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Analysis of Influence Air Spring Mount Bending on Seat Suspension Performance

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Abstract - The vibration mitigation performance of air seat suspensions is influenced by primary suspension components, such as air springs and hydraulic dampers. Additionally, factors like suspension kinematics, seated body mass, and ride height further affect the effective stiffness. This study develops a 3D multibody dynamic (MBD) occupant-seat-suspension model incorporating air spring bending deformations to explore their effects on suspension performance. The validation of the developed model is performed with the reported study. Simulations were performed with different air spring base mount angle considering a body mass of 5th percentile American male population. Simulation results indicate that variation in an air spring base mount angle between 0-10 showed improved vibration isolation performance by lowering the suspension resonance, root mean square (RMS) acceleration, and peak relative travel. These findings emphasize the importance of considering spring bending in existing seat suspension design.

Keywords- Air spring base mount, Seat suspension, Multi-body dynamics.

I. INTRODUCTION

Low natural frequency air suspension seats are widely used to attenuate whole-body vibrations (WBV) in drivers. Air springs undergo both compression/extension and bending deformations, which can alter suspension stiffness and vibration isolation performance [1, 2, 3, 4]. However, the effects of air spring bending on seat suspension performance remain largely unexplored. Identifying changes in ineffective stiffness as a function of spring bending is necessary to improve suspension design.

Air springs offer significant advantages over coil springs by allowing adjustable stiffness based on air pressure and supported mass. This adaptability is essential for vehicles that operate in dynamic environments with varying loads and terrains. Furthermore, air springs perform well in low-frequency vibration conditions, particularly in compliance with ISO-7096, which defines exposure to different spectral classes of excitations.

Most existing studies focus on air spring compression/extension but overlook bending deformations and their effects on suspension performance. This study aims to evaluate the influence of air spring mount inclination using an MBD occupant seat suspension model. The results obtained from simulations showed significant influence of air spring base mount on suspension resonance, rms acceleration and peak relative travel of the seat suspension.

II. MODELING

A. Mathematical modeling of air spring

A air spring mathematical model was formulated to consider the spring vertical force F_s in the MBD seat suspension model. The air spring force F_s is given as:

$$F_s = P_b\, A_e$$

Where is the P_b instantaneous pressure, A_e is the effective area function of volume of air bag and spring deflection (x_1).

The instantaneous pressure of the air spring is derived from ideal gas law and given as:

$$P_b = P_{b0}\left(\frac{V_{b0}}{V_{b0} - A_e x_1}\right)^n$$

Where, P_{b0} and V_{b0} is initial air pressure and volume in the air bag, respectively and *n* is the polytropic constant.

B. Multi-body dynamic seat suspension model

A commercial vehicle seat suspension mechanism was developed in ADAMS/View, including occupant dynamics as shown in Figure 1. The occupant biodynamic model parameters

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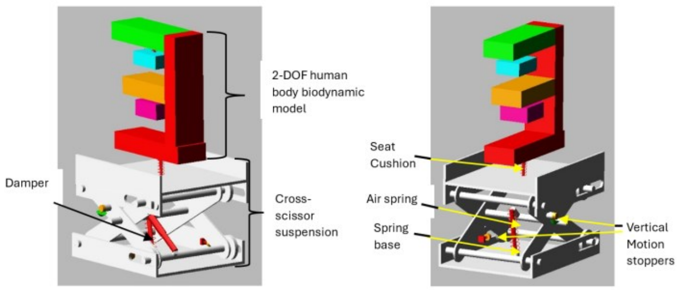

Figure 1: Multi-body dynamic occupant seat suspension model developed using Adams/View.

Table 1 : biodynamic model parameter for 5th percentile American male population

Model parameters						
(N/m)		(Ns/m)		Masses (kg)		
k_1	k_2	c_1	c_2	m_0	m_1	m_2
33234	48621	489	465	4.7	33.8	10.8

were obtained from the reported data by Wei and Griffin (1998)[6] and was verified with Apparent Mass (AM) responses idealized range from ISO-5982. The model consists of cross-linkages providing vertical motion, air springs, hydraulic damper, and cushion as show in Figure 1. The air spring inclination angle was modeled as a function of seat height and deflection.

