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Model Validation of The 1997 Jeep Cherokee For the National Advanced Driving Simulator

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ABSTRACT

This paper presents an evaluation of a complete vehicle dynamics model for a 1997 Jeep Cherokee to be used for the National Advanced Driving Simulator. Vehicle handling and powertrain dynamics are evaluated and simulation results are compared with experimental field-testing. NADSdyna, the National Advanced Driving Simulator vehicle dynamics software, is used. The Jeep evaluation covers vehicle directional dynamics that include steady state, transient and frequency response, and vehicle longitudinal dynamics that include acceleration and braking.

INTRODUCTION

The National Advanced Driving Simulator (NADS) is a state-of-the-art real-time vehicle driving simulator, funded by the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) [1]. NADS will materially assist federal agencies, commercial organizations, and researchers in general in enhancing human factors and crash avoidance research, hardware-in-the-loop simulation and design including intelligent transportation systems applications, and other subjects related to highway safety. When operational, NADS will have initially four vehicle models: Ford Taurus, Jeep Cherokee, Chevrolet Malibu, and a tractor-semitrailer.

An advanced driving simulator such as the NADS must include a detailed, highly accurate vehicle dynamics simulation to predict the movements of the simulated vehicle in response to both control and disturbance inputs. To show accuracy, the simulation must be validated thoroughly with experimental results. The Ford Taurus was validated extensively and the results were published [2-6]. Those results confirmed that NADSdyna, the NADS vehicle dynamics software, is a powerful simulation tool that can predict vehicle physics with excellent fidelity.

This paper validates the Jeep model presented in previous publication [7]. This is basically a continuation of the NADSdyna validation efforts by the Vehicle Research and Test Center (VRTC) that will include all four vehicles specified as part of the NADS initial operation.

The simulation validation methodology used for the Jeep is essentially similar to previous VRTC validation work. The methodology consists of three main phases: experimental data collection, vehicle parameter measurement, and comparison of simulation predictions with experimental data. Measuring the actual physical responses is not an error-free exercise due to the inability to control the systematic error and random errors within the system. The validation confidence should be improved when more than one vehicle is validated. Analytical diagnostics, or sanity checks, should be applied along with this definition so that the simulation predictions match the desired model behavior. The inconsistencies between numerical simulation and vehicle field experiments with identical control inputs could be due to problems in several areas that include model formulation, simulation programming, vehicle parameter identification, numerical accuracy and stability, and low quality experimental results [4]. Trying to find sources of discrepancy between simulation and experiments by looking at the vehicle as one unit is a hopeless effort due to the complex interactions between many subsystems. Therefore each subsystem should be examined with care and checked independently, vis-à-vis the requirements needed to guarantee certain simulation quality in the linear and nonlinear range.

Simulation validation is performed in both the time and frequency domains. The experimental driver inputs (steering, braking, and throttle) are used as inputs to drive the simulation. The simulation predictions are compared to the experimental outputs. Validation in the time domain is good for demonstrating that the simulation can correctly predict steady-state conditions and that nonlinear effects are properly modeled. High frequency transient phenomena, however, are very difficult to study in the time domain. The effects of increasing input frequency on the correctness of a simulation's predictions are best determined through frequency domain studies.

VEHICLE FIELD TESTING

VRTC is doing an extensive vehicle testing program to provide data for simulation evaluation. The Jeep instrumentation and field-testing are essentially similar to the Ford Taurus [3]. The test vehicle used is a 1997 Jeep Cherokee Sport (VIN number 1J4F68S3VL579212). The Jeep has a 4.0-liter I6 engine, four-speed automatic transmission, cruise control, and four-wheel anti-lock brakes. Goodyear Wrangler RT/S P225/75R15 tires with a cold inflation pressure of 33 psi are used for all testing. The tires were purchased together, and are from the same batch.

The vehicle field-testing was designed to minimize the effects of driver variability and provide repeatable open-loop experimentation. For each maneuver, the driver control inputs were repeated and the mean values and 95% confidence intervals were computed. The simulation is driven using the mean values. The mean experimental driver input used to drive the simulation (250 Hz), is obtained using linear interpolation of experimental sampled values (100 Hz).

