FMVSS NO. 126
Electronic Stability Control Systems
Compliance Test Program

NHTSA's Technical Workshop and Demonstration
November 7, 2007

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Workshop Overview

<u>Morning</u>

- Welcome and Introductory Remarks
- ESC Related Statistics
- Rule History and Phase-In
- Final Rule Highlights
- NHTSA ESC System Compliance Program
- NHTSA FMVSS No. 126 Compliance Test Procedure

<u>Afternoon</u>

- Test Demonstration and Data Post Processing
- Test Procedure Issues/Discussion of Comments
- NHTSA Points-of-Contact
- Available Information

ESC Related Statistics

- NHTSA estimates that the installation of ESC will reduce single vehicle crashes of passenger cars by 34 percent and single vehicle crashes of sport utility vehicles by 59 percent.

- NHTSA estimates that ESC has the potential to prevent 71 percent of the passenger car rollovers and 84 percent of the sport utility vehicle rollovers that would otherwise occur in single-vehicle crashes.

Data as provided in 72 FR 17236 of April 6, 2007 (FMVSS No. 126 final rule)

Rule History and Phase-In

- Final Rule published Apr. 6, 2007 (72 FR 17236)
- Phase-in Schedule begins Sept. 1, 2008, requires that all light vehicles be equipped with compliant ESC systems on and after Sept. 1, 2011
- Correcting Amendment published Jun. 22, 2007 (72 FR 34409)
- Interpretation to GM issued Aug. 29, 2007.
- Response to petitions (pending)

Final Rule Highlights

- Applies to PCs, MPVs, trucks and buses with GVWR of 4,536 kg (10,000 lb) or less.
- To comply, vehicles must be equipped with an ESC system that:
  - Is capable of applying brake torques individually to all four wheels and has a control algorithm that utilizes this capability to limit vehicle oversteer and understeer;
  - Has a means to determine the vehicle's yaw rate and to estimate its side slip or side slip derivative with respect to time;
  - Has a means to monitor driver steering inputs;

Final Rule Highlights - continued

- Applicable vehicles must be equipped with an ESC system that:
  - Has an algorithm to determine the need, and a means to modify, engine torque, as necessary, to assist driver in maintaining vehicle control;
  - Is operational during all phases of driving including acceleration, deceleration (including braking), coasting (except when system is disabled, or vehicle speed is below 15 km/h (9.3 mph) or when being driven in reverse);
  - Remains capable of activation even if the ABS or traction control system is also activated.

Final Rule Highlights - continued

- A vehicle manufacturer must make available upon request ESC technical documentation including;
  - System Diagram

    Identifies ESC system hardware.
  - Written explanation

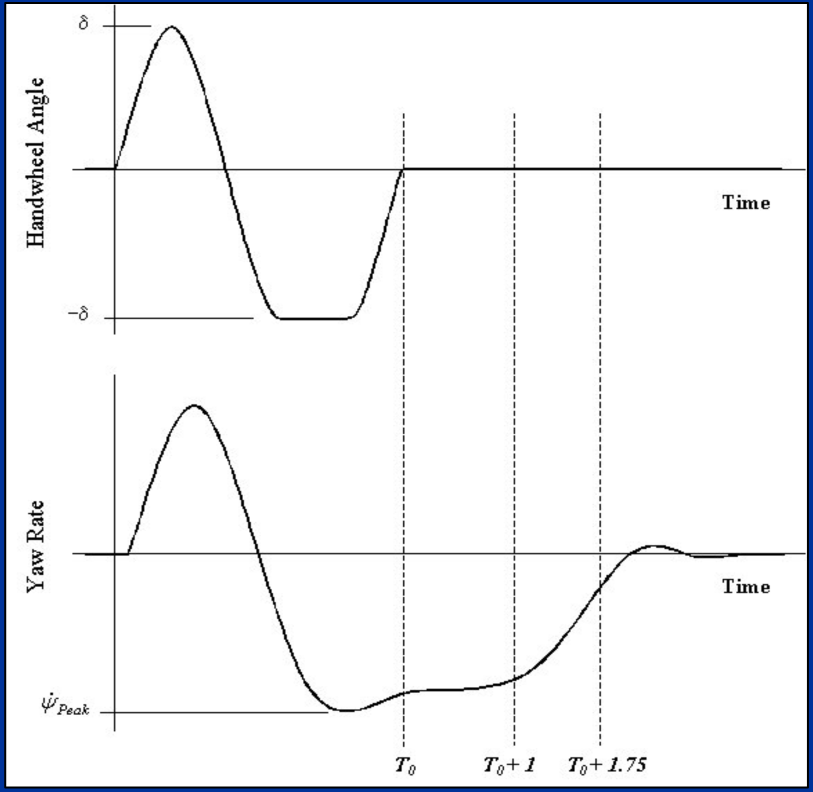
    Provides basic operational characteristics.
  - Logic diagram

    Supports written explanation.
  - Discussion

    Explains how system mitigates understeer.

Final Rule Highlights - continued

- When tested per test conditions and procedures provided in the final rule a vehicle equipped with a compliant ESC system must meet the following performance requirements;
  - Stability Requirements
    - Yaw rate measured 1 second after completion of a sine with dwell maneuver must not exceed 35% of the first peak value of yaw rate recorded after the steering wheel angle changes sign.
    - Yaw rate measured 1.75 seconds after completion of a sine with dwell maneuver must not exceed 20% of the first peak value of yaw rate recorded after the steering wheel angle changes sign.



Final Rule Highlights - continued

- When tested per test conditions and procedures provided in the final rule a vehicle equipped with a compliant ESC system must meet the following performance requirements;

- Responsiveness Requirements
  - At specific steering wheel angles the lateral displacement of a vehicle's CG with respect to its initial straight path must be at least;
    - 1.83 m (6 ft) for vehicles w/GVWR of 3,500 kg (7,716 lb) or less,

    - 1.52 m (5 ft) for vehicles w/GVWR greater than 3,500 kg (7,716 lb)

when computed at 1.07 seconds after beginning of steer.

Final Rule Highlights - continued

- Malfunction Telltale
  - Telltale must provide warning of the occurrence of one or more malfunctions that affect the generation or transmission of control or response signals in the ESC system.
  - Telltale must extinguish at the next ignition cycle after malfunction has been corrected.

