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Research Article

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Stability analysis of Caravan

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Abstract In order to improve the lateral stability of the trailer RV train, it provides a reference for the design and optimization of the trailer RV and the user's use.[1] In this paper, the Trucksim model is established according to the parameters of the real vehicle and the accuracy is verified by the real vehicle test. The effects of vehicle speed, tongue weight and center of mass deflection on the lateral stability of trailer RV train were investigated by simulation model. The simulation results show that the lateral stability of the train will be reduced by increasing the speed, reducing the tongue weight and the transverse deviation of the center of mass.

Keywords Caravan, Lateral stability, Simulation test

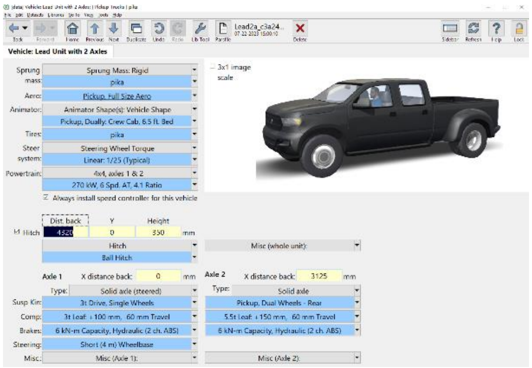
1. Introduction

In recent years, more and more people choose self-driving travel as a way to travel,[2-4] and the trailer has gradually been favored by everyone with the advantages of living and traveling together. However, under the same working conditions, compared with ordinary passenger cars, trailer RV trains are more prone to sideslip, tail dump and other phenomena, for drivers with less experience driving trailer RV trains, it is difficult to properly deal with such dangerous conditions as tail dump. Therefore, it is necessary to explore the factors affecting the lateral stability of the trailer RV train, and improve the stability from two aspects of design and use.[5-8]

2 Simulation model building

TruckSim is a simulation software for automotive dynamics models. Users can model the vehicle body structure, drive system, braking system, steering system, tires, suspension, etc., according to their own needs, and can also set the speed, gear setting, steering wheel Angle, road conditions, etc., according to the test conditions. In addition, TruckSim can be co-simulated with Simulink, so that users can control the model and view the simulation results. The whole process of simulation can be presented by animation, and the user can intuitively see the changes of the body attitude during the test.

In order to ensure the accuracy of the simulation model, this paper sets the simulation model according to the real parameters of a trailer RV train, as shown in Fig. 1 and Fig. 2. The vehicle simulation model is shown in Figure 3.



[data] Vehicle: Lead Unit with 2 Axles | Pickup Trucks | pika

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Vehicle: Lead Unit with 2 Axles

Sprung mass: Sprung Mass: Rigid
pika
Aero: Pickup, Full Size Aero
Animator: Animator Shape(s): Vehicle Shape
Pickup, Dually: Crew Cab, 6.5 ft. Bed
Tires: pika
Steer system: Steering Wheel Torque
Linear: 1/25 (Typical)
Powertrain: 4x4, axles 1 & 2
270 kW, 6 Spd. AT, 4.1 Ratio
☑ Always install speed controller for this vehicle

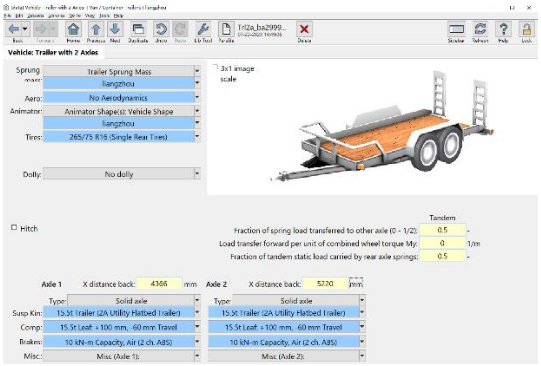
☐ 3x1 image scale

☑ Hitch: Dist. back 4320, Y 0, Height 350 mm
Hitch
Ball Hitch
Misc (whole unit):

