

Performance Optimization for the Centre Axle Trailer Combination

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ABSTRACT

In addition to ride comfort, handling stability and other conventional vehicle performances, we should also focus on other aspects of performance to a center axle trailer combination, such as the maximum stable side-inclination, the anti-rolling stability, the lateral stability and so on. Based on the finite element method, a rigid-flexible coupling model for the truck combination was built and analyzed in the multi-body environment (ADAMS), in which the key components of the chassis and cab suspension were treated as flexible bodies. A series of simulations were carried out to evaluate the lateral stability of the center axle trailer in accordance with the relevant regulations of the vehicle. The influence of design variables on the lateral stability was studied by an experiment. Furthermore, in order to improve the lateral stability of the trailer combination, the optimal design was obtained by the co-simulation of the ADAMS/Car, iSIGHT and Matlab.

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INTRODUCTION

The central axle trailer whose load is located in the center of trailer's gravity is a form of a full trailer. A central axle trailer is made up of a traction vehicle and a trailer with central axle and low chassis, which are connected by the master and slave hooks. The connecting device cannot move vertically relative to the trailer. While the vehicle is working, only a small vertical load is applied to the traction vehicle.

The central axle trailer has a unique advantage in the transportation of commercial vehicles. First of all, the relatively low chassis and small turning radius increases the dragging ability of the master vehicle. Secondly, the central axle trailer improves the efficiency of transportation and saves fuel consumption and resource, as well as enhances better safety performance. Finally, the central axle trailer can reduce the probability of accidents, which has an important meaning for transfinite governance.

Some studies were relative to the effects of parameter variations on the dynamic stability of the trailer combination. Hac et al [1] used a linear analysis model to describe lateral and yaw motions of a vehicle-trailer combination and studied the effects of parameter variations on the trailer for the dynamic stability of the system and limitations of different control strategies. Yanget al [2] conducted a parametric design for a tractor semi-trailer based on Multi-Objective Linear Programming (MOLP) method by optimizing the configuration parameters to comprehensively improve the lateral dynamics performance. Several instabilities associated with truck-trailer combinations had been well documented and predicted using mathematical models by Minaker and Rieveley [3], and more elaborate mathematical models are used to evaluate various vehicle design configurations. As to various types of and numbers of

suspension, trailers and/or semi-trailers, Barbieri et al [4] conducted a study to compare the differences in dynamic behavior and the resulting stability of the different configurations in different conditions of speed and maneuvers. Law and Janajreh [5] developed a simplified computational tool that can be used to understand and predict the effects of various tire characteristics and truck design parameters on rollover under steady cornering and non-tripped conditions. An analysis approach was proposed to assess tractor trailer performance due to wind speed and wind gusts on slippery surfaces by Tremblay et al [6].

Due to the varied operating conditions, the stability of a car-trailer system cannot be guaranteed with a passive mechanism. To address this problem, various active control methods had been proposed. Stability control is needed for combination vehicles and how the vehicle stability can be improved was illustrated by Oh et al [7]. The controller structures and design methods of combination vehicle stability program (CVSP) were also proposed. Chan et al [8] developed a hardware-in-the-loop simulation setup for a B-doubles trailer combination and found that an active trailer stability system in the combination was beneficial to mitigating rollover and increasing the combination safety margin for roll. Shamim et al [9] compared three active control strategies to improve lateral stability of car-trailer systems by using numerical simulations, which are active trailer steering control (ATSC), active trailer braking (ATB), and a variable geometry approach (VGA). All the stability control systems showed superior performance to the baseline case. The applicability of an active trailer differential braking (ATDB) controller designed by using a linear CT model was tested and evaluated by Sun et al [10]. Sun and He [11] conducted case studies to test the effectiveness of the phase-plane method of analyzing the lateral stability of a car-trailer combination represented by a nonlinear vehicle model.

generated using the CarSim software package, and an innovative phase-plane analysis technique was developed in order to effectively assess the lateral stability of articulated vehicles.

In the present work, the lateral stability performances such as maximum stable side-inclination, the anti-rolling stability, the lateral stability and so on were emphatically investigated except for conventional ride, handling and braking requirements. This paper was organized as follows: the vehicle modeling was described firstly; and a series of simulation analysis of lateral stability were carried out secondly; the sensitivity analyses and optimization were conducted by co-simulation thirdly; finally, the experiments were done to be compared with simulation.