  Requirements deferred until Sept. 1, 2011
  - Telltale must be identified by the symbol or abbreviations specified in FMVSS No 101.
  - Telltale must be mounted inside the occupant compartment in clear view of the driver.
  - Telltale must illuminate only when a malfunction exists and remain illuminated as long as the malfunction exists.
  - Telltale must be activated as a check of lamp function when ignition locking system turned on.

Final Rule Highlights - continued

- ESC Off Telltale
  - If the vehicle can be put into a mode that will not meet the performance requirements of the standard, the manufacturer must provide an ESC Off telltale.
  - Telltale must remain continuously illuminated for as long as the ESC is in this mode.
  - Telltale must extinguish after the ESC system has been returned to its fully functional default mode.

Requirements deferred until of Sept. 1, 2011

- Telltale must be identified by the symbol or abbreviations specified in FMVSS No 101.
- Telltale must be mounted inside the occupant compartment in clear view of the driver.
- Telltale must be activated as a check of lamp function when ignition locking system turned on.

Final Rule Highlights - continued

- ESC Off and Other System Controls
  - A manufacturer may include an "ESC Off" control or other system controls that have an ancillary effect upon ESC operation.
  - If these controls place the ESC system into a mode that no longer satisfies the performance requirements of the standard then the ESC system must always return to a mode that satisfies the standard requirements at the initiation of each new ignition cycle (Except for a mechanical control used for selection of a 4-wheel, low-speed, off-road mode).
  - As of Sept. 1, 2011, the "ESC Off" control must be identified by the symbol or abbreviations specified in FMVSS No. 101.
  - As of Sept 1, 2011, other ancillary controls need not be identified by the "ESC Off" identifier symbol or abbreviations, but the ESC off status must be identified by the "ESC Off" telltale.

NHTSA Compliance Program -General Information-

- Select a wide variety of vehicles by manufacturer, make and model.
- New vehicles are purchased or leased.
- OVSC does not execute optional tests on vehicles as requested and supplied by vehicle manufacturers.
- Protocol for test results indicating non-compliance.
  - Check procedure executed
  - Re-validate calibration of instrumentation
  - Review data
  - Contact manufacturer
  - Execute retest

NHTSA ESC Compliance Program Fiscal Year 2007

- Issued preliminary NHTSA Compliance Test Procedure dated April 6, 2007. (posted on NHTSA website)
- Completed test procedure validation and demonstration program with independent test lab (TRC).
  - TRC developed detailed in-house test procedure based upon NHTSA preliminary test procedure.
  - TRC instrumented and tested four vehicles to requirements of FMVSS No. 126.

  NOTE: Test vehicles were not required to meet FMVSS No. 126 (Indicant tests)
- Vehicles Tested
  - MY 2007 VW Passat (ESC system – TRW)
  - MY 2007 Honda Odyssey (ESC system – Continental Teves)
  - MY 2007 Chevrolet Avalanche (ESC system - Bosch)
  - MY 2008 Toyota Highlander (ESC system - ADVICS)

NHTSA ESC Compliance Program Fiscal Year 2007

- Indicant Test Results
  - Stability and Responsiveness

Vehicle Make/Model and (ESC System Supplier/Model)	Model Year	SIS Steer Angle (degrees)	Direction of Steer	Max. YRR (%) 1.0 sec * after COS	Max. YRR (%) 1.75 sec * after COS	Min. Lateral Displacement (ft)
VW Passat	2007	28.6	LR	17.43	2.74	10.2
(TRW Automotive - EBC 440)			RL	17.49	1.86	10.0
Honda Odyssey	2007	38.2	LR	2.00	5.51	8.9
(Continental Teves, MK60i)			RL	3.05	1.10	8.6
Chevrolet Avalanche	2007	41.0	LR	2.22	0.68	8.2
(Bosch, ESC System 8.0)			RL	2.94	0.60	8.1
Toyota Highlander	2008	36.8	LR	5.10	0.26	9.5
(ADVICS Co, 44540-48230)			RL	3.88	0.68	9.7
			Requirements	< 35%	< 20 %	> 6ft

*** Note: Several values in these columns were revised after the workshop presentation**

NHTSA ESC Compliance Program
Fiscal Year 2007

- Indicant Test Results… continued
  - Malfunction and "ESC Off" Telltale Symbols Used

NHTSA ESC Compliance Program
Fiscal Year 2007

- Indicant Test Results… continued
  - ESC-Off controls varied.

  - Ancillary control affecting ESC.

NHTSA ESC Compliance Program Fiscal Year 2007

- Indicant Test Results… continued
  - Malfunction simulations executed;
    - Disconnected ABS wheel speed sensors
    - Disconnected yaw rate sensor
    - Disconnected steering angle sensor
    - Disconnected electronic brake control module

NHTSA ESC Compliance Program Fiscal Year 2008

- Hold Test Procedure Workshop and Demonstration in November 2007.
- Post NHTSA Final Test Procedure on NHTSA web site.
- Post MATLAB routines used for FMVSS No. 126 Compliance Testing data post processing on NHTSA web site.
- Award Compliance Test Program Contracts.
- Begin Executing Compliance Test Program with vehicles certified by vehicle manufacturers.

NHTSA FMVSS No. 126
Compliance Test Procedure

- Test Preparation
- Test Instrumentation
- Test Conditions
- Test Procedure Execution

Compliance Test Procedure

Test Preparation

Documentation

- NHTSA requests system design and function information from the vehicle manufacturer prior to start of compliance testing.
  - (Form FMVSS 126)[1] has 5 sections requiring the manufacturer to:
  1) Identify the vehicle systems which may effect dynamic stability
  2) Provide compliance details and information on the operational characteristics of the system
  3) Provide information on the ESC Malfunction Telltale
  4) Provide information on the ESC OFF Telltale and Controls
  5) Provide information on ESC Malfunction Simulation methods
- NHTSA Reviews the supplied information (from above) and the vehicle owner's manual both for compliance and to better understand the operation of the vehicle's ESC systems and controls.

Compliance Test Procedure

Test Preparation - continued

Documentation - continued

- Verify the calibration status of the test instrumentation (all test equipment must be calibrated against a higher order standard on a minimum of 12 month cycle).

Vehicle

- Inspect the vehicle for physical damage and correct build content
- The vehicle is tested with the tires installed on the vehicle at the time of initial vehicle sale. The tires are inflated to the vehicle manufacturer's recommended cold tire inflation pressure(s) specified on the vehicle's placard or tire inflation pressure label.
  - The installed tire size, brand and model are documented. All compliance test tires must be new and the same size as listed on the vehicle's FMVSS 110 placard.

