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SIMON and EDVDS Validation Study: Steady State and Transient Handling

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

ABSTRACT

This research compares the responses of vehicle modeled in SIMON and EDVDS in the HVE simulation operating system against instrumented responses of a 3-axle tractor, 2-axle semi-trailer combination. The instrumented tests were previously described in SAE 2001-01-0139 and SAE 2003-01-1324. The vehicle inertial parameters were measured by UMTRI (University of Michigan Transportation Research Institute). The tire data was provided by Smithers Scientific Services, Inc. and UMTRI.

The series of tests discussed herein compares the modeled and instrumented vehicle responses during quasi-steady state and transient handling maneuvers.

The time response of the following variables is compared graphically:

1. Tractor lateral acceleration
2. Tractor yaw rate
3. Trailer lateral acceleration

SIMON and EDVDS simulated responses are found to reasonably follow the trends of the instrumented vehicle. SIMON is found to more closely simulate the truck dynamics of the experimental vehicle than EDVDS. SIMON responses correlated well to the experimental values in both step steer transient phases and steady state phases in all tests except for the steady state phase of the Step Steer at 20 m/sec.

INTRODUCTION

<u>SIMON and EDVDS</u>
SIMON™ (SImulation MOdel Non-linear) and EDVDS™ (Engineering Dynamics Vehicle Dynamics Simulator) are simulation programs which function within the HVE™ (Human-Vehicle-Environment) operating system. SIMON and EDVDS contain full three-dimensional vehicle models for use in the study of vehicle dynamics and heavy vehicle crash reconstruction. Full descriptions of HVE, SIMON and EDVDS can be found in the literature provided by Engineering Dynamics Corporation [1,2].

SIMON has been previously validated in several maneuvers by Day [3]. Included in that research was a comparison to a tractor-semitrailer test.

EDVDS was based upon the Phase IV program created by UMTRI. Differences between EDVDS and Phase IV have been described by Day [4]. A Description of Phase IV can be found in the published literature. [5]. Fittanto, et al. previously compared EDVDS to the instrumented response of a loaded livestock tractor-semitrailer in steady state limit lateral acceleration tests and transient maneuvers [6].

<u>VRTC</u>
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 Freuhauf 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. [7].

Results of several tests were later published in a validation effort for the National Advanced Driving Simulator (NADS) by Salaani, et al. [8].

The raw experimental data for the tests described in SAE 2001-01-0139 [7] were provided to the authors by Paul Grygier of the National Highway Traffic Safety Administration (NHTSA) and VRTC. Several of these tests were also referenced within SAE 2003-01-1324 [8].

This paper utilized experimental data collected and provided by VRTC in a validation effort for SIMON and EDVDS.

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 [9]. 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 [10]. Tires of this construction had previously published data available [11].

Tire testing was conducted by Smithers Scientific Services, Inc. and UMTRI utilizing the UMTRI Mobile Tire Dynamometer at the Dana test facility in Ottawa Lake, Michigan. The tire data for the drive tire referenced in [11] and the steer tires 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.

The Dana test track had the following characteristics [12]:

Peak skid	91.06 +/- 1.728
Slide skid	77.67 +/- 1.146

The VRTC test track reportedly had the following characteristics:

Peak skid	87 to 90
Slide skid	77 to 80

Both test surfaces were measured according to ASTM E274 and ASTM E1337.

TRAILER PAYLOAD

VRTC ran vehicle tests with both an empty trailer and a loaded trailer. This paper addresses the empty trailer runs and therefore, the loaded configuration is not described herein. Additional inertial data for the test payloads is required.

VEHICLE MODELING IN HVE

INERTIAL and MECHANICAL PROPERTIES

INERTIAL PROPERTIES

The data provided by UMTRI allowed for the accurate modeling of the inertial properties for the tractor and semi-trailer sprung and unsprung masses. The suspension springs were modeled as part of the unsprung mass.

SUSPENSION

In anticipation of comparing the SIMON and EDVDS models to the unloaded tractor semi-trailer configuration, vehicle models were constructed utilizing the vehicle parameters that most closely approximated an unloaded condition.

