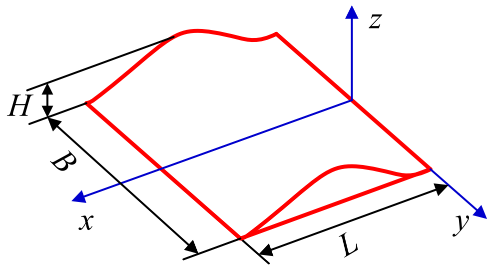

Fig 1.1: A rough sketch of the road surface along the whole length

2. Objectives

This study presents a seven-degree-of-freedom dynamic model to investigate the ride comfort of an electric vehicle with leaf spring and air suspension systems.

3. Methods

Seven generalized coordinates will be included in the structural model of the electric vehicle used to investigate ride comfort, including:

- The motion of a sprung mass can be described by three degrees of freedom: Z, ϕ, and β

- The motion of the mass that is not suspended from the front axle is described by two degrees of freedom, Z_{11} and Z_{12}.

- Z_2 and ϕ_2 are the two degrees of freedom that describe the motion of the mass that is not suspended from the rear axle.

dolor sit amet consectetur adipiscing elit. Cursus sit amet dictum sit amet justo donec.

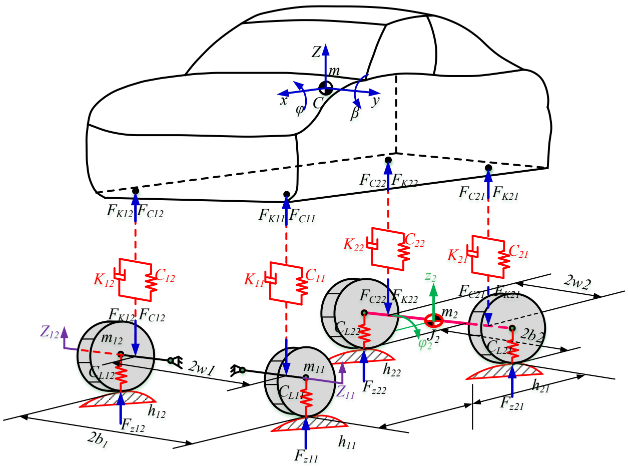

Fig 3.1: Spatial dynamics model describing the oscillation of an electric vehicle using a leaf-spring suspension system

The sprung mass consists of translational motion along the vertical axis (Z), rotational motion around the x-axis (ϕ), and rotational motion around the y-axis (β).

$$m.\ddot{Z} = F_{K11} + F_{K12} + F_{K21} + F_{K22} + F_{C11} + F_{C12} + F_{C21} + F_{C22} \quad (1)$$

$$J_x.\ddot{\varphi} = \begin{pmatrix} F_{K11} + F_{C11} \\ -F_{K12} - F_{C12} \end{pmatrix}.w + \begin{pmatrix} F_{K21} + F_{C21} \\ -F_{K22} - F_{C22} \end{pmatrix}.b \quad (2)$$

$$J_y.\ddot{\beta} = -\begin{pmatrix} F_{K11} + F_{C11} + \\ F_{K12} + F_{C12} \end{pmatrix}.l_1 + \begin{pmatrix} F_{K21} + F_{C21} + \\ F_{K22} + F_{C22} \end{pmatrix}.l_2 \quad (3)$$

- The unsprung mass of the front axle consists of the vertical translational movement of the left unsprung mass (Z_{u1}) and the vertical translational movement of the right unsprung mass (Z_{u2}).

$$m_{u1}.\ddot{Z}_{u1} = -F_{K11} - F_{C11} + F_{CL11} \quad (4)$$

$$m_{u2}.\ddot{Z}_{u2} = -F_{K12} - F_{C12} + F_{CL12} \quad (5)$$

- The unsprung mass from the rear axle includes translational motion in the vertical direction (Z_{u3}) and rotational motion around the x-axis ($ϕ_u$).

