Passenger Vehicle Steady-State Directional Stability Analysis Utilizing EDVSM and SIMON

Daniel A. Fittanto, M.S.M.E., P.E. and Adam Senalik, M.S.G.E., P.E.
Ruhl Forensic, Inc.

ABSTRACT

Steady-state directional control was studied for several passenger cars and two sport utility vehicles using EDVSM and SIMON in the HVE 4.4 operating system. Constant velocity, variable steer tests were performed and relevant data recorded and analyzed.

The modeled vehicles were taken directly from the HVE Vehicle Database. These vehicles represented various class categories. Two vehicles were modified by selecting different tires from within the HVE Tire Database. The modeled vehicle configurations were as follows:

1. 1990-1995 Chevrolet Corvette
2. 1996-2000 Honda Civic
3. 1996-2000 Honda Civic modified with low-profile tires
4. 1995-2001 Ford Explorer
5. 2002 Pontiac Grand Am
6. 1991-1997 Chevrolet Impala SS
7. 1991-1997 Chevrolet Impala SS modified with 70-series tires
8. 1992-1999 Chevrolet Suburban K1500

Steering diagrams and/or handling diagrams were generated from the results of these simulated tests and the understeer characteristics were analyzed. Relative comparisons were made between vehicles both in EDVSM and SIMON. Similarities and differences between EDVSM and SIMON responses for each vehicle were also observed and discussed.

Vehicles exhibited intuitive and expected relative understeer characteristics within both EDVSM and SIMON. For each vehicle, the SIMON-modeled vehicle exhibited a greater level of understeer than the EDVSM-modeled vehicle. Aerodynamic forces were found to only slightly influence the vehicle responses in SIMON.

INTRODUCTION

The path of an automobile in a steady state turn is determined by speed, steer angle, wheelbase and the properties of the steering systems, suspension and tires.

At 'zero' speed, the Ackerman angle is defined by the vehicle wheelbase and the radius of curvature.

$$\delta_A = \frac{57.3L}{R} \tag{1}$$

Where:

δ_A is the Ackerman steer angle (deg)
L is the vehicle wheelbase (ft)
R is the radius of the turn (ft)

To maintain equilibrium as vehicle speed increases in a turn the increased centrifugal force must be balanced by the steer angles and tire slip angles. If there is greater compliance--resulting in higher slip angles--at the front tires than the rear tires, the vehicle is *understeer*. If there is greater compliance—resulting in higher slip angles—at the rear tires than the front tires, the vehicle is *oversteer*. Equation 1 is modified to include front and rear slip angles and is rewritten as Equation 2.

$$\delta = \frac{57.3L}{R} + (\alpha_f - \alpha_r) \quad (2)$$

Where:

δ is the steer angle (deg)
α_f is the front slip angle (deg)
α_r is the rear slip angle (deg)

If the front and rear compliances, and thus slip angles are equivalent, the required steer angle at any level of lateral acceleration remains the Ackerman angle and the vehicle is considered *neutral steer* [1,2,3,4].

The relationship in (2) is often expressed as,

$$\delta = \frac{57.3L}{R} + K\frac{V^2}{gR} \quad (3)$$

Where:

δ is the steer angle
K is the understeer gradient (deg/g)
V is the forward velocity of the vehicle (ft/s)
g is the acceleration due to gravity (ft/s^2)

Generally speaking, understeer vehicles are more stable but less responsive to steering inputs, while oversteer vehicles are more responsive but can become directionally unstable at certain levels of speed and lateral acceleration. Several sources provide detailed discussions regarding vehicle non-linear steady-state cornering [2,3,4].

This paper describes how two simulation packages within HVE can be used to assess the understeer characteristics of a vehicle. EDVSM and SIMON are utilized for the analysis, and their results compared and contrasted.

SIMULATION

EDVSM and SIMON were utilized within the HVE 4.4 operating system to model the subject vehicles and simulate the selected maneuvers.