Tractor Unloaded – The suspension properties measured by UMTRI at the test load that most closely approximated the static load on the tractor axles with the unloaded trailer were utilized.

Trailer Unloaded - The suspension properties measured by UMTRI at the test load that most closely approximated the static load on the trailer axles without payload were utilized.

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 SIMON and EDVDS. Descriptions of the SIMON and EDVDS tire models can be found in the literature [1,2].

The tire models used by EDVDS and SIMON allow for data at 3 test loads. Experimental cornering stiffness and frictional data at 25%, 100% and 150% rated load were input into the tire model.

STEERING RATIO

Initially there was a discrepancy in the steering gear among various data sources. Additionally the compliance in the steering column can cause a modeling problem when utilizing steering wheel angle (SWA) data. Each of these issues needed to be resolved for proper modeling.

UMTRI Data

The UMTRI data for the tractor indicated a steering gear ratio of 12.8 at 53.38kN (12,000 lbs) of vertical load. This number was unrealistic by inspection. An author of the UMTRI report was contacted and graciously reviewed the data. No obvious problem with the conditioning of the raw sensor signals or the analysis of the data could be found. It is speculated by the authors that there was an initial calibration error with the raw sensor signals.

VRTC Model

Conversations with VRTC revealed that they were aware of the low reported steering gear ratio. It was the position of VRTC that there was an approximate 2:1 error factor. A review of [10] shows the VRTC simulation model utilized a steering gear ratio of 25.5.

Vehicle Specifications

UMTRI provided the author with the VIN for the tractor. A review of the line sheet revealed that the tractor was originally equipped with a TRW TAS-65 steering gear with a 20.4 ratio.

The VRTC data contained Pitman arm measurements. As a check, the average ratio of SWA measurements to Pitman arm measurements for the quasi-steady state slowly increasing steer test was calculated at approximately 22.9. When considering compliance in the steering column and free play in the steering wheel, this value would seem to be consistent with a steering gear ratio of 20.4

SIMON and EDVDS Input

To determine the steering input data for SIMON and EDVDS the Pitman arm measurements were multiplied by the specification steering gear ratio of 20.4. As long as this ratio is used in the steering model this ratio becomes arbitrary for purposes of simulation. VRTC ultimately took a similar approach in their simulation model [8].

The HVE vehicle model utilizes a fixed steering gear ratio and does not model torsional compliance at this time. By using the Pitman arm data rather than the 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 steering wheel to 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. Thus the overall steering ratio modeled in HVE was 22.67.

ENVIRONMENT

All simulations were run using the HVE proving ground 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 [8]. 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 SIMON and EDVDS are:

1. Slowing increasing steer at 14 m/sec (30 mph)
2. Step steer (J-turn) at 14 m/sec (30 mph)
3. Step steer at 14 m/sec (30 mph)
4. Step steer at 20 m/sec (45 mph)
5 Lane change at 18 m/sec (40 mph)

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 SIMON and EDVDS. To make the number of steering input values manageable, measured values at 0.5 second intervals were used to generate the steering profile.

In several runs a negative (counter-clockwise) Pitman arm value was recorded prior to a steering event with no appreciable lateral acceleration induced to the vehicle. For modeling purposes the Pitman arm angle data was calibrated to a zero value at the start of the run (i.e. when no lateral acceleration induced). The driver inputs tables were calculated based on these adjusted Pitman arm values.

A check was performed on the adjusted Pitman arm values. The ratio of SWA values to adjusted Pitman arm values was calculated to check for a reasonable value based upon the steering gear specification. After the calibration, right and left steer maneuvers had consistent calculated steering gear ratios, whereas there was a wide discrepancy when using the raw data.

Figures 1, 5, 9, and 13 depict the experimentally measured steering wheel angle (SWA) and the simulation SWA input for both SIMON and EDVDS. The simulated SWA is consistently less than the experimental SWA, as expected. This is due to the steering wheel free play and the steering column compliance. If the simulated steering gear was, in fact, lower than the actual gear, this would be an additional cause of the discrepancy. Again, the actual ratio is not relevant for purposes of simulation as long as the simulation vehicle model is consistent with the ratio used to create the driver steering input tables.

