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M. Mark Leonard, Wesley D. Grimes
Mecanica Scientific Services Corporation

Marco Garcia
U-Haul International

Jason Jupe
Rimkus

ENGINEERING DYNAMICS COMPANY, LLC

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Abstract

Forty (40) SAE J2664 test runs were performed with two different vehicle-trailer combinations on a closed test track, then these test runs were simulated using Engineering Dynamics Corporation's EDVTS and SIMON modules. The SAE J2664 test data was analyzed to determine the combination damping ratio and damped frequencies of the vehicle combinations. Each test run was simulated in the EDVTS and SIMON modules with the HVE-default yaw moment of inertia and the test yaw moment of inertia for the trailers. The simulation data was then analyzed the same way as the test data to determine the combination damping ratio and damped frequencies. The results of the actual testing and simulations were then compared. The comparison of the simulation models between the HVE default MOI and measured MOI showed a difference in the damping ratio, damped frequency, and the critical speed of the combination. There was also a difference between the test data and the simulation data. Both simulation modules are adequate to compare how changes to vehicle and trailer parameters will affect damping ratio, damped frequency, and critical speed. In other words, the simulations are adequate to analyze the trends when parameters are changed. The simulations did not accurately predict the actual damping ratio, damped frequency, or critical speed of the combinations using default vehicle parameters.

Introduction

Expanding the work of Klein, et al (1979), SAE International developed standard J2807, Performance Requirements for Determining Tow-Vehicle Gross Combination Weight Rating and Trailer Weight Rating, weight ratios for trailer towing, and assists vehicle and trailer manufacturers in ratings for similar vehicle platforms (i.e.: pickup trucks) [1] and SAE J2807 references SAE J2664, Trailer Sway Response Test Procedure, which establishes a consistent procedure for conducting sway-mode stability tests. This testing is used to determine the yaw-oscillation response, or damping ratio, of a vehicle-trailer combination [2]. To date, the primary method for J2807 compliance is real world testing.

Computer based simulation software has provided accident investigators, reconstructionists, and vehicle designers with a vital tool to model and analyze the dynamics of motor vehicles while potentially avoiding the time and cost of real-world testing. Engineering Dynamics Company LLC (EDC) Human, Vehicle, Environment (HVE) software is one such software that has aided the accident reconstruction community [1]. Two modules inside the HVE software, EDVTS (Vehicle -Trailer Simulator) and SIMON (SImulation MOdel Non-linear), can simulate combination-vehicle dynamic maneuvers. However, the simulations are only as valid as their ability to reproduce the real-world situation that they propose to simulate or to analyze trends based on different vehicle parameters. A popular method to validate simulation software is by comparing the simulated results to real-world instrumented testing. The present paper proposes to compare the simulated EDVTS and SIMON results to actual real-world testing of thirty-nine SAE J2664 test runs for two different vehicle-trailer combinations.

Combination Sway-Mode Stability

The SAE J2807 Recommended Practice, Performance Requirements for Determining Tow-Vehicle Gross Combination Weight Rating and Trailer Weight Rating was first published in 2008. This J-document established tow-vehicle performance requirements for combination vehicle acceleration, gradeability, understeer, trailer sway response, braking and park brake at GCWR, and tow-vehicle hitch/attachment structure of the Trailer Weight Rating.[2]. For this paper, only the trailer sway response tests were utilized. This trailer sway response section used SAE J2664, Trailer Sway Response Test Procedure for the test and data analysis procedures. The SAE J2664 standard established a consistent procedure for conducting sway-mode stability tests. This test data was then used to determine the yaw-oscillation response, or damping ratio, of a vehicle-trailer combination.

For a SAE J2664 test, each test run is initiated from a steady-state driving condition. This means the steering wheel angle (SWA) should be approximately 0 degrees ($\pm$10 degrees) and a constant vehicle speed. To have a valid test run, the tow vehicle speed, trailer articulation angle, and steering wheel input must be within the specified ranges [3]. At least three target test speeds are used, 72 kph (45 mph), 88 kph (55 mph), and 105 kph (65 mph), along with steering in each direction. A minimum of three valid test runs at each target test speed and steering direction are required to ensure data integrity.