$$m_{u3}.\ddot{Z}_{u3} = -F_{K21} - F_{C21} - F_{K22} - F_{C22} + F_{CL21} + F_{CL22} \quad (6)$$

$$J_u.\ddot{\varphi}_u = \begin{pmatrix} -F_{K21} - F_{C21} \\ +F_{K22} + F_{C22} \end{pmatrix}.b + (F_{CL21} - F_{CL22}).w \quad (7)$$

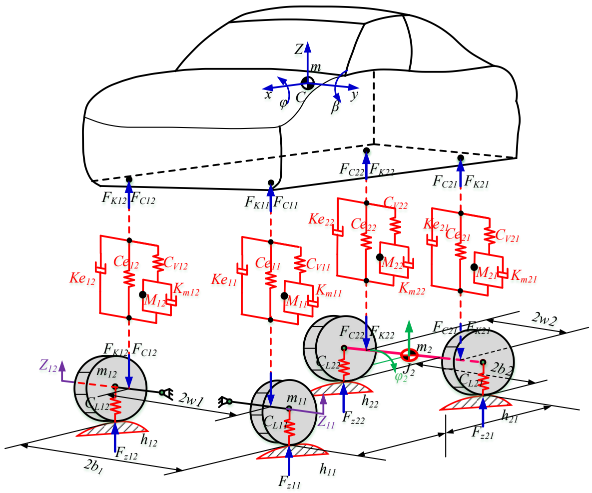

Fig 3.2: A spatial dynamics model describes the oscillation of an electric vehicle using a air suspension system.

The sprung mass consists of translational motion along the vertical axis (Z), rotational motion around the x-axis (ϕ), and rotational motion around the y-axis (β).

$$\begin{aligned} m.\ddot{Z} &= F_{Ke11} + F_{Ke12} + F_{Ke21} + F_{Ke22} \\ &+ F_{Cv11} + F_{Cv12} + F_{Cv21} + F_{Cv22} \\ &+ F_{Ce11} + F_{Ce12} + F_{Ce21} + F_{Ce22} \end{aligned} \quad (8)$$

$$J_x.\ddot{\varphi} = \begin{pmatrix} F_{Ke11} + F_{Cv11} + F_{Ce11} \\ -F_{Ke12} - F_{Cv12} - F_{Ce12} \end{pmatrix}.w + \begin{pmatrix} F_{Ke21} + F_{Cv21} + F_{Ce21} \\ -F_{Ke22} - F_{Cv22} - F_{Ce22} \end{pmatrix}.b \quad (9)$$

$$J_y.\ddot{\beta} = -\begin{pmatrix} F_{Ke11} + F_{Cv11} + F_{Ce11} \\ +F_{Ke12} + F_{Cv12} + F_{Ce12} \end{pmatrix}.l_1 + \begin{pmatrix} F_{Ke21} + F_{Cv21} + F_{Ce21} \\ +F_{Ke22} + F_{Cv22} + F_{Ce22} \end{pmatrix}.l_2 \quad (10)$$

- The unsprung mass of the front axle consists of the vertical translational movement of the left unsprung mass (Z_{u1}) and the vertical translational movement of the right unsprung mass (Z_{u2}).

$$m_{u1}.\ddot{Z}_{u1} = -F_{Ke11} - F_{Km11} - F_{Ce11} + F_{CL11} \quad (11)$$

$$m_{u2}.\ddot{Z}_{u2} = -F_{Ke12} - F_{Km12} - F_{Ce12} + F_{CL12} \quad (12)$$

- The unsprung mass from the rear axle includes translational motion in the vertical direction (Z_{u3}) and rotational motion around the x-axis ($ϕ_u$).

$$\begin{aligned} m_{u3}.\ddot{Z}_{u3} &= -F_{Ke21} - F_{Km21} - F_{Ce21} - F_{Ke22} \\ &- F_{Km22} - F_{Ce22} + F_{CL21} + F_{CL22} \end{aligned} \quad (13)$$

$$J_u.\ddot{\varphi}_u = \begin{pmatrix} -F_{Ke21} - F_{Km21} - F_{Ce21} \\ +F_{Ke22} + F_{Km22} + F_{Ce22} \end{pmatrix}.b + \left(F_{CL21} - F_{CL22}\right).w \quad (14)$$