Velocity

Velocity for the combination vehicle was measured at the trailer. Throttle was input into to the SIMON and EDVDS models to maintain a velocity profile matching the measured data as close as possible.

Output Variables

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

Tractor lateral acceleration

Tractor yaw rate

Trailer lateral acceleration

RESULTS

Slowing increasing steer at 14 m/sec (30 mph)

Figures 2-4 depict the tractor lateral acceleration, tractor yaw velocity and trailer lateral acceleration for the slowly increasing steer test at a nominal speed of 14 m/sec (30 mph).

The magnitude of the SIMON and experimental responses were consistently greater than the EDVDS response for all three variables in all tests.

SIMON and EDVDS tractor lateral acceleration responses were appreciably lower than the measured tractor lateral acceleration values. This trend was consistent in all tests.

Fife, et al. observed an unusually large difference in the measured and calculated tractor lateral acceleration that was not observed in the trailer [7]. No problem could be found in the sensors or data acquisition hardware. In the published VRTC evaluations of NADS a similar trend of tractor chassis lateral accelerations reporting lower than the experimental values was observed [8].

SIMON tractor yaw rate response closely correlated to the experimental data. SIMON response deviated from the experimental data by less than 5% at peak magnitude. EDVDS response was approximately 13% lower than the experimental data at peak magnitude.

SIMON trailer lateral acceleration response correlated very closely with the experimental data throughout the maneuver with no significant deviation at peak magnitude. EDVDS reached a peak magnitude approximately 18% below the experimental value.

