An Overview of the use of Hardware-in-loop (HIL) Simulation to Support Chassis Controls System Development at General Motors

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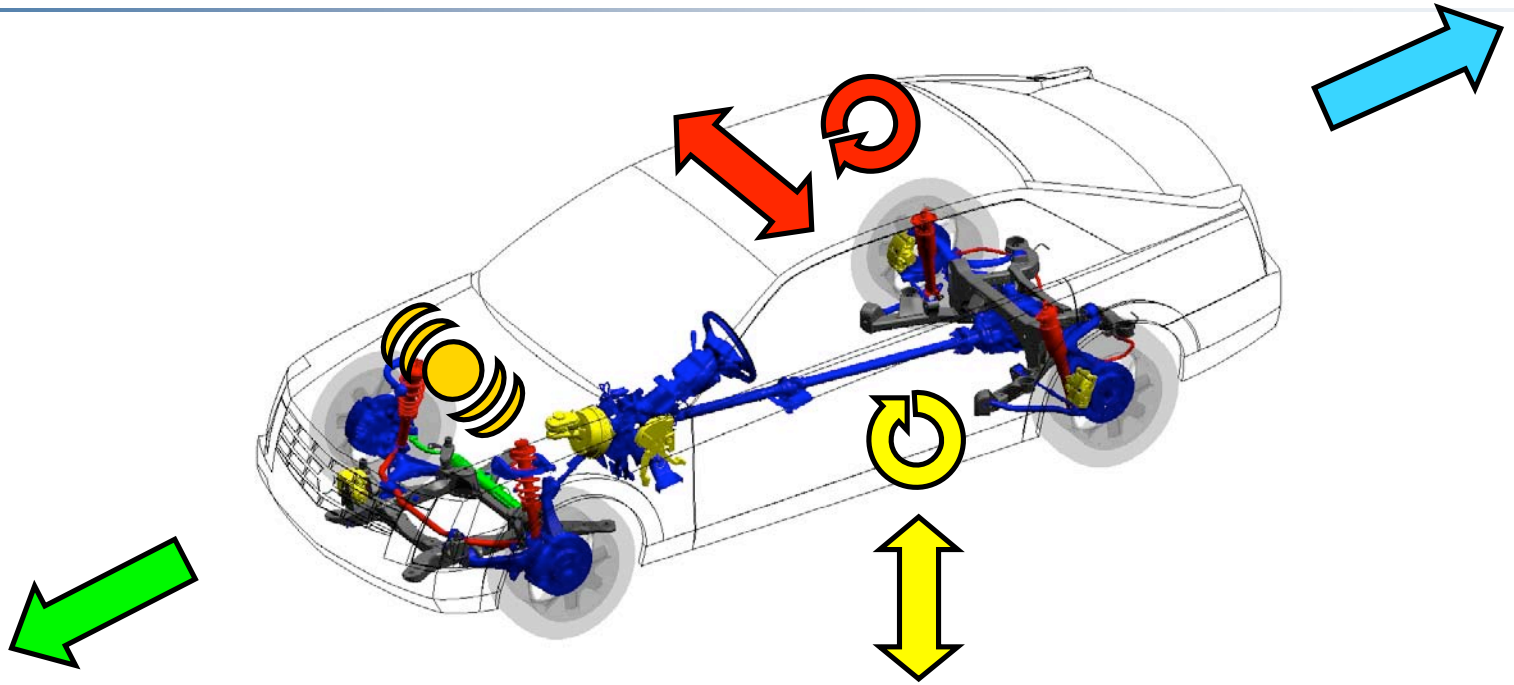
October 23, 2008

Agenda

- Traditional hardware approach to Vehicle Dynamics engineering
- Challenges facing Vehicle Dynamics engineering
- Benefits and Enablers to using Simulation as a tool for Chassis Controls engineering
- Vehicle Dynamics modeling process overview
- Hardware-In-the Loop (HIL) laboratory set-up
- Physical vs. Virtual test maneuver case studies:
  - NHTSA NCAP Fishhook test
  - NHTSA FVMSS 126 Sine-with-dwell test
- Summary and Conclusions

Nurburgring Nordschleife

Vehicle Dynamic Performance



Ride	Heave, Pitch, and Roll Vehicle Motions
Handling	Lateral and Yaw Vehicle Dynamics
Braking	Stopping Distance, Pedal Feel, Fade Resistance, Noise, Pulsation, and Brake Dust
Traction	Straight Line (On and Off-Road), Handling, and Safety/Security Performance on FWD, RWD, 4WD, and AWD Drivelines
Noise & Vib.	Powertrain N&V, Road N&V, Component N&V, Squeak & Rattle, Wind Noise, and Pass-By Noise

Vehicle Dynamics Engineering

- **Set Competitive Requirements**
- **Analytical Simulation and Synthesis**
- **Setting Up Architectures**
- **Selecting Appropriate Vehicle Systems**
- **Hardware Development**
- **Subjective Evaluation**
- **Fine Tuning**
- **Objective Validation**
- **Certification (where applicable)**

Business Challenges

- **Shorter Cycle Time**
- **Reduced Development Hardware**
- **Increased Product Complexity**
- **Non-traditional Launch Timing**
- **Globalization**

Technical Challenges

- **Government Regulations**
  - **Fishhook (NCAP)**
  - **FMVSS-126 (Sine with Dwell)**
- **Fuel Economy**
- **Alternative Fuel Powertrains**

Chassis Controls Engineering Challenges

- **Chassis controls systems (e.g., ABS, ESC, & Traction Control) are becoming standard equipment on the vast majority of vehicles below 10,000 GVW**
  - **Market place**
  - **Government regulations**
- **Vehicle equipped with chassis controls must pass stringent validation testing**
- **The number of required validation tests increase with the number of unique powertrains and tires**
- **Vehicle testing resources are shrinking**
- **Controlling the test environment is very difficult**