EDVSM

EDVSM is based on the HVOSM VD2 model developed at CalSpan [5,6]. A full description of the tire model used by HVOSM and EDVSM is found in [6].

SIMON

SIMON utilizes the EDC semi-empirical tire model developed for EDVDS. The basis for the EDC semi-empirical tire model is the HSRI tire model developed at the University of Michigan Transportation Institute (UMTRI). The SIMON implementation of the tire model has been extended for large slip angles and drive torque. It has also replaced the method of partial derivatives with a table look-up method for determining load- and speed-dependant tire properties. An overview of the extended model is provided by Day with reference to the original HSRI model [7].

The modeled vehicles were taken directly from the HVE Vehicle Database. These vehicles represented various class categories. Two vehicles were modified be selecting different tires from within the HVE Tire Database. The modeled vehicle configurations were as follows:

1. 1990-1995 Chevrolet Corvette
2. 1996-2000 Honda Civic
3. 1996-2000 Honda Civic modified with P215/55R16 tires
4. 1995-2001 Ford Explorer
5. 2002 Pontiac Grand Am
6. 1991-1997 Chevrolet Impala SS
7. 1991-1997 Chevrolet Impala SS modified with P215/70R15 tires
8. 1992-1999 Chevrolet Suburban K1500

Originally the Corvette, Civic and Civic-modified were modeled with the default aerodynamic drag coefficients. Follow-up simulations were conducted on these vehicles with the aerodynamic drag coefficient reduced to 0. The remaining vehicles were tested with the aerodynamic drag coefficient set to 0. This was done such that there would be a more direct comparison of the vehicle models, particular the tire models between EDVSM and SIMON.

The overall steering ratio was assumed constant for all vehicles throughout the tests. No steering compliance was modeled.

TESTING AND ANALYSIS

TEST PROCEDURES

SAE J266

SAE J266 "Steady-State Directional Control Test Procedures for Passenger Cars and Light Trucks", outlines test and analysis procedures for assessing vehicle steady-state handling response. J266 outlines five test methods [1]:

Method 1—Constant radius test
Method 2—Constant steering wheel angle test
Method 3—Constant speed/variable radius test
Method 4—Constant speed/variable steer test
Method 5—Response gain/speed test

The first four methods yield substantially similar data [1].

ISO 4138 acknowledges Methods 1-4 above but only defines the constant radius test method and is therefore a subset of J266 [1,10].

Several tests were performed in accordance with SAE J266 Method 4—Constant speed/variable steer test.

In the simulated tests an initial speed near the test speed of 45 mph was input. After 1.0 seconds a ramp steer was input over 0.5 seconds. Iterations were conducted until an initial velocity and constant throttle were found such that the vehicle reached a steady-state condition with a forward speed of 45 mph +/- 0.01mph. Steer angle was incrementally increased and the simulations re-run. Steer angle increments were chosen as to increase the lateral acceleration by approximately 0.05 g in accordance with J266.

The vehicles that were subjected to this test procedure were the Corvette, Civic, Civic-Modified and Explorer. The data for the tests were used to create the steering diagrams as per J266 and described herein, as well as handling diagrams as described herein.

MODIFIED PROCEDURE

The remaining vehicles were subjected to the same general test procedure. However in the interest of time efficiency the steady-state speed was not held as precisely about 45 mph (+/- 0.6 mph) and the incremental steer increases were larger resulting in larger steps in lateral acceleration. Handling diagrams as described herein were generated for these vehicles undergoing this modified test procedure. Steering diagrams were not created.

Tests were also conducted for constant radius / variable speed conditions, and the resulting handling diagrams were compared to the constant speed / variable steer handling diagrams. As expected, both test methods yielded substantially similar handling diagrams. The constant radius / variable speed handling diagrams were performed solely as a check of the results and are not included in this paper.

STEERING DIAGRAMS

A method of analysis for a constant speed/variable steer test is the steering diagram plotting steer angle versus lateral acceleration [1].