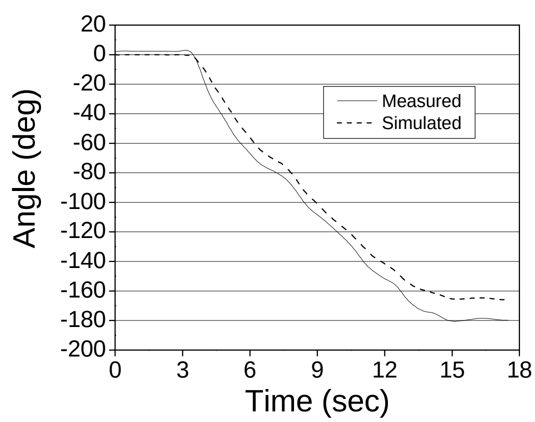

Figure 1. Steering Wheel Angle Input – Slowly Increasing Steer at 14 m/sec

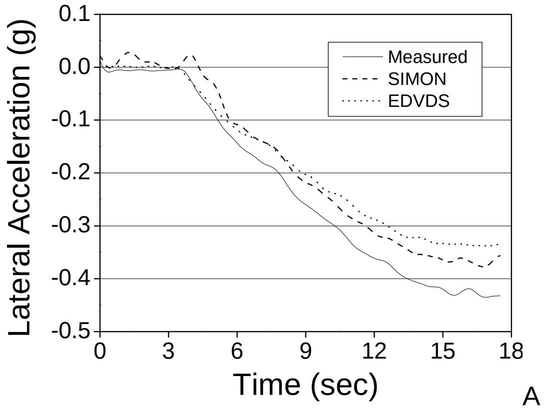

Figure 2. Tractor Lateral Acceleration – Slowly Increasing Steer at 14 m/sec

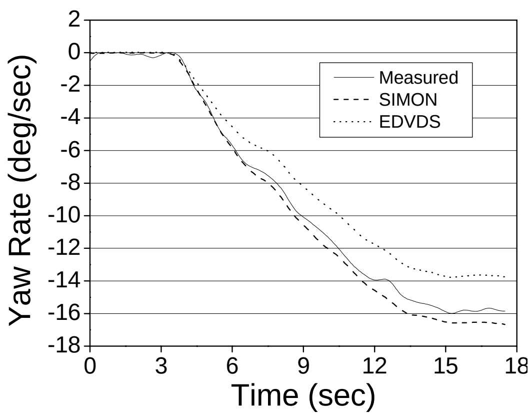

Figure 3. Tractor Yaw Velocity – Slowly Increasing Steer at 14 m/sec

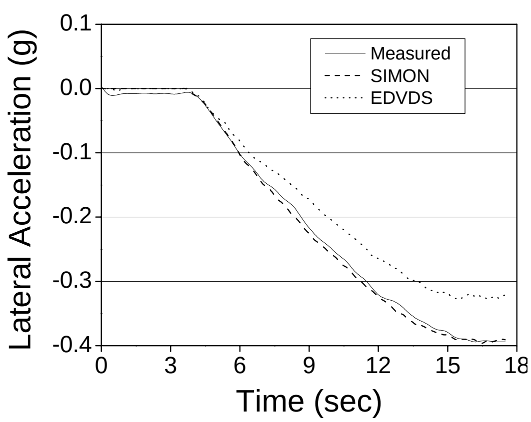

Figure 4. Trailer Lateral Acceleration – Slowly Increasing Steer at 14 m/sec

<u>Step steer (J-turn) at 14 m/sec (30 mph)</u>

Figures 6-8 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).

The magnitude of the SIMON and experimental responses were consistently greater than the EDVDS response for all three variables.

SIMON and EDVDS tractor lateral acceleration responses closely correlated to the experimental data during the majority of the step steer transient phase. SIMON and EDVDS reached steady state values approximately 16% and 30% lower than the measured values, respectively.

SIMON and EDVDS tractor yaw rate responses closely correlated to the experimental data during the majority of the step steer transient phase. SIMON and EDVDS reached steady state values approximately 11% above and 15% below the experimental values, respectively.

SIMON and EDVDS trailer lateral acceleration responses closely correlated to the experimental data during the majority of the step steer transient phase. SIMON correlated well with the experimental data throughout the maneuver with no significant difference in steady state magnitude. EDVDS reached a steady state value approximately 24% below the experimental value.

