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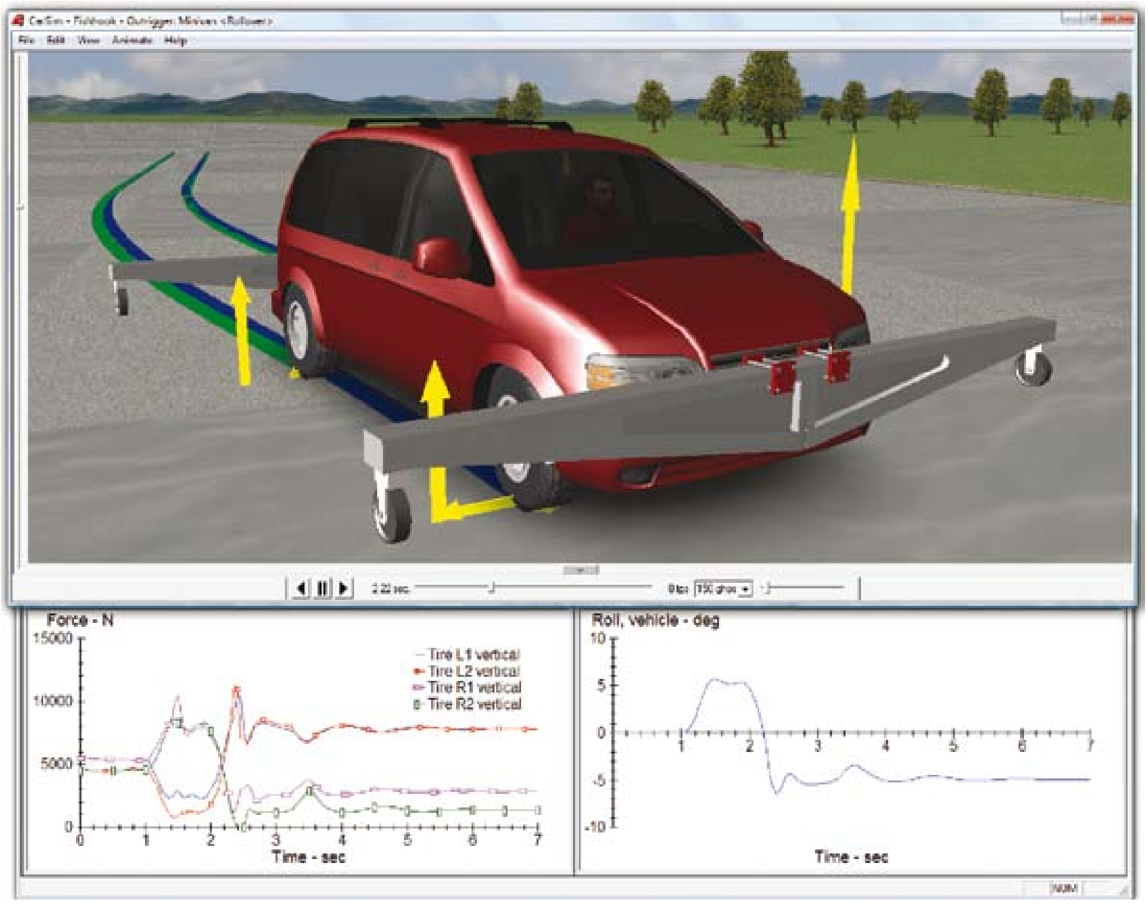
Chassis control simulation processes

CarSim from Mechanical Simulation enables GM engineers to simulate vehicle maneuvers in a lab long before a vehicle is available for testing

RIC MOUSSEAU, GENERAL MOTORS PROVING GROUNDS



A screenshot of a CarSim GUI and simulation animation

■ To ensure that every vehicle's chassis control system performs in a safe, reliable, and unobtrusive manner, extensive vehicle testing is performed at General Motors' Milford Proving Ground (MPG), and various remote winter test sites. This includes vehicle testing to measure the performance of ABS, traction control, and electronic stability control (ESC) systems during various braking, acceleration and turning maneuvers, and combinations thereof. These vehicle tests are performed on dry pavements, wet pavements, snow surfaces, and ice surfaces. Other tests include the FMVSS-126 sine with dwell (SWD) maneuver to measure ESC performance, and the NHTSA fishhook test to quantify tire lift-off during extreme emergency lane change maneuvers. GM has made a tremendous investment in facilities, equipment, manpower, and training to support this high level of vehicle performance testing.