Axle 1 X distance back: 0 mm
Type: Solid axle (steered)
Susp Kin: 3t Drive, Single Wheels
Comp: 3t Leaf: +100 mm, -60 mm Travel
Brakes: 6 kN-m Capacity, Hydraulic (2 ch. ABS)
Steering: Short (4 m) Wheelbase
Misc: Misc (Axle 1):

Axle 2 X distance back: 3125 mm
Type: Solid axle
Pickup, Dual Wheels - Rear
5.5t Leaf: +150 mm, -60 mm Travel
6 kN-m Capacity, Hydraulic (2 ch. ABS)
Misc (Axle 2):

Figure 1 Tractor



[data] Vehicle: Trailer with 2 Axles | Van / Container Trailers | liangzhou

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Vehicle: Trailer with 2 Axles

Sprung mass: Trailer Sprung Mass
liangzhou
Aero: No Aerodynamics
Animator: Animator Shape(s): Vehicle Shape
liangzhou
Tires: 265/75 R16 (Single Rear Tires)
Dolly: No dolly

☐ 3x1 image scale

☐ Hitch

Tandem
Fraction of spring load transferred to other axle (0 - 1/2): 0.5 -
Load transfer forward per unit of combined wheel torque My: 0 1/m
Fraction of tandem static load carried by rear axle springs: 0.5 -

Axle 1 X distance back: 4366 mm
Type: Solid axle
Susp Kin: 15.5t Trailer (2A Utility Flatbed Trailer)
Comp: 15.5t Leaf: +100 mm, -60 mm Travel
Brakes: 10 kN-m Capacity, Air (2 ch. ABS)
Misc.: Misc (Axle 1):

Axle 2 X distance back: 5220 mm
Type: Solid axle
15.5t Trailer (2A Utility Flatbed Trailer)
15.5t Leaf: +100 mm, -60 mm Travel
10 kN-m Capacity, Air (2 ch. ABS)
Misc (Axle 2):

Figure 2 Trailer

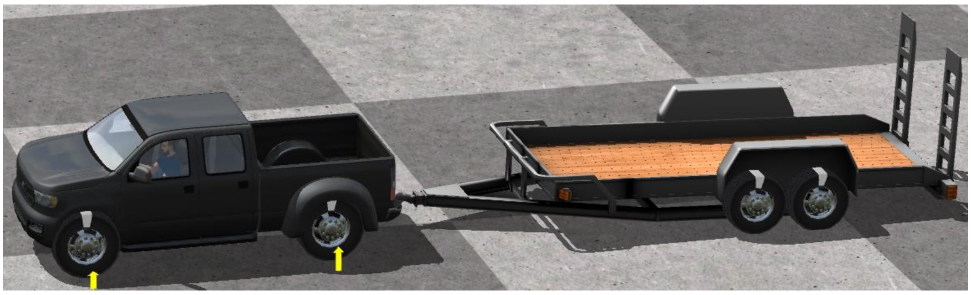


Figure 3 Complete vehicle model drawing

3. Verification of simulation model

In order to ensure the accuracy of the simulation model and the effectiveness of the simulation test. In this paper, the real car test is designed to verify the accuracy of the simulation model, and the reason of the error between the real car test and the simulation test is analyzed.

According to the test requirements of GB/T 25979-2010 "Test Method for lateral Stability of Heavy commercial vehicle Trains and Articulated passenger cars on Road Vehicles", vehicles need to be in the maximum load state, so this test selected a pickup truck and a two-axle trailer RV as test objects, and made the RV fully loaded by adding counterweight. And adjust the position of the counterweight properly, set the tongue weight to 6%, and then connect the two cars through the ball head hinge. After the vehicle is connected, it is shown in Figure 4.