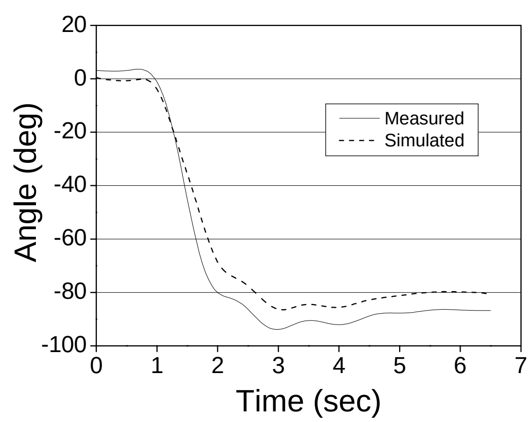

Figure 5. Steering Wheel Angle Input – Step Steer at 14 m/sec

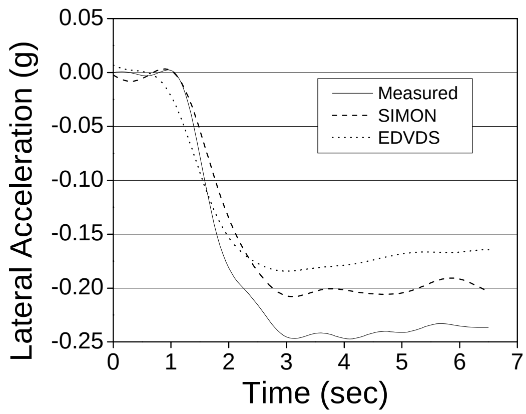

Figure 6. Tractor Lateral Acceleration – Step Steer at 14 m/sec

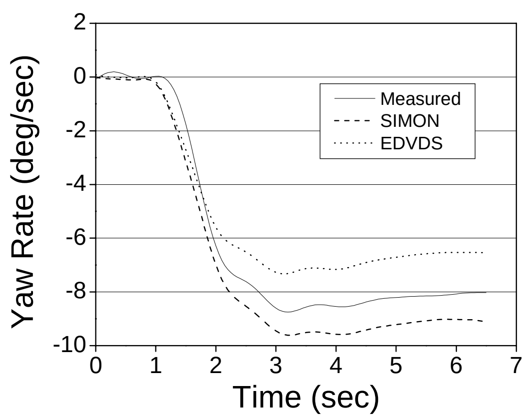

Figure 7. Tractor Yaw Velocity – Step Steer at 14 m/sec

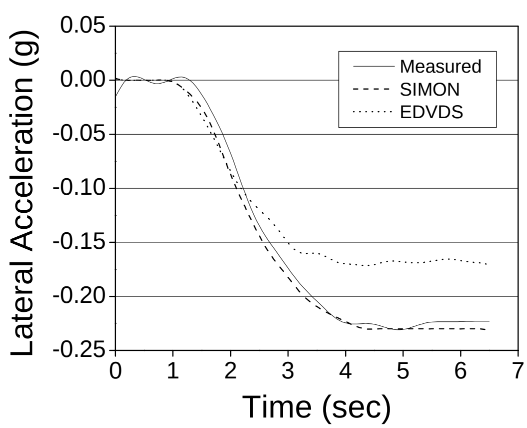

Figure 8. Trailer Lateral Acceleration – Step Steer at 14 m/sec

<u>Step steer at 14 m/sec (30 mph)</u>

Figures 10-12 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).

The magnitude of the SIMON and experimental responses were consistently greater than the EDVDS response for all three variables.

SIMON and EDVDS tractor lateral acceleration responses closely correlated to the experimental data during the majority of the step steer transient phase. SIMON and EDVDS reached steady state values approximately 11% and 23% lower than the measured values, respectively.

SIMON and EDVDS tractor yaw rate responses closely correlated to the experimental data during the majority of the step steer transient phase. SIMON correlated well with the experimental data throughout the maneuver and reached a steady state value within approximately 0.4% of the test data. EDVDS reached a steady state value approximately 16% below the experimental value.

SIMON and EDVDS trailer lateral acceleration responses closely correlated to the experimental data during the majority of the step steer transient phase. SIMON correlated well with the experimental data throughout the maneuver into the steady state phase. EDVDS reached a steady state value approximately 16% below the experimental value.

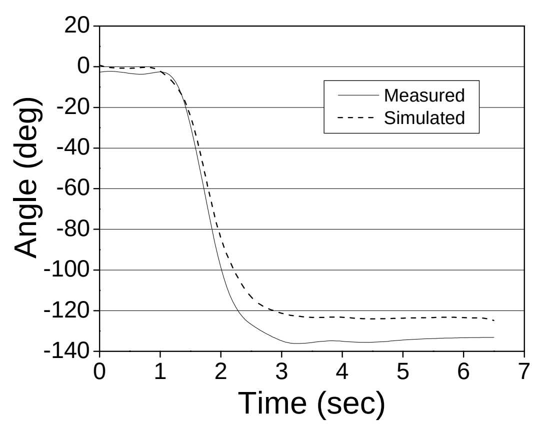

Figure 9. Steering Wheel Angle Input – Step Steer at 14 m/sec (2)

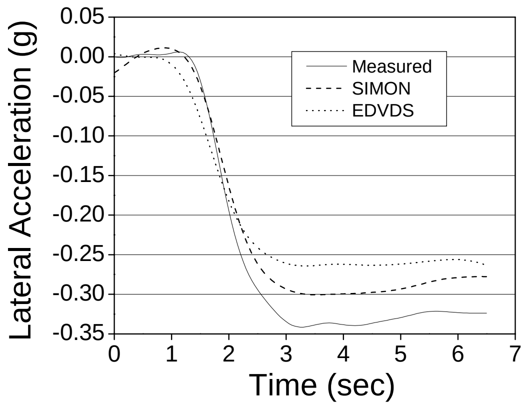

Figure 10. Tractor Lateral Acceleration – Step Steer at 14 m/sec (2)