Compliance Test Procedure

Test Preparation - continued

Vehicle - continued

- Fill the fuel tank and inspect all fluid reservoirs to levels necessary for normal operation (fill if necessary).
- Measure the Unloaded Vehicle Weight (UVW).

The Unloaded Vehicle Weight (UVW) is the weight of a vehicle with maximum capacity of all fluids necessary for vehicle operation, but without cargo, occupants, or accessories that are ordinarily removed from the vehicle when they are not in use.

Compliance Test Procedure

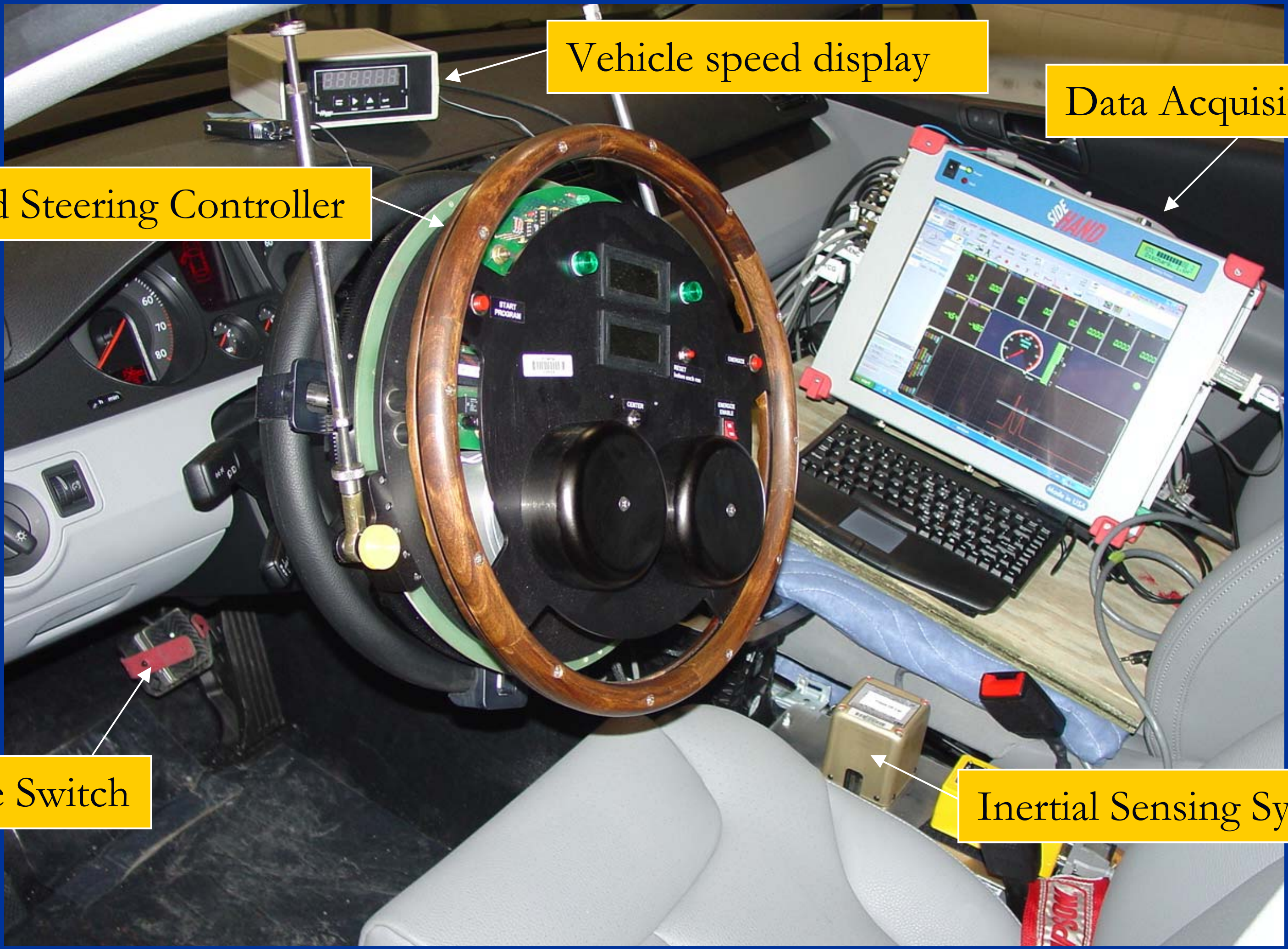
Test Equipment & Instrumentation

- The equipment and Instrumentation necessary to perform FMVSS 126 include:
  - Automated Steering Controller
  - Multi-Axis Inertial Sensing System
  - Vehicle Speed Sensor
  - Ultrasonic Distance Sensors
  - Data Acquisition System
  - Platform Weight Scales
  - Coordinate Measurement Machine
  - Brake Pedal switch
  - Outriggers

NHTSA - Government Furnished Equipment (GFE) Assigned to the Contracted Test Laboratories