This test requires measurement of steering wheel Angle of tractor, yaw speed and lateral acceleration of tractor and RV. Therefore, gyroscopes are installed on the front and rear vehicles respectively to extract the lateral acceleration and yaw velocity data of the vehicle. Install steering wheel sensors on the tractor to obtain steering wheel Angle. In order to ensure the unity of all test data on the timeline, the sensor data was collected by imc data collector in this test, and then transmitted to the computer for analysis.

The rear amplification factor is the ratio of the peak value of the motion variable of the following vehicle unit to the peak value of the motion variable of the first vehicle unit during the specified driving operation. Since the lateral acceleration and yaw velocity of the vehicle can be measured, the rear amplification factor of lateral acceleration and rear amplification factor of yaw velocity is planned to be used as the standard to evaluate the stability of the train in this test.

Figure 4 Complete vehicle diagram

The test method of steering wheel pulse was adopted in this test, and the specific requirements are shown in Figure 5.

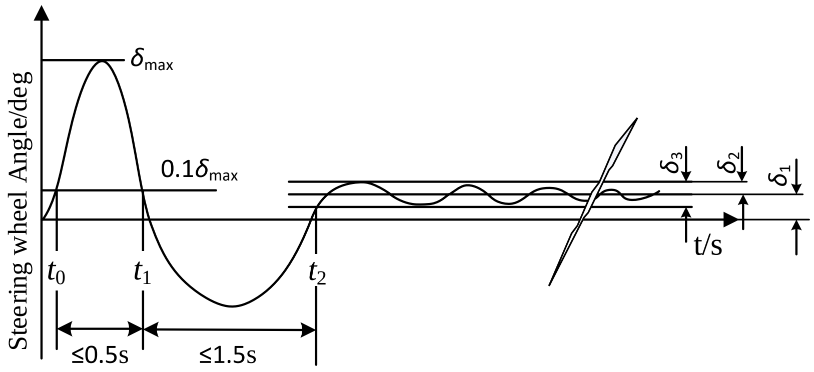


Figure 5 Steering wheel Angle time history

t_0 is the time when the amplitude of the steering wheel Angle first exceeds 10% of its maximum amplitude (δ_{max}). t_1 is the time when the steering wheel Angle first decreases to 10% of its maximum amplitude after a peak occurs.

t_2 is a specific time after which the steering wheel Angle remains within the required range of variation.

The test requires that at a certain speed, the vehicle begins to swing laterally through the pulse input of the steering wheel, and then the steering wheel is properly corrected to make the vehicle return to the initial driving route. Finally, the steering wheel is kept unchanged in the forward driving position of the vehicle, and after t_2, the average deviation of the steering wheel Angle (δ_1) cannot exceed 10% of its maximum amplitude. The maximum amplitude of the mean deviation (δ_3) cannot exceed 5% of its maximum amplitude. In addition, it should be noted that the steering pulse period (t_1-t_0) should not exceed 0.5s, and the steering wheel correction time (t_2-t_1) should not exceed 1.5s.

In the real car test, the actual steering wheel Angle is shown in Figure 6.

