WP# 2006-2

Tractor-Semitrailer Handling Analysis Using EDVDS and EDVTS

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ABSTRACT

A 2005 HVE Forum Whitepaper compared simulated responses in SIMON and EDVDS against instrumented responses for a tractor-semitrailer combination. The instrumented tests involved a three-axle tractor with an unloaded two-axle trailer in a series of handling maneuvers.

In this research the same series of tests are simulated using EDVTS. Simulated results are compared to experimental results and previously reported EDVDS results. The time response of the following variables is compared graphically:

1. Tractor lateral acceleration
2. Tractor yaw rate

The initial EDVTS results are found to more closely correlate with EDVDS than with SIMON from the past series of tests.

For EDVDS and EDVTS, the steering gain (steering gear ratio) was varied, without changing the shape of the steering profile or changing vehicle parameters to determine if simulated vehicle responses similar to the experimental tests could be found. Simulated results for trailer lateral acceleration were also compared with experimental results for EDVDS.

Modifications were then made to the tire data as used by EDVTS and EDVDS to more closely approximate the lateral tire forces that would have occurred during full-scale tire testing. The maneuvers were rerun in EDVTS and good agreement was found with the experimental data without modification to the steering gear ratio. EDVDS results were improved.

Several observations regarding the lateral and yaw responses of the three HVE tractor-semitrailer simulation programs, SIMON, EDVDS and EDVTS are discussed.

INTRODUCTION

SIMON, EDVDS and EDVTS

SIMON™ (SImulation MOdel Non-linear), EDVDS™ (Engineering Dynamics Vehicle Dynamics Simulator) and EDVTS™ (Engineering Dynamics Vehicle-Trailer Simulator) are all simulation programs utilized within HVE™ (Human-Vehicle-Environment) that have tractor-semiltrailer modeling capability. SIMON and EDVDS are full three-dimensional tractor-semitrailer models. The models describe sprung and unsprung bodies with numerous degrees of freedom. EDVTS™ is a two-dimensional yaw-plane vehicle model with only 4 degrees of freedom, including translation and rotation of the tow vehicle and a trailer articulation angle [1,2,3].

OBJECTIVE

WP 2005-3 compared simulated responses in SIMON and EDVDS against instrumented responses for a tractor-semitrailer combination [4]. The instrumented tests involved a three-axle tractor with an unloaded two-axle trailer in a series of handling maneuvers. Transient and steady-state responses were compared graphically. SIMON responses were found to more closely match the experimental vehicle responses than EDVDS. EDVDS steady-state response magnitudes for lateral acceleration and yaw rate were found to fall appreciably below the experimental results in all tests. SIMON had been found to compare well with the instrumented results in tests up to 0.4 g's of lateral acceleration. In the J-turn test exceeding 0.5 g's, SIMON did not reach the steady-state magnitude of the instrumented vehicle, but fell approximately 17% below as measured at the trailer lateral acceleration.

The 2005 research utilized 'exact' experimental steer tire angles as input and the results were directly reported. That is, the steer profile as measured was modeled in the simulation and not altered to match a response. In this paper, the instrumented vehicle tests are simulated using EDVTS in the same manner. The responses in EDVTS are compared to the responses of EDVDS and the experimental data.

EDVTS is a computer simulation with less fidelity to the real vehicle and far fewer degrees of freedom than the 3D programs. It employs a more basic tire model that utilizes less data than the 3D programs. As such, one might not expect that handling responses in EDVTS would likely correlate with experimental results as well as the 3D programs. In this regard, we develop a pair of hypothesis for this paper.

First hypothesis: *By adjusting only the steering gain, can we bring the simulated responses from EDVTS and EDVDS more in line with the experimental responses in these maneuvers?*

Second hypothesis: *Can a method be developed that applies the tire data from the more sophisticated tire models to EDVTS and EDVDS, in a manner other than the automatic assignment of middle test load parameters, that will more accurately model the real-world vehicle and improve the correlation between simulated and experimental responses?*

TESTING OVERVIEW

Descriptions of the instrumented testing, the test vehicle and the vehicle modeling in HVE were previously described in detail in WP 2005-3. They are briefly summarized here.

VRTC

A continuous research effort in the area of vehicle dynamics has been undertaken at the Vehicle Research and Test Center (VRTC) in East Liberty, Ohio. As part of this research a 1991 Volvo GMC WIA64T 3-axle tractor and a 1992 Fruehauf trailer, (model FB-19.5NF2-53) were instrumented and run through a series of maneuvers.

The results for several of these tests were previously published in a validation effort for VDM RoAD™ and VDANL™ by Milich, et al. [5].

Results of several tests were later published in a validation effort for the National Advanced Driving Simulator (NADS) by Salaani, et al. [6].

The raw experimental data for the tests described in SAE 2001-01-0139 [5] were provided to the authors by the National Highway Traffic Safety Administration (NHTSA) and VRTC. Several of these tests were also referenced within SAE 2003-01-1324 [6].

TEST VEHICLE

INERTIAL and MECHANICAL PROPERTIES

The University of Michigan Transportation Research Institute measured the geometric, inertial and mechanical properties for the 1991 Volvo-GMC WIA64T tractor and 1992 Fruehauf trailer, model FB-19.5NF2-53, and their individual components [7]. Detailed suspension data including roll center height, spring rate and roll steer coefficient was provided for three test loads.

TIRE DATA

The combination vehicle tested by VRTC had General Ameri S380LP 295/75R22.5 tires installed at the steer axle and the trailer axles. The tractor drive axles had Goodyear G167A 295/75R22.5 tires installed [8]. The tire testing was conducted by Smithers Scientific Services, Inc. and UMTRI. The data for the drive tire was referenced in [9] and the steer tire data was provided to the authors by VRTC. Tire data was measured for seven test loads ranging from 25-percent rated load to 200-percent rated load.

TRAILER PAYLOAD

VRTC ran vehicle tests with both an empty trailer and a loaded trailer. This paper addresses the empty trailer runs.

VEHICLE MODELING IN HVE

INERTIAL PROPERTIES

3D SIMULATIONS

As described in WP 2005-3, the vehicles in the current study were modeled for use in the 3D programs utilizing the data provided by UMTRI. The data was used to accurately model the inertial properties for the tractor and semi-trailer sprung and unsprung masses, as well as detailed suspension properties. The 2005 research utilized the same modeled tractor and semitrailer created in the HVE Vehicle Editor without any modifications between the programs.

EDVTS

When a vehicle is created in the HVE Vehicle Editor, and that vehicle will be used in both 3D and 2D programs, there are some issues that may affect the results of a simulation. In the 3D programs the assigned CG location is for the sprung mass body. These programs subtract the unsprung masses from the entered overall weight of the vehicle, which directly affects the calculation of axle loads. 2D programs use the specified CG location to calculate axle loads for the rigid body. In the case of a passenger car, this may have a minor effect. However, when modeling a tractor-semitrailer, particularly an unloaded vehicle, where the unsprung masses are relatively large, the differences in axle loads for the same vehicle as used in SIMON or EDVDS, or as used in EDVTS can be significant.

In this research, separate vehicles were created for use in EDVDS and EDVTS. This was done so that axle loads consistent with the experimental vehicle could be modeled for each program, which required significantly different CG locations. If the 3D vehicles had been used in EDVTS without modifications, the steer axle would have been too heavily loaded for purposes of these tests.

TIRE DATA

The tire data obtained by Smithers Scientific Services, Inc. and UMTRI were used to create a drive tire and steer tire for use in the HVE tractor-semitrailer simulation programs. HVE allows for data to be entered for 3 test loads. Experimental cornering stiffness and frictional data at 25%, 100% and 150% rated load were input into the tire model.

Simulation programs within HVE draw the parameters required for their particular tire force algorithm from the tire data within an HVE modeled vehicle.

SIMON, for example, utilizes data from all three tests loads in its tire model. At a given timestep during the simulation, the vertical load on all tires is calculated. The cornering stiffness assigned to a tire at a timestep is determined through linear interpolation between two test loads.

EDVTS does not have a load-dependent tire model. The cornering stiffness remains constant for a tire throughout the simulation, even though tire vertical loads change in the program during dynamic maneuvers through rigid body load transfer. EDVTS, like other 2D programs in HVE, draws tire data from the middle test load. In the initial tests herein, no changes were made to the tire data in the Vehicle Editor.