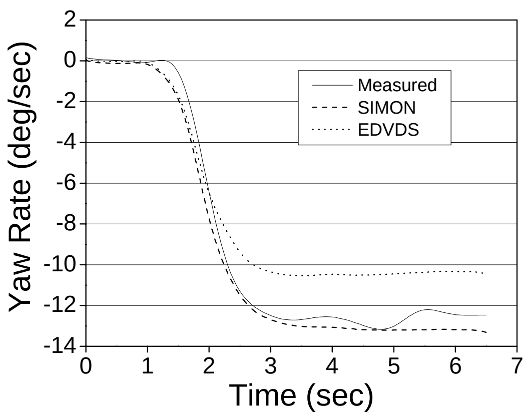

Figure 11. Tractor Yaw Velocity – Step Steer at 14 m/sec (2)

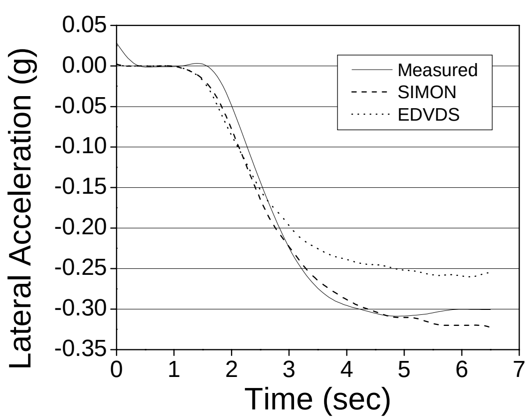

Figure 12. Trailer Lateral Acceleration – Step Steer at 14 m/sec (2)

<u>Step steer at 20 m/sec (45 mph)</u>

Figures 14-16 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).

The magnitude of the SIMON and experimental responses were consistently greater than the EDVDS response for all three variables.

SIMON and EDVDS tractor lateral acceleration responses closely correlated to the experimental data during the majority of the step steer transient phase. SIMON and EDVDS reached steady state values approximately 27% and 36% lower than the measured values, respectively.

SIMON and EDVDS tractor yaw rate responses closely correlated to the experimental data during the majority of the step steer transient phase. SIMON and EDVDS reached steady state values approximately 9% and 25% below the experimental values, respectively.

SIMON and EDVDS trailer lateral acceleration responses closely correlated to the experimental data during the majority of the step steer transient phase. SIMON and EDVDS reached steady state values approximately 17% and 38% below the experimental values, respectively.