VEHICLE MODELING

A central axle trailer consists of a traction vehicle and a central axle trailer. The traction vehicle is made up of the cab, frame, steering, powertrain, front suspension, rear suspension, front and rear tires and other systems (without the breaking system), as shown in [Figure 1](#).

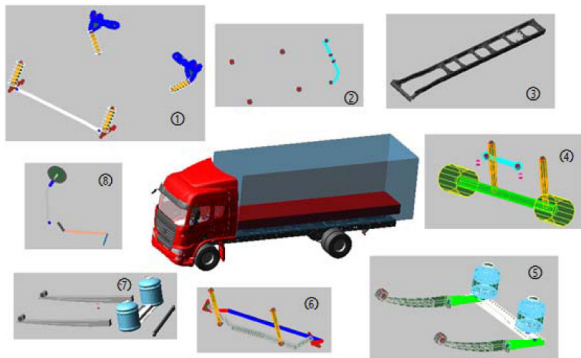


Figure 1. The tractor vehicle model in Adams/Car

Model description:

- ①. The form of cab suspension is full floating, and the anti-roll bar of the cab was built as a flexible part.
- ②. The powertrain is supported by the elastomeric bushings, and the flexible torsion bar was built as the auxiliary mounting.
- ③. The frame is modeled as a flexible body to ensure the natural frequency.
- ④. The rear axle is equipped with a damper and a lateral connecting rod.
- ⑤. The rear suspension is a mixed structure of 1/2 leaf spring and air spring.
- ⑥. The front axle is equipped with a damper and a lateral connecting rod which modeled as a flexible body.
- ⑦. The rear suspension is also a mixed structure of 1/2 leaf spring and air spring.
- ⑧. It is a steering system.

The central axle trailer consists of the bracket, frame, trunk, front and rear suspension, tires and other systems. Bushing, the flexible connecting method, was used to simulate the revolute attachment

(along Z axis) between the bracket and the traction vehicle, and to simulate the revolute attachment (along Y axis) between the bracket and the central axle trailer, as shown in [Figure 2](#).

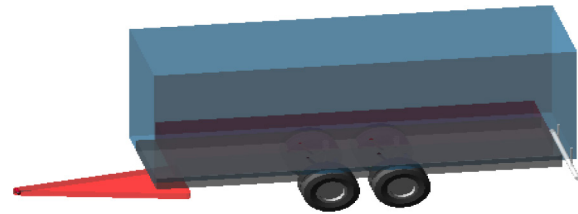


Figure 2. The center axle trailer model in Adams/Car

The central axle trailer combination consisted of a tractor and a trailer as shown in [figure 3](#). The total mass of the vehicle was 35000kg, which was made up of the unloaded train(18000kg), the tractor cargo(7000kg), and the trailer (10000kg).

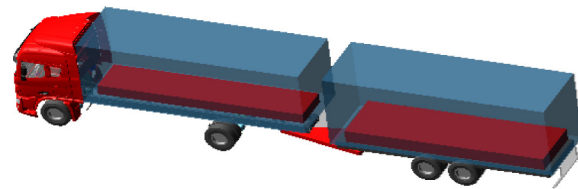


Figure 3. The center axle trailer model in Adams/Car

LATERAL STABILITY ANALYSIS

Lateral stability analysis of the center axle trailer includes the analysis of the maximum stable side-inclination angle, turning clearance circle, lateral stability and anti-rolling stability - steady circle.

The Maximum Stable Side-Inclination Angle

The maximum stable side-inclination angle characterizes the vehicle's inherent ability to resist lateral forces in static conditions.

Based on the vehicle's model, the maximum roll stability angle test bench was built, as shown in [Figure 4](#).

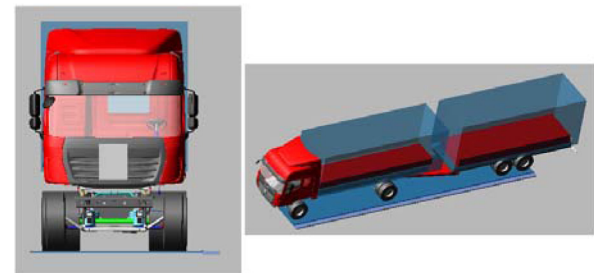


Figure 4. The maximum roll stability angle test bench

There were four working conditions: unloaded-left rolling, unloaded-right rolling, full-loaded-left rolling and full-loaded-right rolling. The rolling angle was turned at the speed of not more than 0.5°/s. The maximum roll stability angle was shown in [Figure 5](#). The analysis result was shown in [Table 1](#).