The tire load dependency is not active in the EDVDS tire model. In the 2005 research, no changes were made to the vehicle tire data between SIMON and EDVDS.

STEERING RATIO

To determine the steering table input data for SIMON, EDVDS and EDVTS the experimental Pitman arm measurements were multiplied by the vehicle specification steering gear ratio of 20.4. As long as this ratio is consistently used within the steering model, this ratio becomes arbitrary for purposes of simulation.

No HVE tractor-semitrailer simulation programs model torsional compliance at this time. By using the Pitman arm data rather than the steering wheel angle (SWA) data, the steering column compliance is bypassed and does not become a source of error.

An additional factor was calculated in determining the overall steering ratio from the steering wheel to the steer tires to be modeled. The UMTRI data provided measurements of the Pitman arm and the steering arm. From these values, a reduction factor of 1.1 from the Pitman arm angle to the steer tire due to the steering linkage was calculated. Note: This relationship is assumed linear via small angle approximation through the range of steer tire angles experienced in these tests. Thus the overall steering ratio modeled in HVE was 22.67, which includes the steering gear ratio *and* the reduction due to the steering linkage.

ENVIRONMENT

All simulations were run using the HVE proving ground environment with a friction factor of 1.0. All frictional data was contained within the tire models.

VEHICLE TESTING AND SIMULATION

VEHICLE TESTS

VRTC conducted a series of accelerating, handling, braking and combined steering and braking tests [5,6]. There were tests with loaded trailer and empty trailer configurations. This paper addresses the subset of empty trailer handling tests.

The experimental tests simulated in EDVDS and EDVTS are:

1. Slowing increasing steer at 14 m/sec (30 mph)
2. Step steer at 14 m/sec (30 mph)
3. Step steer at 14 m/sec (30 mph)
4. Step steer at 20 m/sec (45 mph)

The lane change tests reported in the previous Whitepaper have not been analyzed herein. It has been determined that the raw data needs to be reevaluated and adjustments made for proper modeling of these tests. This issue was addressed in WP 2005-3.

SIMULATION

DRIVER INPUT TABLE

The measured Pitman arm values were multiplied by the steering gear ratio as per vehicle specifications to calculate the values used for the driver input table in EDVDS and EDVTS. To make the number of steering input values manageable, measured values at 0.5 second intervals were used to generate the steering profile. The 2-Hz data was plotted and compared to the full data set and found to adequately represent the steering input profile.

Graphs comparing the simulated SWA inputs to the experimental SWA can be found in the previous research [4].

THROTTLE

Throttle was input into to the EDVDS and EDVTS models to maintain a velocity profile matching the measured data as closely as possible.

OUTPUT VARIABLES

Numerous output channels were measured by VRTC. The recorded measurements compared to the simulation data within this paper are:

a. Tractor lateral acceleration

b. Tractor yaw rate

c. Trailer lateral acceleration (EDVDS only)

EDVTS does not report trailer lateral acceleration, therefore no comparison is made with the experimental data.

Tractor Lateral Acceleration

A consistent trend in WP 2005-3 and reported here is that the experimental tractor lateral acceleration outpaced, often significantly, the simulated data and the experimental data for the trailer lateral acceleration.

Milich, et al. observed an unusually large difference in the measured and calculated tractor lateral acceleration that was not observed in the trailer [5]. No problem could be found in the sensors or data acquisition hardware. In the published VRTC evaluations of NADS, a similar trend of simulated tractor chassis lateral accelerations reporting lower than the experimental values was observed. The hypothesis was that the torsional rigidity of the simulated tractor chassis was the cause [6]. SIMON, like that version of NADS, does not model torsional compliance in the tractor. EDVDS can model some torsional compliance, but it was not done for purposes of these tests. EDVTS, a 2D program, does not model frame torsional compliance.

Where attempts were made herein to adjust the steering gain to better match the experimental results, the target data was the tractor yaw rate.

MODIFIED STEERING GAIN

The tests were first run with the original steering gear ratio of 22.67. The EDVDS results are the same as those reported in [4]. In all tests, EDVTS response magnitudes, as with EDVDS, fell below those of the experimental responses, although EDVTS responses were closer to the experimental responses.

Next, in all tests the shapes of the steering profiles were held constant (steer tables were not altered), but the steering gain was increased (steering gear ratio reduced) as necessary until the simulated tractor yaw velocity steady-state values reached the experimental values. The response curves were plotted.

SLOWLY INCREASING STEER AT 14 M/SEC (-0.4G)

Figures 1-3 depict the tractor yaw velocity, tractor lateral acceleration, and trailer lateral acceleration for the slowly increasing steer test at a nominal speed of 14 m/sec (30 mph).

Figures 4-6 depict the EDVTS and EDVDS responses after the steering gear ratio was modified. Table 1 summarizes the modified ratios for all tests.

Table 1. Modified Steer Ratios

	Ratios*	
Test	**VTS**	**VDS**
Slowly Increasing Steer at 14 m/s (-0.4 g)	19.0	16.2
Step Steer at 14 m/s (-0.2 g)	19.0	16.7
Step Steer at 14 m/s (-0.3 g)	18.5	16.5
Step Steer at 20 m/s (0.5 g)	15.0	14.0

*Original Ratio 22.67

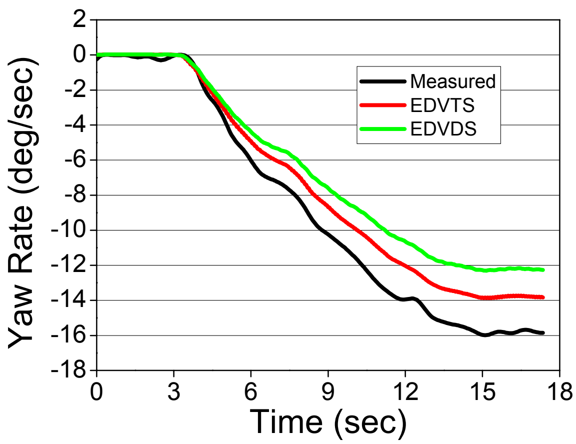

Figure 1. Tractor Yaw Velocity – Slowly Increasing Steer at 14 m/sec (-0.4 g) (Steer Ratios: 22.67)

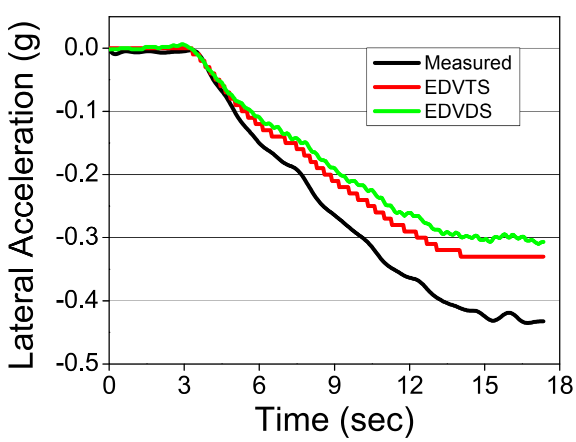

Figure 2. Tractor Lateral Acceleration – Slowly Increasing Steer at 14 m/sec (-0.4 g) (Steer Ratios: 22.67)

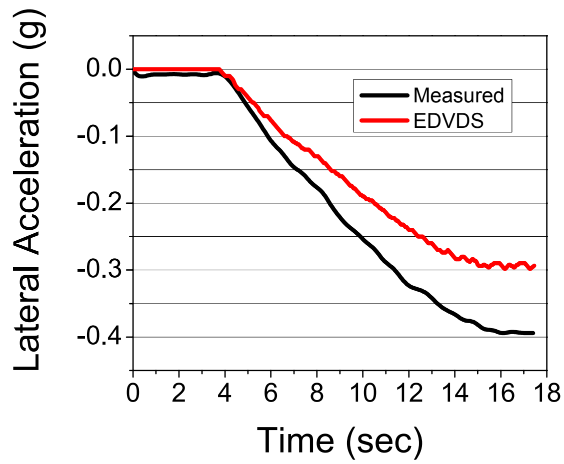

Figure 3. Trailer Lateral Acceleration – Slowly Increasing Steer at 14 m/sec (-0.4 g) (Steer Ratios: 22.67)