4. Results

Vehicle speeds of 10 km/h, 20 km/h, 30 km/h, 40 km/h, 50 km/h, and 60 km/h were considered to compare the performance of two types of suspension systems—air suspension and leaf springs—in terms of ride comfort when the vehicle travels on a bumpy road surface (Fig 1.1) and is fully loaded. The wheels pass over a slope of L = 0.5 m, and the height of the bumping (H) is equal to 0.2 m. It was also assumed that the vehicle is moving straight and is not subjected to horizontal forces. Vehicle displacement and acceleration values were used for evaluation in this study.

4.1. The front wheel passing over the bump:

In this scenario, the front wheel must encounter bumps. The ride comfort of a vehicle is evaluated using two key indicators: vehicle displacement and vehicle acceleration. These metrics are directly compared between two types of suspension systems: leaf springs and air suspension systems, at two different speed ranges: 10 km/h and 60 km/h.

The results indicate that vehicle speed significantly affects the amplitude of body oscillation. As speed increases from 10 km/h (Fig 4.1.1 and Fig 4.1.2) to 60 km/h (Fig 4.1.3 and Fig 4.1.4), both the displacement and acceleration of the vehicle body exhibit a marked increase. At higher speeds, specifically 60 km/h, the frequency of excitation from the road surface also rises, resulting in oscillations with larger amplitudes that compromise the stability of the vehicle body.