Compliance Test Procedure

Test Equipment & Instrumentation - continued



Compliance Test Procedure

Test Equipment & Instrumentation - continued

- Automated Steering Controller

NHTSA Compliance Tests use:
Heitz Sprint 3 Programmable Steering Machine

Compliance Test Procedure

Test Equipment & Instrumentation - continued

- Automated Steering Controller

NHTSA Compliance Tests use:
Heitz Sprint 3 Programmable Steering Machine

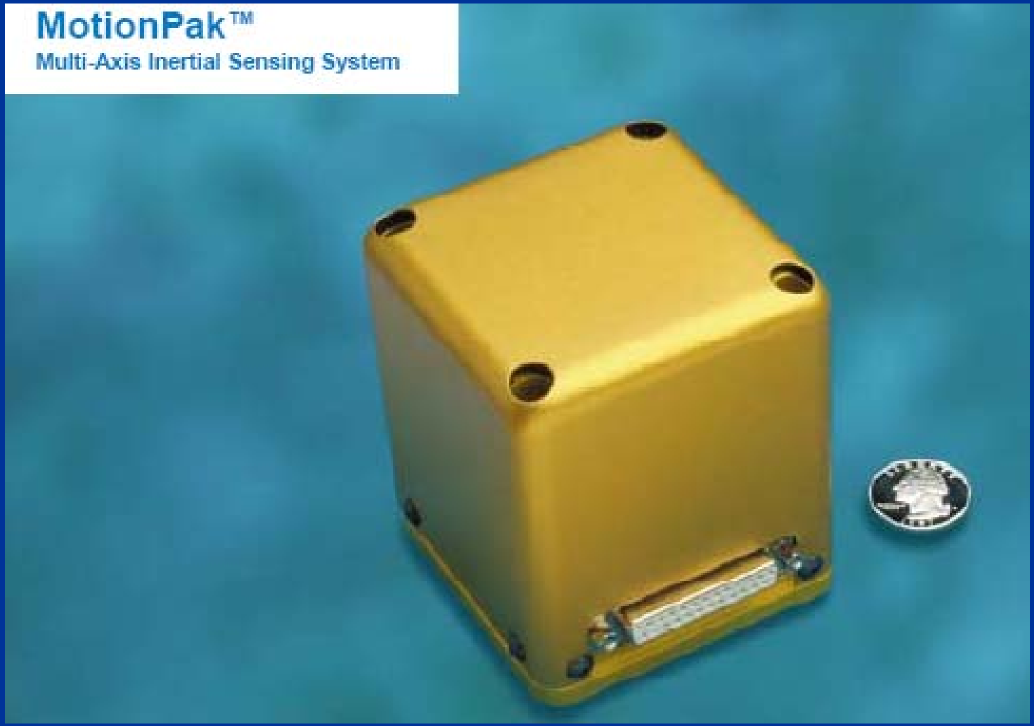
- It is capable of supplying input torques between 40 to 60 Nm (29.5-44.3 lb-ft). (as required in FMVSS 126 S6.3.5)
- It is capable of steering velocities up to 1200 deg/sec. (as required in FMVSS 126 S6.3.5)
- It has an automated controller capable of controlling steering wheel angle input and output.
- It is able to accept vehicle speed sensor feedback to initiate steering programs at preset road speeds
- It has hand-wheel angle resolution of .25 degrees and accuracy of $\pm$ 0.25 degrees.

Compliance Test Procedure

Test Equipment & Instrumentation - continued

- Multi-Axis Inertial Sensing System

NHTSA Compliance Tests use:
BEI Motion PAK



Compliance Test Procedure

Test Equipment & Instrumentation - continued

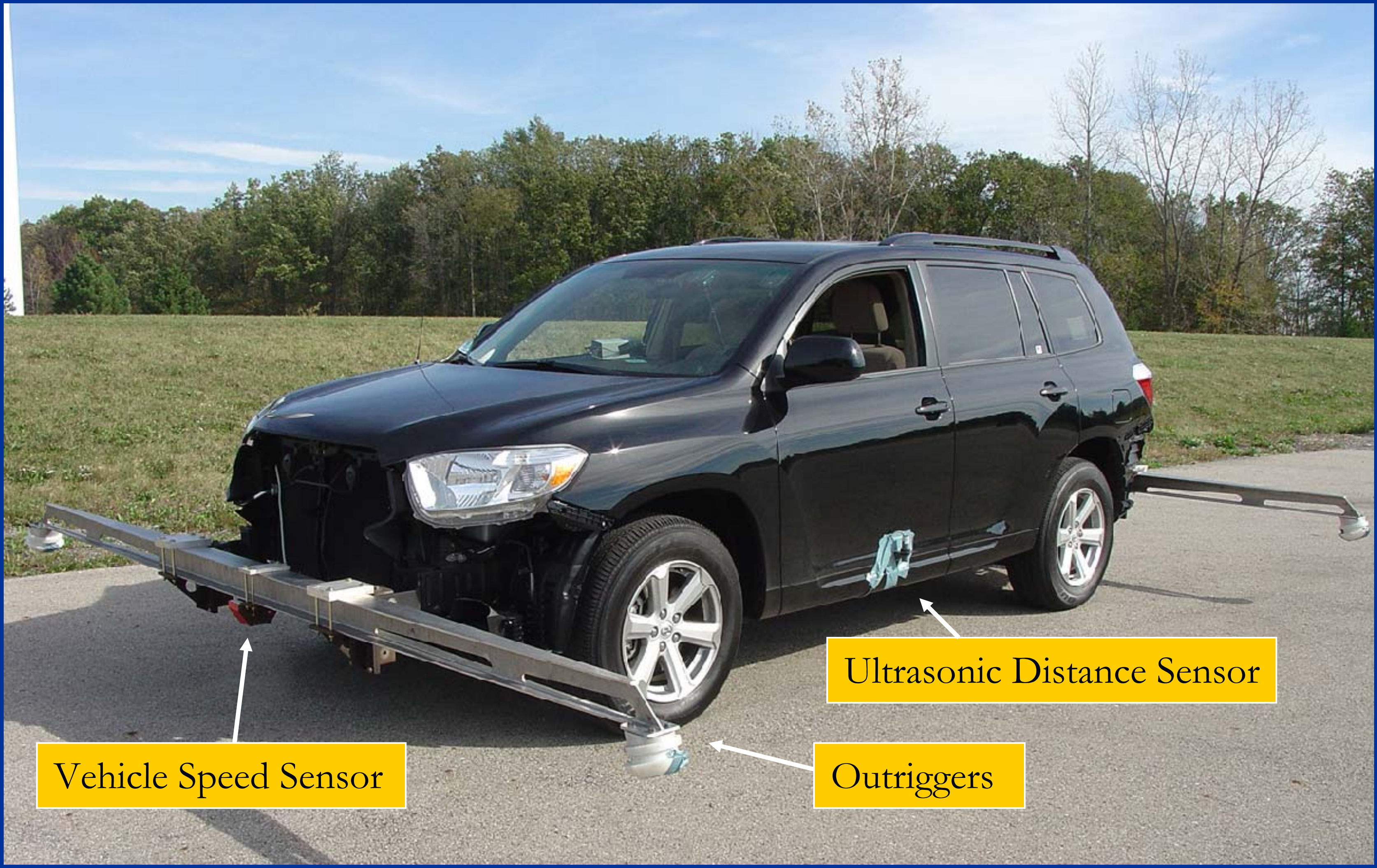
- Multi-Axis Inertial Sensing System

NHTSA Compliance Tests use:
BEI Motion PAK

  - Measures longitudinal, lateral and vertical accelerations
  - Measures roll, yaw and pitch rates
  - Accelerometer range $\pm$ 2 g, resolution $\leq$10ug, and accuracy $\leq$0.05% of full range
  - Angular rate sensors range $\pm$100 degrees/sec, resolution <0.004 deg/sec and accuracy 0.05% of full range