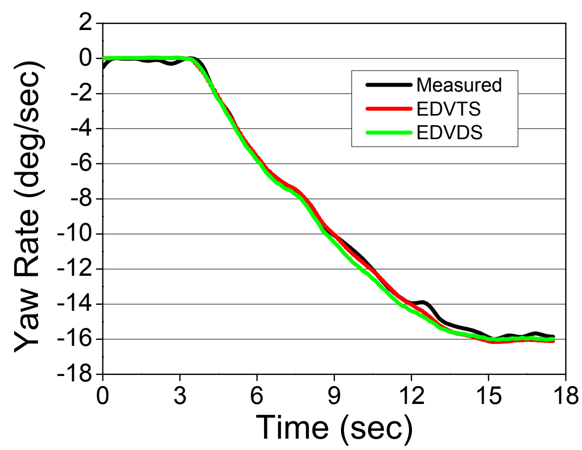

Figure 4. Tractor Yaw Velocity – Slowly Increasing Steer at 14 m/sec (-0.4 g) (Steer Ratios: VTS =19.0, VDS=16.2)

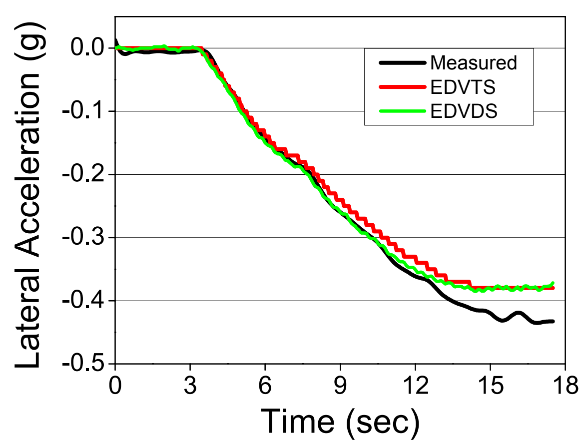

Figure 5. Tractor Lateral Acceleration – Slowly Increasing Steer at 14 m/sec (-0.4 g) (Steer Ratios: VTS=19.0, VDS=16.2)

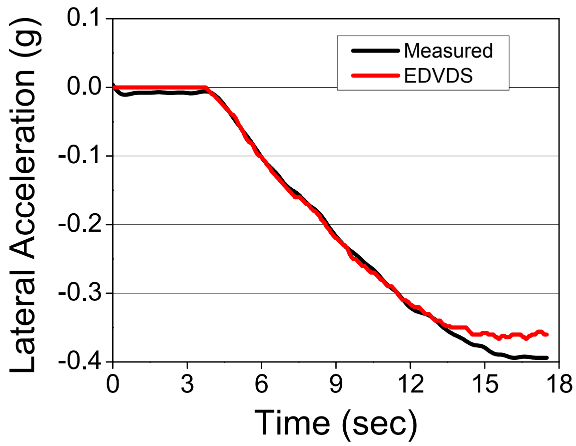

Figure 6. Trailer Lateral Acceleration – Slowly Increasing Steer at 14 m/sec (-0.4 g) (Steer Ratio: VDS=16.2)

STEP STEER (J-TURN) AT 14 M/SEC (-0.2 G)

Figures 7-9 depict the tractor lateral acceleration, tractor yaw velocity and trailer lateral acceleration for a step steer test at a nominal speed of 14 m/sec (30 mph) (-0.2 g test).

Figures 10-12 depict the EDVTS and EDVDS runs after the steering gear ratio has been modified. Table 1 contains the modified ratios for all tests.

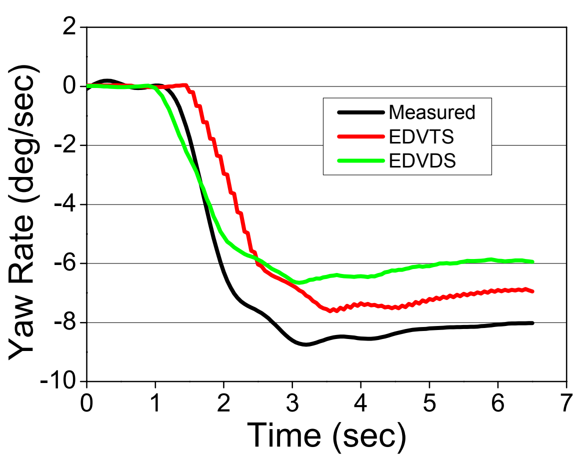

Figure 7. Tractor Yaw Velocity – Step Steer at 14 m/sec (-0.2 g) (Steer Ratios: 22.67)

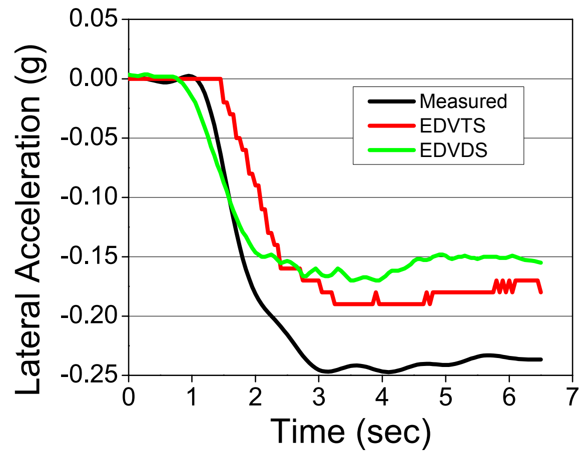

Figure 8. Tractor Lateral Acceleration – Step Steer at 14 m/sec (-0.2 g) (Steer Ratios: 22.67)

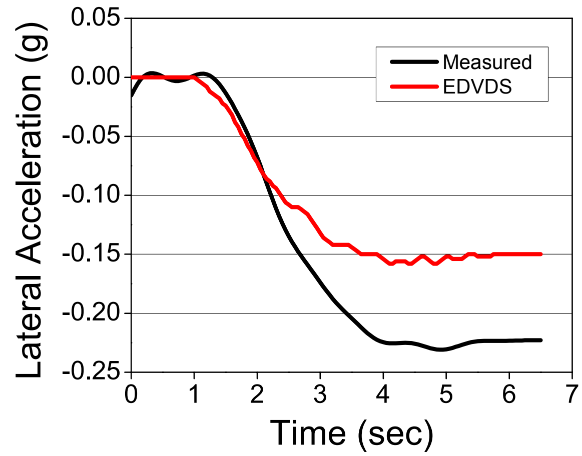

Figure 9. Trailer Lateral Acceleration – Step Steer at 14 m/sec (-0.2 g) (Steer Ratios: 22.67)

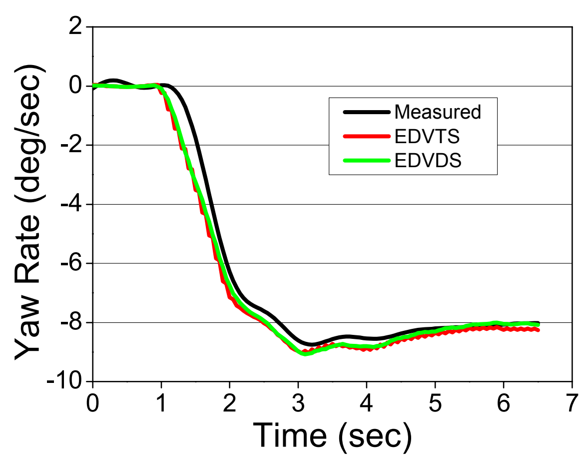

Figure 10. Tractor Yaw Velocity – Step Steer at 14 m/sec (-0.2 g) (Steer Ratios: VTS =19.0, VDS=16.7)

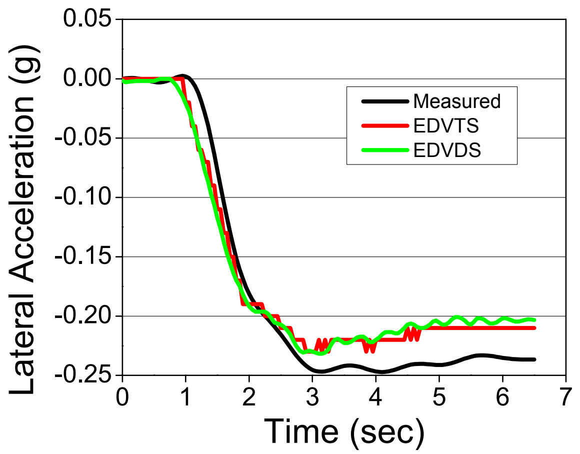

Figure 11. Tractor Lateral Acceleration – Step Steer at 14 m/sec (-0.2 g) (Steer Ratios: VTS =19.0, VDS=16.7)