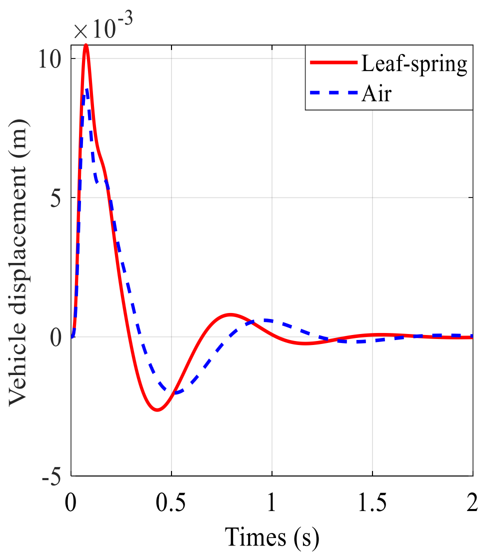

Fig 4.1.1: Vehicle displacement, speed 10 km/h

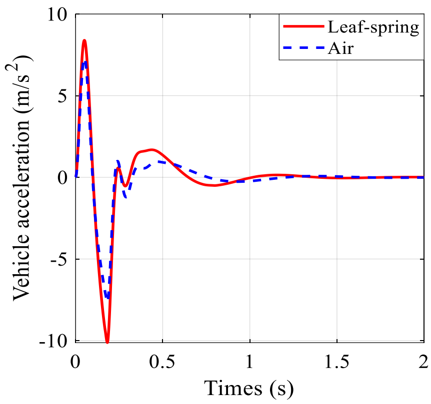

Fig 4.1.2: Vehicle acceleration, speed 10 km/h

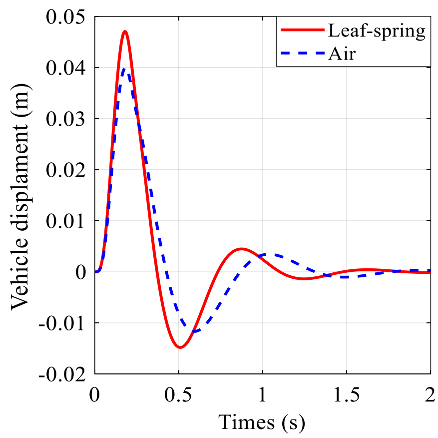

Fig 4.1.3: Vehicle displacement, speed 60 km/h

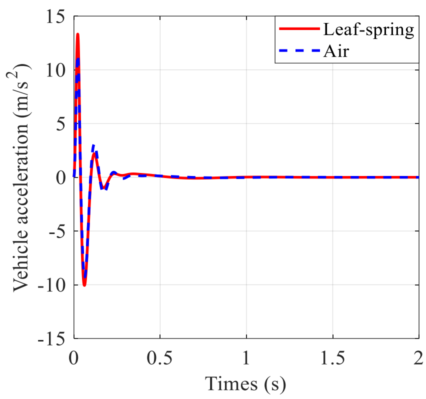

Fig 4.1.4: Vehicle acceleration, speed 60 km/h

Air suspension systems demonstrate greater stability and control over vehicle position compared to leaf spring suspension. The range of air suspension movement is typically smaller, and it tends to dampen oscillations more quickly, helping to maintain better vehicle posture when driving over uneven road surfaces. At both speed ranges, air suspension significantly reduces the peak acceleration value of the vehicle body compared to leaf spring suspension. This reduction in acceleration improves driver comfort and reduces the dynamic load on the cargo and the vehicle's mechanical structure.

TABLE 4.1.1: COMPARE AIR SUSPENSION RIDE COMFORT TO LEAF SPRING SUSPENSION WHEN THE FRONT WHEEL HITS A BUMP.

Velocity (km/h)	RMS Vehicle displacement		Reduction rate (%)	RMS Vehicle acceleration		Reduction rate (%)
	Leaf-spring	Air		Leaf-spring	Air	
10	1.14	1.09	***4.81***	0.42	0.40	***5.61***
20	1.36	1.31	***3.83***	0.49	0.47	***5.05***
30	1.71	1.63	***4.70***	0.59	0.56	***5.76***
40	2.27	2.18	***4.42***	0.70	0.66	***6.52***
50	3.39	3.26	***3.86***	0.81	0.74	***10.53***
60	6.59	6.39	***3.07***	0.89	0.78	***14.37***

Based on simulation results of the root mean square (RMS) values of vehicle body displacement and acceleration, the performance of the air suspension system was compared to that of leaf-spring suspension across a speed range of 10 km/h to 60 km/h. It was found that:

- When the speed increases from 10 km/h to 60 km/h, the RMS displacement value of both systems increases sharply. Specifically, at 60 km/h, the RMS displacement value is 6.59 mm for leaf spring suspension and 6.39 mm for air suspension.

- Air suspension systems continuously maintain lower displacement compared to leaf spring suspension across all speed ranges. The reduction rate remains stable, ranging from 3.07% to 4.81%.

- This difference shows that air suspension helps maintain better vehicle body stability, minimizing large-amplitude oscillations when the vehicle is operating at high speeds.

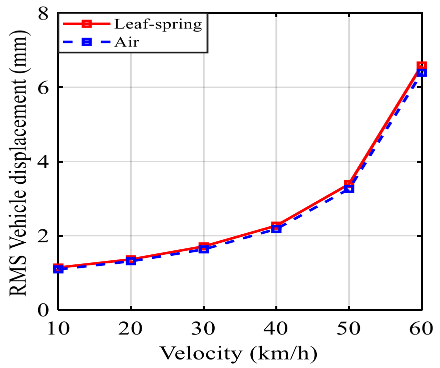

Fig 4.1.5: Compared RMS values of vehicle displacement for air and leaf spring suspensions

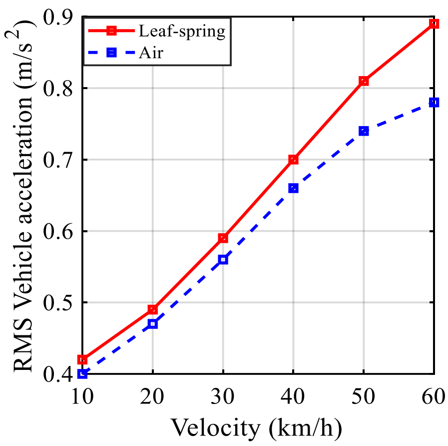

Fig 4.1.6: Compared RMS values of vehicle acceleration for air and leaf spring suspensions