Determining the steer angle gradient (change with lateral acceleration) from Equation 3 yields,

$$\frac{d\delta}{d(a_y/g)} = K + \frac{57.3Lg}{V^2} \tag{4}$$

where a_y is the lateral acceleration of the vehicle (g's).

Thus, the line for neutral steer (K=0) can be plotted on the steering diagram with slope gL/V^2. Steering gradients greater than the K=0 slope indicate understeer, while steering gradients less than the K=0 slope indicate oversteer. When the oversteer vehicle steering gradient reaches 0 the vehicle becomes unstable. See Figure 1.

HANDLING DIAGRAMS

A means to clearly observe the steady-state handling characteristics of a vehicle called the "handling diagram" was broadly developed by Pacejka [4]. Fittanto previously presented examples of handling diagrams applied to EDVDS and SIMON simulations for tractor-semitrailers [11].

Equation 3 can be expressed as,

$$\frac{V^2}{gR} = -\frac{1}{K}\left(\frac{57.3L}{R} - \delta\right) \tag{5}$$

Figure 3 depicts a handling diagram. The steering diagram has been rotated 90 degrees and the horizontal axis now becomes the difference between the Ackerman angle and the steer angle. The slope of the vehicle response curves at any point is the negative inverse understeer gradient (-1/K). The neutral steer condition is the infinite slope line of K=0. Understeer vehicles exhibit a negative slope and oversteer vehicles a positive slope on the diagram. Oversteer vehicles become unstable for a given velocity when,

$$-1/K > V^2/gL \quad (6)$$

When radius is not held constant in the steady-state tests, the term **r**L/V, where **r** is yaw rate, can be substituted for L/R on the horizontal axis to determine the Ackerman angle for the instant R [12].

RESULTS

COMPARISON OF VEHICLES

Figure 1 depicts the steering diagram comparing the Corvette, Civic, Civic-modified and Explorer in EDVSM. Figure 2 depicts the steering diagram comparing the same vehicles in SIMON.

The relative understeer characteristics of the vehicles was consistent between EDVSM and SIMON with one exception. The Explorer exhibited the greatest understeer, the Civic was second and the Corvette was closest to neutral steer. The modified Civic actually exhibited slightly oversteer behavior in EDVSM while exhibiting slightly understeer behavior in SIMON. The curves for the Corvette and Civic-modified were similar for both EDVSM and SIMON, but reversed their relative positions between the two simulations.

The Explorer did exhibit notable behavior in EDVSM. With no steer angle there was a lateral acceleration exhibited. There was also a very non-linear understeer gradient observed in the first 0.15 g's.

