Modelling and verification of two-axle tractor ride model

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ABSTRACT: This study focuses on the modelling and verification of a two-axle tractor ride model as part of the development of a tractor-semitrailer ride model. The two-axle tractor is utilized to develop the tractor ride model. The tractor ride model equations of motion are derived, which include 3 degree-of-freedom (DOF) for body motions and 4-DOF for unsprung mass motions. The MATLAB/Simulink software is used to simulate the developed tractor ride model while TruckSim software is used to verify the developed ride model by simulating it on a flat road. For all investigated parameters, the percentage differences in RMS values between the developed and TruckSim model are less than 5%. It grants the assurance that the developed model established in this study can be used to develop the tractor-semitrailer model.

Keywords: *Two-axle Tractor; Modelling; Verification*

1. INTRODUCTION

Tractor-semitrailers have already established themselves as an essential mode of transporting goods, particularly in the logistics and transportation industries. This is due to the tractor-semitrailers capability to transport a large amount of goods and access a wider range of transportation areas. Tractor-semitrailers, on the other hand, have low maneuverability and dynamic stability due to the vehicle's high center of gravity [1]. This characteristic causes the tractor-semitrailer to rollover, especially during rapid lane changes and excessive cornering at highway exit ramps. As a result, a dynamic study of the tractor-semitrailer is required in order to determine the cause of the rollover.

2. METHODOLOGY

This study begins with the following modelling assumptions: The two-axle tractor is modelled with 3-DOF body motion, which includes vertical, roll, and pitch motions, and 4-DOF represents each tire's vertical motion. The tractor model's sprung and unsprung masses are connected to a suspension system model, which is represented by spring elements and viscous dampers. Besides that, the aerodynamic effect of the tractor is ignored, and the road is assumed to be flat except for road bumps. It's also considered that the tractor remains grounded at all times during moving and that all four tires keep contact with the ground.

Then, as shown in Figure 1, the derivation of equations of motion for a tractor ride model is based on a schematic diagram of a two-axle tractor model equipped with a suspension system [2].

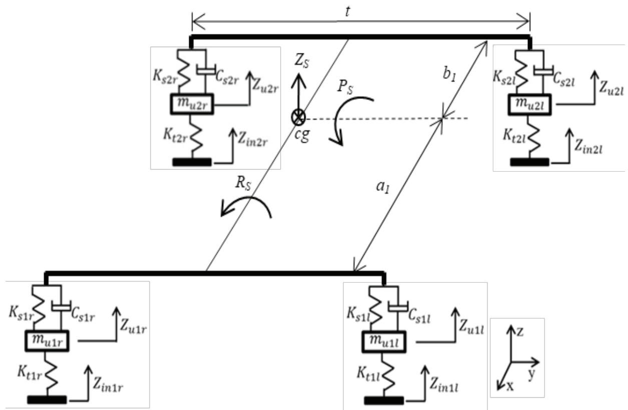

Figure 1 Schematic diagram of a two-axle tractor model equipped with suspension system

As a result, the equations of motion are derived from the equations listed below:

$$\sum F_s = m_s \ddot{Z}_s \tag{1}$$

$$\sum M_P = I_{yy} \ddot{P}_s \tag{2}$$

$$\sum M_R = I_{xx} \ddot{R}_s \tag{3}$$

Where, F_s is the sprung mass force; m_s is the sprung mass; $\ddot{Z}_s$ is the body vertical acceleration; M_P is the body pitch moment; I_{yy} is the pitch mass moment of inertia; $\ddot{P}_s$ is the body pitch acceleration; M_R is the body roll moment; I_{xx} is the roll mass moment of inertia; $\ddot{R}_s$ is the body roll acceleration.

The derived tractor model equations are modelled in MATLAB/Simulink software. The sprung mass, unsprung mass, tires, springs, and dampers are all included in the derived equations. The input data for the tractor ride test is established when the right side tires hit the 10 cm height bump at the speed of 90 km/h. This process begins with the identification of parameters, and the parameters are established based on Liu [3]. The simulation produces the tractor body roll angle, body pitch angle and body vertical acceleration.

After modelling process, the tractor ride model is verified by using the TruckSim software. The two-axle cab over tractor is used for the tractor simulation ride test. The truck travels at a constant speed of 90 km/h on a flat road, and the tractor's right side tires strike the 10 cm height bump at 1.6 seconds to generate tractor motion responses.