The damping ratio estimates from the trailer articulation test data can be evaluated using one of three different methods [4]. These methods are the Equation Fit Method, Average Peak-to-Peak Method (Logarithmic Decrement Method), and the ISO Method (Logarithmic Decrement Method). In the Equation Fit method, the data is fit to the solution of a viscously damped, free-vibration equation of motion for the under-damped case (damping ratio, ζ, <1) and uses the equation shown in Equation 1.

$$y = y_{SS} + C_1 e^{-\zeta \varpi_n t} \sin(\sqrt{1-\zeta^2}\,\varpi_n t) + \ldots + C_2 e^{-\zeta \varpi_n t} \sin(\sqrt{1-\zeta^2}\,\varpi_n t) \quad (1)$$

The Peak-to-Peak method is a logarithmic decrement method which uses a number of free vibration peak-to-peak amplitudes from the test data to determine an intermediate value, N, shown in Equation 2. The intermediate value is then used to estimate the damping ratio (ζ) by averaging the damping ratio for the number of free peak-to-peak amplitudes, shown in Equation 3.

$$N_{i_{t\to n-1}} = \frac{ln\frac{X_i}{X_{i+1)}}}{\pi} \quad (2)$$

$$\zeta = \frac{\sum_{i=1}^{n-1}\sqrt{\frac{N_i^2}{(1+N_1^2}}}{n-1} \quad (3)$$

The last method that can be used to calculate damping ratio is the method outlined in ISO Standard 9815 [5]. This method is essentially the same as the peak-to-peak method, however, it uses a slightly different equation and averaging method, as indicated in equations 4 and 5.

$$N = \frac{1}{n-1}[\sum_{i=1}^{n-1}\frac{X_i}{X_{i+1}}] \quad (4)$$

$$\zeta = \frac{lnN}{\sqrt{\pi^2+(lnN)^2}} \quad (5)$$

Test Vehicles, Trailers, and Data

The testing was performed at Exponent's Test and Engineering Center in Phoenix, Arizona. Several different tests were performed on each combination, including sway-mode stability, understeer, straight-line braking, and level acceleration. Only the sway-mode stability test data were used for this paper.

Prior to testing on the track, each trailer was measured to determine its yaw moment of inertia (MOI). The procedure to determine the yaw MOI was similar to the procedure performed by Richard Klein and Henry Szostak in the late 1970's study for the National Highway Traffic Safety Administration [6].

Two instrumented vehicle combinations were tested. The instrumentation on each combination included a speed transducer, steering wheel angle transducer, 3-axis accelerometer, 3-axis rate transducer, brake pedal force transducer, hitch ball load cell, and articulation angle transducer. The first combination was a 2015 Dodge Durango sport-utility vehicle (SUV) towing a tandem-axle trailer. The second combination was a 2016 Hyundai Tucson SUV towing a single-axle trailer. Both tow vehicles were loaded with a driver and instrumentation. Both trailers were equipped with a ball-and-socket type coupler and were approximately loaded to their respective gross vehicle weight rating (GVWR). The dimensional and inertial specifications for the Dodge are listed in Table 1. Specifications for the trailers and Hyundai are listed in Appendix I.

Table 1. Tow Vehicle 1 (SUV) Specifications

Total Mass	2,431.3 kg (5,360 lbs)
Front Axle Mass	1,174.8 kg (2,590 lbs)
Overall Length	5,105.4 mm (201 in)
Wheelbase	3,035.3 mm (119.5 in)
Rear Overhang	1,181.1 mm (46.5 in)
Overall Width	1,945.6 mm (76.6 in)
Front Track	1,633.2 mm (64.3 in)
Rear Track	1,628.1 mm (64.1 in)
Rear Axle to Connection Point	1,346.2 mm (53.0 in)
Hitch Ball Height	457.2 mm (18.0 in)
Sprung Yaw MOI	5,008.2 kg-m^2 (44,326 in-lb-sec^2)

Test Data Analysis

The damping ratio and damped natural frequency were calculated for each test run 72 kph (45 mph), 88 kph (55 mph), 105 kph (65 mph); right and left steer) via the equation-fit method (Equation 1). The damping ratio and damped natural frequency data were then plotted versus the average test run velocity during the time the data was analyzed. A linear regression model was then employed for the damping ratio and frequency data, using the method of least squares (Figures 2 and 3).