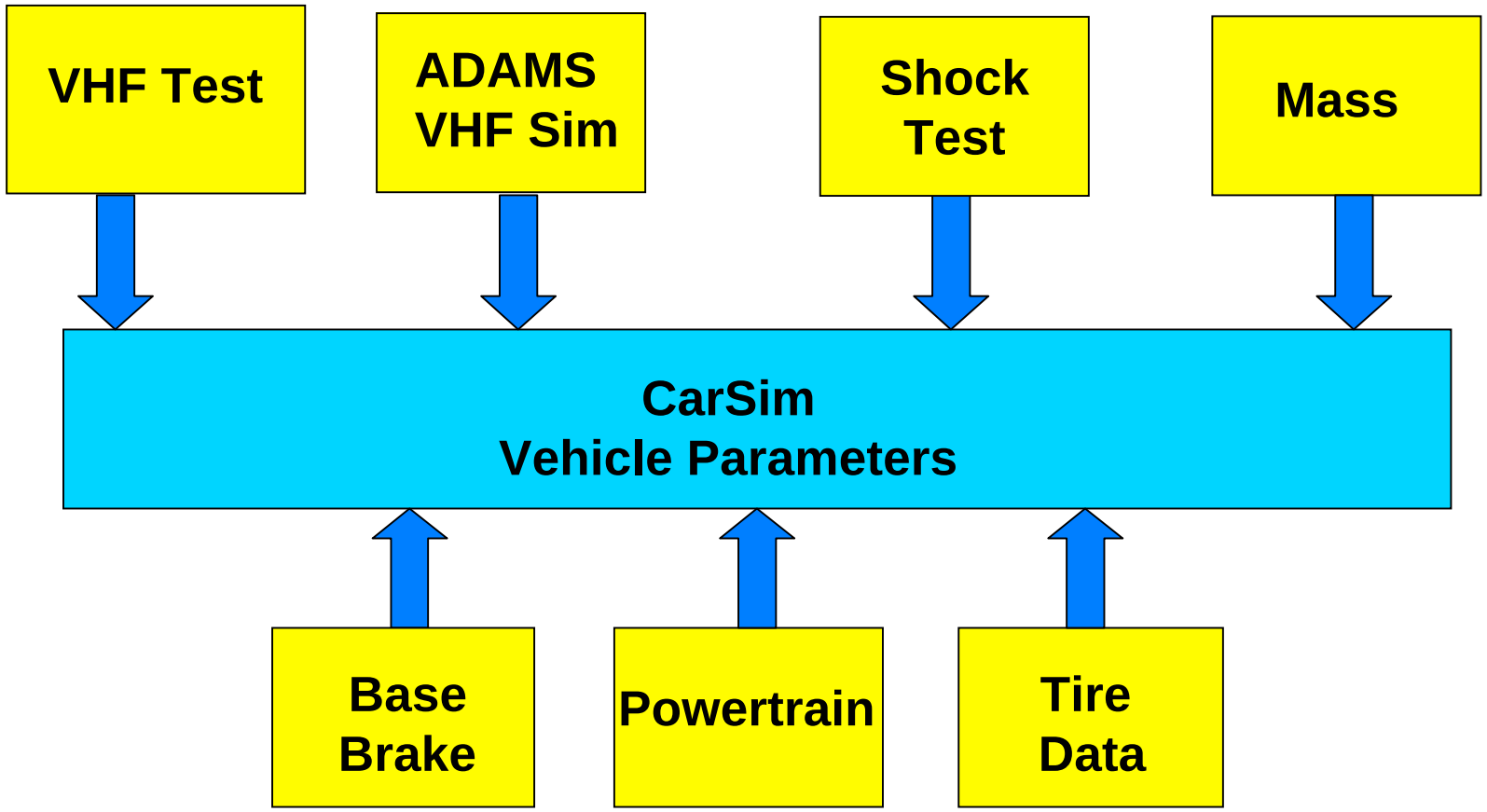
Benefits of using Vehicle Dynamics Simulation

- **Reduce Risk**
  - Fill-in gaps in the validation test matrices
  - Simulate more vehicle variants to provide valuable information for engineering judgments
- **Reduce Vehicle Development Time**
  - Support validation with Hardware-In-the-Loop (HIL)
  - Reduce Vehicle-Hours/Year Usage Time
- **Better Property Utilization**
  - HIL Properties are reusable
  - Series of tests can be automated to run overnight
- **Controlled Test Environment**
  - Yields more repeatable results than physical test (ideal for sensitivity and statistical studies)