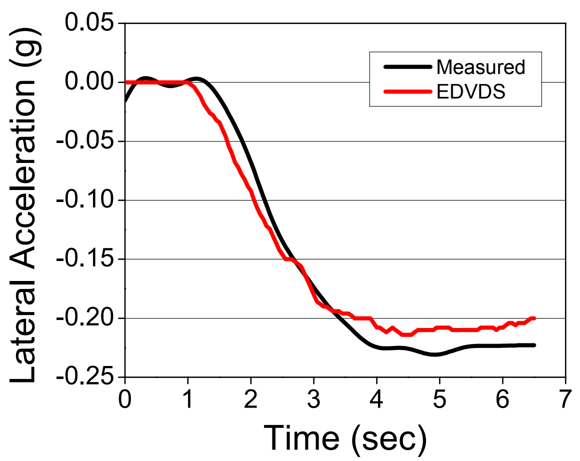

Figure 12. Trailer Lateral Acceleration – Step Steer at 14 m/sec (-0.2 g) (Steer Ratio: VDS=16.7)

STEP STEER (J-TURN) AT 14 M/SEC (-0.3 G)

Figures 13-15 depict the tractor lateral acceleration, tractor yaw velocity and trailer lateral acceleration for a second step steer test at a nominal speed of 14 m/sec (30 mph) (-0.3 g test).

Figures 16-18 depict the EDVTS and EDVDS runs after the steering gear ratio has been modified. Table 1 contains the modified ratios for all tests.

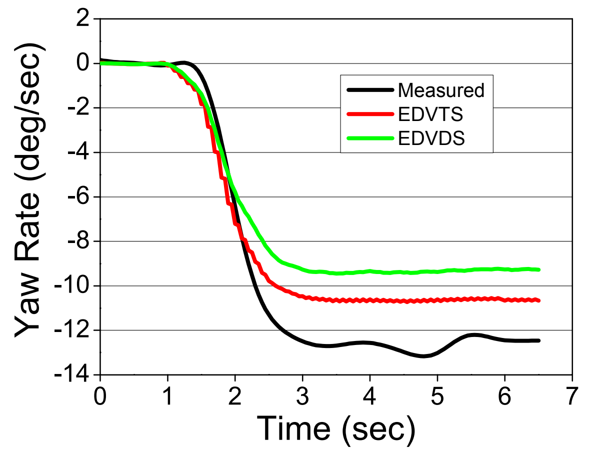

Figure 13. Tractor Yaw Velocity – Step Steer at 14 m/sec (-0.3 g) (Steer Ratios: 22.67)

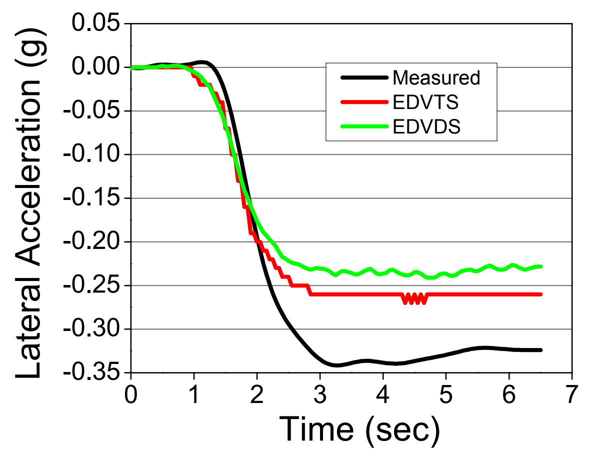

Figure 14. Tractor Lateral Acceleration – Step Steer at 14 m/sec (-0.3 g) (Steer Ratios: 22.67)

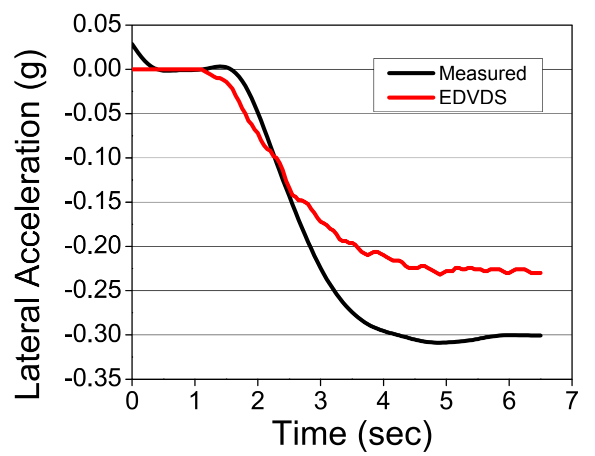

Figure 15. Trailer Lateral Acceleration – Step Steer at 14 m/sec (-0.3 g) (Steer Ratios: 22.67)

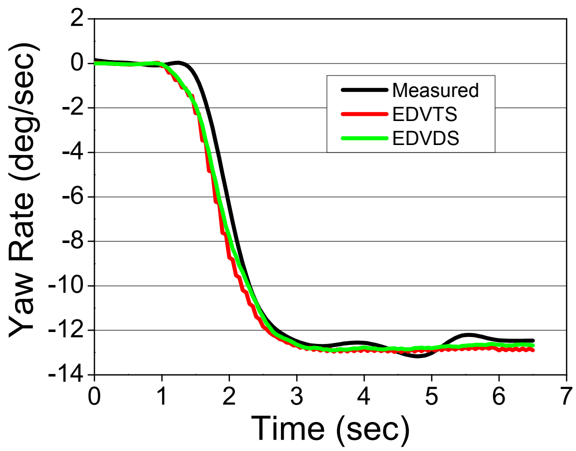

Figure 16. Tractor Yaw Velocity – Step Steer at 14 m/sec (-0.3 g) (Steer Ratios: VTS =18.5, VDS=16.5)

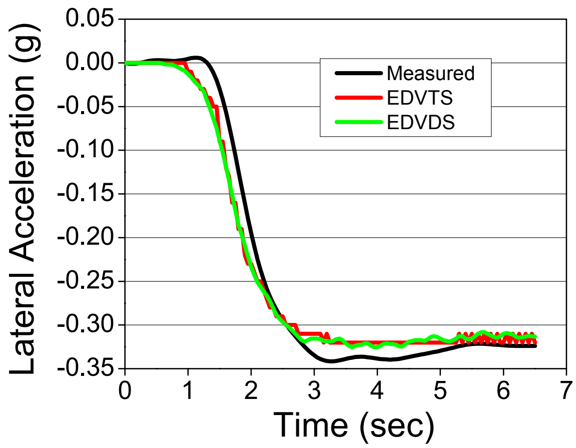

Figure 17. Tractor Lateral Acceleration – Step Steer at 14 m/sec (-0.3 g) (Steer Ratios: VTS =18.5, VDS=16.5)

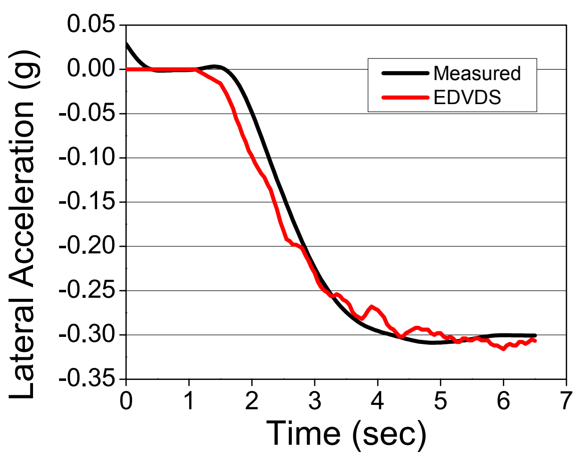

Figure 18. Trailer Lateral Acceleration – Step Steer at 14 m/sec (-0.3 g) (Steer Ratios: VTS =18.5, VDS=16.5)

STEP STEER AT 20 M/SEC (0.5 G)

Figures 19-21 depict the tractor lateral acceleration, tractor yaw velocity and trailer lateral acceleration for the step steer test at a nominal speed of 20 m/sec (45 mph).