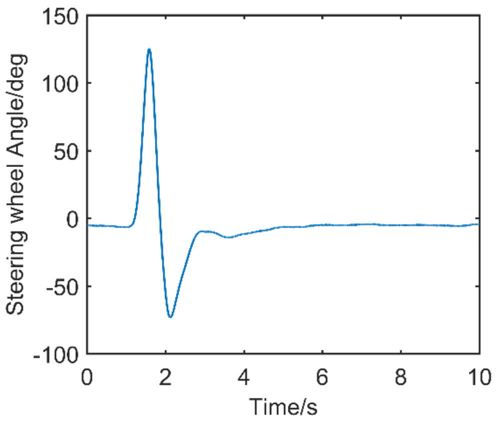


Figure 6 Steering wheel Angle

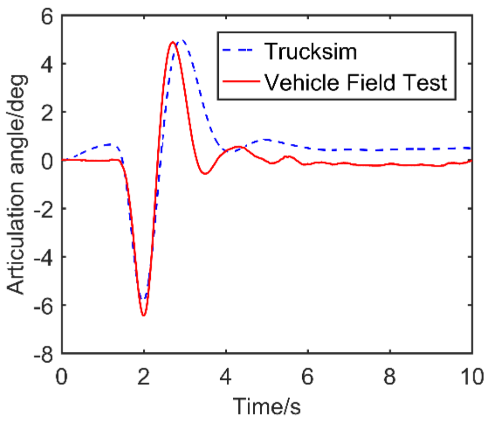


Figure 7 Comparison between real car test and simulation

During the simulation, in order to achieve the same working conditions as the real car test as much as possible, the steering wheel Angle data during the real car test was extracted and then input into the Trucksim simulation model. The simulation was carried out at a speed of 50km/h, and the obtained simulation results were compared with the test results of the real vehicle test, as shown in Figure 7. As can be seen from FIG. 7, the overall trend and amplitude of hinge Angle change in real vehicle test and simulation are roughly the same, but the time to stabilize in real vehicle test is shorter. In general, the simulation model is in good agreement with the real vehicle test.

The causes of errors in real vehicle test and simulation are analyzed as follows:

1) The suspension parameters of the real car are difficult to obtain, which leads to the difference between the suspension parameters of the simulation model and the real car.

2) In the real car test, the driver does not maintain the speed well in the process of controlling the pulse input of the steering wheel, and the time for the vehicle to stabilize will become shorter due to the decrease of the speed.

4. Lateral stability analysis

Because of the risk of lateral stability test, many scholars choose to study vehicle stability by simulation. This paper will also explore the effects of vehicle speed, tongue weight, lateral shift of center of mass, RV mass and moment of inertia on the lateral stability of the trailer RV train through simulation.

4.1 Effect of speed

The transverse stability test of the vehicle speed of 60, 70, 80, 90 and 100km/h was simulated respectively. In order to meet the test requirements of the lateral acceleration of the RV at 4±1m/s2, each test speed makes the train swing through the input of different steering wheel corners. The lateral acceleration curve of tractor and RV obtained by the simulation test with a speed of 80 km/h is shown in Figure 8. It can be seen from the curve that the peak lateral acceleration of RV is obviously greater than that of tractor and has a certain lag. The rear amplification factor under this condition can be calculated according to the curve.