Vehicle acceleration, much like displacement, is directly proportional to vehicle speed. However, the increase in acceleration with air suspension occurs at a significantly slower rate compared to leaf spring suspension. At low speeds, specifically at 10 km/h, the reduction in acceleration is only 5.61%. In contrast, at higher speeds of 60 km/h, air suspension reduces the root mean square (RMS) acceleration by as much as 14.37% compared to leaf spring suspension, decreasing from 0.89 m/s^2 to 0.78 m/s^2. This enhanced damping of acceleration at greater speeds suggests that air suspension offers superior non-linear damping characteristics, leading to a smoother ride in electric vehicles.

4.2. When the two front wheels go over bumps:

In this case, simulating the situation where the two front wheels pass over an uneven surface with a height of 0.2m and a length of 0.5m, the ride comfort of the car is evaluated using two parameters: vehicle displacement and vehicle acceleration. These results are directly compared between two suspension systems: leaf-spring and air suspension, at two speed ranges: 10 km/h and 60 km/h.

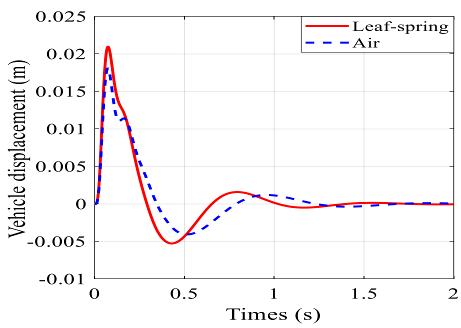

Fig 4.2.1: Vehicle displacement, speed 10 km/h

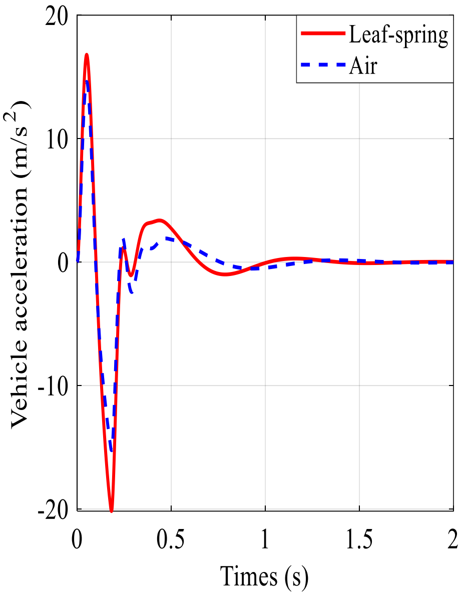

Fig 4.2.2: Vehicle acceleration, speed 10 km/h

At low speeds (10 km/h), the vehicle body displacement showed that both suspension systems ensured relatively excellent vibration absorption. The air suspension system, on the other hand, had a smaller vibration amplitude and a faster damping time than the leaf spring suspension system. At the same time, the results for the vehicle body's acceleration (Fig 4.2.2) showed that the air suspension's maximum acceleration value was lower than that of the leaf spring suspension system. This made the ride more comfortable for both the driver and the passengers.