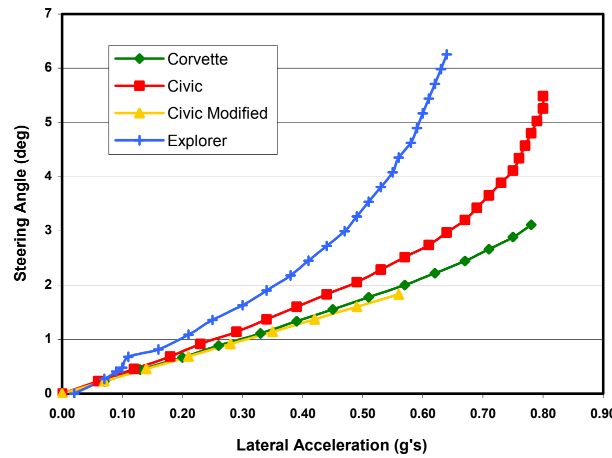

Figure 1. EDVSM – Steering Diagram as per J266

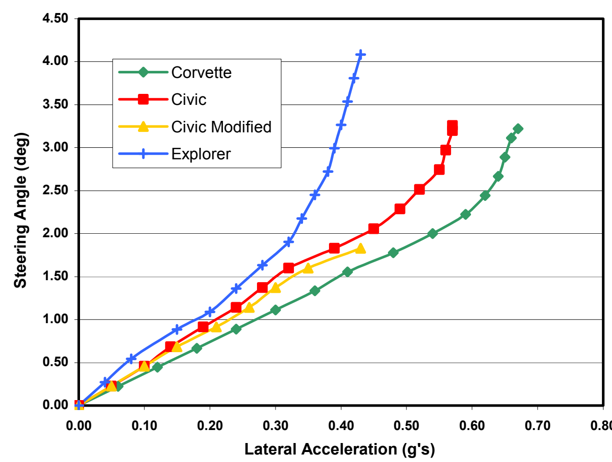

Figure 2. SIMON – Steering Diagram as per J266

Figure 3 depicts the handling diagram for all of the tested vehicles in EDVSM. Figure 4 depicts the handling diagram for these vehicles in SIMON.

The relative understeer characteristics were largely consistent between EDVSM and SIMON for all vehicles in lateral acceleration ranges below approximately 0.35 's. At higher levels of lateral acceleration there was greater divergence between the vehicle responses in the two simulations. A comparison of the individual vehicle responses in EDVSM and SIMON follows.

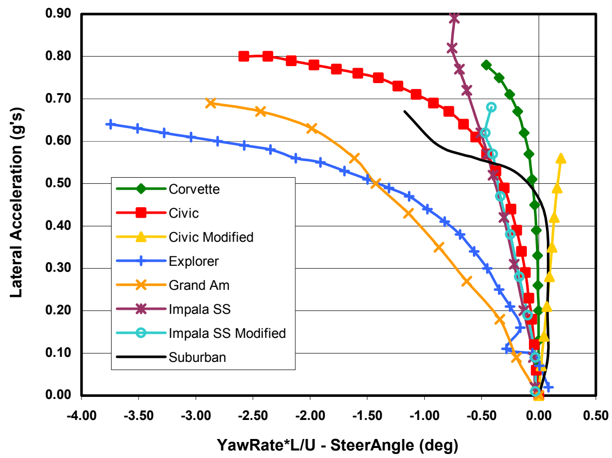

Figure 3. EDVSM – Handling Diagram for all Vehicles

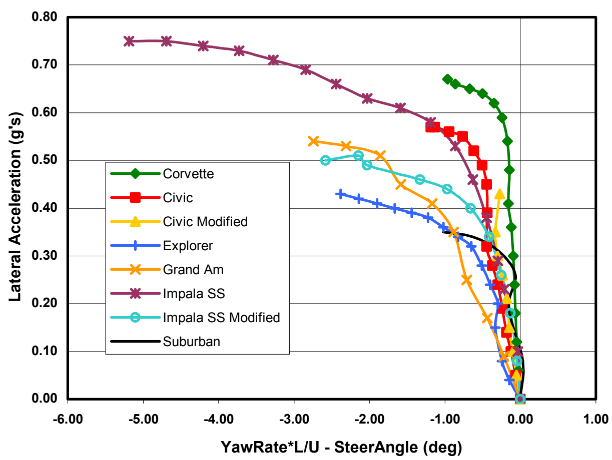

Figure 4. SIMON – Handling Diagram for all Vehicles

COMPARISON BETWEEN EDVSM AND SIMON

Figures 5-8 depict the steering diagrams for the Corvette, Civic, Civic-modified and Explorer, respectively for both EDVSM and SIMON.

In all cases the SIMON-modeled vehicles exhibited greater understeer than the EDVSM-modeled vehicles. For much of the test range of lateral accelerations the quantitative differences in steer angle between vehicles in EDVSM and SIMON was relatively small, as can be observed by close inspection of the graph scales.

The steady-state limit lateral acceleration for the SIMON vehicles was observed to be significantly lower than those in EDVSM.