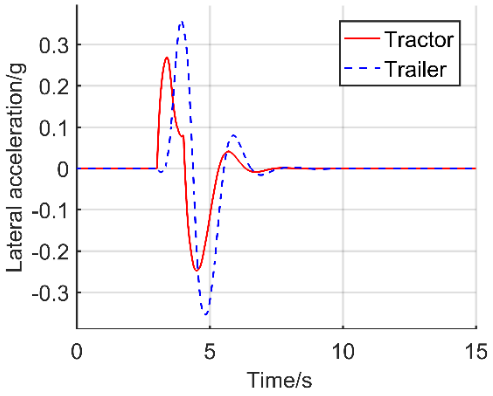


Figure 8 Comparison of lateral acceleration between tractor and RV

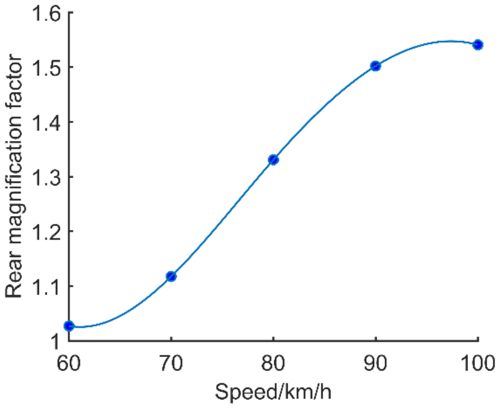
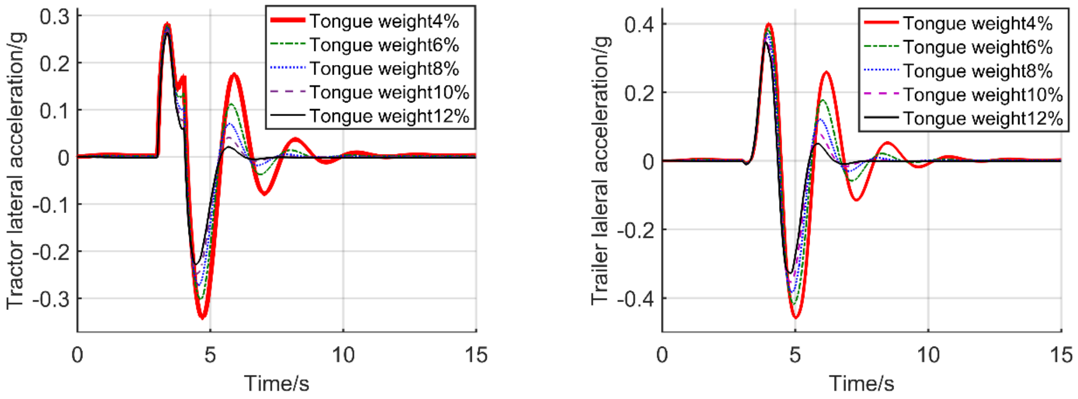


Figure 9 Rear magnification factor at different speed

The rear magnification coefficient under different speed is shown in Figure 9. As the speed increases, the rear magnification coefficient of the train becomes significantly larger. In other words, the higher the speed, the greater the influence of the transverse movement of the tractor on the stability of the RV, and the worse the lateral stability of the trailer. Therefore, when the speed is high, do not carry out a large steering wheel operation, so as not to cause the swing phenomenon of the RV.

4.2 The effect of heavy tongue

The test speed was set at 80km/h, and the steering wheel pulse test with an Angle of 100° was carried out. The motion state of the train was simulated when the tongue weight was 4%, 6%, 8%, 10% and 12% respectively. The lateral acceleration curves of the tractor and RV were shown in Figure 10. The rear amplification coefficients under different tongue weights were calculated separately and fitted into a curve, as shown in figure 12.



（a） Tractor *（b） Trailer*

Figure 10 Comparison of lateral acceleration of different tongue weights

As shown in Figure 10, with the increase of tongue weight, the peak lateral acceleration of both tractor and RV decreases, and the stabilizing time decreases significantly, especially when tongue weight changes from 4% to 6% and 8%. This shows that the lateral stability of the trailer car can be effectively improved by properly increasing the tongue weight. However, with the increase of tongue weight, the rear amplification factor also gradually increases, as shown in Figure 11, which indicates that the larger the tongue weight, the greater the impact of the tractor's lateral movement on the RV.