3. RESULTS AND DISCUSSION

This section compares the simulation results of the proposed tractor ride model to the verification results obtained using TruckSim software. The tractor body roll angle responses during the ride simulation test at a speed of 90 km/h are shown in Figure 2. In order to evaluate the performance of the tractor ride model, the root mean square (RMS) values for proposed and TruckSim models are established [4]. The proposed tractor model's roll angle response is found to be 3.95 % error from the Trucksim response. As a result, it is clear that the maximum error range is less than 5% [4].

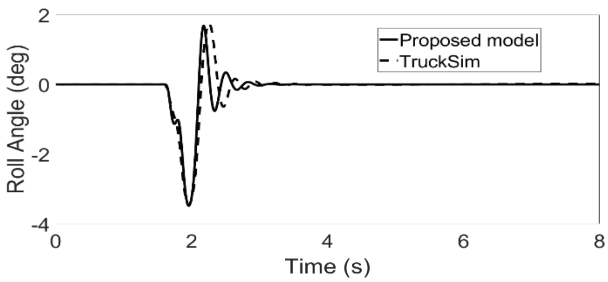

Figure 2 Tractor body roll angle

Figure 3 depicts the tractor body pitch angle response during the ride simulation test at a speed of 90 km/h. As shown in Figure 3, the tractor body pitch angle response is initially generated at 1.6 seconds when the tractor front tire begins to hit the bumps. In terms of tractor model verification, the proposed tractor model response closely follows the TruckSim model response with a 3.25% error. Figure 4 depicts the tractor vertical acceleration during the simulation ride test at 90 km/h. Figure 4 shows that the proposed tractor model response is significantly in close agreement with the TruckSim model, with a 4.16% error. Table 1 shows the percentage of RMS value differences for all investigated parameters between the proposed model and the TruckSim model.

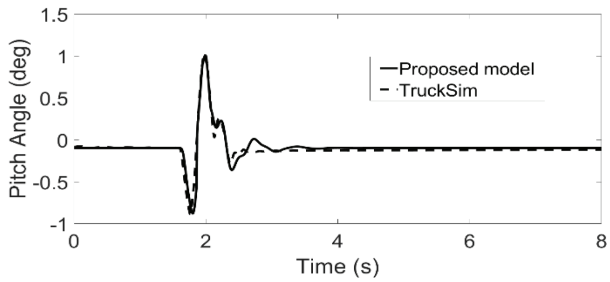

Figure 3 Tractor body pitch angle

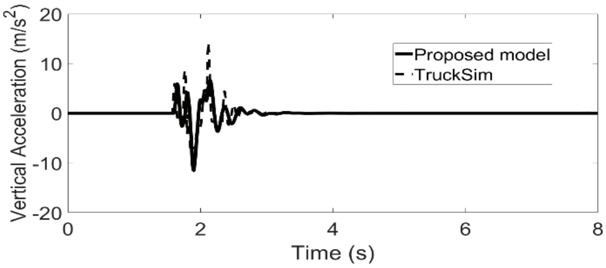

Figure 4 Tractor body vertical acceleration

Table 1 Percentage values of RMS differences

Tractor Responses	RMS		Percentage Difference (%)
	Proposed Model	TruckSim Model	
Roll Angle	0.0228	0.0237	3.95
Pitch Angle	0.1139	0.1176	3.25
Vertical Acc.	0.1179	0.1228	4.16

4. CONCLUSION

The modelling of two-axle tractor ride model equations of motion was established successfully. In MATLAB/Simulink software, the proposed tractor ride model equations of motion were effectively modelled and simulated. TruckSim software was used to successfully validate the dynamic responses of the developed model. The results showed a significant similarity between the proposed and TruckSim model responses. For all investigated parameters, the percentage differences in RMS values between the proposed and TruckSim models were less than 5%. It gives the confidence to use the proposed model established in this study to develop the tractor-semitrailer model.

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REFERENCES

[1] Z. Ma, X. Ji, Y. Zhang, and J. Yang, "State estimation in roll dynamics for commercial vehicles", *Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility*, vol. 55, pp. 313-337, 2017.

[2] M. H. Harun, K. Hudha, P. M. Samin, S. A. A. Bakar, and U. Ubaidillah' "Stability and roll effect of the straight truck suspension system", *Journal of Advanced Manufacturing Technology*, vol. 14, no. 1, pp. 89-100, 2020.

[3] P. Liu, "Analysis, detection and early warning control of dynamic rollover of heavy freight vehicles", Ph.D. dissertation, Concordia University, Canada, 1999.

[4] V. R. Aparow, K. Hudha, Z. A. Kadir, M. M. H. Megat, and S. Abdullah, "Modeling, validation and control of electronically actuated pitman arm steering for armoured vehicle", *International Journal of Vehicular Technology*, pp. 1-12, 2016.