Compliance Test Procedure

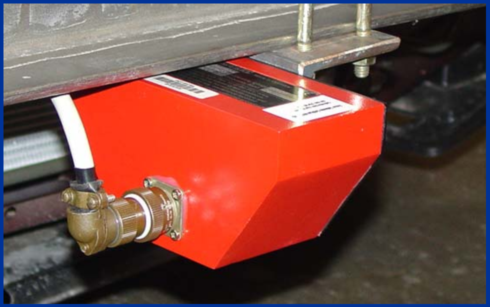
Test Equipment & Instrumentation - continued



Compliance Test Procedure

Test Equipment & Instrumentation - continued

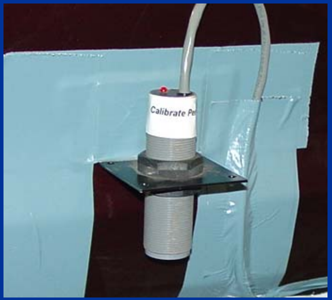
- Vehicle Speed Sensor



NHTSA Compliance Tests use:
Deuta-Werker Model DRS-6

  - Non-contact radar speed sensor with dashboard display
  - Range 125 mph, resolution .009 mph, accuracy ± .25% of full scale

- Ultrasonic Distance Sensors



NHTSA Compliance Tests use:
MASSA Model M-5000/220

  - Measures roll displacement used to calculate body roll angle
  - Range 4-40 in., resolution 0.01 in. accuracy ± .25% of maximum distance

Compliance Test Procedure

Test Equipment & Instrumentation - continued

- Outriggers
  - Required for testing trucks, MPVs and buses.
  - Standard outriggers will be used on vehicles with baseline weight (UVW plus 73 kg (160 lb) driver) below 2,722 kg (6,000 lb).
    - Outrigger maximum weight of 32 kg (70 lb) and maximum roll moment of inertia of 35.9 kg-m^2 (26.5 ft-lb-sec^2)
  - Heavy outriggers will be used on vehicles with baseline weight equal to or greater than 2,722 kg (6,000 lb).
    - Outrigger maximum weight of 39 kg (86 lb) and a maximum roll moment of inertia of 40.7 kg-m^2 (30 ft-lb-sec^2)

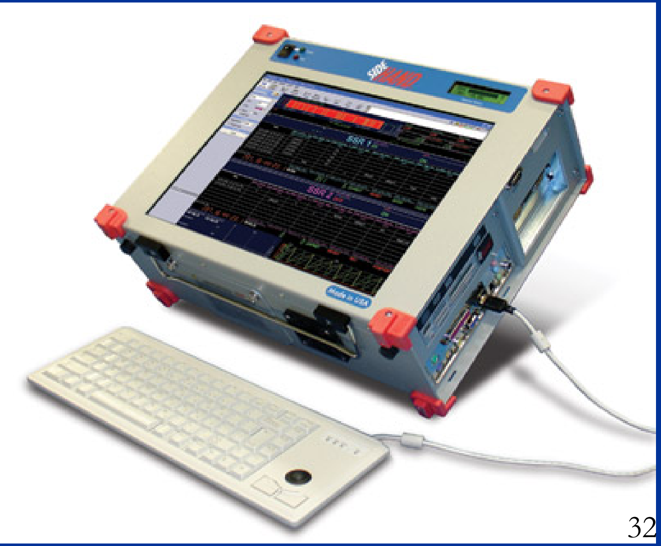
NHTSA titanium outriggers are used for compliance testing (see NHTSA Docket # 2007-7662-11)

Compliance Test Procedure

Test Equipment & Instrumentation - continued

- Data Acquisition System
  - Record and display vehicle speed, time, 3 accelerations, 3 rates, steering wheel angle and body ride height.
  - Amplifier gains are selected to maximize signal to noise ratio.
  - Filtering is done with two-pole low pass Butterworth filters with 25 Hz cut-off frequencies selected to prevent aliasing.
  - Sampling rate of 200 Hz

(non- GFE) TRC Equipment
Dewetron Sidehand Model DA-121-16



Compliance Test Procedure

Test Equipment & Instrumentation - continued

- Platform Weight Scales for determining vehicle loads TRC (Mettler Toledo Model JXGA1000)

Platform scales have a maximum graduation of 1 kg (0.5 lb) and have an accuracy of at least ± 1% of the measured reading

Compliance Test Procedure

Test Equipment & Instrumentation - continued

- Coordinate Measurement Machine
  TRC (Faro International Model N10)
  - Used to locate X-Y-Z coordinates for the Multi-Axis Inertial Sensing System in the vehicle

- Brake Pedal Switch/Load Cell
  TRC (Datron Model DTM-LPA)
  - Used only as an indicator of accidental brake application by the test driver

Compliance Test Procedure

Test Conditions

- Ambient conditions
  - The ambient temperature is between 7- 40˚C (45-104 ˚F)
  - The maximum wind speed is no greater than 10 m/s (22 mph) for passenger cars and 5 m/s (11 mph) for MPVs, trucks and buses
- Road test surface
  - The tests are conducted on a dry, uniform, solid-paved surface.
  - The road surface must produce a peak friction coefficient (PCF) of 0.9
  - The test surface has a consistent slope between level and 1%.
- Test Weight
  - The vehicle is loaded with the fuel tank filled to at least 75 percent of capacity
  - A total interior load of 168 kg (370 lb) comprising of the test driver, test equipment and ballast

NHTSA FMVSS No. 126 Compliance Test Procedure

- Test Preparation
- Test Instrumentation
- Test Conditions
- **Test Procedure Execution**

NHTSA FMVSS No. 126 Compliance Test Procedure

- Test Procedure Execution
  - ESC System Definition
  - Telltales and Controls
  - Instrumentation and Equipment Installation
  - Vehicle Loading and CG Coordinates
  - Instrumentation Operational Check
  - Brake Conditioning
  - Tire Conditioning
  - SIS Maneuver
  - SWD Maneuver
  - Calculations of Performance Metrics
  - Malfunction Detection

Test Procedure Execution
ESC System Definition

- Verify that the vehicle is equipped with an ESC system that meets the ESC system definition utilizing manufacturer submitted documentation.
  - Identify hardware components used to determine yaw rate, estimated side slip or side slip derivative, driver steering inputs, generate brake torques at each wheel, and to modify engine torque.
  - Ensure manufacturer has specified the vehicle speed range and driving phases under which the ESC system can activate.
  - Ensure that the manufacturer has provided an explanation and logic diagram that illustrates the basic operational parameters of the ESC system.
  - Ensure that the manufacturer has provided a discussion of how the system mitigates understeer scenarios.