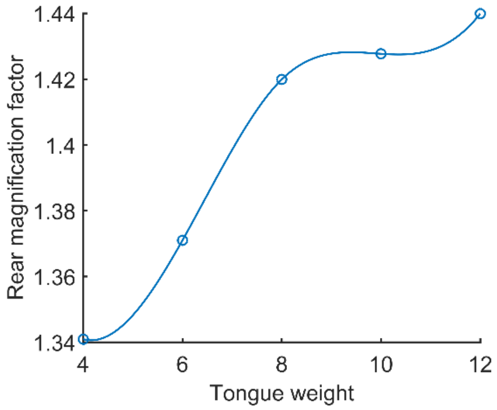


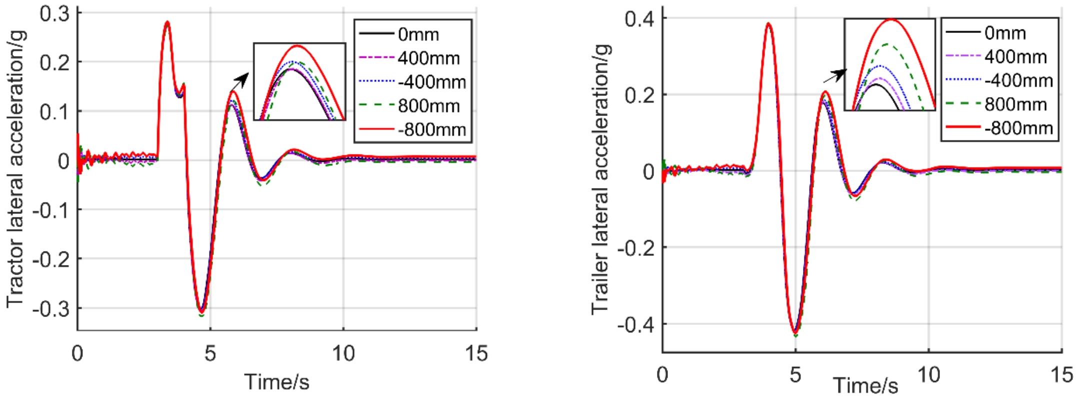
Figure 11 Posterior magnification factor of different tongue weights

In addition, before adjusting the tongue weight of the real car, it is necessary to first consider whether the adjusted tongue weight is less than the maximum bearing pressure of the trailer hook; Whether the rear axle load of the tractor exceeds the maximum rear axle load pressure specified by the vehicle; Whether the tire load is less than the maximum bearing pressure of the tire. If the above conditions are met, the tongue weight can be appropriately increased to improve the lateral stability of the train.

In summary, in the case that the mechanical structure strength of the vehicle meets the requirements, it is recommended to adjust the tongue weight near 6% to improve the stability of the train.

4.3 Lateral shift of center of mass

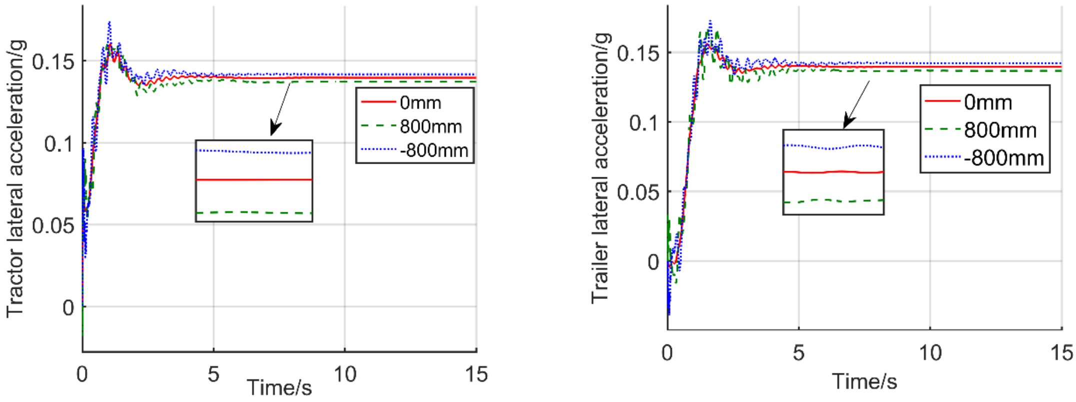
The steering wheel pulse test with tongue weight of 6% and speed of 80km/h was designed to simulate the motion state of the RV center of mass position offset to the left and right by 400mm and 800mm, respectively. The lateral acceleration curves of the tractor and RV are shown in Figure 12. The fitting curves of the rear amplification coefficient under different centroid positions are shown in Figure 13.



