

Handling and Ride Performance Sensitivity Analysis for a Truck-Trailer Combination

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ABSTRACT

A truck-trailer combination is modeled using ADAMS/Car from MSC Software for handling and ride comfort performance simulations. The handling events include a double lane change and lateral roll stability. The ride comfort performance events include several sized half-rounds and various RMS courses. The variables for handling performance evaluation include lateral acceleration, roll angles and tire patch normal loads. The variables for ride performance evaluation are absorbed power and peak acceleration. This study considers the trailer spring stiffness, anti-roll bar and jounce bumper gap as the design variables. Through DOE simulations, we derived the response surface models of various performance variables so that we could consider the performance sensitivities to the design variables.

Key Words

Vehicle Dynamics, Suspension, Truck-Trailer, Sensitivity

INTRODUCTION

Responsive handling and superb ride comfort performances are the two primary vehicle design objectives. Due to their conflicting nature, the vehicle designer must optimize the balance and the capabilities for attaining sufficiently high performance in various operating conditions to meet or exceed customer expectations. To accomplish the optimization, understanding the key design factors affecting these performances is critical. Further, for different vehicle combinations-such as trailer versus no trailer-the influences of various design factors on these two performances may differ in terms of directions and magnitudes. Since the coupling and integration of components and subsystems for various vehicle combinations change dynamically, making a general guideline about the influences of these critical factors for various vehicle combinations is highly difficult. Thus, a

systematic method that performs a sensitivity analysis of these performances to the key design factors is necessary and useful.

One can find many studies [1,2,3,4,5,6,7,8,9,10,11,12,13,14] on the ride or handling dynamics simulation and analysis of truck-trailer combinations in the literature. These studies employ dynamics models of various complexity levels; models that range from two degrees of freedom (DOF) lumped-mass models to hundreds of DOF multi-body dynamics models, as well as field testing data or driving simulator data. The handling and stability analyses range from typical driving events; double lane change (DLC), slowly increasing steer, pulse steer, step steer, and straight-line braking maneuvers [3,4,5,6,7,8,9,10,11,12,13,14]; to severe events that result in potential roll-overs, including the rollover potential in high crosswinds [1] or driver-induced overturning [2]. The ride performance analyses conducted in [15,16,17] include tuning suspension ride frequency, vehicle frame flexibility, and assessment of several factors affecting the vehicle ride quality, including driver vibration, ease of steering, and interior cab noise.

The literature review shows that the double lane change event, lateral roll stability and random road events are the commonly used events for handling and ride performance evaluations. Furthermore, few studies focus on both ride and handling performances for tractor and trailer combinations. This paper shows a systematic process to predict the sensitivity of ride and handling performances to certain important suspension tuning factors: the spring stiffness, anti-roll bar stiffness, and suspension jounce travel (associated with CG height). We apply the North Atlantic Treaty Organization (NATO) double lane change, lateral roll stability and half-round bump and random road with various root mean square (RMS) values for simulations.

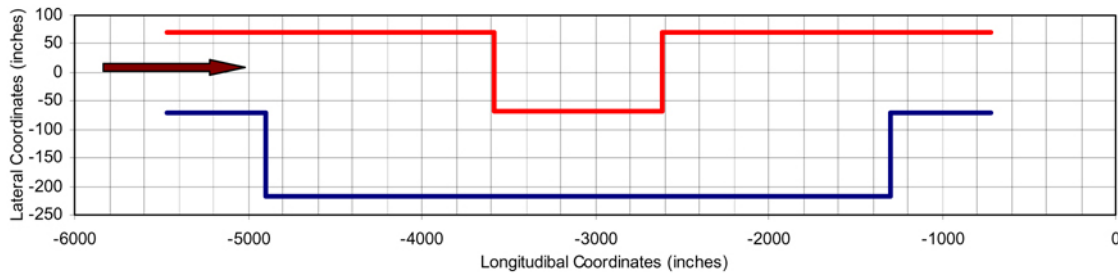


Figure 2. NATO Double-Lane Change Event Path Boundary for Truck-Trailer Combination.