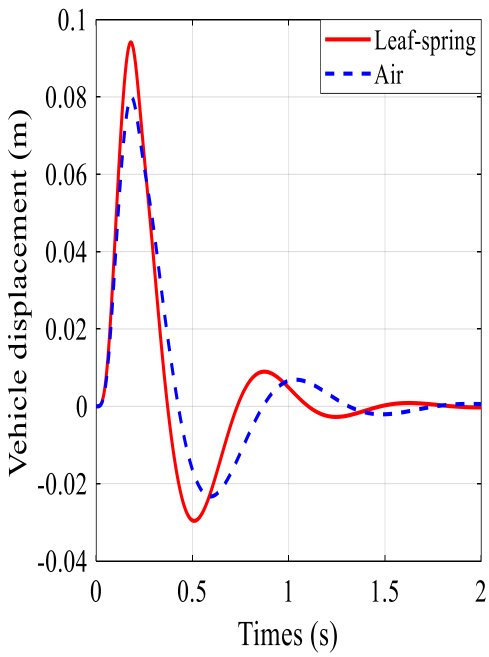

Fig 4.2.3: Vehicle displacement, speed 60 km/h

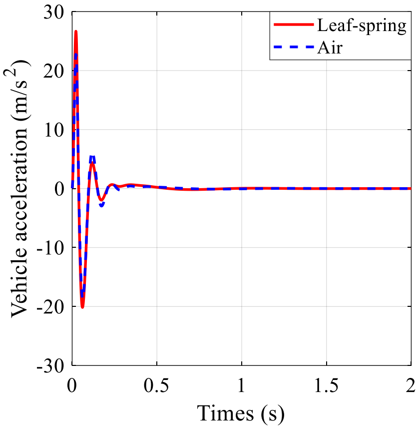

Fig 4.2.4: Vehicle acceleration, speed 60 km/h

As the speed increased to 60 km/h, the difference between the two suspension systems became more apparent. The resulting body displacement (Fig 4.2.3) showed that the leaf spring suspension exhibited larger amplitude oscillations and tended to maintain oscillations for longer periods, while the air suspension maintained better oscillation control. In particular, under strong excitation conditions due to high speed, the air suspension showed better adaptability to road conditions, resulting in improved ride comfort and enhanced vehicle handling compared to the leaf spring suspension. The results of body acceleration at 60 km/h (Fig 4.2.4) showed that the maximum acceleration in the case of using the leaf spring suspension increased significantly, reflecting a greater degree of vibration transmitted to the body. Conversely, the air suspension significantly reduced oscillation acceleration, thereby improving dynamic stability and reducing dynamic loads on the vehicle frame structure.

TABLE 4.2.1: AIR SUSPENSION AND LEAF SPRING SUSPENSION FOR BUMPY RIDES ON THE TWO FRONT WHEELS.

Velocity (km/h)	RMS Vehicle displacement		Reduction rate (%)	RMS Vehicle acceleration		Reduction rate (%)
	Leaf-spring	Air		Leaf-spring	Air	
10	2.28	2.19	***4.16***	0.85	0.81	***5.12***
20	2.75	2.64	***4.17***	0.99	0.94	***5.27***
30	3.40	3.28	***3.85***	1.17	1.11	***5.52***
40	4.54	4.36	***4.28***	1.40	1.32	***6.51***
50	6.79	6.51	***4.23***	1.63	1.47	***10.33***
60	13.18	12.79	***3.09***	1.78	1.52	***17.35***

Table 4.2.1 presents the results comparing the RMS values of body displacement and acceleration between leaf spring suspension and air suspension systems in

the speed range of 10 to 60 km/h when both front wheels simultaneously pass over bumps. For body displacement, the RMS value increases with speed for both suspension systems (Fig 4.2.5). Specifically, as the speed increases from 10 km/h to 60 km/h, the RMS displacement of the leaf spring suspension increases from 2.28 mm to 13.18 mm, while the air suspension increases from 2.19 mm to 12.79 mm, and the air suspension consistently shows a smaller value than the leaf spring suspension at all surveyed speeds. The percentage reduction in displacement ranges from 3.09% to 4.28%, indicating a relatively stable but not excessively large improvement.

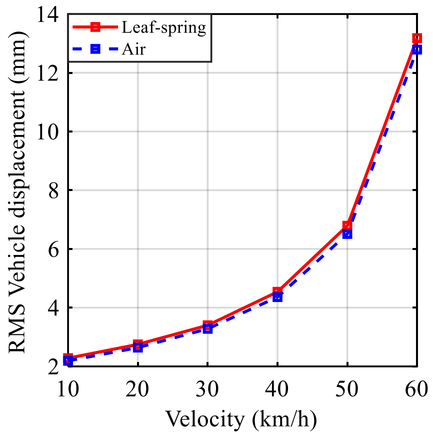

Fig 4.2.5: Compared RMS values of vehicle displacement for air and leaf spring suspensions