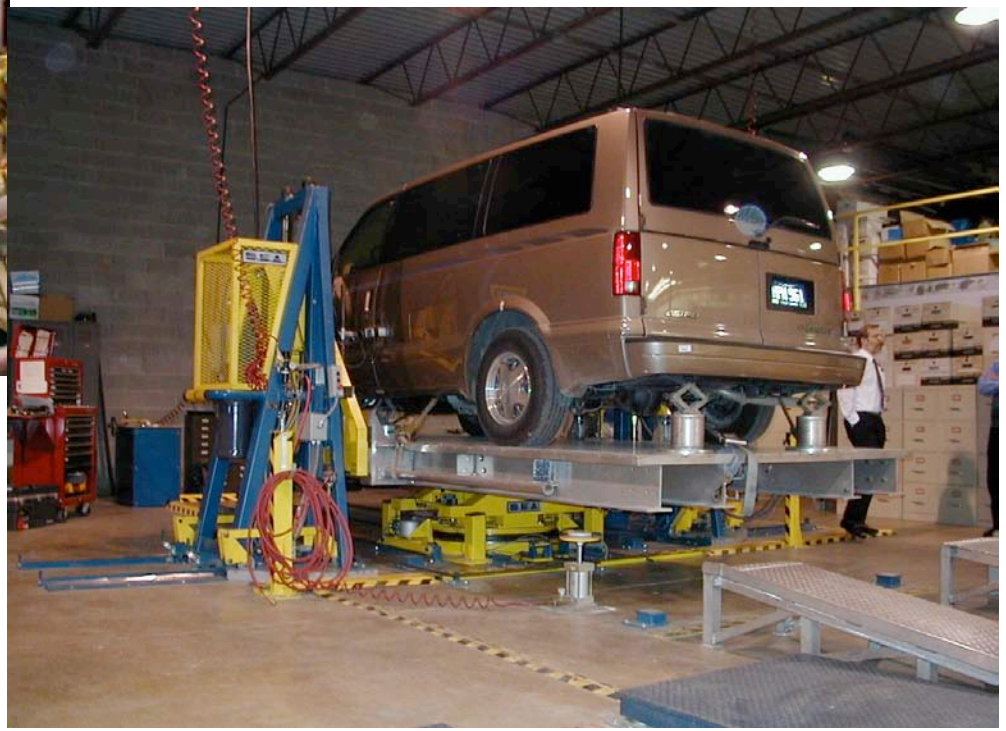
Enablers to use Vehicle Dynamics Simulation

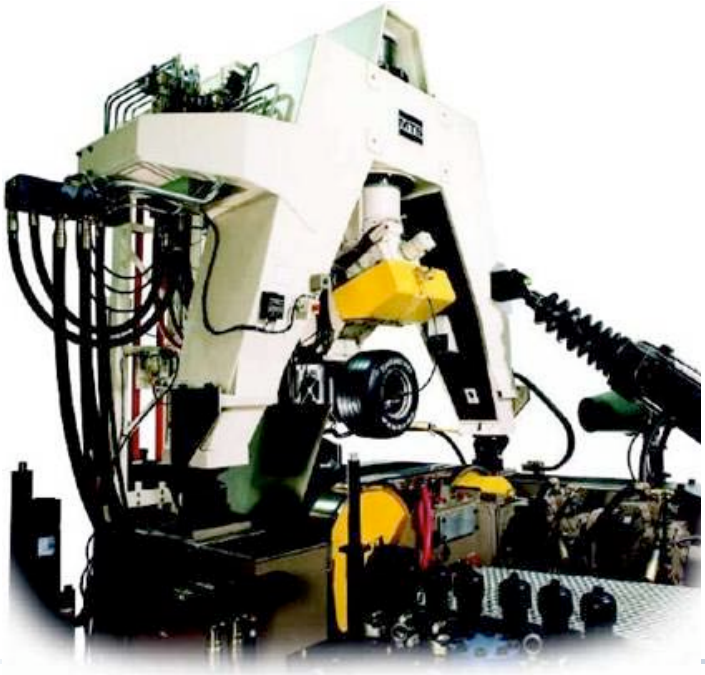
- **Accuracy of lumped parameter model data inputs:**
  - **Vehicle kinematics**
  - **Vehicle mass and inertia**
  - **Tire force and moment data**
- **LAN electrical interface and diagnostics**
  - **All controllers must behave as in a real vehicle**
- **Accurate vehicle sensor models**
  - **Wheel Speeds (WSS)**
  - **Yaw/Lat**
  - **Steering Wheel Angle (SWA)**
- **Representative hardware bench set-up**
  - **Nonlinear system elements**
  - **Especially hydraulics**
- **Applicable output data post processing tool**