In this paper, the tractor-trailer combination is first modeled using ADAMS/Car, followed by a description of the handling and ride comfort performance evaluation criteria. Full-factorial designs of experiment for the considered design variables are formulated and the sensitivity analysis process is described. Finally the sensitivities of handling and ride comfort performances of the tractor-trailer combinations to the design variables are derived with detailed discussions.

MULTI-BODY DYNAMICS MODEL DESCRIPTION

The objective of this study is to perform ride and handling performance sensitivity analyses of a truck-trailer vehicle combination to the trailer spring stiffness, anti-roll bar stiffness and the initial suspension jounce travel; thus, the accuracy of the vehicle model is critical. A prototype vehicle is chosen such that majority of the vehicle model parameters are available. The truck-trailer combination is illustrated in [Figure 1](#), where all front, rear and trailer suspensions are typical short-long arm (SLA) with the truck having a front rack-pinion steer system.

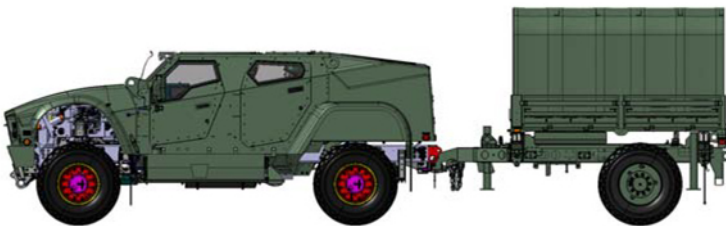


Figure 1. Side-View Layout of Truck-Trailer Combination.

The truck and trailer bodies are modeled as rigid parts and their masses and moments of inertia are derived from the CATIA model. Since the suspension travel and bushing deformations are large in rough road load events, all of the bushings and their forces are assumed to be nonlinear functions of their deflections and linear functions of velocities in the three translational and three rotational directions. All suspension components are represented with rigid bodies in view of their flexible mode frequencies being much higher than the concerned road and steering input

frequencies. The total degrees of freedom of the full vehicle model are 156. The model is first well correlated with the target kinematics and compliance properties before using it for full vehicle simulations.

HANDLING AND RIDE COMFORT PERFORMANCE EVALUATIONS

In this study, various simulation events are applied to evaluate the ride and handling performances of the truck-trailer combination. The six events are (i) NATO double-lane change with 40mph forward velocity, (ii) lateral roll stability with 15mph forward velocity, (iii) 4-inch in-phase single half-round course with 50mph forward velocity, (iv) 10-inch in-phase single half-round course with 5mph forward velocity, (v) 1.0-inch in-phase RMS random course with 30mph forward velocity, and (vi) 2.5-inch in-phase RMS random course with 13mph forward velocity. Among these, events (i) and (ii) are for handling performance and events (iii) through (vi) are for ride performance, respectively.

Based on the nature of the simulation events, the handling performance evaluation variables considered in this study include truck and trailer CG lateral accelerations and roll angle and normal forces at truck and trailer tire-road contact patches. For ride performance simulations, the evaluation variables include absorbed acceleration power [18] at driver/passenger seats for RMS Courses, and the peak accelerations at driver/passenger seats for half-round courses.

The NATO double-lane change path boundary is determined from the overall length (400.14 inches) and width (96 inches) of the truck-trailer combination shown in [Figure 2](#).

<[figure 2](#) here>

DESIGN OF EXPERIMENTS AND SENSITIVITY ANALYSIS PROCESS

There are many design factors affecting the vehicle ride and handling performances. For a truck-trailer combination, the trailer's design may also significantly affect the overall vehicle performance-particularly the handling performance-due to the dynamic coupling between the truck and the trailer

via the fifth wheel or pintle. Among the many factors, we considered the coil spring and anti-roll bar at the trailer suspension to be the most important.

Besides supporting the weight of a vehicle, we know that the coil springs in SLA type suspension control the ride height and keep the tires in contact with the road. Springs directly affect the ride performance that is associated with the ride frequency. Springs also affect the handling performance by controlling the tire patch normal loads that directly affect the tire patch lateral loads. Additionally, the anti-roll bar is essentially a transverse-mounted torsion bar designed to reduce body-roll during turns. The anti-roll bar exerts no influence on the suspension when the left and right wheels bounce in unison (in phase). If vertical movement on one side exceeds the vertical movement on the other, the anti-roll bar exerts an opposing force. Besides its primary function of reducing body-roll, the anti-roll bar will also reduce the combined cornering force and the adhesion limits of the side-by-side tires that the bar acts upon. Consequently, modifying the location and stiffness of the bar can influence the over- or under-steer characteristics of the vehicle.