The following maneuvers are compared with simulation: slowly increasing steer, step steer, pulse steer, double lane change, straight-line braking, and straight-line acceleration. Developing simulation models which result in analytical predictions that compare well with experimental measurements is not an easy task, particularly when extreme maneuvering conditions are considered. For limit performance maneuvers, only the trends or relatively close results should be expected, since the mechanics of these extreme conditions (especially tires) are extremely difficult to model.

VEHICLE DIRECTIONAL DYNAMICS

SLOWLY INCREASING STEER - The slowly increasing steer, Figures 1-4, involves supplying the simulation with the measured slowly increasing handwheel angle (on the order of 10 degrees per second) while maintaining a constant vehicle speed until maximum lateral acceleration is achieved. At high lateral acceleration levels, front tire force saturation comes into play, and the steady-state curve is asymptotic to some limit of lateral-g level, which is an indication of limit understeer effect. The maximum lateral acceleration achieved was followed by a reduction in acceleration, because the lateral tire forces saturated and the front tires plowed out. As a result, further increases in the handwheel angle no longer increase lateral acceleration. Results indicate appropriate nonlinear vehicle model properties as well as appropriate model tire forces up to saturation. The simulated roll angle is compared to front and rear suspension roll.

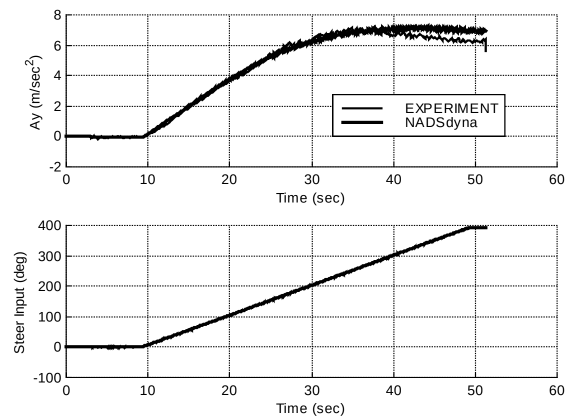

Figure 1. Lateral acceleration and handwheel angle at constant speed 11 m/s

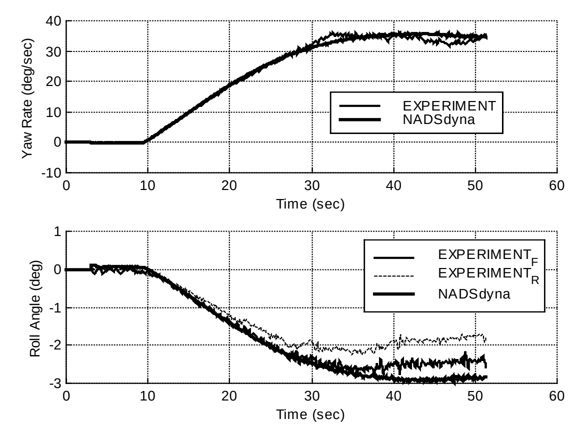

Figure 2. Yaw rate and roll angle at constant speed 11 m/sec

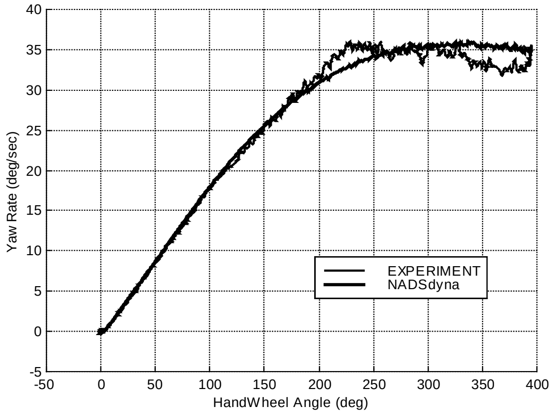

Figure 3. Yaw rate versus handwheel angle at constant speed 11 m/sec

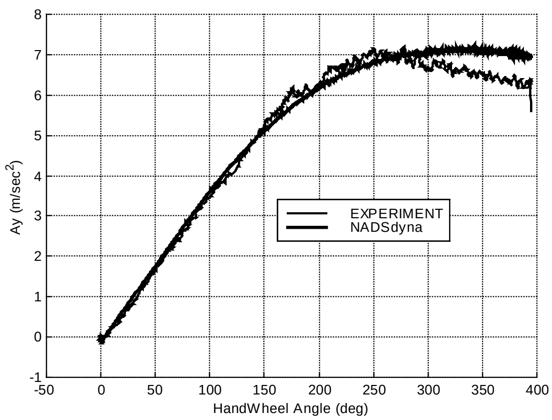

Figure 4. Lateral acceleration versus handwheel angle at constant speed 11 m/sec

STEP STEER INPUT - This maneuver (J-turn) is a pseudo-step input of handwheel angle, Figures 5-8. It is used to determine steady-state as well as transient responses. The tire model is quasi-static; however, lateral force dynamics are included using a first-order lateral slip angle differential equation. The timing and peak levels of lateral acceleration and yaw rate for the simulation and experiment are close. The simulated roll angle is close to the front suspension roll angle.