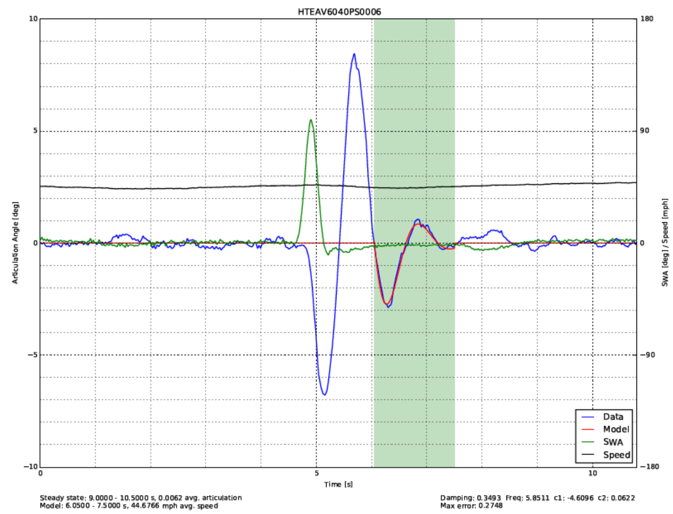

Figure 1. Sample test run Time-History Plot and model fit of damping ratio for the selected data. Damped natural frequency was also calculated to use in damping ratio estimate.

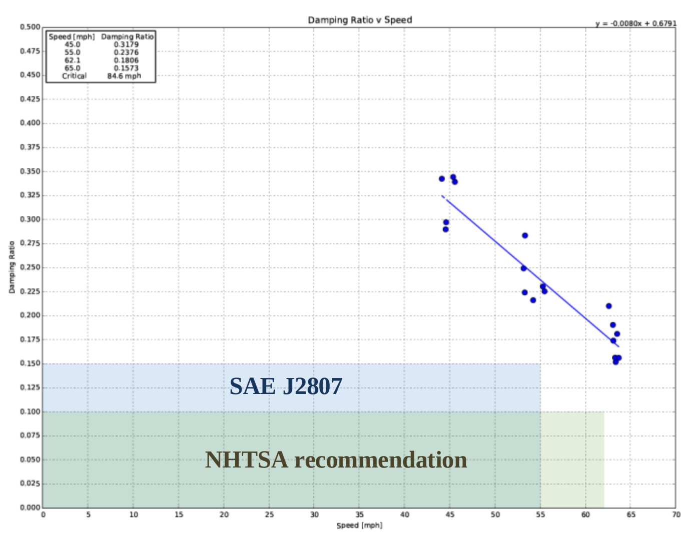

Figure 2. Example of a Damping Ratio versus Speed Plot. Linear regression was used to determine the damping ratio at each target test speed, SAE J2807 performance requirement speed, and critical speed. The equation of the linear regression line is in the upper right corner of the plot.