Simulation Data Inputs



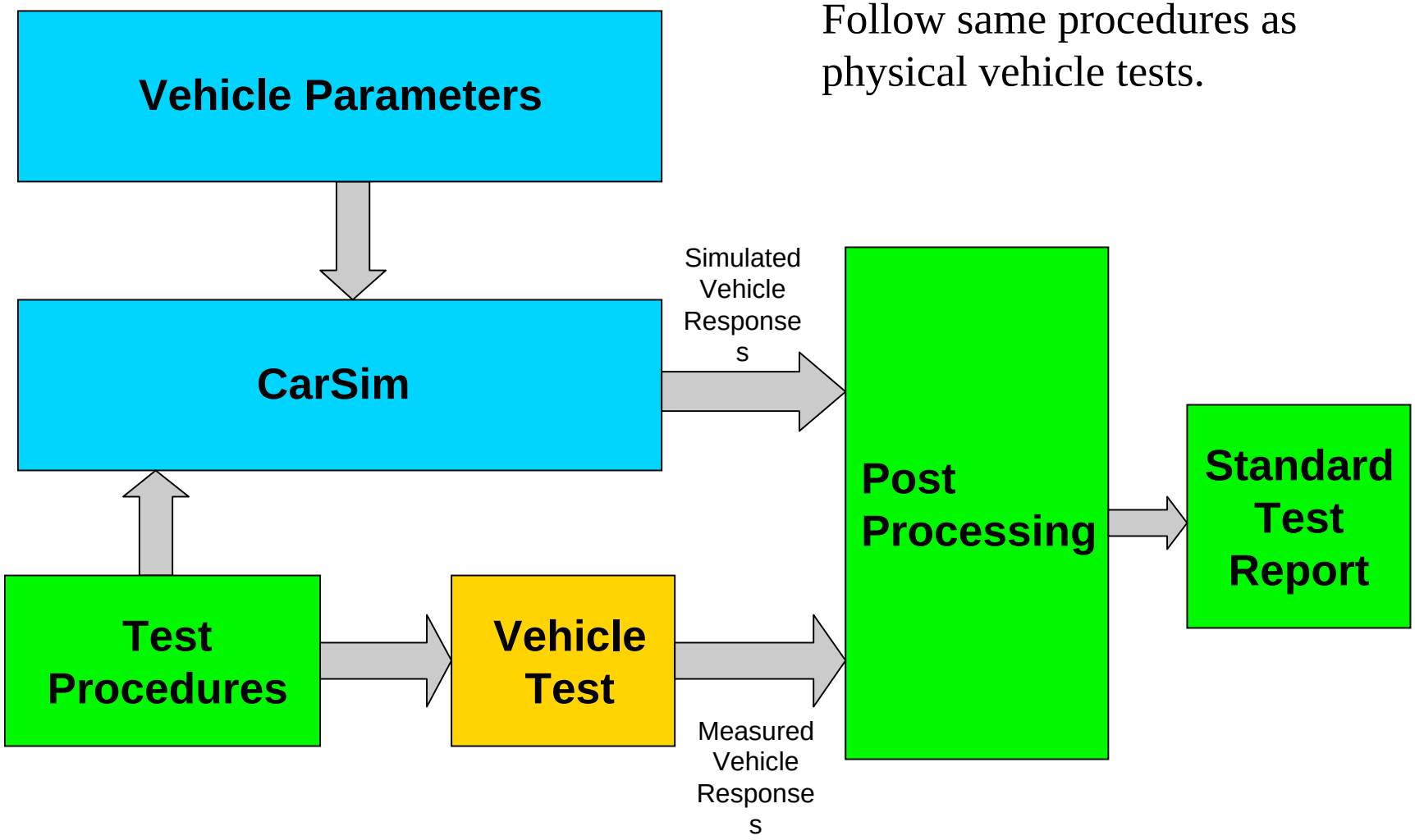
Vehicle Dynamics Parameter Measurements





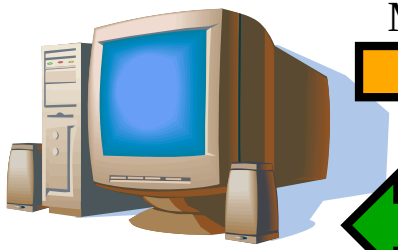
Simulation/Test Data Flow

Follow same procedures as physical vehicle tests.



HIL (Hardware in the Loop) Overview

Host Computer (running VehSim and Matlab/Simulink)