Figures 22-24 depict the EDVTS and EDVDS runs after the steering gear ratio has been modified. Table 1 contains the modified ratios for all tests.

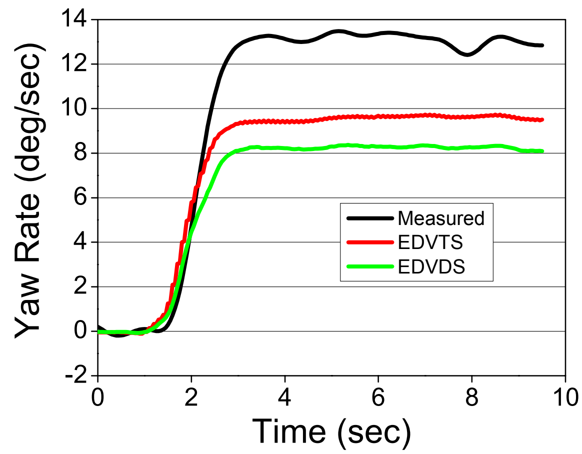

Figure 19. Tractor Yaw Velocity – Step Steer at 20 m/sec (0.5 g) (Steer Ratios: 22.67)

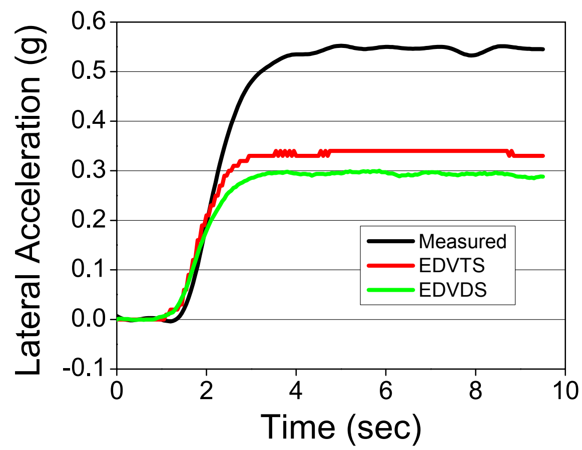

Figure 20. Tractor Lateral Acceleration – Step Steer at 20 m/sec (0.5 g) (Steer Ratios: 22.67)

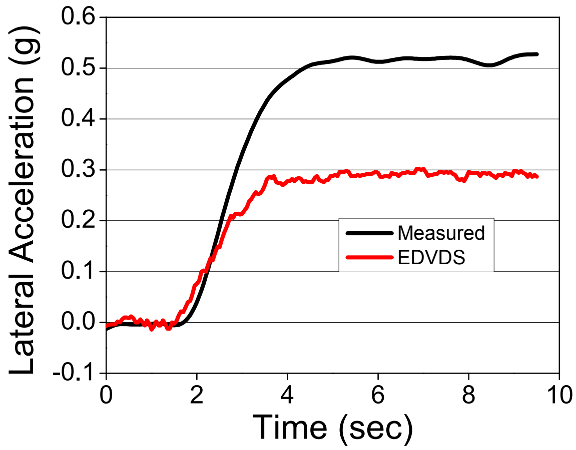

Figure 21. Trailer Lateral Acceleration – Step Steer at 20 m/sec (0.5 g) (Steer Ratios: 22.67)

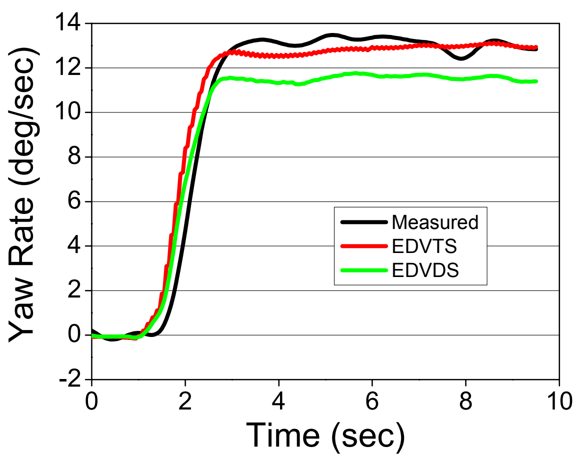

Figure 22. Tractor Yaw Velocity – Step Steer at 20 m/sec (0.5 g) (Steer Ratios: VTS =15.0, VDS=14.0)

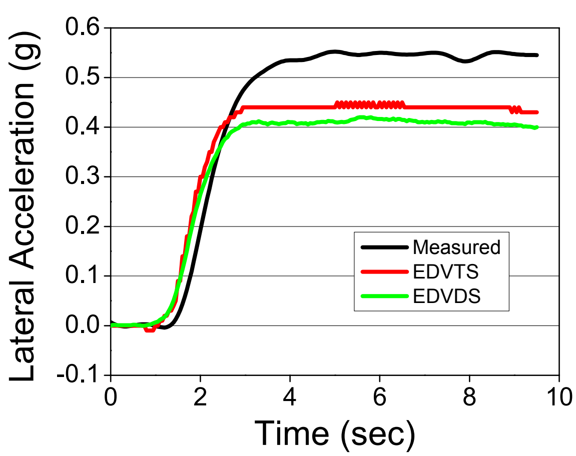

Figure 23. Tractor Lateral Acceleration – Step Steer at 20 m/sec (0.5 g) (Steer Ratios: VTS =15.0, VDS=14.0)

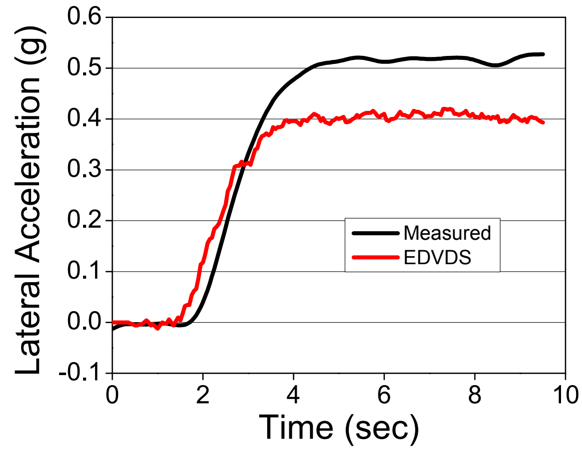

Figure 24. Trailer Lateral Acceleration – Step Steer at 20 m/sec (0.5 g) (Steer Ratios: VDS=14.0)

MODIFIED CORNERING STIFFNESS

EDVTS and other 2D simulation programs utilize a constant cornering stiffness as a principal tire parameter. Unlike the real-world vehicle or 3D simulation programs with more sophisticated tire models, in a 2-D program, the cornering stiffness will not change with changes in vertical loads on a tire. EDVDS also uses a constant cornering stiffness in the current tire model.

Cornering stiffness (lb/deg) determines the magnitude of lateral tire force that will be generated per degree of slip angle for a tire. In reality, cornering stiffness increases with increased vertical load. However, the increase in lateral force is not necessarily proportional to the increase in vertical load. So while cornering stiffness increases with vertical load, cornering coefficient (lb/deg/lb or 1/deg) decreases. Moreover it can decrease non-linearly. The result can be a net loss of lateral force on an axle due to lateral load transfer.

<u>PROPOSED METHOD</u>

When using a program that utilizes constant cornering stiffness in the tire force algorithm, there are some suggested steps that can increase the accuracy of the simulation results to the real-world situation to be modeled.

1. Determine the static axle loads and model them into the subject program accurately. As mentioned earlier, a vehicle taken out of the Vehicle Editor that was specifically designed for use with a 3D

simulation program may not have the appropriate axle weights for analysis with a 2D program. Unloaded tractor-semitrailers are a common example. Modify the vehicle CG positions to get the correct axle loads.

2. Determine the appropriate cornering stiffness for the static tire loads. HVE tires have data, including cornering stiffness, for three test loads. The 2D programs, like EDVTS, will utilize the data from the middle test load. If the test load is not similar to the actual vertical load, the cornering stiffness will not be accurate. Issues like this are more likely to arise when the heavy vehicle with heavy truck tires is not loaded. If the loads are not similar, then one can manually perform a linear interpolation within the HVE tire data to determine a more accurate cornering stiffness for the tire vertical load.