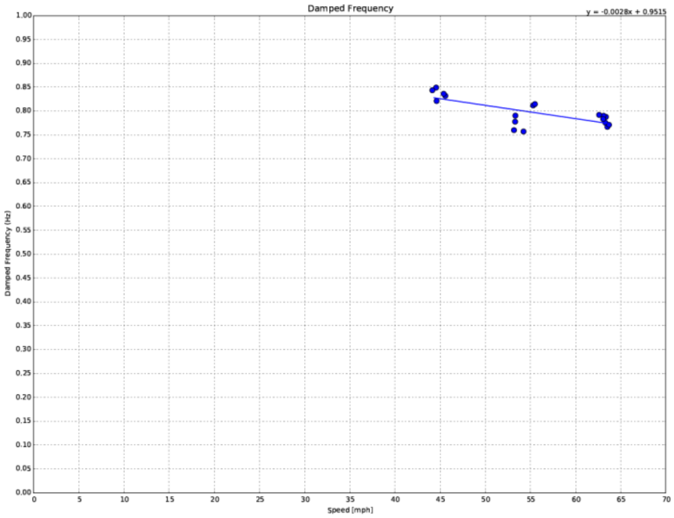

Figure 3. Example of a Damped Natural Frequency versus Speed Plot. Linear regression was used to determine the damped frequency at each target test speed. The equation of the line is in the upper right corner of the plot.

The calculated damping ratio estimates for each test combination and speeds are in Table 2. The damped natural frequencies calculated from the test data are shown in Table 3.

Table 2. Combination damping ratios from the test data for both combinations.

Speed	**Combination 1 Damping Ratio**	**Combination 2 Damping Ratio**
72.4 kph (45 mph)	0.3179	0.3523
88.5 kph (55 mph)	0.2376	0.3034
100 kph (62.1 mph)	0.1806	0.2686
104.6 kph (65 mph)	0.1573	0.2544
Critical Speed	136.2 kph (84.6 mph)	188.1 kph (116.9 mph)

Table 3. Combination damped natural frequency from the test data of both combinations.

Speed	**Combination 1 Frequency**	**Combination 2 Frequency**
72.4 kph (45 mph)	0.8255 Hz	0.9240 Hz
88.5 kph (55 mph)	0.7975 Hz	0.9050 Hz
100 kph (62.1 mph)	0.7776 Hz	0.8915 Hz
104.6 kph (65 mph)	0.7695 Hz	0.8860 Hz

Simulation Setup

Both SIMON and EDVTS were used to evaluate the sway-mode response of the test combinations. The vehicles and trailers used in the simulation were found in the HVE vehicle library. For most of the parameters, the vehicle and trailer default values from the HVE software were used. Some parameters were edited based on the measurements obtained during testing. These parameters included mass (weight), overall length, overall width, overall height, wheelbase, track widths, connection location, tire sizes, and measured center of gravity positions. The default steering and suspension parameters were used for both vehicles. In the SIMON module, the "connection point" on the vehicle and trailer were input according to the test measurements. The hitch ball and couple heights are required to be the same in the EDVTS module. The trailer connection point was adjusted to the vehicle connection point height in the simulations using the EDVTS module.

When the simulated combinations were driven in a straight line on the "Proving Grounds" environment, it was noted the combination slowed significantly. To maintain the combination speed for the simulation, the combination was driven in a straight line and the "throttle position" driver control was adjusted until the speed loss for a one second interval was less than the SAE J2664 requirements. Some speed loss is expected during the steering pulse due to the lateral movement of the tires as the trailer oscillates.

Each individual test run was analyzed to determine the average speed over the event and the steering pulse. The average speed was determined from the test data damping ratio calculations (Figure 1). Each vehicle combination was driven in a straight line for over one second in order to stabilize the speed and yaw of the combination prior to the steering input. The steering wheel data from each test run was analyzed to determine a nominal SWA for each test run (Figure 4). A nominal steering wheel pulse would be used if a combination was being evaluated without test data. Simulations using both the default trailer yaw MOI and the measured yaw MOI were performed.