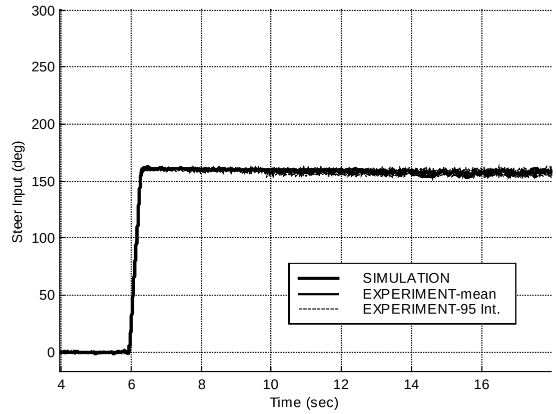

Figure 5. Steering input at constant speed 12 m/s

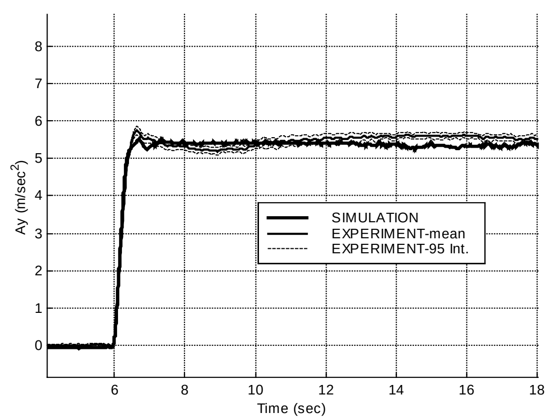

Figure 6. Lateral acceleration at constant speed 12 m/s

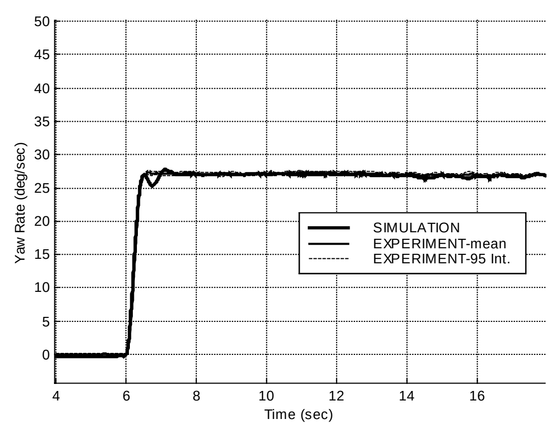

Figure 7. Yaw rate at constant speed 12 m/s

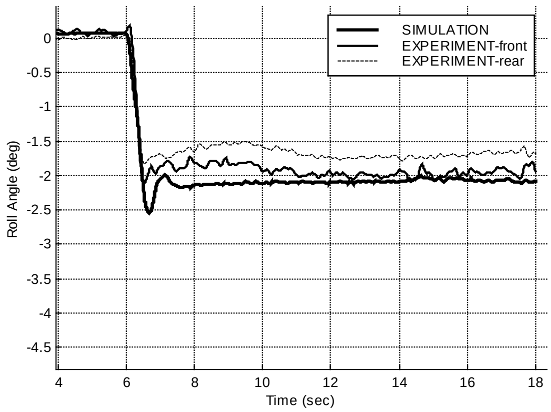

Figure 8. Roll angle at constant speed 12 m/s

LANE CHANGE MANEUVERS - Besides the evaluation of steady-state, transient, and frequency response predictions, the simulation is checked against maneuvers that replicate real-world complex scenarios like lane-change maneuvers. No statistical analysis was done since only one run was performed for each maneuver. The steering input represents driver-vehicle closed-loop performance, with sufficient amplitude to produce moderate to high lateral accelerations. Figures 9-12 show that the simulation predicted well the lateral acceleration and the yaw rate. The roll angle is also reasonably predicted and it is close to the front suspension roll.