At GM, every opportunity needs to be explored to maximize vehicle safety and performance while simultaneously reducing the cost of testing vehicles. The capability of vehicle dynamics simulation has reached a level of sophistication where it can be relied upon to replace some physical vehicle testing. In several regions throughout the world, GM engineers use a product from Mechanical Simulation called CarSim in a wide range of vehicle design and testing tasks. Simulation presents an opportunity to reduce costs, improve quality, and shorten time to market. Vehicle maneuvers can be executed by the computer in a controlled laboratory environment which lets engineers evaluate system performance months before a physical vehicle is available for testing.

Simulation is less costly than physical testing since vehicles do not need to be equipped with expensive data acquisition hardware every time a test needs to be run. Finally, the test reports generated by dynamic simulation can be made to appear the same as the physical vehicle test reports that are generated at the proving ground. This test report format, familiar to GM vehicle development engineers, helps facilitate the validation of the simulation models.

Hardware-in-the-loop (HIL) simulation is extensively used by GM MPG engineers to support the integration of chassis control systems. The fundamental idea behind HIL is to use simulation for the vehicle systems that can be modeled with high confidence and actual vehicle hardware for the systems that are difficult to model in real-time software. For example, the hardware part of an ABS HIL simulation may include the brake controller/modulator from an actual base brake system with the vacuum assist and a master cylinder. This system is difficult to model in software due to the complex non-linear temperature-dependent performance of the hydraulic system. However, the rest of the vehicle can be modeled with higher confidence and is well suited for simulation. This example is often referred to as a wet bench, because it includes the hydraulic system. Another approach is to model only the base brake system and brake modulator in software – so the only hardware is the ABS brake controller. This is often referred to as a dry bench.

At the GM MPG, the wet bench approach is most commonly used because it has proved to yield results close to real-world testing. The HIL system consists of the CarSim-RT vehicle dynamics simulation program, brake buck, and real-time simulation computer. The CarSim GUI, which controls data input and program execution, resides on the host computer. The CarSim solver, which performs the vehicle dynamics simulation, resides on the real-time simulator. The figure shows how line pressure measurements, CANbus messages, and other signals pass to and from the brake buck to the simulator.

CarSim is ideally suited for simulating vehicle performance, because its data requirements are compatible with the GM vehicle development process. The vehicle dynamics model has 10 degrees of freedom (DOF): six define position and attitude of the vehicle sprung body, and the other four define the jounce positions for the unsprung bodies. Additional DOF model tire spin, steering system rotation, and brake system dynamics.

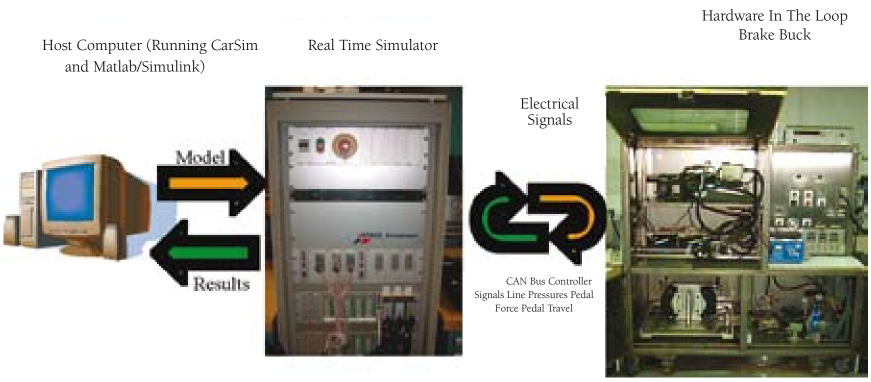
Other unsprung body motions, such as suspension toe and camber, are defined through constraint equations. The CarSim models are defined with a combination of performance constants and multidimensional lookup tables. Typically, the data is obtained from vehicle design data and from physically measuring complete vehicles and/or their subcomponents. Vehicle data includes, for example, sprung mass, CG position, roll, pitch, and yaw inertia, shock absorber force-velocity data, and suspension kinematic and compliance data. Another important set of parameters includes the tire force and moment data, which is typically measured over the expected load, slip, and camber operating range. All of this data is available from GM internal databases, which, coupled with the CarSim data structure, makes the vehicle modeling process very efficient.