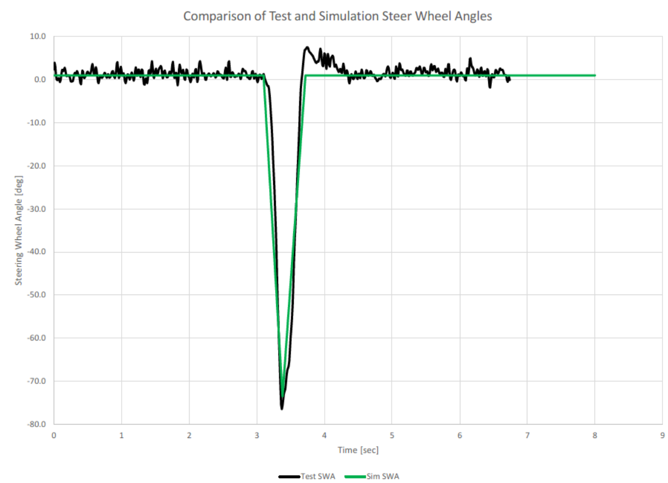

Figure 4. Comparison of test steering wheel angle and simulation steering wheel angle input.

Simulation Data Analysis

For each simulation run, the driver controls, vehicle data, and variable output files were printed. The variable output files included vehicle speed (Vtotal), steering wheel angle, tow vehicle yaw angle, trailer yaw angle, tow vehicle yaw velocity, forward acceleration, lateral acceleration, and trailer yaw articulation. To determine the trailer articulation angle relative to the tow vehicle, the difference of the tow vehicle yaw angle and trailer yaw angle was calculated for each time step.

The data was then processed in the same manner as the test data. The damping ratio and damped natural frequency data were then plotted versus the average test run velocity during the time the data was analyzed. A linear regression model was then employed for the damping ratio and frequency data, using the method of least squares.

An example of the calculated damping ratio estimates for combination 1 using the SIMON simulation module with the different yaw MOI, and speeds are in Table 4. The damped natural frequencies calculated from the simulation data for combination 1 are in Table 5. Each simulation module and combination are shown in the tables in Appendix II.

Table 4. Combination damping ratio of combination 1 for SIMON module simulation runs.

Speed	HVE Trailer MOI Damping Ratio	Test Trailer MOI Damping Ratio
72.4 kph (45 mph)	0.2998	0.3345
88.5 kph (55 mph)	0.2468	0.2386
100 kph (62.1 mph)	0.2092	0.1705
104.6 kph (65 mph)	0.1939	0.1427
Critical Speed	163.5 kph (101.6 mph)	128.6 kph (79.9 mph)

Table 5. Combination damped natural frequency of combination 1 for SIMON module simulation runs.

Speed	HVE Trailer MOI Frequency	Test Trailer MOI Frequency
72.4 kph (45 mph)	0.6408 Hz	0.5434 Hz
88.5 kph (55 mph)	0.6008 Hz	0.5344 Hz
100 kph (62.1 mph)	0.5724 Hz	0.5280 Hz
104.6 kph (65 mph)	0.5608 Hz	0.5254 Hz

Comparisons of Simulation and Test Data

Simulations using HVE Default Trailer Yaw Inertia versus Tested Trailer Yaw Inertia

The simulations used two yaw moment of inertias for the trailer. The first was the trailer yaw MOI calculated in HVE based on the weight of the trailer. The second was the measured trailer yaw MOI by the method above. The HVE yaw MOI and measured yaw MOI of the single-axle trailer was 9,517 in-lb-sec^2 and 13,332 in-lb-sec^2, respectively. For the tandem-axle trailer, the HVE and measured yaw MOIs were 23,491 and 35,724 in-lb-sec2, respectively. This was a 29.4% difference for the single-axle trailer and a 34.2% difference for the tandem-axle trailer.

For the single-axle trailer, in the EDVTS module, the difference in the damping ratios between the HVE and measured yaw MOIs varied from 19% at 72 kph (45 mph), to 41% at 105 kph (65 mph). The damped frequency varied from 3% to 5% from 72 kph (45 mph) to 105 kph (65 mph). For the SIMON module, the damping ratio difference was 22% at 72 kph (45 mph) and 38% at 105 kph (65 mph). The damped frequency varied from 3% to 8% from 72 kph (45 mph) to 105 kph (65 mph).

For the tandem-axle trailer, the damping ratio difference was between -15% to 10% using the EDVTS module. The damped frequency was between -2% and 5% using the EDVTS module. For the SIMON module the damping ratio varied between -11% at 72 kph (45 mph) to 27% at 105 kph (65 mph). The damped frequency varied from 15% at 72 kph (45 mph) and 6% at 105 kph (65 mph).