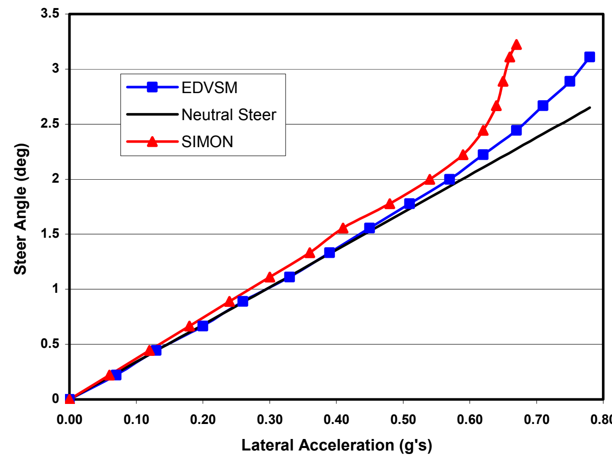

Figure 5. Steering Diagram as per J266 – Corvette

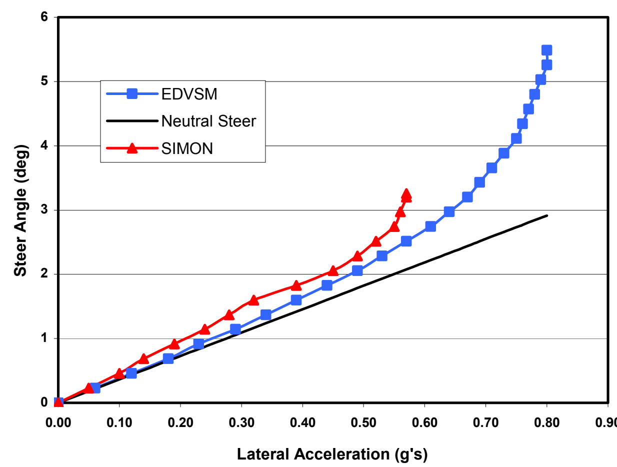

Figure 6. Steering Diagram as per J266– Civic

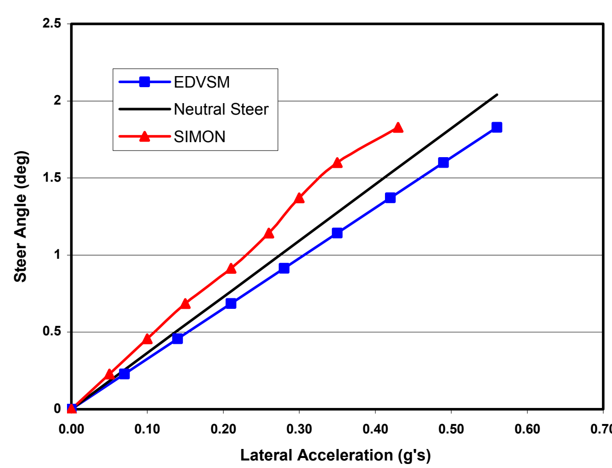

Figure 7. Steering Diagram as per J266 – Civic-Modified

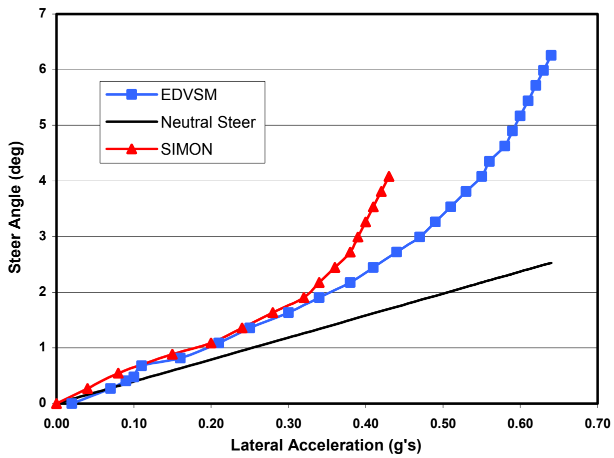

Figure 8. Steering Diagram as per J266 – Explorer

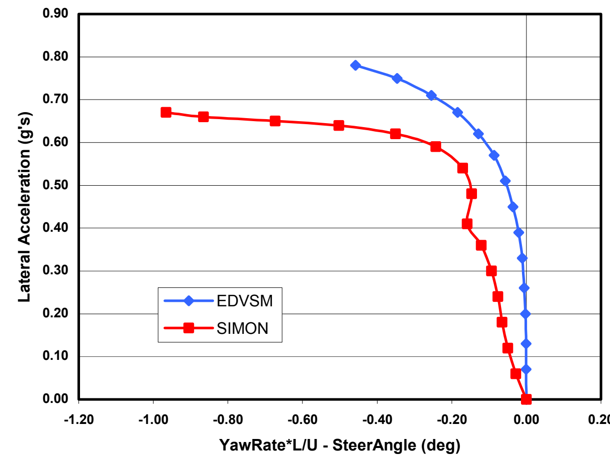

Figure 9. Handling Diagram – Corvette

Figures 9-16 depict the handling diagrams for each of the vehicles for both EDVSM and SIMON.

Again in the handling diagrams it is seen that in all cases the SIMON-modeled vehicles exhibit greater understeer than the EDVSM-modeled vehicles. Also, again for much of the test range of lateral accelerations the quantitative difference in steer angles between vehicles in EDVSM and SIMON was relatively small. Finally, in all vehicles the steady-state limit lateral acceleration for the SIMON vehicles was significantly lower than those in EDVSM.

Of all the vehicles, the Civic-modified exhibited the greatest qualitative difference between responses in the two simulations, in that the vehicle was oversteer in EDVSM and understeer in SIMON.

Also, the Chevrolet Suburban exhibited oscillating understeer/oversteer behavior over approximately the first 0.20 g's. Suggested future analysis would include additional data points for this vehicle in this highly non-linear range of data.