The biodynamic model parameters considered in this study are presented in Table 1. The suspension component parameters for air spring, damper, seat cushion, end stoppers were considered form the reported study by Dorugade D. et. al. (2024)[7].

III. Simulations

Simulations were performed with occupant body masses of 5th percentile American male population at mid-ride height with white noise (WN) excitation magnitude of 1 m/s^2 rms to evaluate the impact of air spring base mount inclination on vibration performance. The air spring base mount angle was varied in the range of 0-10˚ to analyze the seat suspension performance in terms of suspension resonance, rms acceleration and peak relative travel.

The results obtained from the simulations performed are presented in Table 2.

Table 2: suspension resonance, rms acceleration and peak relative travel at different air spring angle mount

Body mass	Air spring	WN (1 m/s^2 rms)		
kg	Base mount angle (°degree)	Resonance (Hz)	RMS seat acceleration (m/s^2)	Peak Relative travel (mm)
65.8	0 (Nominal)	1.52	0.60	10
	5	1.47	0.48	8
	10	1.40	0.45	8

It was observed for the simulations that with increase in the base mount angle of the air spring of the suspension seat the suspension resonance tends lower along with the rms acceleration and relative travel. From the reported studies it is evident that a lower suspension resonance preferably below 1.5Hz provides enhanced performance of the seat suspension [7].

IV. Conclusion and Future Scope

This study developed an MBD seat suspension model incorporating air spring bending deformations. Simulation results highlight the importance of air spring base mount angle to improve suspension performance. Key findings include:

- Increasing the mount angle reduces suspension resonance, RMS acceleration and relative travel for the considered seated body mass.

- Existing seat suspension designs available in the market can be modified easily to enhance the suspension performance and provide comfort to the occupant for the considered seated body mass.

- The MBD modeling approach provides convenient way to modify the air spring base mount angle and co-ordinates to identify the influence on seat suspension performance.

Future research should consider extensive experimental work to identify precise behavior of air spring with different base mount angle to identify the variation in the force-deflection properties. The occupant MBD model can be simulated by considering different seated body masses and the model can further be used to identify optimal parameters improve the seat suspension performance.

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References

[1] I. Maciejewski, L. Meyer, and T. Krzyzynski, "Modelling and multi-criteria optimisation of passive seat suspension vibro-isolating properties," *J. Sound Vib.*, vol. 324, no. 3–5, pp. 520–538, 2009.

[2] M. Duke and G. Goss, "Investigation of Tractor Driver Seat Performance with Non-linear Stiffness and On-off Damper," *Biosyst. Eng.*, vol. 96, no. 4, pp. 477–486, 2007.

[3] P. S. A. Burdorf, "The effect of seat suspension on exposure to whole body vibration of proffessional drivers," *Br. Occupatinoal Hyg. Soc.*, vol. 37, no. 1, pp. 45–55, 1993.

[4] S. Rakheja, Y. Afework, and S. Sankar, "An Analytical and Experimental Investigation of the Driver-Seat-Suspension System," *Veh. Syst. Dyn.*, vol. 23, no. 1, pp. 501–524, 1994.

[5] I. Hostens, K. Deprez, and H. Ramon, "An improved design of air suspension for seats of mobile agricultural machines," *J. Sound Vib.*, vol. 276, no. 1–2, pp. 141–156, 2004.

[6] L. Wei and M. J. Griffin, "Mathematical models for the apparent mass of the seated human body exposed to vertical vibration," *J. Sound Vib.*, vol. 212, no. 5, pp. 855–874, 1998.

[7] D. V. Dorugade, S. Rakheja, Z. Zheng, and P. É. Boileau, "Coupled occupant-suspension-seat system analysis and vehicle-specific design optimization," *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.*, 2024.