From the previous work from Klein and Szostak, as seen in Equations 6 and 7, the damping ratio and damped frequency are inversely proportion to trailer moment of inertia [6]. Specifically, the critical speed of the combination should decrease as the trailer's yaw moment of inertia increases. When using the EDVTS module, the critical speed increased with the increase in tandem-axle trailer's MOI and decreased with the increase single-axle trailer's MOI. The increase in the critical speed was not consistent with the increase in trailer yaw moment of inertia. With the SIMON module, both the critical speed and damped frequency decreased as the trailer's yaw moment of inertia increased.

$$\zeta_{\eta ta} = \frac{\sqrt{l_2^3 Y_{a3}}}{U_0 \sqrt{2 I_{t_h}}} \tag{6}$$

$$\omega_{\eta ta} = \sqrt{\frac{2 Y_{a3} l_2}{I_{t_h}}} \tag{7}$$

HVE Simulations versus Test Data

When the results from the simulation data were compared to the test data, there was one simulation for each combination where the critical speed was less than ±10%. For the tandem-axle combination, the SIMON simulation with the test yaw MOI had a critical speed approximately 6% different from the test data results (79.7 vs. 84.9 mph). The damping ratios for this simulation varied from -4% to 11%. For the tandem-axle combination, the variation of the damping ratio between the simulation results and the test results increased as the combination speed increased. The EDVTS simulations with the tandem-axle combination had a higher variation in damping ratios and critical speeds compared to the SIMON simulations. The damped natural frequencies for the simulations varied significantly from the test data and were typically lower. Comparison of the damped frequency between the SIMON data and test data for combination 1 are in Figure 5.

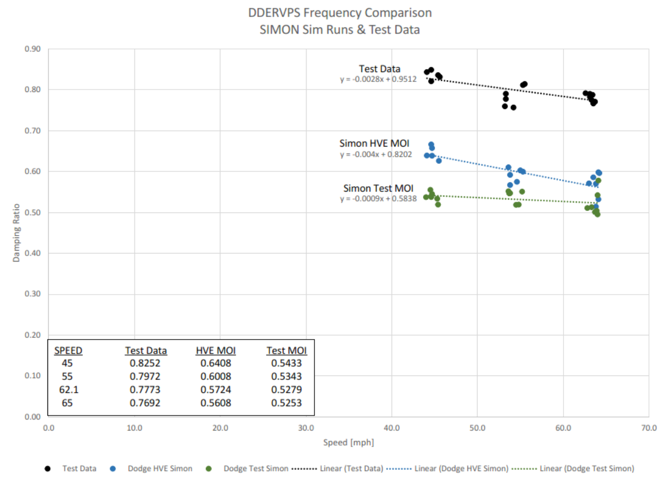

Figure 5. Comparison of test and SIMON simulation damped frequencies with Combination 1.

For combination 2, single-axle trailer, the critical speed for both simulations varied between -2% and 29%. Although the -2% appears to be a fairly good comparison, the damping ratios for this simulation varied by 16% and the damped frequency varied from 16% to 23%. With the EDVTS module simulating the single-axle combination, the damping ratios varied between 12% and 53%, with the variation increasing as the speed increased. With SIMON runs using the HVE MOI, the damping ratios varies by 16%, but the runs using the Test MOI had a variation of 35% to 48%.

Other vehicle parameters can influence the damping ratio and natural frequency of the combination. Some of these parameters include tire stiffnesses, suspension characteristics, steering properties, and aerodynamic effects. The study of these parameters or the changing of these parameters was not the purpose of this paper. Using default values from the software for these additional parameters did not yield acceptable simulation results to the test data.

Additional work will be required to determine the accuracy of the EDVTS and SIMON models when using measured vehicle parameters. This work was focused on changing the trailer yaw moment of inertia while using correct dimensional characteristics along with default data, such as suspension, tire, and steering characteristics.