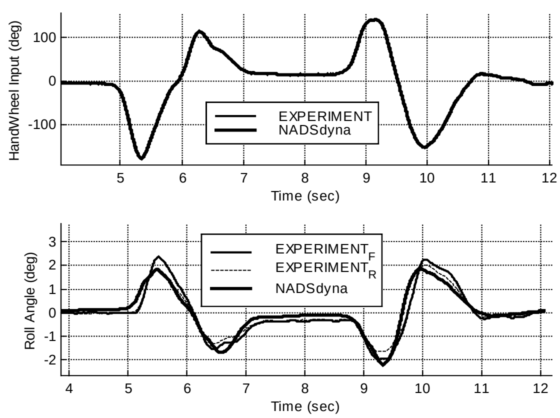

Figure 9. Handwheel input and roll angle at constant speed 12 m/s

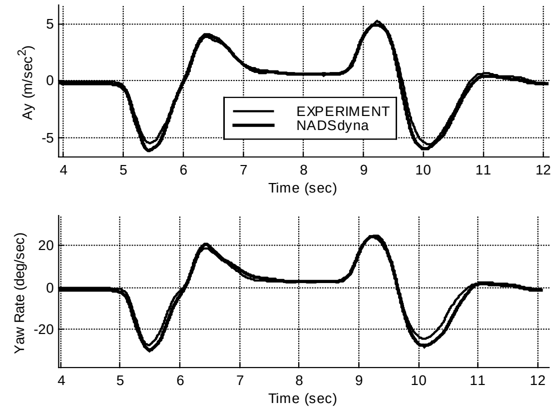

Figure 10. Lateral acceleration and yaw rate at constant speed 12 m/s

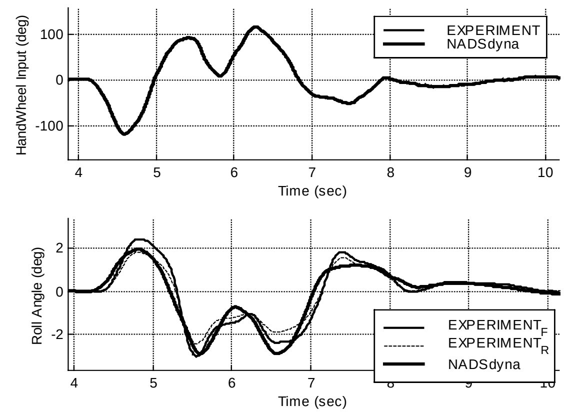

Figure 11. Handwheel input and roll angle at constant speed 22.5 m/s

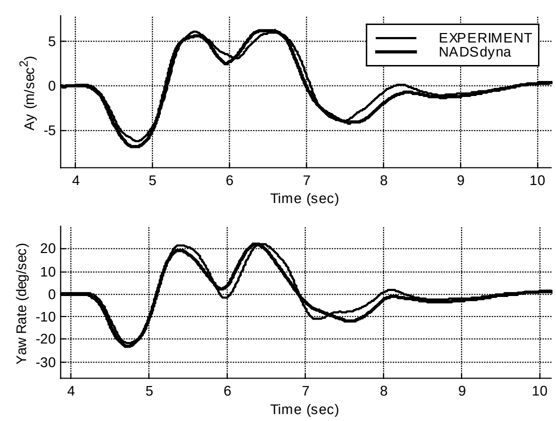

Figure 12. Lateral acceleration and yaw rate at constant speed 22.5 m/s

PULSE STEER FREQUENCY RESPONSE - Instead of using sinusoidal sweep input, random input, or discrete sinusoidal input testing, pulse steer maneuvers are used to generate vehicle frequency responses to steering inputs. By judiciously selecting the proper short duration of pulse input to drive a system, it is possible to excite a full range of frequencies using a single experimental test or simulation run.