（a）Tractor *（b）Trailer*

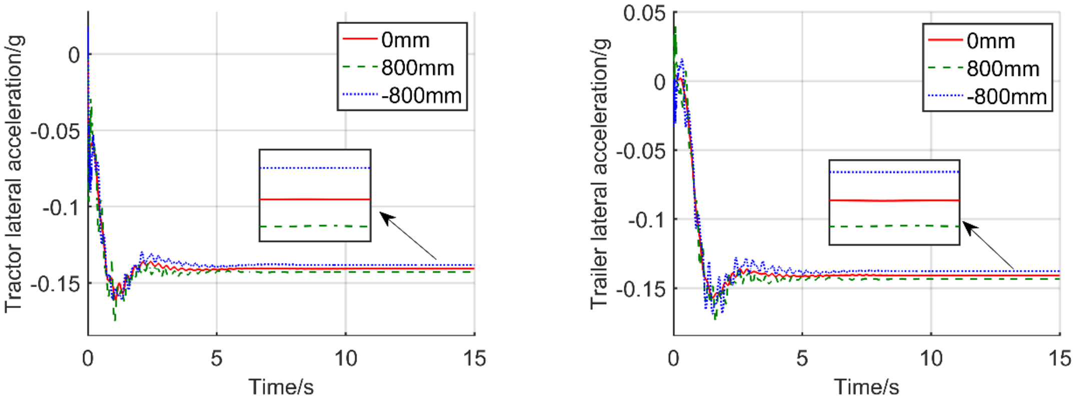
Figure 12 Lateral acceleration at different centroid positions

As can be seen from Figure 12, when the RV's centroid is shifted laterally, the peak lateral acceleration of both tractor and RV will be affected. In addition, when the centroid deviation distance is the same, the influence of left and right deviation on the stability of the train is related to the motion pattern of the train. By simulating the steady-state circular motion of the train to the left, it can be seen that the deviation of the center of mass to the right will increase the lateral acceleration of the tractor and RV, while the deviation of the center of mass to the left will decrease the lateral acceleration of the tractor and RV, as shown in Figure 14. When the train makes a steady circular motion to the left, the left deviation of the center of mass will increase the lateral acceleration of the tractor and RV, while the right deviation of the center of mass will decrease the lateral acceleration of the tractor and RV, as shown in Figure 15. However, in the actual running process, the motion state of the train is often changed, so the centroid deviation often leads to the decline of the lateral stability of the train.



（a）Tractor *（b）Trailer*

Figure 14 Left-turn circular motion



（a） Tractor （b） Trailer

Figure 15 Right circular motion

It can be seen from FIG. 13 that the centroid shift has little influence on the rear magnification coefficient, and the difference between the rear magnification coefficient of the left-right centroid shift of 400mm and 800mm and the rear magnification coefficient of the centroid position is less than 0.02.

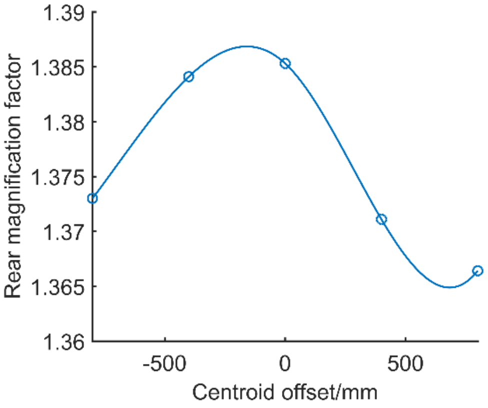


Figure 13 Rear magnification coefficients for different centroid positions

To sum up, the lateral deviation of the centroid position will reduce the stability of the trailer RV train, and the centroid position should be controlled in the center of the RV as far as possible.

5 Conclusion

In this paper, the Trucksim simulation model was established and verified through the real car test, and the influence of body structure parameters on the lateral stability of the towed RV train was analyzed. Through the simulation results, it can be seen that increasing the speed, decreasing the tongue weight and the transverse deviation of the center of mass will reduce the lateral stability of the train. And the vehicle speed has a great influence on the rear magnification factor.

Therefore, in the case of high speed, as far as possible to reduce the steering wheel input. In addition, the tongue weight can be appropriately increased within the scope of mechanical structure strength to improve lateral stability. When placing items in the RV, try to place them evenly to reduce the center of mass deviation of the RV.

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