Test Procedure Execution
Telltales and Controls

- Check location and symbol or abbreviation used for ESC malfunction telltale.

ESC

ESC OFF

- Check location and symbol or abbreviation used for ESC off telltale.

- Cycle ignition locking system to verify telltale bulb function and color.

Test Procedure Execution
Telltales and Controls

- Determine if vehicle is equipped with an "ESC Off" control or other control that has an ancillary effect on ESC performance.
- Check "ESC Off" control is labeled as required by FMVSS No.101.
- Turn the ignition locking system to the on/run position.
- Activate each control separately.
- Verify that upon activation of each control the ESC off telltale illuminates.
- Cycle ignition locking system to verify telltale extinguishes indicating the ESC system has been reactivated.
- If a mechanical control for low speed off road operation is provided cycle control manually and verify operation of ESC off telltale.

Test Procedure Execution
Instrumentation and Equipment Installation

- If outriggers are required, remove bumper assemblies, manufacturer mounting brackets, and mount outriggers.
- Install inner tubes on vehicles equipped with outriggers.
- Re-weigh vehicle to obtain UVW with outriggers.
- Remove driver's side air bag and install steering controller as specified by controller manufacturer.
- Manufacture and install inertial sensing system mounting plate.
- Install data acquisition system onto front passenger seat.

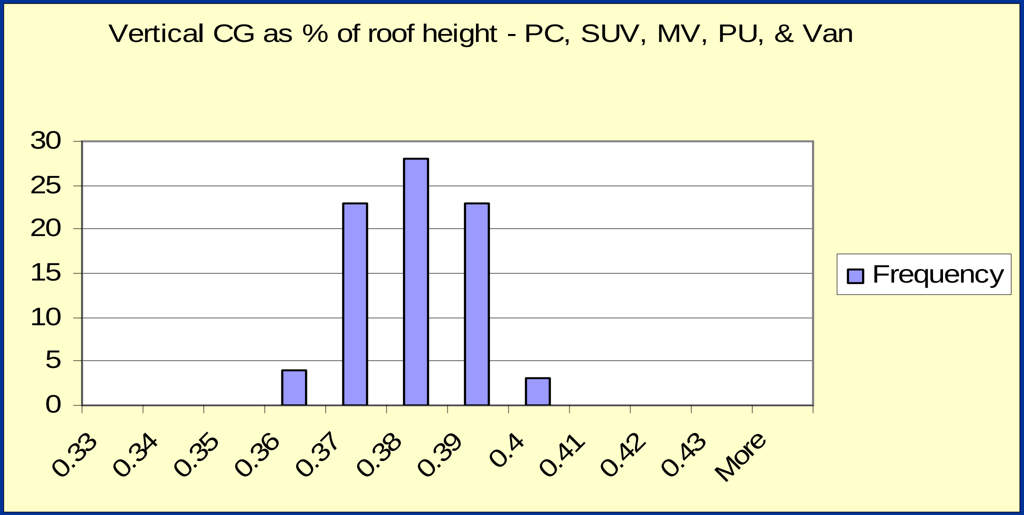
Test Procedure Execution
Instrumentation and Equipment Installation

- Install inertial sensing system onto mounting plate.
- Install brake pedal load cell.
- Install vehicle speed sensor onto front bumper assembly or outrigger along vehicle centerline.
- Install speed sensor dashboard display.
- Install distance (body roll) sensors.

Test Procedure Execution
Vehicle Loading and CG Coordinates

- Load ballast on floor behind passenger front seat and weigh vehicle to obtain vehicle loaded weight.
- Level the inertial sensing system.
- Using a Coordinate Measurement Machine, determine inertial sensing system coordinates relative to vehicle coordinates.
- Determine vehicle CG coordinates of loaded vehicle.
  - Measure vehicle's wheelbase and front track width.
  - Sum moments to determine lateral and longitudinal coordinates.
  - Estimate a vertical coordinate to be 38% of roof height based on historical data.

Test Procedure Execution
Vehicle Loading and CG Coordinates



Vehicle Type	Quantity	% CG Height Relative to Maximum Roof Height
Passenger Cars	33	37.82
Sport Utility Vehicles	25	38.36
Mini-Vans	8	37.25
Pick-up Trucks and Vans	14	38.07
Total Vehicles	80	37.98

Test Procedure Execution Instrumentation Operational Check

- Power up data acquisition system.
  - Ensure all data channels are operating by viewing real time data output.
  - Set sampling frequency (200Hz).
  - Set signal conditioning parameters (filtering for aliasing w/2-pole Butterworth filter set at 25hz cut-off freq, amplifier characteristics set to maximize signal-to-noise ratio).
  - Set calibration scale factors for each sensor channel.
  - Apply simulated sensor output voltages to each input channel to verify and confirm resultant speed, accelerations and rates are accurately measured and displayed.

Test Procedure Execution
Instrumentation Operational Check

- Execute Steering Controller operational check.
  - Ensure full rotation of controller results in 360 degree readout on DAS.
  - Verify controller triggers at set vehicle speed and executes a programmed sine with dwell maneuver upon applying a simulated speed sensor voltage to the controller.
- Re-adjust ultra sonic distance sensors to position at vehicle longitudinal CG coordinate.
- Verify distance sensors accurately measure and display body roll displacement values utilizing dimensional block gages.
- Conduct on-track check of speed sensor.
- Obtain 15 seconds of straight line driving at vehicle set speed and verify data output on DAS from all sensors appears accurate.

Test Procedure Execution
Brake Conditioning

- Verify tires are properly inflated to recommended cold inflation pressure.
- Energize DAS so vehicle longitudinal acceleration can be observed by the test driver.
- Measure and record ambient temperature and wind speed.
- Execute 10 brake stops from a speed of 56km/h (35mph) with a target deceleration of .5g. Driver should monitor the deceleration rate and attempt to maintain 0.5g deceleration over the entire brake application.
- Execute 3 stops from a speed of 72 km/h (45 mph) with a brake force great enough to activate the vehicle's ABS for the majority of the braking event. During each stop driver should be able to identify activation of the ABS by feel or sound.
- Drive vehicle at a speed of 72km/h (45 mph) for at least five minutes to cool the brakes.