Since linear frequency response can be developed for linear, time-invariant systems, or approximated for a nonlinear system about some linearized operating condition, transfer functions for vehicle handling dynamics are derived only for constant speed maneuvers, with lateral acceleration not exceeding 3 to 4 m/s^2. The pulse steer is applied with sufficient power; otherwise, noise will dominate the signal and produce invalid numbers in the frequency response. An ideal pulse produces power over all frequencies; however, this is not possible in the physical world. In field experiments, the pulse was generated by a sequence of step increase and step decrease steer with a total duration on the order of 0.2 s, which produces good steering power up to the 3 to 4 Hz frequency range [8].

For the test data, an ensemble frequency response is found by dividing the sum of the cross-spectral densities of the output channels by the sum of the power spectral densities of the input channels. This method provides an effective reduction of any random noise in the individual signals.

The bandwidth, peak amplitude ratio, and peak frequency of yaw rate and lateral acceleration frequency response to steering input are speed-of-response type measures. A wider bandwidth indicates the vehicle response characteristics are maintained for a higher frequency input. Yaw rate frequency response to handwheel angle gives an indication of the frequency where the vehicle starts becoming less responsive. Figures 13 and 14 show that the simulation in general is in good agreement with the experimental results, though the experiments are shown to be of a higher order especially when the frequency is above 10 rad/s.

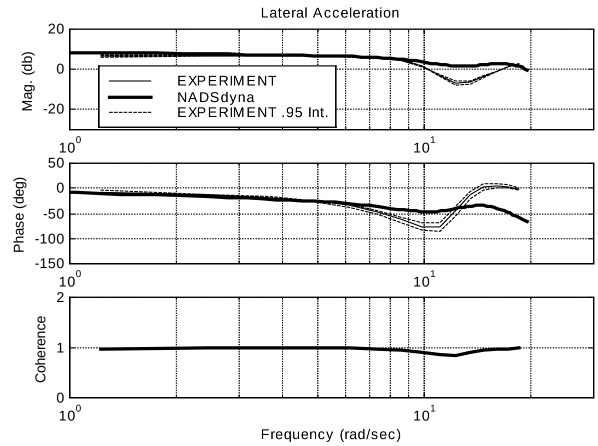

Figure 13. Lateral acceleration frequency response to handwheel angle at a speed of 11 m/s

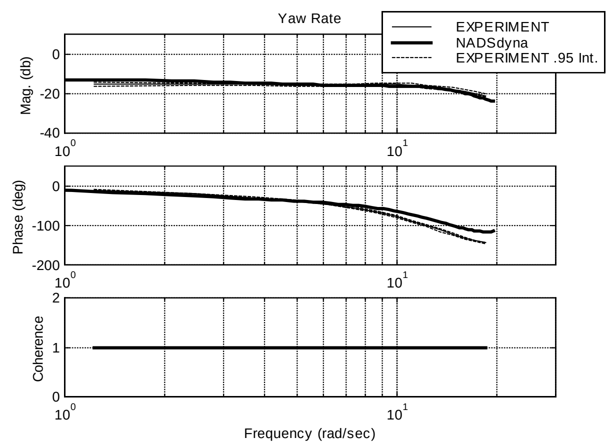

Figure 14. Yaw rate frequency response to handwheel angle at a speed of 11 m/s

LONGITUDINAL DYNAMICS

STRAIGHT-LINE BRAKING - This maneuver is performed from mild to severe conditions. Figures 15-18 contain results from moderate braking runs, while Figures 19-22 contain results from severe braking runs. The results show the simulation predicted reasonable longitudinal deceleration and wheel spin rates. The longitudinal speed is reasonable and consistent with the deceleration. The brake line pressures were also well predicted by the brake model. As it was demonstrated for the Ford Taurus [6], the simulation predicts well vehicle braking.