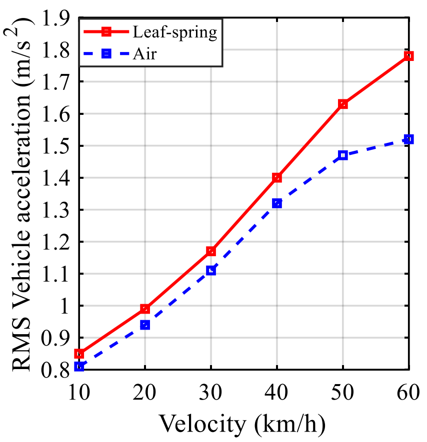

Fig 4.2.6: Compared RMS values of vehicle acceleration for air and leaf spring suspensions

Regarding vehicle acceleration, the difference between the two suspension systems becomes more pronounced (Fig 4.2.6). The RMS acceleration value of the leaf spring suspension rises from 0.85 m/s^2 to 1.78 m/s^2 as the speed increases from 10 km/h to 60 km/h, while the air suspension only rises from 0.81 m/s^2 to 1.52 m/s^2. The acceleration reduction rate reaches 5.12% at low speeds and increases sharply to 17.35% at high speeds. This trend shows that the effectiveness of the air suspension system becomes more apparent as the dynamic excitation conditions increase.

5. Discussion

The study developed a 7-degree-of-freedom spatial dynamics model to evaluate and compare the ride comfort of electric vehicles using two types of suspension systems: leaf spring suspension and air suspension, under sinusoidal turbulent conditions. Through the vehicle body displacement and acceleration (RMS values) at various speed ranges, the study showed:

- Vehicle speed has a significant impact on body oscillation. As speed increases, body displacement and acceleration increase significantly for both suspension systems, reducing ride comfort and stability.

- Air suspension systems consistently outperform leaf spring suspensions in improving ride comfort. Specifically, the RMS value of vehicle body displacement is reduced by approximately 3–5%, and the RMS value of vehicle body acceleration is reduced by 5% to over 17% depending on operating conditions. The acceleration reduction effect is particularly noticeable at higher speeds.

- When both front wheels pass over bumps, the difference between the two suspension systems becomes even more apparent. Air suspension is able to dampen vibrations more quickly, reduce the amplitude of oscillations, and limit the acceleration transmitted to the vehicle body better than leaf spring suspension.

Research findings indicate that pneumatic suspension systems effectively enhance ride comfort, minimize dynamic load, and improve stability in electric vehicles. This is particularly important given the significant weight of electric vehicles, which is largely due to their battery systems.

References

[1] L V Van and N T Tung, Determine the dynamic load acting on the chassis of multipurpose forest fire fighting vehicle, IOP conference series: Materrials science and engineering (IOP MSE), United Kingdom. ISSN 17578981, 1757899X, DOI 10.1088/1757-899X/1173/1/012030

[2] Tung, N.T., Van Van, L. (2022). A Study on the Effects of Tire Vertical Stiffness on Dynamic Load of DVM 2.5 Truck. In: Nguyen, D.C., Vu, N.P., Long,

B.T., Puta, H., Sattler, KU. (eds) Advances in Engineering Research and Application. ICERA 2021. Lecture Notes in Networks and Systems, vol 366. Springer, Cham. https://doi.org/10.1007/978-3-030-92574-1_13

[3] Tung, N.T., Van, L.V. (2022). A Research on the Effects of Suspension Stiffness on Dynamic Load on Dongfeng DVM 2.5 Truck. In: Long, B.T., Kim, H.S., Ishizaki, K., Toan, N.D., Parinov, I.A., Kim, YH. (eds) Proceedings of the International Conference on Advanced Mechanical Engineering, Automation, and Sustainable Development 2021 (AMAS2021). AMAS 2021. Lecture Notes in Mechanical Engineering. Springer, Cham. https://doi.org/10.1007/978-3-030-99666-6_27