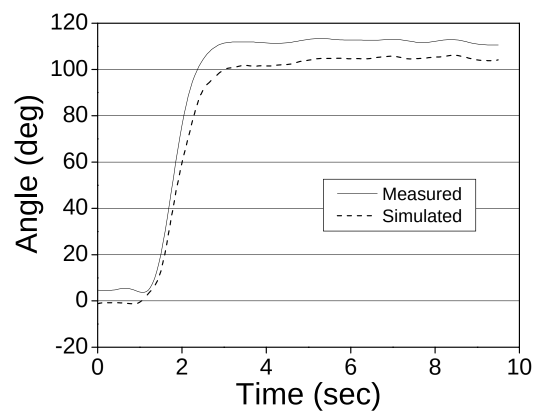

Figure 13. Steering Wheel Angle Input – Step Steer at 20 m/sec

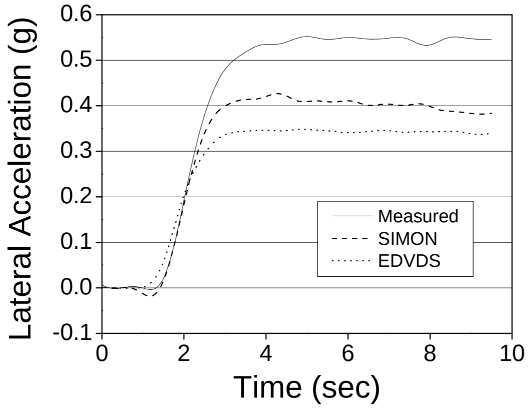

Figure 14. Tractor Lateral Acceleration – Step Steer at 20 m/sec

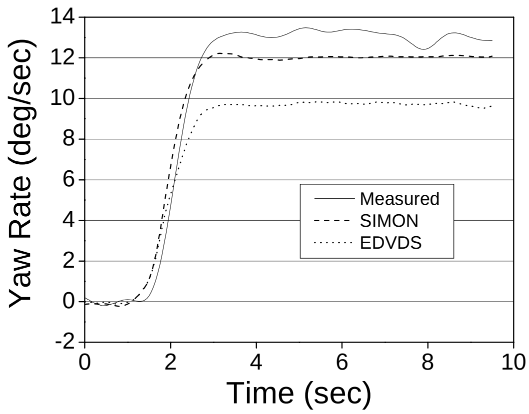

Figure 15. Tractor Yaw Velocity – Step Steer at 20 m/sec

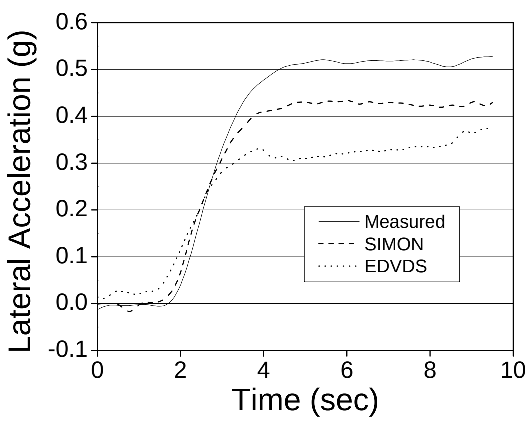

Figure 16. Trailer Lateral Acceleration – Step Steer at 20 m/sec

Lane change at 18 m/sec (40 mph)

Figures 18-20 depict the tractor lateral acceleration, tractor yaw velocity and trailer lateral acceleration for the lane change test at a nominal speed of 18 m/sec (40 mph).

In the gradually increasing steer test and the step steer tests the Pitman arm measurement could be zeroed by using the point of zero lateral acceleration and yaw rate as a point of reference. The lane change data recording began at a point of non-zero lateral acceleration, making such a calibration less precise.

Figure 17 depicts the adjusted steering inputs. Non-adjusted, the modeled steer inputs were significantly shifted. Since the simulated steer will always be a factor below the measured steering wheel inputs, it would seem that the simulated steering input would be more accurate if shifted up by an additional constant value.

Such a shift would also seem warranted based upon inspection of the simulated outputs. SIMON values for tractor yaw rate and trailer lateral acceleration are greater than the experimental values in the right turn phases, but less than the experimental values in the left turn phases.

The aforementioned issues not withstanding, the trends observed in the earlier tests were evident in the lane change test. EDVDS magnitude was less than SIMON and experimental values. SIMON magnitudes correlated closely with the experimental magnitudes for tractor yaw rate and trailer lateral acceleration. Again, experimental tractor yaw rate outpaced the simulated values.