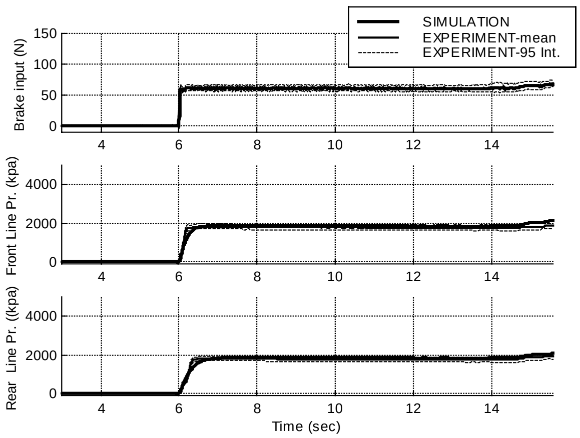

Figure 15. Brake input and line pressures (Moderate braking)

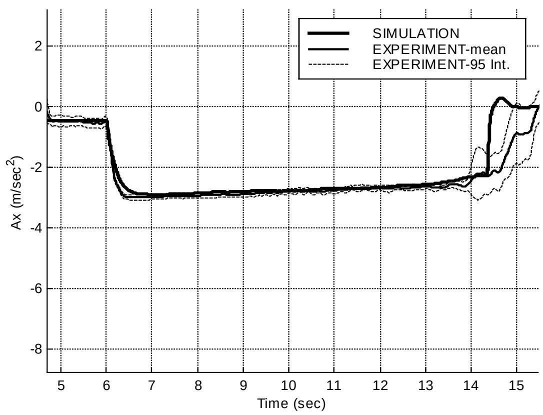

Figure 16. Longitudinal deceleration (moderate braking)

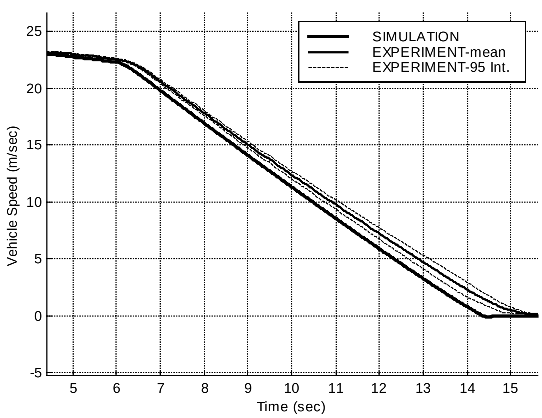

Figure 17. Longitudinal speed (moderate braking)

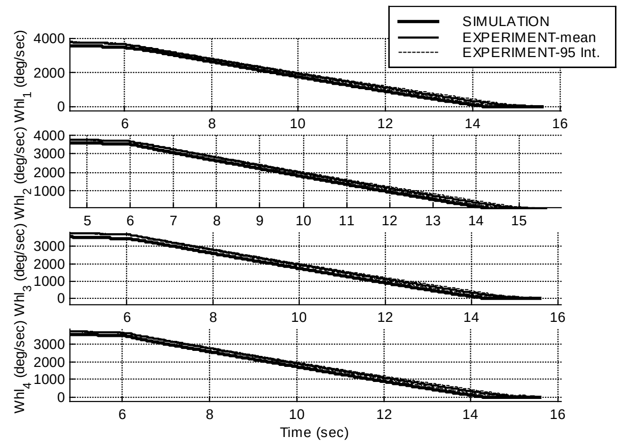

Figure 18. Wheel-spin rates (moderate braking)