Model

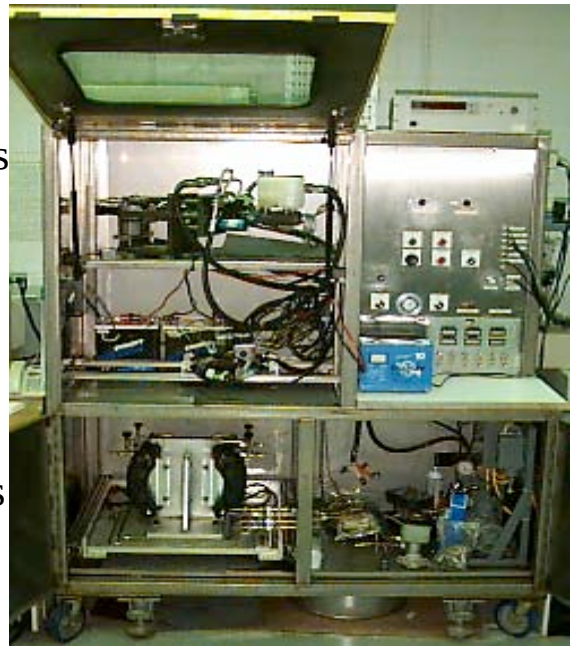
Results

Real Time Simulator

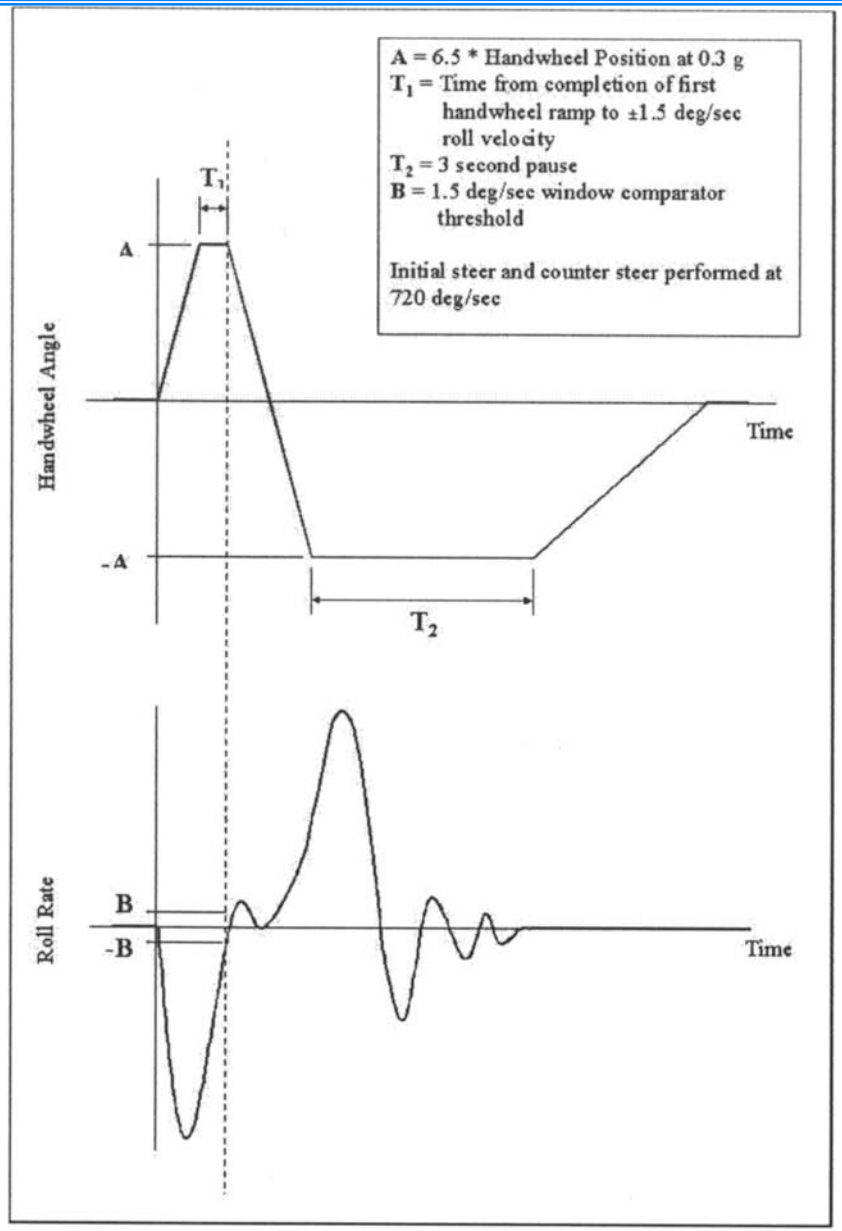
GMLan & Electrical Signals

GMLan Controller Signals
Line Pressures
Pedal Force
Pedal Travel

Hardware in the Loop Brake Buck



NCAP Fishhook Test



- Characterizes **Rollover Resistance** (2 Wheel Lift)
- Steer reversal coincides with Peak Roll Angle (0 Roll Rate)
- Exploits Roll Dynamics
- Roll Rate Feedback
- Steer Controller Required