“CarSim is ideally suited for simulating vehicle performance, because its data requirements are compatible with GM’s development process”

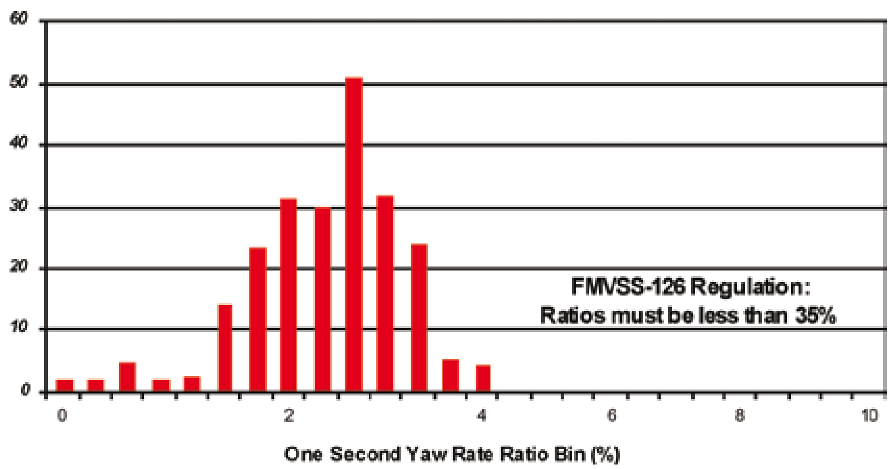
This common database also lets any GM engineer in other global regions import the data into CarSim and start running simulations. After the vehicle dynamics model is verified with standard handling tests, it is ready to be integrated into a HIL simulator.

The brake buck contains all the brake components, including vacuum assist, master cylinder, rotors, calipers, and the proper line lengths. A hydraulic actuator applies a force to the master cylinder input rod to simulate application of pedal force. The rotors, of course, do not spin, but are an important source of brake compliance. Pressure transducers measure the brake caliper pressure at each corner. The signals are fed back to the brake model in the CarSim simulation and are scaled by tables to estimate applied braking torques. The buck also includes the brake ECU, which controls the brake pressure modulator. The brake fluid system is bled, as in an actual car, to remove air bubbles that can potentially degrade system performance.

The real-time simulator computer executes the CarSim model in real time and provides the interface to the brake buck. It digitizes the analog brake line pressure



Above: HIL simulation and signal flow

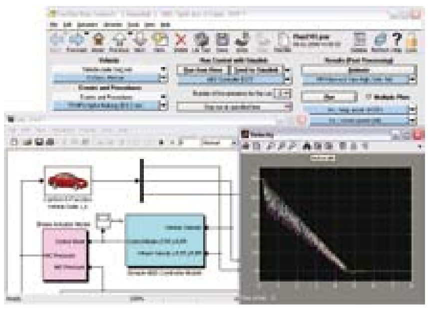


Histogram of 1.0 second yaw rate ratio

signals, which are used to estimate brake torques in the vehicle dynamics model. The real-time simulator also provides the CANbus signal interface for the brake ECU and digital IO for the relevant vehicle sensors. It also provides diagnostic messages to allow the ESC to function.

Most of the simulated vehicle maneuvers primarily involve braking, with little or no throttle application. For these maneuvers, the CarSim powertrain model works well. However, the maneuvers that activate the traction control system require an internally developed, more detailed powertrain model developed in Simulink, which executes in parallel with the CarSim simulation on a separate processor.

A common application of HIL vehicle dynamics simulation at GM MPG is the FMVSS-126 Sine with Dwell (SWD) test maneuver. This maneuver is severe enough to induce oversteer intervention for all vehicles equipped with ESC systems. When the regulation comes in full effect in 2011, all vehicles less than 4,545kg (10,000 lb) GVWR sold within the USA must pass this test. With a few exceptions, this test will cause vehicles without the benefit of ESC to spin out of control.