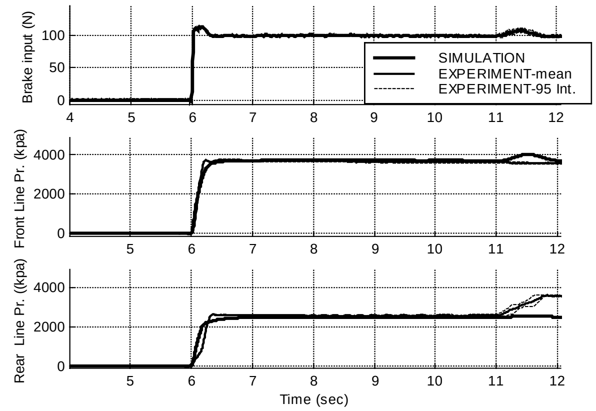

Figure 19. Brake input and line pressures (severe braking)

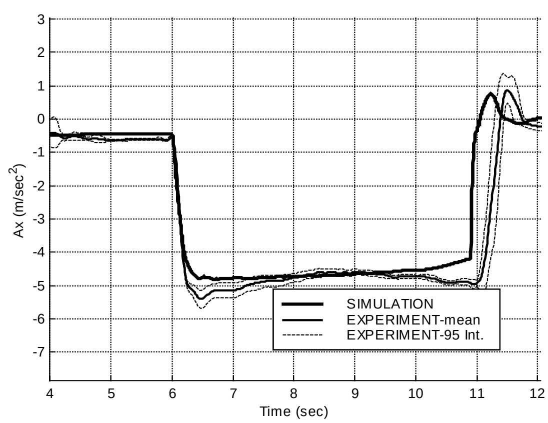

Figure 20. Longitudinal deceleration (severe braking)

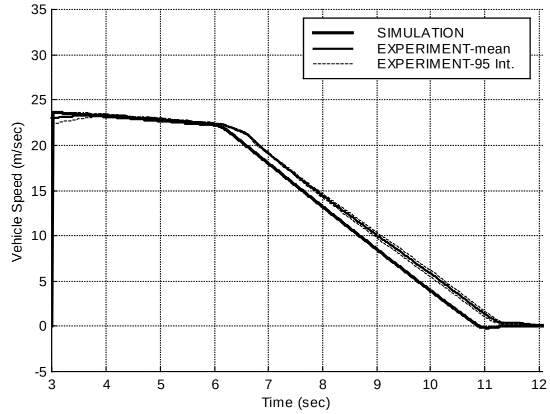

Figure 21. Longitudinal speed (severe braking)

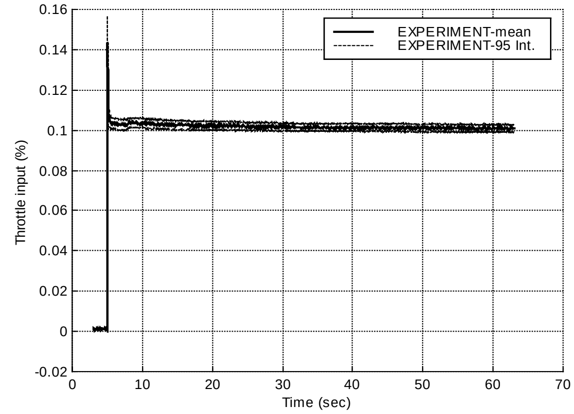

Figure 23. Throttle input

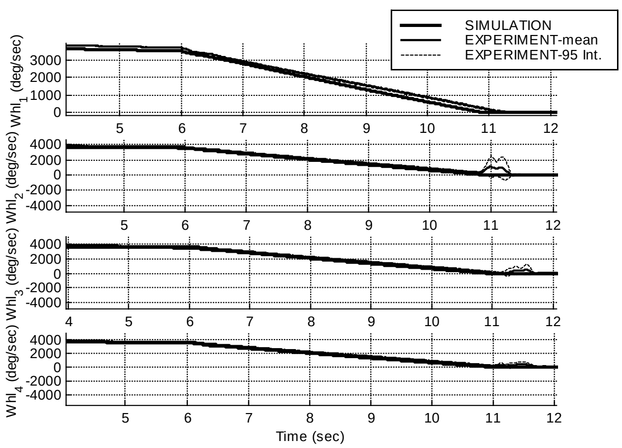

Figure 22. Wheel-spin rates (severe braking)