± A = 6.5 * SWA @ 0.3g

720 deg/sec

T1 = time to ± 1.5 deg/sec roll rate

B = ± 1.5 deg/sec roll rate window

T2 = 3 seconds

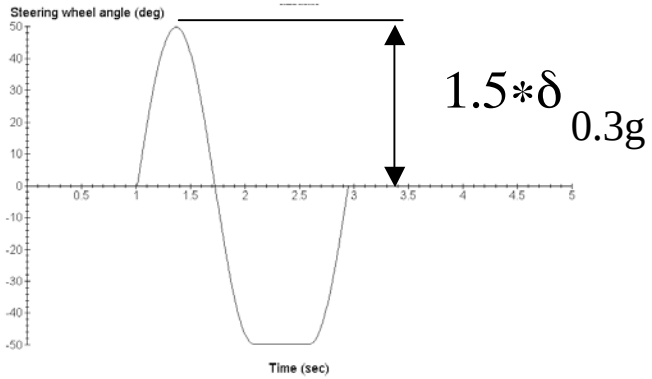
Speed = 35 - 50 MPH

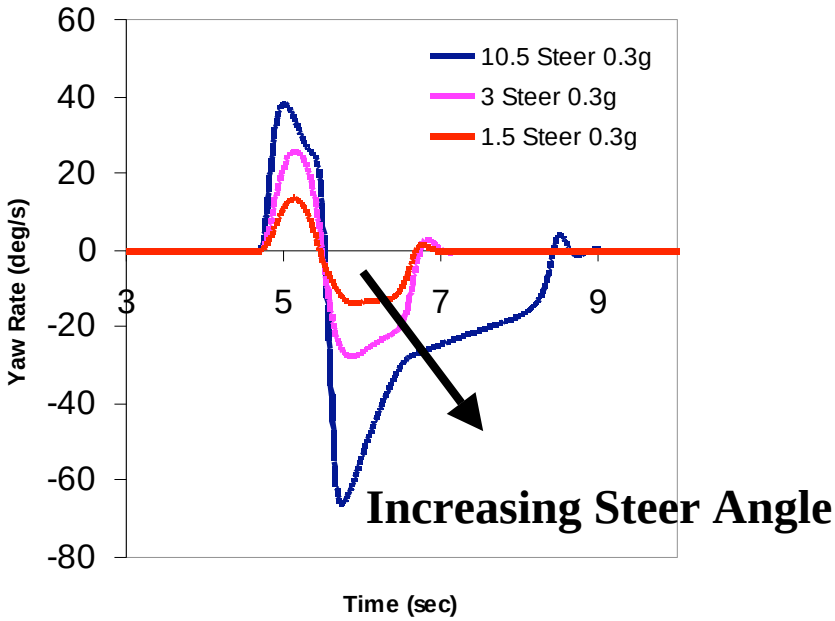
NCAP Fishhook Test - Milford

NCAP Fishhook Simulation Animation

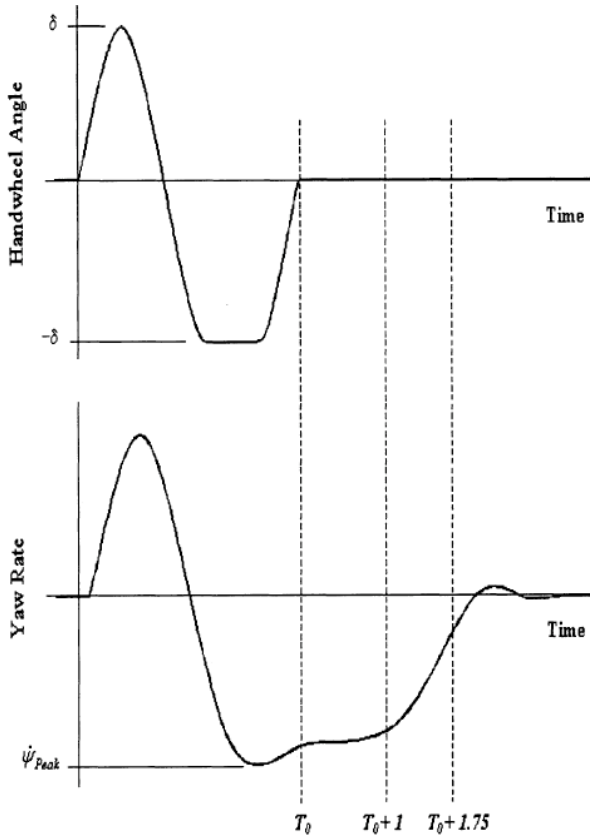
FMVSS 126 HIL Simulation Procedure

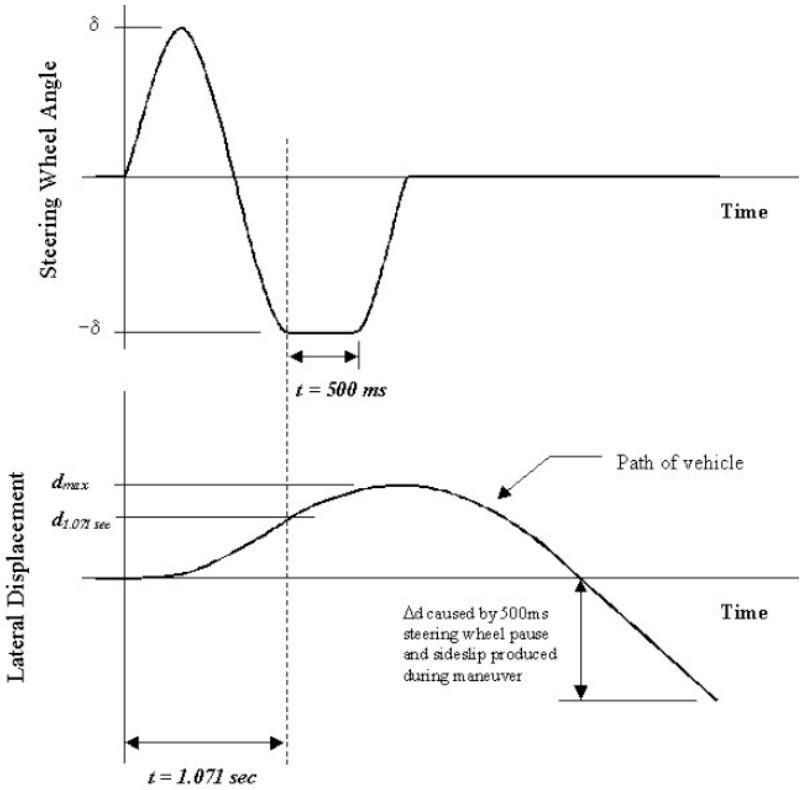
- **Implemented in CarSim for both HIL & PC**
- **Run LH & LH ramp steers @ 13.5 deg/s**
  - **Determine steer angles @ 0.3g lateral acceleration ($\delta_{0.3g}$)**
  - **Run @ 80 KPH**
- **Sine with dwell (SWD) test maneuver**
  - **Run vehicle to above 82 KPH & lift throttle**
  - **Run steer profile at 80 KPH**
    - **Increments of 0.5* $\delta_{0.3g}$**
    - **Lowest SWA is 1.5* $\delta_{0.3g}$**
    - **Highest SWA is greater of 6.5* $\delta_{0.3g}$ or 270**
  - **Run both left & right hand turns**
  - **Evaluate vehicle response metrics for each steer profile**