Test Procedure Execution
Tire Conditioning

- Verify tires are properly inflated.
- Measure ambient temperature and wind speed.
- Energize DAS so vehicle lateral acceleration can be observed by the test driver.
- Drive vehicle around 30 m (100 ft) diameter circle at a speed that produces a lateral acceleration of 0.5-0.6 g for three clockwise laps followed by three counterclockwise laps.
- Driver must visually monitor measured lateral acceleration and attempt to maintain the target lateral acceleration over the entire 30 m (100 ft) diameter circle.

Test Procedure Execution
Tire Conditioning…continued

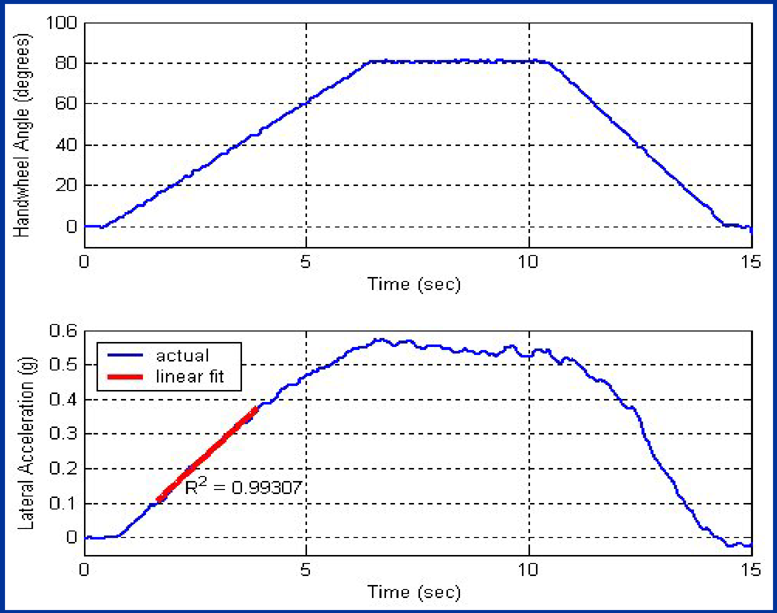
- Execute 4 - 1Hz, 10 cycle sine maneuvers at 56 km/h (35 mph) and a steering wheel angle corresponding to a peak lateral acceleration of 0.5-0.6 g.
  - Execute several preliminary 1 Hz, 3 cycle sine maneuvers, starting with a steering wheel angle of 30 degrees, and changing the angle accordingly, until a peak lateral acceleration of 0.5 – 0.6 g is obtained.
  - Program steering controller to execute the 1 Hz, 10 cycle sinusoidal steering pattern with the steering wheel angle determined above.
  - Execute three maneuvers at that steering wheel angle.
  - Modify the programmed 1 Hz, 10 cycle sinusoidal steering pattern so that the tenth cycle is executed with the steering wheel angle twice that of the other cycles. Execute one maneuver.
  - The maximum time permitted between passes executed is 5 minutes.

Test Procedure Execution

Slowly Increasing Steer Maneuver

- This maneuver is used to determine the steering wheel angle (SWA) capable of producing a lateral acceleration of 0.3g for each unique vehicle.
- This SWA is then used to determine the SWA magnitude used during the sine with dwell maneuvers.

- Maneuver is executed with a steering controller by increasing the SWA linearly at 13.5 degrees per second until a lateral acceleration of approximately 0.5g is obtained.
- Six maneuvers are executed, 3-clockwise and 3-counterclockwise and an average overall SWA is calculated.
- During each maneuver vehicle is driven at a constant speed of 80 ± 2 km/h (50± 1 mph).



Test Procedure Execution

Slowly Increasing Steer Maneuver

- Maneuvers are executed immediately following Tire Conditioning.
- A 15 second static file of each instrument channel is collected for static zeroing of sensor channels during post processing.
- To execute the maneuvers, the steering wheel angle required to achieve a raw lateral acceleration of .5-.6 g is determined.
  - A preliminary left steer maneuver is executed to measure the lateral acceleration at a 30 degree steering wheel angle.
  - Assuming a linear relationship exists between steering wheel angle and lateral acceleration the steering wheel angle at .55g lateral acceleration is calculated.
  - For ease of steering controller programming the calculated steering wheel angle is rounded to the nearest 10 degrees.

Test Procedure Execution

Slowly Increasing Steer Maneuver

- Execute the six required maneuvers utilizing the calculated and rounded SWA.
- At the completion of each maneuver verify that the maximum lateral acceleration obtained was between .5 and .6 g.

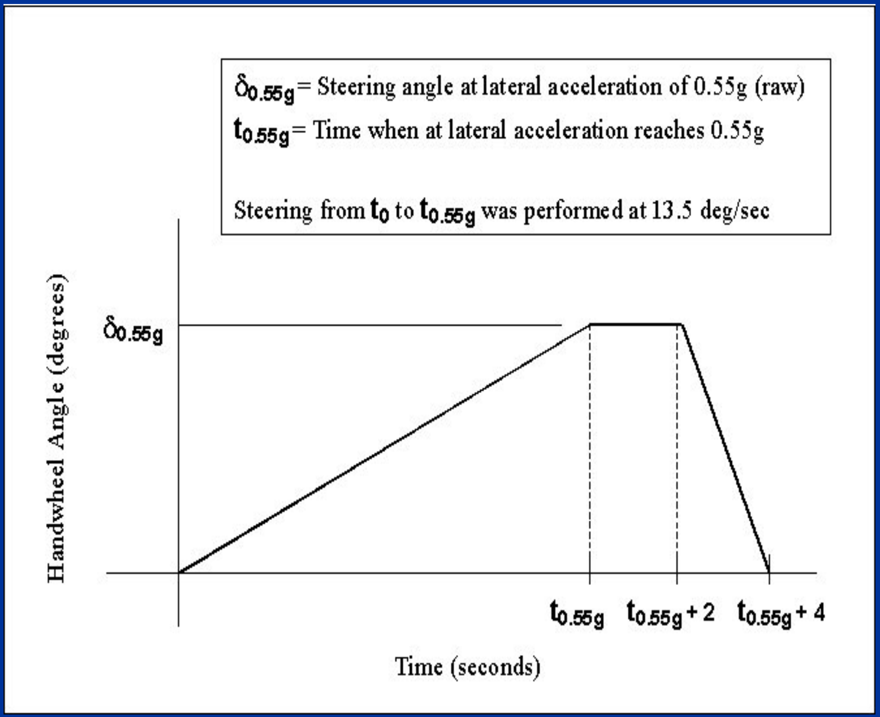


Figure. Slowly Increasing Steer steering profile.