If you are using HVE-2D, where there is only one cornering stiffness value reported, then linear interpolation is not possible. One way to check the feasibility of the value being used is to check the cornering coefficient. Dividing the cornering stiffness by the vertical load on the tire will yield the cornering coefficient. One source of data for cornering coefficient for heavy truck tires by UMTRI indicates a range for new radial tires of approximately 0.11 to 0.16 [10]. Note this published data is for truck tires at rated load. Lower loads will have a higher cornering coefficient and higher loads a lower coefficient.

3. One can further improve the cornering stiffness application by estimating or analyzing the dynamic load shift. This can be done by manual calculation of the rigid body load transfer for an estimate of the lateral acceleration, or can be done iteratively through simulation. If the dynamic vertical loads remain between two test loads, there is no need for further modification as the net result will be the same.

However, if the dynamic load shift acts in such a way that the tires on opposite sides of an axle have vertical loads that fall on opposite sides of a test load within the available tire data, maintaining the same cornering stiffness as the statically loaded vehicle may not be the most accurate way to model the vehicle. An alternative would be to perform the linear interpolation for the load on each side of the axle and average the two resulting cornering stiffness values. By modeling in this way, the net loss in cornering force on an axle due to lateral load transfer can be approximated.

EXAMPLES

Figures 25 and 26 depict the cornering stiffness data for three test loads for the steer tire and drive tire used in these tests, respectively. (Note: The steer tires were used on the trailer as well). The tire algorithm in SIMON utilizes the data at the three loads through linear interpolation. EDVTS and EDVDS would automatically utilize the data from the middle test load, which would be a cornering stiffness of 805 lb/deg for the steer tire, and 826 lb/deg for the drive tires. But the dual tires on the unloaded tractor-semitrailer each have less than 2000 lbs of static vertical load. Through the use of linear interpolation, more appropriate cornering stiffness values for the static loads were calculated and are found in Table 2.

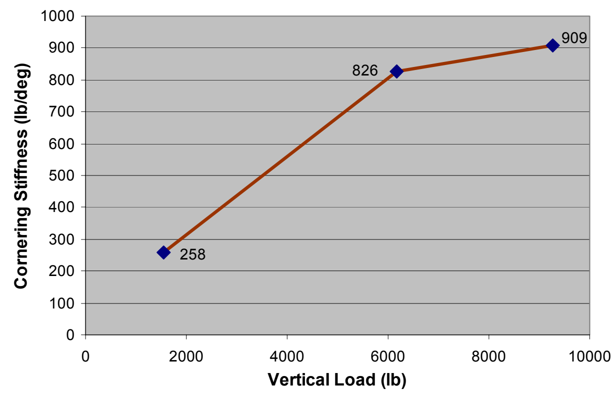

Figure 25. Steer Tire Cα for Three Test Loads

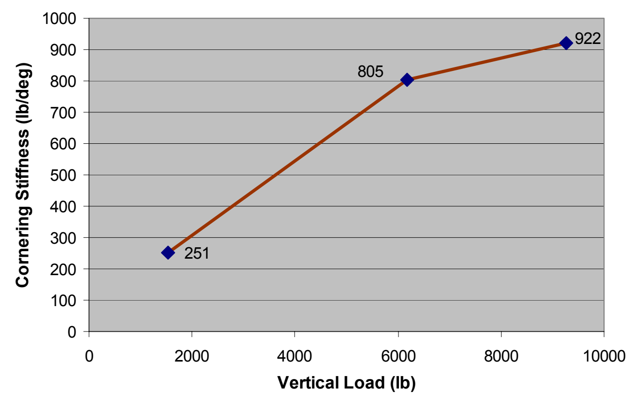

Figure 26. Drive Tire Cα for Three Test Loads

Table 2. EDVTS/EDVDS Cα for Static Tire Loads

	Tire Type	Load/Tire (lb)	Cα (lb/deg)
Axle 1	Steer	5510	744
Axles 2-3	Drive	1742	275
Axles 4-5	Steer	1515	244

The cornering stiffness for Axle 1 can be further modified specifically for each of the four test configurations. Through an iterative process the approximate dynamic loads in the maneuvers can be determined. (Obviously there is an advantage in knowing what type of maneuver is to be followed). The right and left steer axle vertical loads for EDVTS and EDVDS simulations in all tests are observed to fall on opposite sides of the middle test load in Figure 25. Therefore the cornering stiffness for each tire can be determined and the average calculated. Table 3 contains the Axle 1 cornering stiffness values used for each test.

Table 3. Cα for Steer Tire Dynamic Loads

	Cα (lb/deg)	
Test	**VTS**	**VDS**
Slowly Increasing Steer at 14 m/s (-0.4 g)	656	704
Step Steer at 14 m/s (-0.2 g)	704	743
Step Steer at 14 m/s (-0.3 g)	675	718
Step Steer at 20 m/s (0.5 g)	632	675

The tests with the modified cornering stiffness values were performed with the original steering gear ratio (22.67). The results of the EDVTS simulations with the modified cornering stiffness values matched the experimental responses reasonably well and were a good match to SIMON. EDVDS responses improved in the first three tests, but still fell below the experimental responses and would have required some additional steer gain to correlate better with the test data. In the 45 MPH step steer test reaching 0.5 g's, the EDVDS response became yaw divergent.

SLOWLY INCREASING STEER AT 14 M/SEC (-0.4G)

Figures 27-29 depict the tractor yaw velocity, tractor lateral acceleration and trailer lateral acceleration responses for the slowly increasing steer test at a nominal speed of 14 m/sec (30 mph).

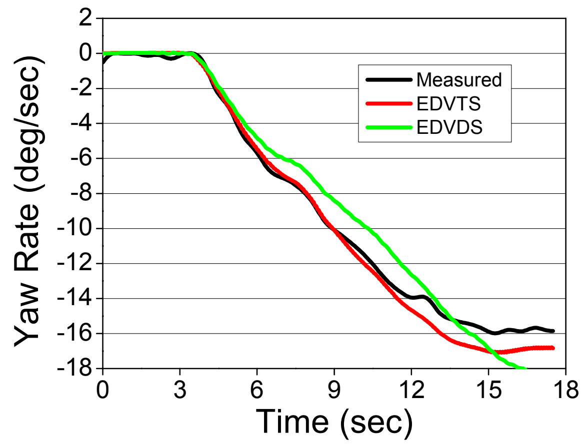

Figure 27. Tractor Yaw Velocity – Slowly Increasing Steer at 14 m/sec (-0.4 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

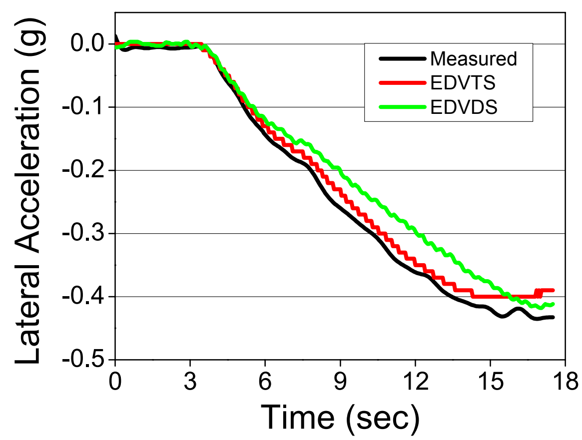

Figure 28. Tractor Lateral Acceleration – Slowly Increasing Steer at 14 m/sec (-0.4 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

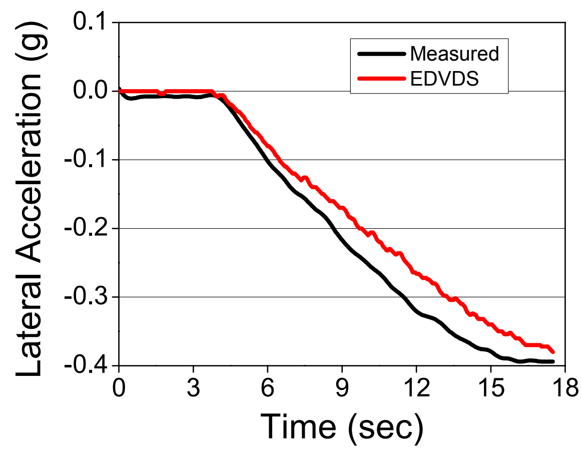

Figure 29. Trailer Lateral Acceleration – Slowly Increasing Steer at 14 m/sec(-0.4 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

STEP STEER (J-TURN) AT 14 M/SEC (-0.2 G)

Figures 30-32 depict the tractor yaw velocity, tractor lateral acceleration, and trailer lateral acceleration for a step steer test at a nominal speed of 14 m/sec (30 mph).