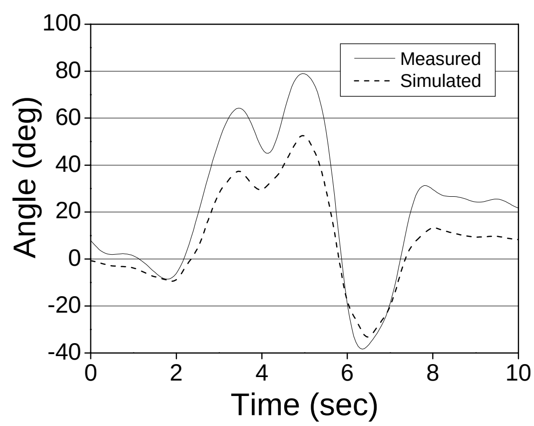

Figure 17. Steering Wheel Angle Input – Lane Change at 18 m/sec

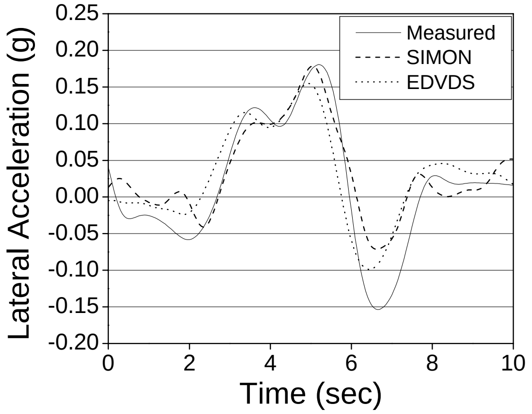

Figure 18. Tractor Lateral Acceleration – Lane Change at 18 m/sec

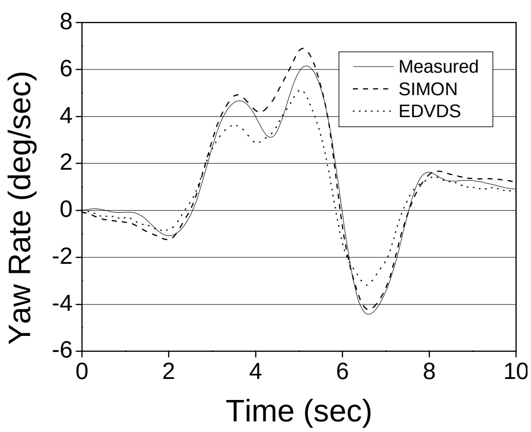

Figure 19. Tractor Yaw Velocity - Lane Change at 18 m/sec

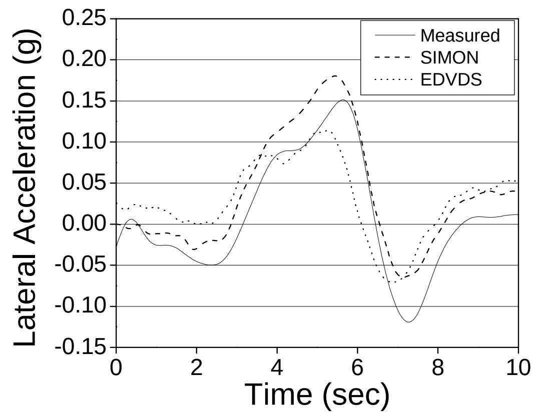

Figure 20. Trailer Lateral Acceleration – Lane Change at 18 m/sec

CONCLUSIONS

1. EDVDS and SIMON simulated responses followed the experimental trends and correlated well to the experimental data throughout the majority of the step steer transient phase.

2. EDVDS steady state responses were consistently of lesser magnitude than both the experimental results and the SIMON response. EDVDS would require greater steer input to reach the experimental levels of lateral acceleration and yaw velocity.

3. SIMON responses correlated well to the experimental values in both step steer transient phases and steady state phases in all tests except for the steady state phase of the Step Steer at 20 m/sec. It is worth noting that his test was run with right steer input whereas the two Step Steer at 14 m/s tests and the Gradually Increasing Steer at 14 m/sec tests were run with left steer input. However, no error in the right turn data has been identified.

4. SIMON tractor lateral acceleration response correlated more closely to the experimental data than did the EDVDS response. SIMON tractor lateral acceleration response had a greater error rate than did the SIMON tractor yaw rate and SIMON trailer lateral acceleration responses. The NADS testing by VRTC showed a similar trend.

5. A discrepancy in the tractor lateral acceleration measurement and calculated

data has been previously discussed in the literature [7]. If, in fact, there was a somewhat high reporting of the experimental tractor lateral accelerations, it would serve to improve the correlation between SIMON and EDVDS to the experimental data.

6. Considering the potential variability in tire data, even among tires of similar construction and of the same tire from test to test, the correlation of the SIMON tractor yaw rate and trailer lateral acceleration responses, particularly in the gradually increasing steer and step steer tests is excellent.

7. SIMON and EDVDS followed the experimental trends in the lane change maneuver. SIMON more closely correlated to the experimental data through the maneuver, particularly in the tractor yaw rate and trailer lateral acceleration responses.

8. The lane change results could potentially improve with a more accurate adjustment of the Pitman arm data.

FUTURE WORK

Simulated vehicle responses will be compared with experimental vehicle responses for the following maneuvers:

a. Handling tests with the loaded trailer configuration

b. Straight-line braking

c. Braking in a turn

d. Acceleration tests

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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