Summary/Conclusions

1. The damping ratio from the simulations with the tandem-axle trailer varied 1% to 16% from the test data at the slower speeds. The variance increased significantly to 11% to 36% at the higher speeds.

2. The damped frequency of the tandem-axle combination varied 6% to 36% from the test data using the EDVTS module. It varied 22% to 34% from the test data using the SIMON module.

3. The damping ratio from the simulations with the single-axle trailer varied from 12% to 53% from the test data using the EDVTS module. The variance was between 16% and 48% using the SIMON module.

4. The damped frequency of the single-axle combination varied from 17% to 22% from the test data using the EDVTS module. It varied 16% to 26% from the test data using the SIMON module.

5. The purpose of this paper was to evaluate the use of default parameters. Further research, where the applicable HVE parameters are adjusted, is required to properly access the viability of using SIMON or EDVTS to accurately predict damping ratio and damped natural frequency of specific vehicle combinations. To fully evaluate the simulation models used, parameters such as tire stiffnesses, suspension characteristics, and steering properties may need to be adjusted from their default values.

6. The simulation results presented in this paper did not compare favorably with the test results. However, not all parameters that can affect damping ratio and damped natural frequency were adjusted from their default values. It is recommended to perform full-scale testing, as opposed to simulation with parameters used in this paper, when determining values of damping ratio and damped natural frequency for a specific vehicle combination.

7. Although the simulation data was not similar to the test data, the trends of the damping ratios varying trailer yaw moment of inertia and speed were consistent with general trends associated with combination vehicle dynamics.

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Contact Information

M. Mark Leonard
Mecanica Scientific Services Corporation
2812 North Norwalk, Suite 123
Mesa, Arizona 85215
480-655-0399

Definitions/Abbreviations

y	articulation angle
yss	steady state offset from zero
C1, C2	constants.
ζ	damping ratio
ω_n	system natural frequency
t	time
X_i	the peak-to-peak amplitude of the i^{th} and (i^{th}+1) free peak amplitudes (Γ_i+Γ_i+1)
n	The number of peak-to-peak amplitudes used in data reduction
N	intermediate value
l_2	Trailer effective tongue length (wheelbase)
Y_{a3}	Trailer tire cornering stiffness
U0	Forward speed
I_{th}	Trailer yaw moment of inertia about the connection point
$\zeta_{\eta ta}$	Damping ratio (trailer's natural frequency) of the trailer alone.
$\omega_{\eta ta}$	Natural frequency of the trailer alone.
SWA	Steering Wheel Angle (degrees)

Appendix I

Table 6. Trailer 1 (tandem axle) Specifications

Total Mass	2014.9 kg (4442 lbs)
Axle Mass(es)	1839.8 kg (4056 lbs)
Tongue Mass	175.1 kg (386 lbs)
Overall Length	5496.6 mm (216.4 in)
Connection Point to Front Axle	3294.4 mm (129.7 in)
Interaxle distance	863.6 mm (34.0 in)
Rear Overhang	1224.3 mm (48.2 in)
Overall Width	2446.0 mm (96.3 in)
Box Width	1930.4 mm (76.0 in)
Front Track	2296.2 mm (90.4 in)
Rear Track	2296.2 mm (90.4 in)
Sprung Trailer Yaw MOI – HVE	2,457.8 kg-m^2 (21,753 in-lb-sec^2)
Trailer Yaw MOI - measured	2,839.9 kg-m^2 (33,986 in-lb-sec^2)

Table 7. Tow Vehicle 2 Specifications

Total Mass	1669.2 kg (3680 lbs)
Front Axle Mass	916.3 kg (2020 lbs)
Overall Length	4483.1 mm (176.5 in)
Wheelbase	2674.6 mm (105.3 in)
Rear Overhang	894.1 mm (35.2 in)
Overall Width	1849.1 mm (72.8 in)
Front Track	1602.7 mm (63.1 in)
Rear Track	1615.4 mm (63.6 in)
Rear Axle to Connection Point	1008.4 mm (39.7 in)
Hitch Ball Height	447.0 mm (17.6 in)
Sprung Yaw MOI	2,939.0 kg-m^2 (26,012 in-lb-sec^2)