FMVSS 126 SWD Objective Metrics

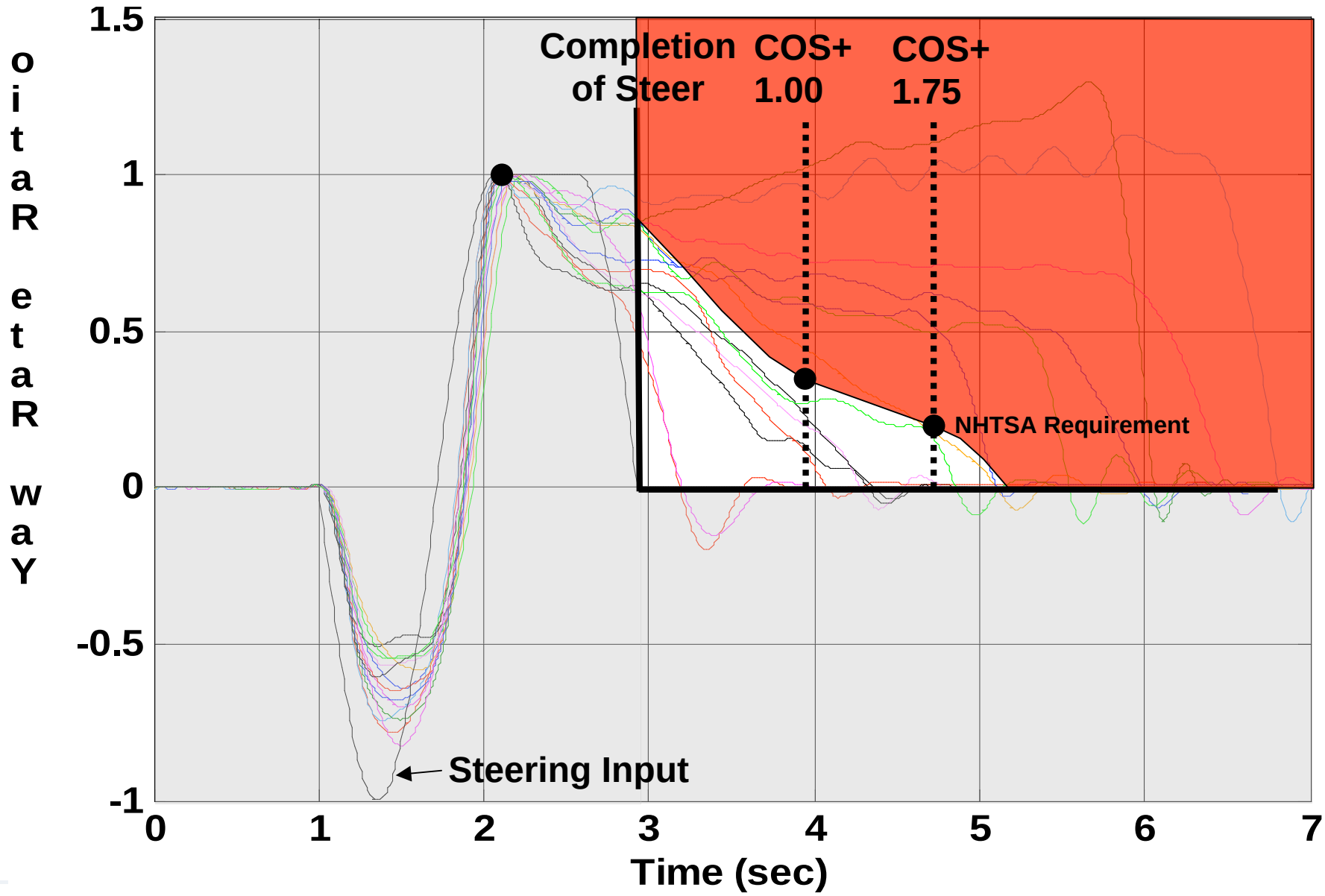




- **Yaw rate ratio metrics for each steer profile**
  - **Determined @ 1 sec & 1.75 sec**
  - **Provides a measure of vehicle spin**

- **Lateral vehicle displacement metric**
  - **Determined @ 0.75 steer cycle**
  - **Provides a measure of vehicle control**