[4] L. Van Van, C. Hung Phi, N. Thanh Tung, Effect of Suspension System Stiffness on Dynamic Load Action Chassis Multi-purpose Forest Fire Fighting Vehicle, International Journal of Engineering, IJE TRANSACTIONS B: Applications Vol. 35, No. 08, (August 2022) 1571-1578, doi: 10.5829/ije.2022.35.08b.13

[5] Mishra A, Saha S, Makhija S, Sinha S, Raychoudhury V, CC S. Empirical study of dynamics of amoebiasis transmission in mobile ad hoc networks (MANETs). Int J Commun Syst. 2020;33:e4186. https://doi.org/10.1002/dac.4186

[6] Luong Van; Cao Hung Phi; Nguyen Thanh Tung; Ho Huu Chan, Effect of road quality to dynamic load action on the rear axle housing multi-purpose forest fire fighting vehicle,

[7] V V Luong, T Q Nguyen, H Q Le, V A Le, P H Tran, X H Nguyen, T Tran V, Determination of Dynamic Loads from the Road Surface Acting on the Chassis by Experimental Methods, IOP Conf. Series: Materials Science and Engineering 886 (2020)

[8] Le VQ (2017) Comparing the performance of suspension system of semi-trailer truck with two air suspension systems. Vibroeng Proc 14:220–226. https://doi.org/10.21595/vp.2017.19224

[9] Van Van, L., Phi, C.H., Tung, N.T. (2023). Effect of Suspension System Stiffness on Dynamic Load Three Axle Vehicle. In: Mo, J.P. (eds) Proceedings of the 8th International Conference on Mechanical, Automotive and Materials Engineering. CMAME 2022. Lecture Notes in Mechanical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-99-3672-4_1

[10] Van, L.V., Tung, N.T. Dynamic Load Determination of a Multi-purpose Forest Fire Fighting Vehicle When Operating on Forestry Road. J. Vib. Eng. Technol. 12, 3507–3517 (2024). https://doi.org/10.1007/s42417-023-01061-w

[11] Zhang Zhiyong, Jianbo Wang, Wu Wenguang, Caixia Huang, Semi-active control of air suspension with auxiliary chamber subject to parameter uncertainties and time-delay, International Journal of Robust and Nonlinear Control 30(17):7130-7149, DOI: 10.1002/rnc.5169

[12] Van, L.V., Tung, N.T. Application of Air Suspension System on Multi-purpose Forest Fire Fighting Vehicle for Reducing Dynamic Load. J. Vib. Eng. Technol. 12, 7219–7230 (2024). https://doi.org/10.1007/s42417-023-01069-2

[13] Nguyen Thanh Tung and Luong Van Van, A study on the vibration of a bus with air suspension system moving on random road surface profiles with different speeds, Engineering Solid Mechanics 11 (2023) 119-124, doi: 10.5267/j.esm.2023.1.004.

[14] Li H, Changyin Zhou, Yeqing Wan Huawei Wang, Vibration Characteristics of Air Spring Suspension Seats, Appl. Sci. 2025, 15(11), 5817; https://doi.org/10.3390/app15115817

[15] Haider J. Abid, Jie Chen, Ameen A. Nassar, Equivalent Air Spring Suspension Model for Quarter-Passive Model of Passenger Vehicles, International Scholarly Research Notices, https://doi.org/10.1155/2015/974020

[16] Sun, X., Chen, L., Wang, S. et al. Vehicle height control of electronic air suspension system based on mixed logical dynamical modelling. Sci. China Technol. Sci. 58, 1894–1904 (2015). https://doi.org/10.1007/s11431-015-5861-9

[17] Xiaoyan Tan, Jiansheng HU, Guisheng Dong and Bo Chen, An Electronic Control Air Suspension System for Commercial Vehicles, IOP Conference Series: Earth and Environmental Science, Volume 267, Issue 4, DOI 10.1088/1755-1315/267/4/042165

[18] Nguyen Thanh Tung, Luong Van Van and Nguyen Thanh Quang, A survey on the effects of bumpy road on the vibration of multi-purpose forest fire fighting vehicle, Engineering Solid Mechanics 9 (2021) 291-298, doi: 10.5267/j.esm.2021.3.001