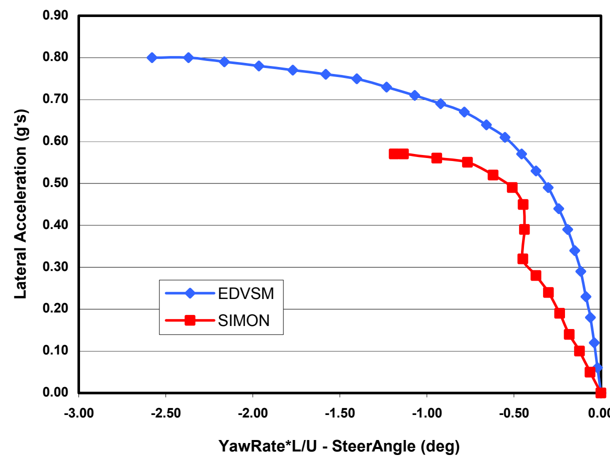

Figure 10. Handling Diagram – Civic

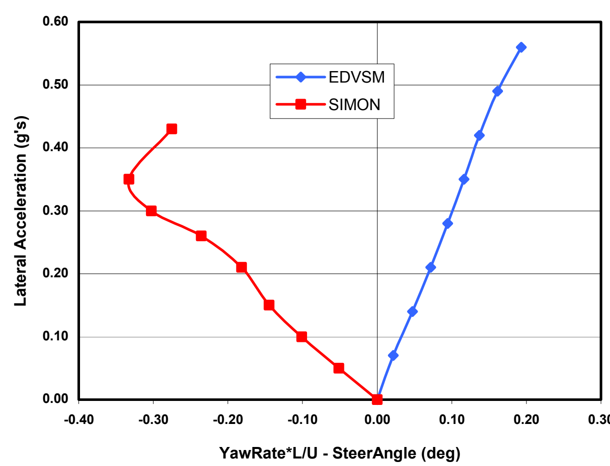

Figure 11. Handling Diagram – Civic-Modified

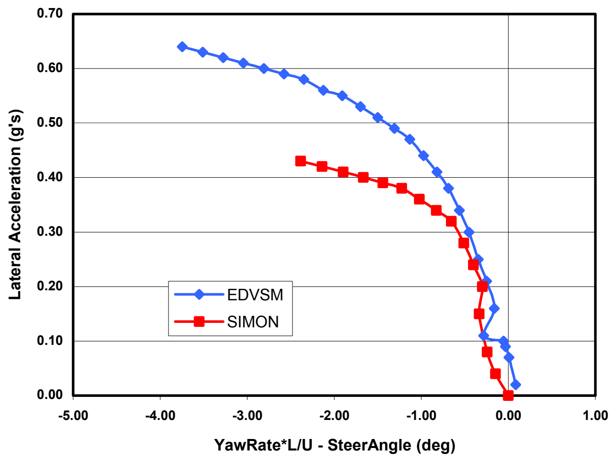

Figure 12. Handling Diagram – Explorer

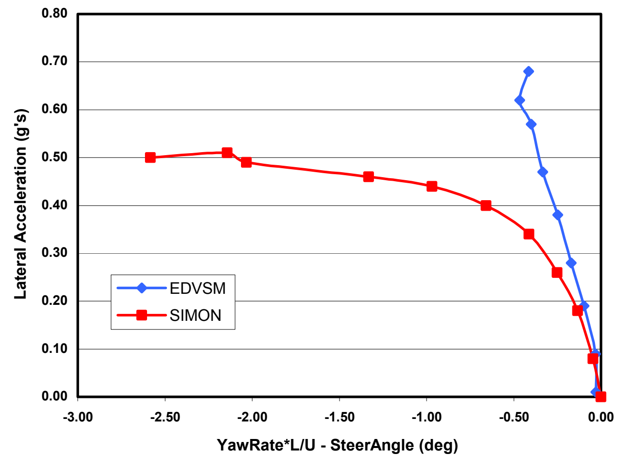

Figure 15. Handling Diagram – Impala SS-modified

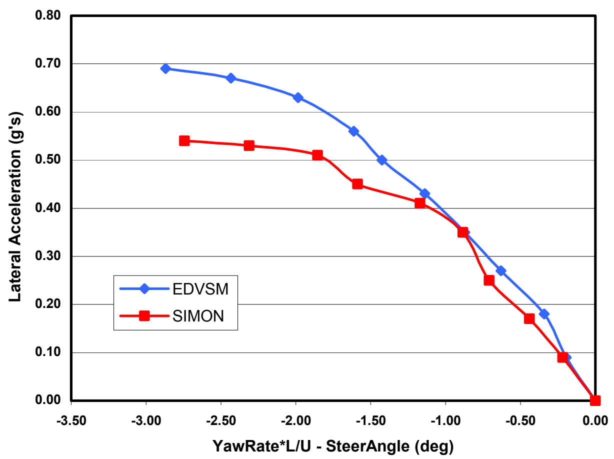

Figure 13. Handling Diagram – Grand Am

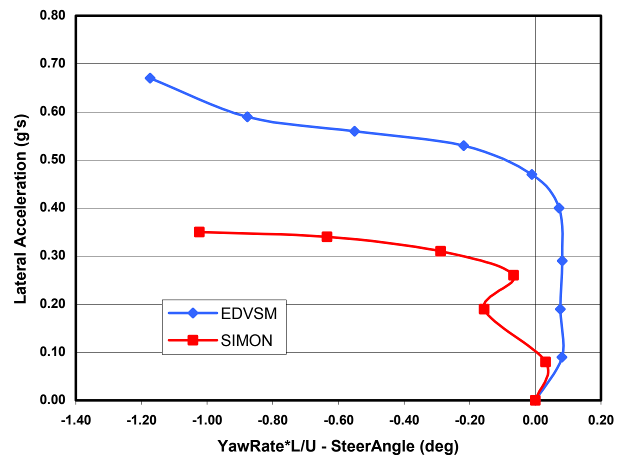

Figure 16. Handling Diagram - Suburban

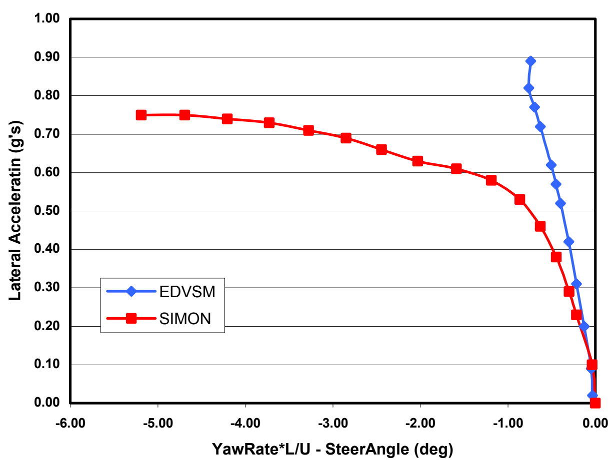

Figure 14. Handling Diagram – Impala SS

The Corvette, Civic and Civic-modified SIMON data were taken with the aerodynamic drag feature activated. Some additional data points were taken with the aerodynamic drag coefficient set to 0. The response curves were observed to be somewhat smoother without the aerodynamic drag modeled. However, the basic understeer gradient was not affected by the aerodynamic drag, nor was the steady-state limit lateral acceleration. The remaining vehicles were modeled with the aerodynamic drag coefficient set to 0.

CONCLUSIONS

1. The simulated vehicles were taken directly from the HVE database and span many of the vehicle class categories. The vehicles represent the actual vehicle

makes and models in terms of inertial data, suspension data and tire data. They do not necessarily represent any specific vehicle in any specific event.

2. The relative understeer characteristics of the vehicles were consistent in both EDVSM and SIMON at levels of lateral acceleration below approximately 0.35 g's, an operating range consistent with vehicles and drivers under most circumstances. At higher levels of lateral acceleration the vehicle responses exhibited greater divergence between the two simulation programs.