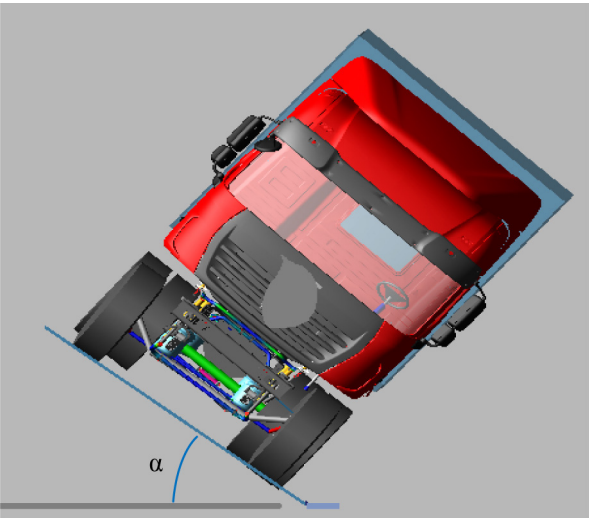


Figure 5. The maximum roll stability angle critical point

Table 1. The maximum roll stability angle value

Cases	Orientation	The maximum roll stability angle $\alpha/^{\circ}$
Unloaded	Left	36.0
	Right	36.6
Full-Loaded	Left	25.0
	Right	25.5

The maximum roll stability angle at an unloaded condition should be not less than 35°. According to the analysis result, the vehicle’s maximum roll stability angle was 36.0° (or 36.6° while rolling right), which met the requirement.

Turning Clearance Circle

Turning clearance circle indicates the ability of the vehicle to pass the curve at a low speed.

The turning clearance circle analysis of the vehicle was conducted at the speed of 10km/h. The turning clearance circle was shown in Figure 6.

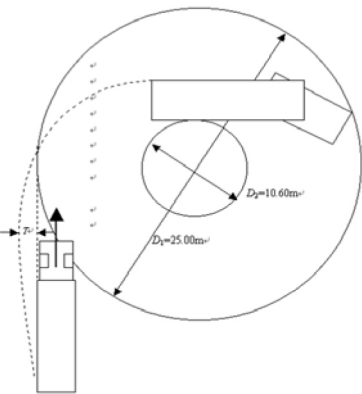


Figure 6. Turning clearance circle sketch map

Requirements:

- a. The vehicle should be able to pass through the turning clearance circle. The diameter of the outer circle is 25000mm. The diameter of the inner circle is 10600mm. The vehicle should move between the outer and inner circle.
- b. When the vehicle moves from straight motion to circular motion, the vehicle outer value, T, should not exceed 800mm.

The simulation analysis was divided into two situations: left turning and right turning. The vehicle trace diagram was shown in Figure 7. The measuring value was shown in Table 2.

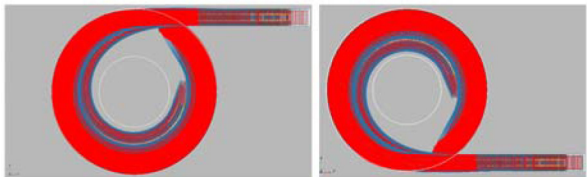


Figure 7. The vehicle trace diagram

Table 2. The measuring value

Cases	Outer value T(m)	Internal diameter D2(m)
Left	0.22	12.0
Right	0.27	11.8

According to the results above, when the outer diameter is 25m, the inner diameter should exceed 10.6m and the outer value should not exceed 0.8m. The inner diameter of the full-loaded vehicle was 12.0m when turning left (11.8m while turning right), and the outer value was 0.22m when turning left (0.27m while turning right), which all met the requirements.

Anti-Rolling Stability - Steady Circle Analysis

Anti-rolling stability indicates the ability that vehicles resist rolling. Steady circle analysis is used to evaluate the vehicle’s anti-rolling stability.

During this test procedure, the vehicle should be steered such that it could move on a circular path at a constant speed. Repeat the procedure at successively faster speeds. The entire procedure should be repeated on paths of at least three different radii.

A standard radius of 100m should be used for one of the paths. Here, the radii of the other paths were 50m, and 200m.

For each radius chosen, the test should be conducted at several speeds. The first speed should be the slowest practical speed. Choose successive speeds such that the increments of centripetal acceleration were not more than 0.5 m/s², where the data that could be useful to make smaller incremental changes varied with centripetal acceleration.