Furthermore, the trailer jounce travel-that can directly affect the trailer body and payload CG height if the payload is located over the tires-is also considered as an important design factor for ride and handling performances. A change in travel will change the location of the jounce bumper engagement thereby affecting the load-sharing path directly. The CG height of the trailer body and payload controlled by the jounce travel will further affect the inertial moments of the trailer during the highly dynamic lane change event and consequently influence the vehicle handling performance.

Therefore, this study uses a design of experiments (DOE) approach to establish a response surface model of the truck-trailer combination that derives the sensitivity of the ride and handling performance to the considered design parameters. The three trailer design variables that this paper primarily considers are (i) the coil spring stiffness, (ii) anti-roll bar roll stiffness and (iii) the suspension jounce travel that is associated with the trailer body CG height. For setting up the models for simulation, we assumed that the CG heights of trailer and its payload were directly associated with the trailer jounce travel limit but any other changes were not associated with the trailer jounce travel limit.

The sensitivity analysis process is illustrated in [Figure 3](#). As mentioned earlier, there are six simulation events for handling and ride performances and three design variables; these yield 750 simulations for a five-level full factorial design matrix. We chose five levels (based on range of $\pm 30\%$ from the nominal values) so that we could investigate the potential nonlinear effects. In this large scale simulation process, an automatic running script from ADAMS/Car Assembly to response variables and multi-CPU are necessary

for the simulation efficiency. With the automatic simulation process, the number of simulation jobs is not a critical issue; thus, we chose the full factorial in this study. This would provide the best statistic response-surface model for the given number of design variable levels.

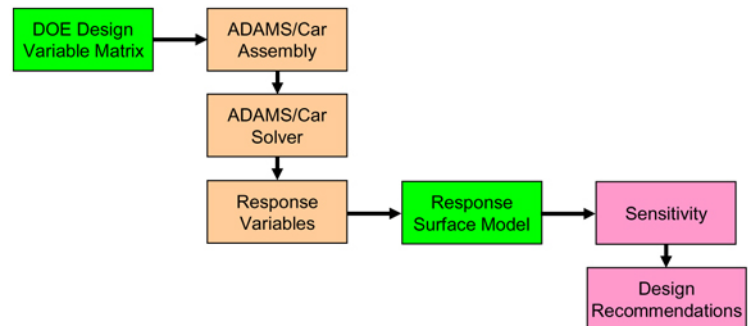


Figure 3. Sensitivity Analysis Process.

SENSITIVITY ANALYSIS RESULTS

After performing the simulation events under each set of design variables, the considered performance evaluation variables mentioned in Section 3 were further derived. Then the response surface model [19, 20] can be estimated to yield the sensitivity of the performance variables to the considered design variables. Since the purpose of this study is to predict the sensitivity at the neighborhood of the nominal values of the design variables, a linear-regression response-surface model [19, 20] is applied to curve-fit the simulation data from multi-body simulations using a least-square approach. The results are illustrated in [Figures 4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21](#), where the plots show 95% global confidence intervals for the predictions as two dash curves.

NATO DOUBLE-LANE CHANGE (DLC) SIMULATION

In this study, the double lane change simulation in accordance with NATO Allied Vehicle Testing Publications (AVTP) 03-160W was used to evaluate the transient dynamics behavior of the truck-trailer combination-where the DLC boundary is illustrated above in [Figure 2](#). The driver's preview path is first optimally tuned to ensure that the nominal designed vehicle can successfully pass the boundary under 40mph. Once the preview path was achieved, it was not changed for other sets of design changes in order to compare the dynamic responses of the vehicle under different design parameters fairly. Furthermore, the response surface model is established based on only those sets of design parameters with which the vehicle can successfully pass (no tire lift-off) the DLC boundary under a given speed.