Stability - Yaw Rate Ratio

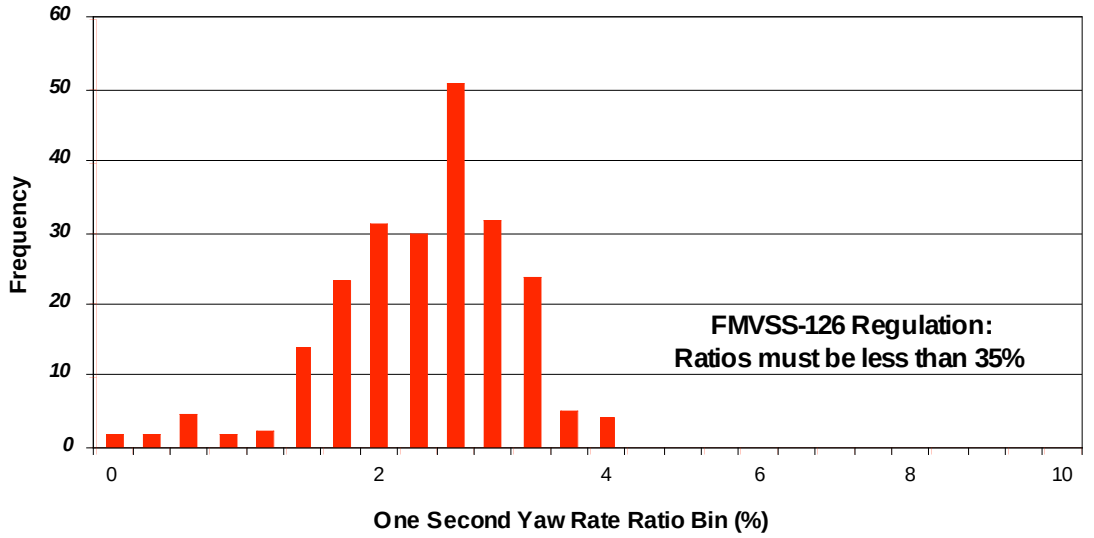


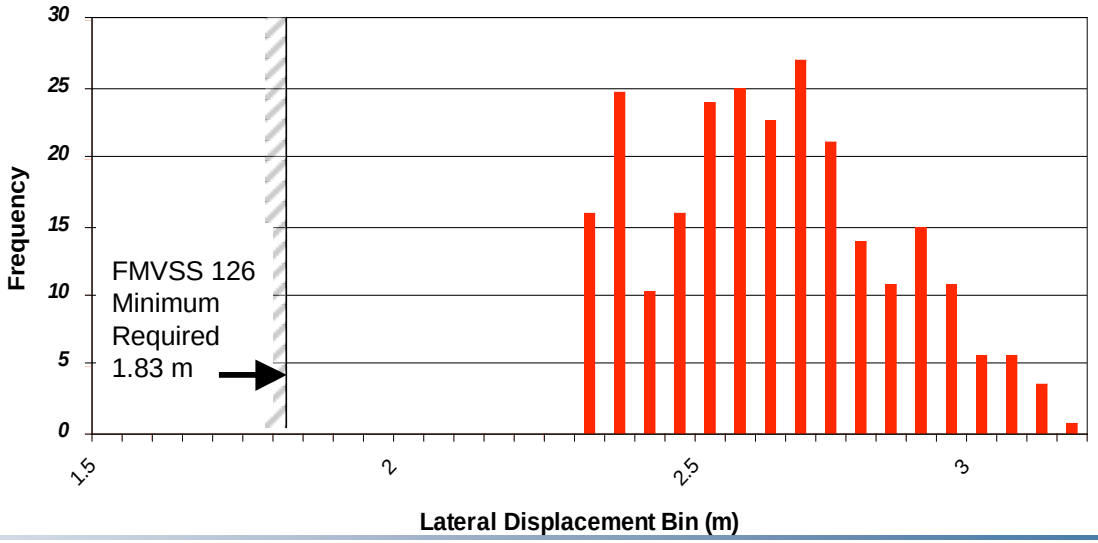
FMVSS 126 SWD Physical Test – Milford

FMVSS 126 – SWD Simulation Animations

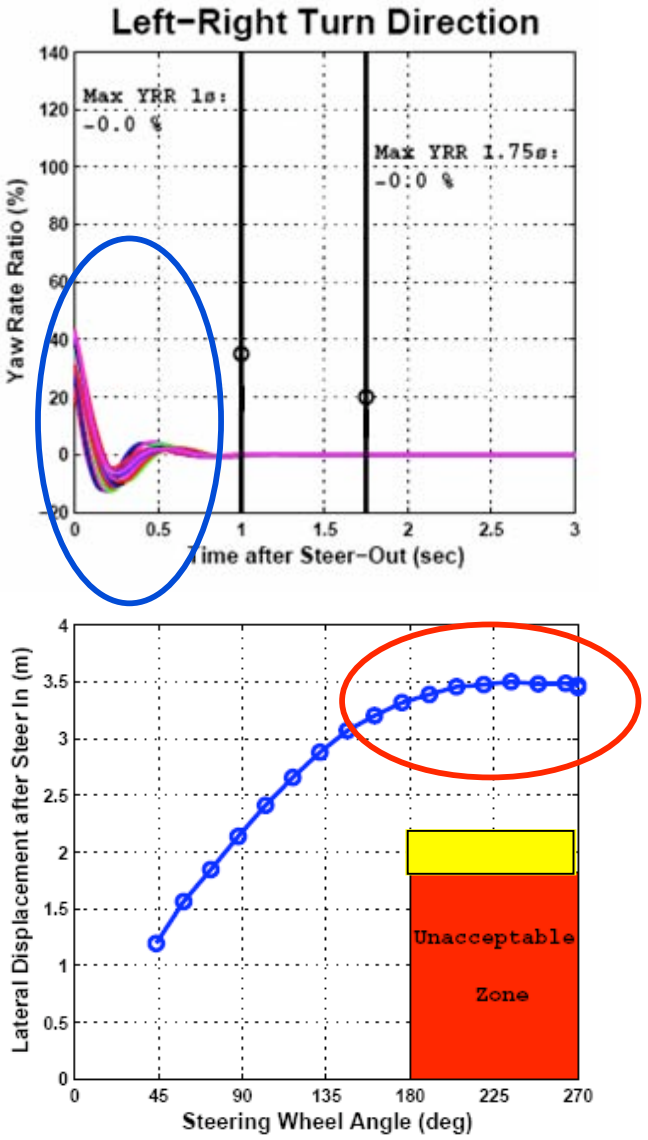
FMVSS 126 SWD Simulation Results

- **Histogram of 1.0 second yaw rate ratio and lateral displacement metrics for a passenger vehicle SWD maneuvers for the 6.0 steer multiplier**
- **Note that the values are well within the limits required by the FMVSS-126 regulation.**
- **Significant number of simulations performed to assess system robustness**

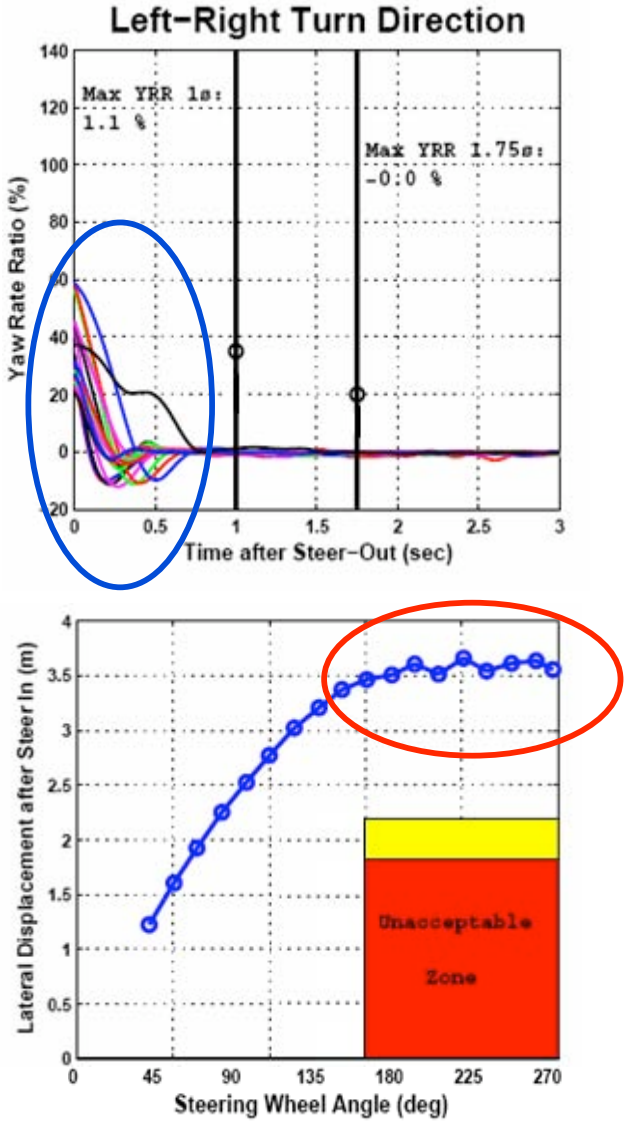




SWD Results: Typical Passenger Vehicle Simulation vs. Physical Test



Simulation



Test

Summary and Conclusions

- Chassis Controls HIL simulation approach fits well within typical vehicle development processes;
- Vehicle dynamics simulation is allowing GM to make much better use of testing resources:
  - **More focus testing requires fewer physical vehicle tests;**
  - **Vehicle performance at the boundaries can more easily evaluated;**
  - **Provides objective metrics to support FMVSS certification;**
- Simulation is very powerful tool to understand:
  - **Design Sensitivity;**
  - **Test Variability;**
  - **System Robustness;**