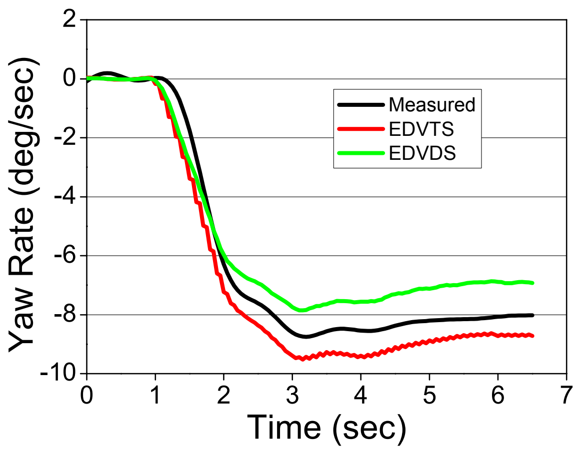

Figure 30. Tractor Yaw Velocity – Step Steer at 14 m/sec (-0.2 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

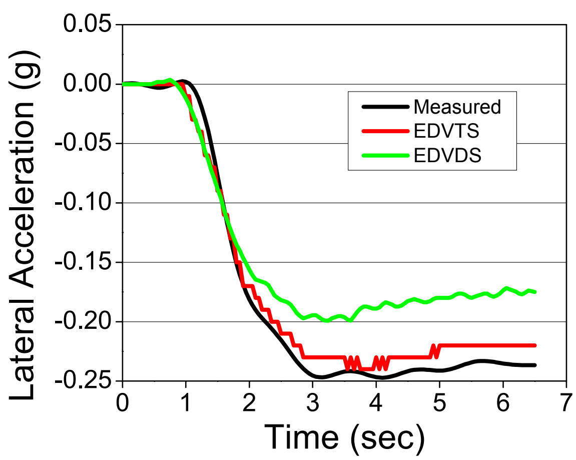

Figure 31. Tractor Lateral Acceleration – Step Steer at 14 m/sec (-0.2 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

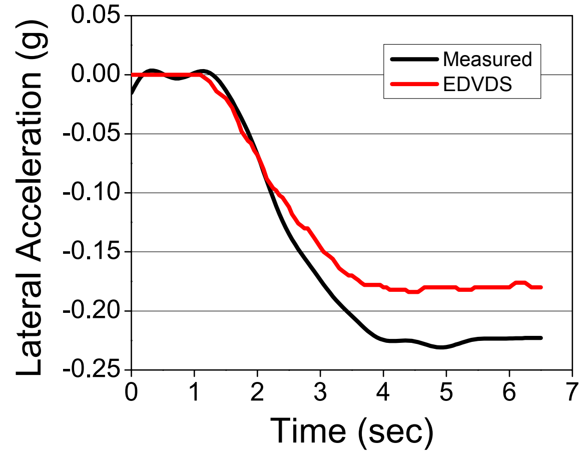

Figure 32. Trailer Lateral Acceleration – Step Steer at 14 m/sec (-0.2 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

STEP STEER (J-TURN) AT 14 M/SEC (-0.3 G)

Figures 33-35 depict the tractor yaw velocity, tractor lateral acceleration, and trailer lateral acceleration for a step steer test at a nominal speed of 14 m/sec (30 mph).

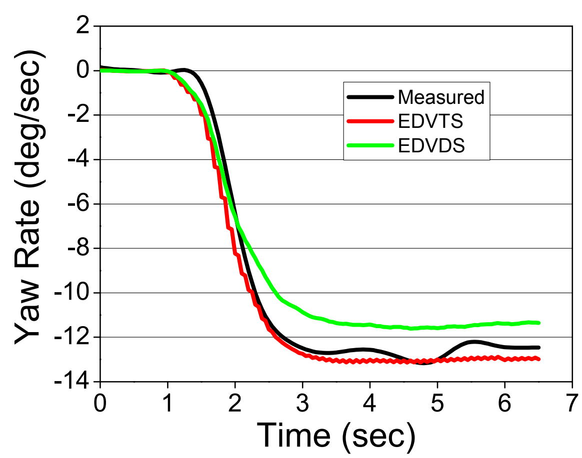

Figure 33. Tractor Yaw Velocity – Step Steer at 14 m/sec (-0.3 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

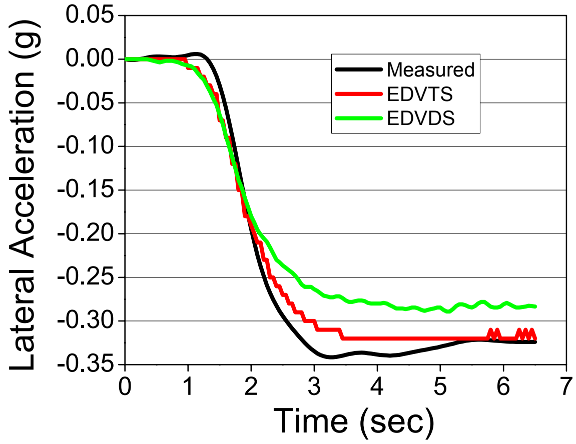

Figure 34. Tractor Lateral Acceleration – Step Steer at 14 m/sec (-0.3 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

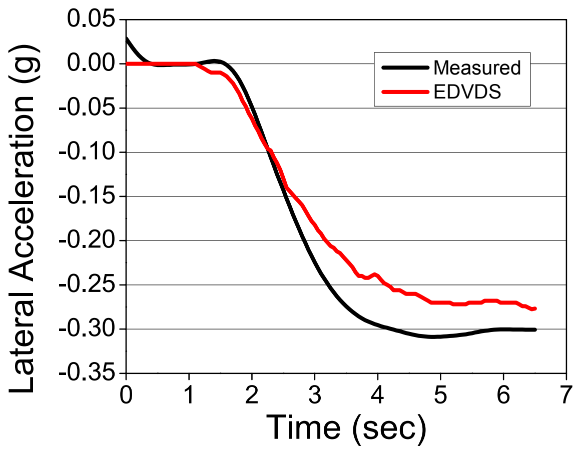

Figure 35. Trailer Lateral Acceleration – Step Steer at 14 m/sec (-0.3 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

STEP STEER AT 20 M/SEC (0.5 G)

Figures 36-38 depict the tractor yaw velocity, tractor lateral acceleration, and trailer lateral acceleration for the step steer test at a nominal speed of 20 m/sec (45 mph).

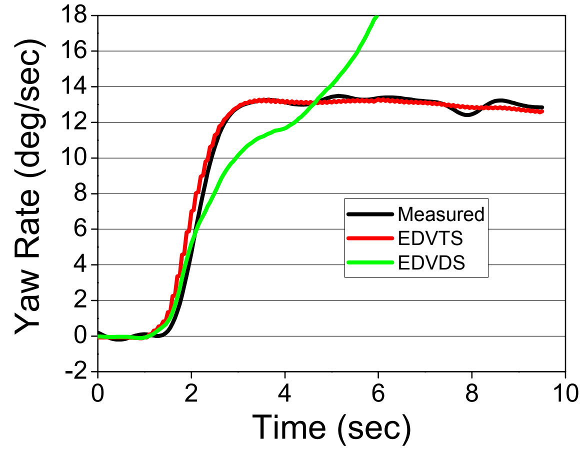

Figure 36. Tractor Yaw Velocity – Step Steer at 20 m/sec (0.5 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