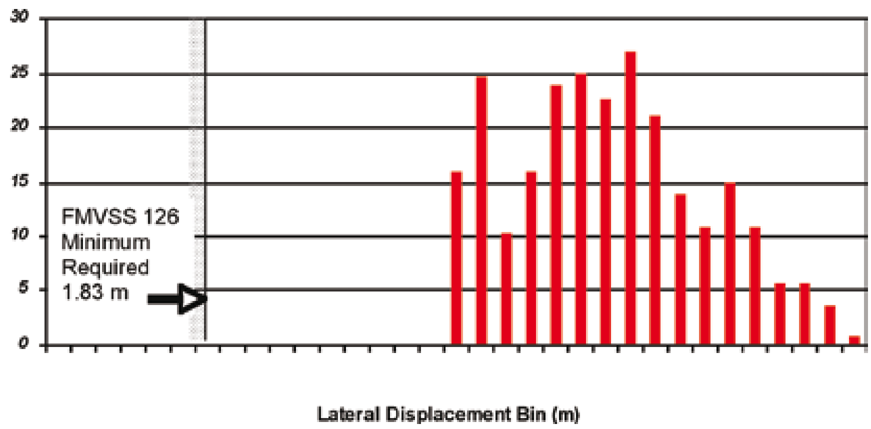


A screenshot of Simulink

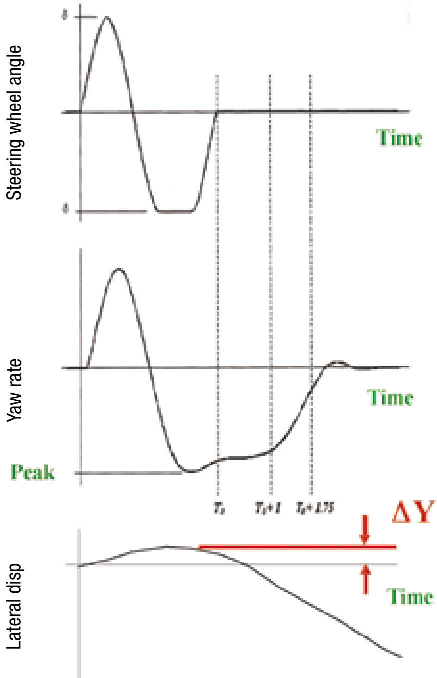
The SWD steering profile required by the FMVSS 126 regulation consists of three quarters of a 0.7Hz sine wave, followed by 0.5 second dwell at 1.07 second as shown in the figure. The last quarter of the sine wave completes the profile. The asymmetry in the steering profile promotes vehicle spin at large steer angles.

The SWD test procedure involves steering the vehicle with this profile scaled by multiples of a reference steer angle measured on the vehicle at 0.3g lateral acceleration in a ramp steer test. The test starts with a steering multiplication factor of 1.5 and ends when the steer amplitude is larger than either a multiple of 6.5 times the reference steer angle or 270 degrees of steer. Metrics calculated from the test data include the 1.0 second and 1.75 second yaw rate ratios (measures of vehicle spin), and the lateral displacement at three-quarter steer cycle (measure of vehicle maneuverability). The FMVSS-126 regulation requires the vehicle to achieve a lateral displacement of at least 1.83m during the maneuver, while the 1.0 second yaw rate must be less than 35% of the peak value during the maneuver, and the 1.75 second yaw rate less than 20% of the peak.

Understanding how the test metrics can be influenced by vehicle build and test-surface variability is an important part of the certification process. Model parameters that influence the vehicle handling test metric include tire cornering force properties, weight distribution, suspension stiffness and damping, and test entry speed. Studies using Monte Carlo analysis to randomly vary the vehicle parameters within the CarSim HIL simulation have proved useful for understanding vehicle control system robustness. Typically these studies may involve over 1,000 HIL simulation runs,



Histogram of lateral displacement metrics



SWD steering profile and test evaluation metrics

which can be completed in 24 hours. The histogram plots illustrate how the variables can affect the test metrics of the 1.0 second yaw rate ratio and the lateral displacement requirement. Despite the variability, the yaw rate ratio is always much lower than the 35% limit and the lateral displacement is always well in excess of the 1.83m requirement. Tests such as these help show that the control system is sufficiently robust to ensure compliance with the regulations.

Being able to perform these tests within the simulation environment illustrates the value of vehicle dynamic software like CarSim as the foundation for the vehicle development process. CarSim fits well into the vehicle development process and complements test resources. HIL simulation has proved to be a very effective tool for extensive robustness studies that require a very large number of vehicle tests. CarSim is also used to isolate problems that are difficult to reproduce in actual vehicle testing environments, and to identify problematic vehicle configurations for testing. In summary, HIL simulation is a powerful tool for optimizing vehicle performance testing, which has been shown to reduce cost and improve quality.

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