3. In all cases, the SIMON-modeled vehicles exhibited greater understeer than the EDVSM-modeled vehicles. For much of the test range of lateral accelerations the quantitative difference in steer angles between vehicles in EDVSM and SIMON was relatively small.
4. The steady-state limit lateral acceleration for the SIMON-modeled vehicles was significantly lower than the EDVSM-modeled vehicles.
5. Several vehicles exhibited notable behavior in these tests: The Ford Explorer in EDVSM generated lateral accelerations at a 0-degree steer angle and the understeer gradient was highly non-linear within the first 0.12 g's. Also, the Chevrolet Suburban exhibited oscillating understeer/oversteer behavior over the first 0.20 g's. The Civic-modified exhibited the greatest qualitative difference between responses in the two simulations in that the vehicle was oversteer in EDVSM and understeer in SIMON
6. The aerodynamic drag force in SIMON caused some slight roughness in the understeer gradient curves in the Corvette, Civic and Civic-modified. The overall understeer gradient was not significantly affected, nor was the steady-state limit lateral acceleration.
7. For a given vehicle the greatest influence on the understeer characteristics is the tire data and for a simulated vehicle it is the tire model and the tire data. The observed differences between the EDVSM and SIMON understeer responses primarily originate from the differences in the tire models between the programs. Suggested future work would explore exactly what aspects of the tire models results in the similarities and difference in the steady-state directional stability of the simulated vehicles.

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CONTACT

Daniel A. Fittanto, M.S.M.E., P.E.
Ruhl Forensic, Inc.
800.278.4095
dafittanto@ruhl.com

Adam Senalik, M.S.G.E., P.E.
Ruhl Forensic, Inc.
800.355.7800
casenalik@ruhl.com