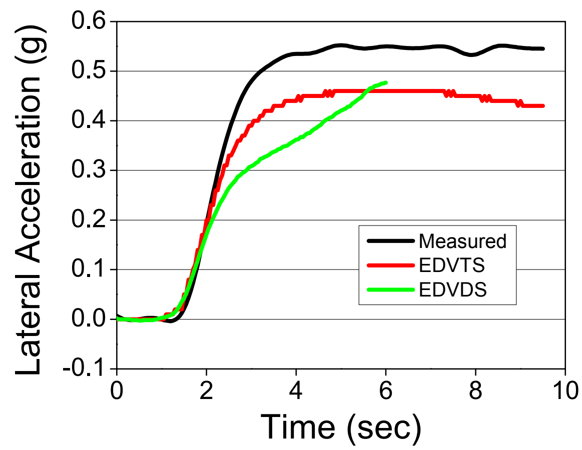

Figure 37. Tractor Lateral Acceleration – Step Steer at 20 m/sec (0.5 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

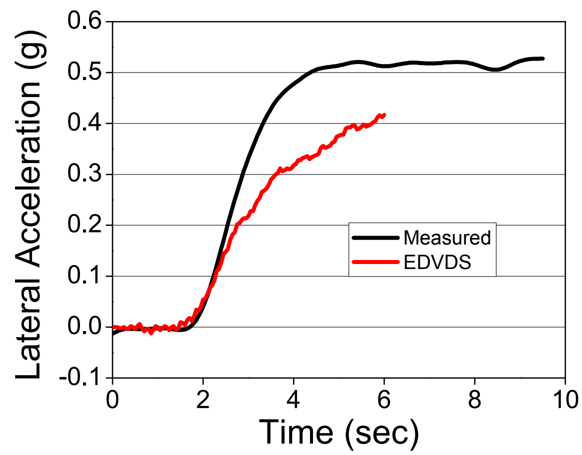

Figure 38. Trailer Lateral Acceleration – Step Steer at 20 m/sec (0.5 g) (Steer Ratio: 22.67). Modified Cornering Stiffness

CONCLUSIONS

The SIMON responses from WP 2005-3 were previously shown to correlate well with the experimental data for the unloaded tractor-semitrailer for the maneuvers reported up to approximately 0.4 g, which spans the 'normal' operating range of a tractor-semitrailer and approaches the lateral and roll limits.

EDVDS steady-state responses were consistently of lesser magnitude than both the experimental results and the SIMON response. The unloaded EDVDS vehicle, which incorporated the middle test load from the tire data, had a higher than representative cornering stiffness at the drive axle and trailer tire positions. This resulted in over-represented lateral tire forces at these positions and a more understeer vehicle than the real-world vehicle. This observation is true for the vehicle configurations and tests reported here, but not necessarily for all vehicle configurations. In loaded configurations, the default cornering stiffness values used by EDVDS would be more representative of the real-world vehicle.

Initial EDVTS responses to these tests were similar to EDVDS responses. EDVTS results were slightly closer to the experimental results. Since both programs utilized the same cornering stiffness data, the similarity in results is predictable. That is, the EDVTS vehicle was also more understeer than the real-world vehicle.

When using a vehicle from the HVE Vehicle Editor in both 2D and 3D heavy vehicle simulations with unloaded vehicles, attention should be paid to the static axle loads. In these vehicle configurations, the same vehicle will report significantly higher steer axle loads in the 2D program, resulting in a more understeer vehicle.

Both EDVDS and EDVTS responses could be brought into good agreement with the experimental responses by increasing the steer gain (decreasing the ratio) in the tests below 0.4 g. The responses of the higher-g test (0.5 g) has been found to be difficult to replicate in all simulations to date.

EDVDS and EDVTS results were improved with initial modeling improvements for the unloaded vehicle. Constant cornering stiffness values appropriate for the static axle loads were input into the model. At the steer axle, cornering stiffness values more applicable to the load transfers experienced at the steady-state lateral accelerations were determined and input into the model. This change was made at the steer axle because the dynamic loads on either side of the axle fell on opposite sides of a test load in the tire data. By modeling in this way, the net reduction in cornering force at the axle due to lateral load transfer was approximated. No changes were made to the steering gain or inputs. EDVTS results correlated well with SIMON results, and the experimental results in the first three tests. Again, as with SIMON in the highest-g test (0.5 g), the steady-state values fell below the experimental values. EDVDS results improved in the first three tests, but fell below the EDVTS, SIMON and experimental results. An increase in steering gain would be required to bring the EDVDS model into better agreement. Also, at the highest-g test (0.5 g), the EDVDS vehicle became yaw divergent.

In step steer maneuver simulations, the EDVTS and EDVDS simulated response lag times were generally slightly less (≈0.1-0.2 sec) than the experimental data.

REFERENCES

1. SIMON User's Manual, Version 1, Engineering Dynamics Corp., January 2001
2. EDVDS User's Manual, Version 1, Engineering Dynamics Corp., January 2001
3. EDVTS User's Manual, Fifth Edition, Engineering Dynamics Corp., August 2004.
4. Fittanto, Daniel A., and Senalik, C. Adam, "SIMON and EDVDS Validation Study: Steady-state and Transient Handling", WP# 2005-3, 2005 HVE Forum, Miami, FL
5. Milich, Edward P., Fife, Neil F. and Guenther, Dennis A., "A Validation Study of Dynamics Simulations for Heavy Truck Handling Maneuvers", SAE 2001-01-0139
6. Salaani, Mohamed Kamel, Grygier, Paul Al, and Gary J. Heydinger, "Evaluation of Heavy Tractor-Trailer Model used in the National Advanced Driving Simulator", SAE 2003-01-1324
7. Winkler, C.B., Bogard, S.E., Karamihas, S.M., "Parameter Measurements of a Highway Tractor and Semitrailer", Final Technical Report UMTRI-95-47, University of Michigan Transportation Research Institute, December 1995
8. Pottinger, Marion G., Pelz, Wolfgang, "Free-Rolling Cornering, Straight-Line Braking, and Combined Cornering and

Braking for a 295/75\275/80R22.5 Drive Axle Tire, NHTSA Contract DTNH22-92-C-17189, SAE Cooperative Research, January 31, 1997
9. Pottinger, Marion G., Pelz, Wolfgang, Pottinger, Derek M., Winkler, Christopher B., “Truck Tire Wet Traction: Effects of Water Depth, Speed, Tread Depth, Inflation, and Load”, SAE 96153
10. Factbook of the Mechanical Properties of the Components for Single-Unit and Articulated Heavy Trucks, Prepared for NHTSA by the University of Michigan Transportation Institute, PB87-228433, December 1986
11. Fittanto, Daniel A., “Yaw Stability of Single Versus Tandem Axle Tractors”, WP# 2002-1, 2002 HVE Forum, New Orleans, LA
12. Salaani, Mohamed Kamel, Heydinger, Gary J., and Paul A. Grygier, “Heavy Tractor-Trailer Vehicle Dynamics Modeling for the National Advance Driving Simulator”, SAE 2003-01-0965
13. Day, Terry D., "Validation of the SIMON Model for Vehicle Handling and Collision Simulation - Comparison of Results with Experiments and Other Models," SAE 2004-01-1207, Terry D. Day, Engineering Dynamics Corp., 2004
14. Day, Terry D., “Differences Between EDVDS and Phase 4,” SAE Technical Paper 1999-01-0103
15. MacAdam, C.C., Fancher, P.S., Hu, G.T., Gillespie, T.D., "A Computerized Model For Simulating the Braking and Steering Dynamics of Trucks, Tractor-Semitrailers, Doubles, and Triple Combinations, Users' Manual - Phase 4," UM-HSRI 80-58, September 1980.
16. Clark, B. A., Ruhl, R. L., Strauss, Mark G., Mahal, Tim, and Dan A. Fittanto, “Dynamics and Roll Stability of a Loaded Class 8 Tractor-Livestock Semi-Trailer”, SAE Technical Paper 1999-01-3732, 1999.
17. Day, Terry D., "An Overview of the HVE Vehicle Model," SAE 950308, Engineering Dynamics Corp., 1995
18. Day, Terry D., "SIMON: A New Vehicle Simulation Model for Vehicle Design and Safety Research," SAE 2001-01-0503, Terry D. Day & Syndey G. Roberts, Engineering Dynamics Corp., & Allen R. York, A.R.York Engineering, 2001.
19. "EDVDS Validation Study", Engineering Dynamics Corporation, Beaverton, OR 1998
20. Fittanto, Daniel A., "Dynamics and Roll Stability of a loaded Class 8 Tractor-Livestock Semi-Trailer: An EDVDS Application", WP# 2000-4, 2000 HVE Forum, San Diego, CA

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