Table 8. Trailer 2 (single axle) Specifications

Total Mass	1326.3 kg (2924 lbs)
Axle Mass(es)	1199.8 kg (2645 lbs)
Tongue Mass	126.6 kg (279 lbs)
Overall Length	4015.7 mm (158.1 in)
Connection Point to Front Axle	2824.5 mm (111.2 in)
Interaxle distance	N/A
Rear Overhang	1077.0 mm (42.4 in)
Overall Width	2021.8 mm (79.6 in)
Box Width	1513.8 (59.6 in)
Front Track	1803.4 mm (71.0 in)
Rear Track	N/A
Trailer Yaw MOI – HVE	1030.0 kg-m^2 (9,116.22 in-lb-sec^2)
Trailer Yaw MOI - measured	1461.1 kg-m^2 (12,932 in-lb-sec^2)

Appendix II

Table 9 Combination damping ratio of combination 1 for EDVTS module simulation runs.

Speed	**HVE Trailer MOI Damping Ratio**	**Test Trailer MOI Damping Ratio**
72.4 kph (45 mph)	0.3020	0.2689
88.5 kph (55 mph)	0.2586	0.2567
100 kph (62.1 mph)	0.2278	0.2480
104.6 kph (65 mph)	0.2152	0.2445
Critical Speed	184.4 kph (114.6 mph)	265.7 mph

Table 10. Combination damping ratio of combination 2 for SIMON module simulation runs.

Speed	**HVE Trailer MOI Damping Ratio**	**Test Trailer MOI Damping Ratio**
72.4 kph (45 mph)	0.2938	0.2291
88.5 kph (55 mph)	0.2536	0.1811
100 kph (62.1 mph)	0.2251	0.1471
104.6 kph (65 mph)	0.2134	0.1332
Critical Speed	190.0 kph (118.1 mph)	149.3 kph (92.8 mph)

Table 11. Combination damping ratio of combination 2 for EDVTS module simulation runs.

Speed	**HVE Trailer MOI Damping Ratio**	**Test Trailer MOI Damping**
72.4 kph (45 mph)	0.3073	0.2493
88.5 kph (55 mph)	0.2538	0.1829
100 kph (62.1 mph)	0.2158	0.1358
104.6 kph (65 mph)	0.2003	0.1165
Critical Speed	165.0 kph (102.5 mph)	82.6 mph

Table 12. Combination damped natural frequency of combination 1 for EDVTS module simulation runs

Speed	**HVE Trailer MOI Frequency**	**Test Trailer MOI Frequency**
72.4 kph (45 mph)	0.9180 Hz	0.8800 Hz
88.5 kph (55 mph)	0.7040 Hz	0.6920 Hz
100 kph (62.1 mph)	0.5521 Hz	0.5585 Hz
104.6 kph (65 mph)	0.4900 Hz	0.5040 Hz

Table 13 Combination damped natural frequency of combination 2 for SIMON module simulation runs

Speed	**HVE Trailer MOI Frequency**	**Test Trailer MOI Frequency**
72.4 kph (45 mph)	0.7100 Hz	0.6863 Hz
88.5 kph (55 mph)	0.7280 Hz	0.6853 Hz
100 kph (62.1 mph)	0.7408 Hz	0.6846 Hz
104.6 kph (65 mph)	0.7460 Hz	0.6843 Hz

Table 14. Combination damped natural frequency of combination 2 for EDVTS module simulation runs

Speed	**HVE Trailer MOI Frequency**	**Test Trailer MOI Frequency**
72.4 kph (45 mph)	0.7403 Hz	0.7180 Hz
88.5 kph (55 mph)	0.7383 Hz	0.7070 Hz
100 kph (62.1 mph)	0.7369 Hz	0.6992 Hz
104.6 kph (65 mph)	0.7363 Hz	0.6960 Hz