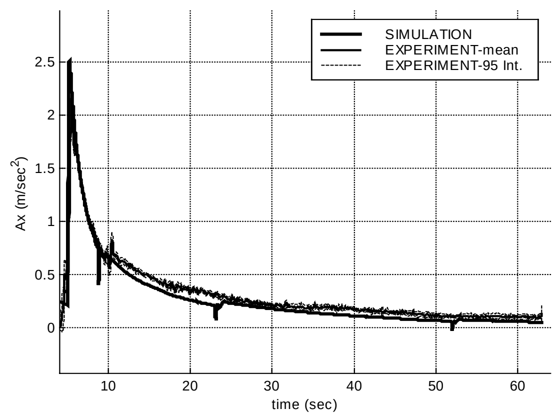

Figure 24. Longitudinal acceleration

STRAIGHT-LINE ACCELERATION - The maneuver is a step throttle input, Figures 23-27. The results show that the acceleration, wheel spin rate, and vehicle speed are well predicted. The trends in engine speed are similar, and efforts to improve the modeled transmission shift points are currently underway.

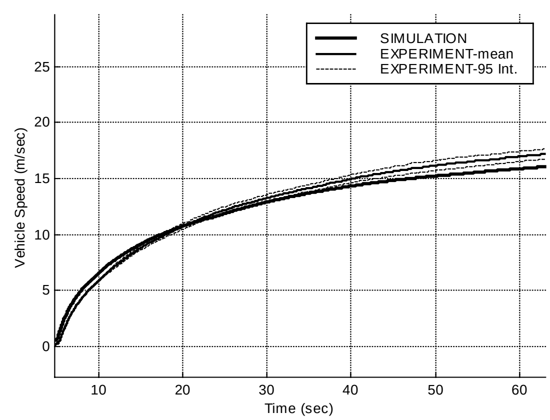

Figure 25. Vehicle longitudinal speed

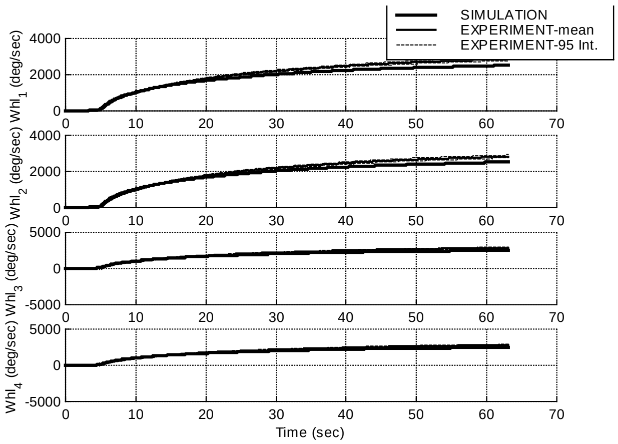

Figure 26. Wheel spin rates

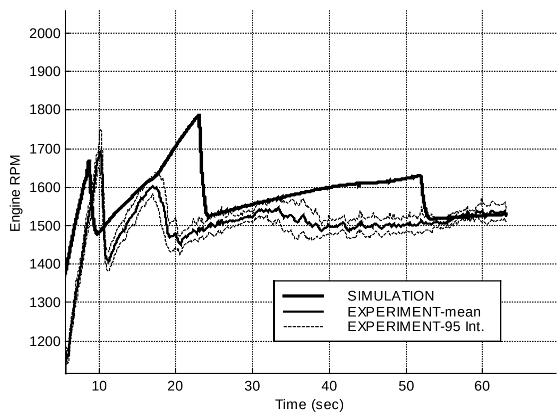

Figure 27. Engine speed

CONCLUSION

The evaluation of the 1997 Jeep Cherokee model has shown that the NADSdyna simulation predicts the fundamental mechanics of the vehicle handling responses. Simulation predictions were compared with experimental responses for slowly increasing steer, step steer, and lane change maneuvers. The simulation evaluation included comparisons of vehicle frequency responses for pulse steer tests. Straight-line braking and accelerating maneuvers were also evaluated.

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