Test Procedure Execution

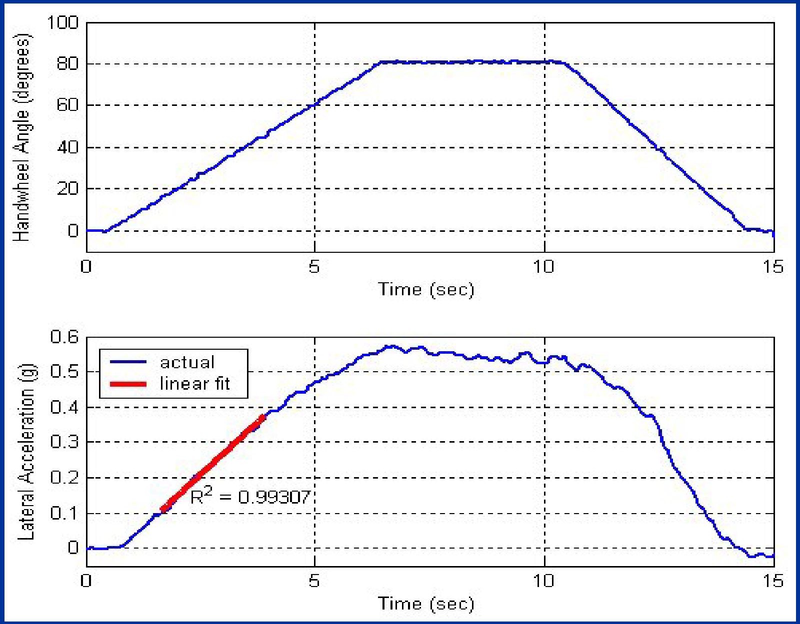
Slowly Increasing Steer Maneuver

- SIS Data Post Processing
  - NHTSA MATLAB routines are used.
  - Raw lateral acceleration data is filtered with a 12-pole phaseless Butterworth filter and a cut-off frequency of 6HZ.
  - Data is zeroed to remove sensor offset utilizing static pretest data.
  - Lateral acceleration data is corrected by removing the effects caused by vehicle body roll and correcting for sensor placement via use of coordinate transformation. Equations used are shown and discussed later.

Test Procedure Execution

Slowly Increasing Steer Maneuver

- Using linear regression techniques determine the "Best-fit" linear line equation for each of the six completed SIS maneuvers.
- For each maneuver the steering wheel angle to the nearest 0.1 degree at 0.3 g is determined.
- The SIS overall steering wheel angle is the average value of the absolute value data from each of the six maneuvers.



Test Procedure Execution

Slowly Increasing Steer Maneuver

- SIS Maneuver Sample Data From MATLAB Routine

File	Vehicle	EventPt	DOS	MES [mph]	Mean SPD [mph]	AYcount_3	THETAEI	AYCG_CD2_3 [g]	r_squared	ZeroBegin	ZeroEnd
0006.mat	2007 Chevrolet Avalanche	1305	1	49.858757	50.15107007	2003	-40.964	-0.301007115	0.99816	1105	1305
0007.mat	2007 Chevrolet Avalanche	1070	1	49.881978	49.82434361	1738	-41.155	-0.296832006	0.999398	870	1070
0008.mat	2007 Chevrolet Avalanche	1455	1	50.051393	49.90380708	2080	-41.404	-0.301857604	0.998914	1255	1455
0010.mat	2007 Chevrolet Avalanche	930	0	50.386186	49.70177229	1529	40.6467	0.306305046	0.997977	730	930
0011.mat	2007 Chevrolet Avalanche	968	0	50.146943	49.74780565	1576	41.234	0.306183473	0.997702	768	968
0012.mat	2007 Chevrolet Avalanche	1692	0	49.508663	49.73989244	2286	40.3219	0.300516957	0.999378	1492	1692
	Averages						41	0.302117034			
	Scalars	Steering Angles (deg)									
	1.5	62									
	2	82									
	2.5	103									
	3	123									
	3.5	144									
	4	164									
	4.5	185									
	5	205									
	5.5	226									
	6	246									
	6.5	267									
	6.6	270									

Test Procedure Execution

Sine with Dwell Maneuver

Maneuver used to determine a vehicle's Lateral Stability and Responsiveness Characteristics.

- The vehicle is subjected to two series of test runs using a 0.7 Hz frequency sine wave steering pattern with a 500ms delay beginning at the second peak amplitude.

- One series uses counterclockwise steering for the first half cycle and the other series uses clockwise steering for the first half cycle.

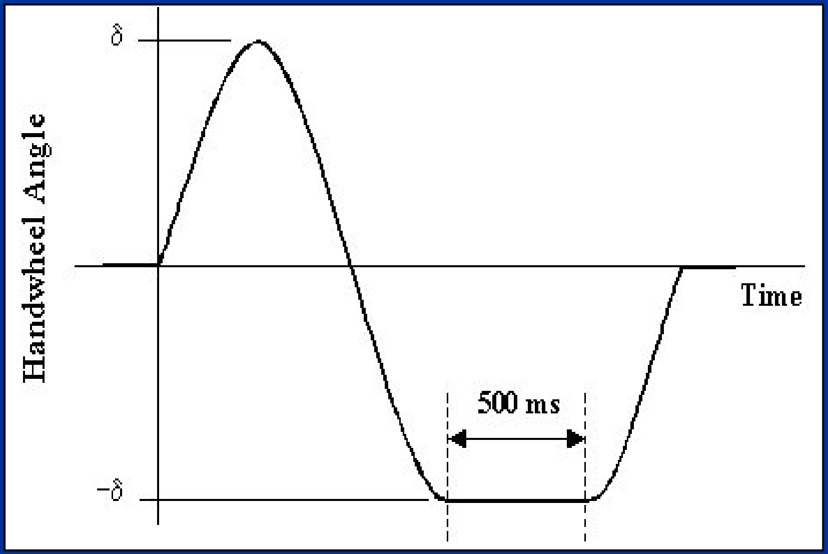


Figure 3. Sine with Dwell steering profile.

Test Procedure Execution

Sine with Dwell Maneuver

- Begin within 2 hours after completing the SIS tests.
- Execute immediately following Tire Conditioning.
- A 15 second static file of each instrument channel is collected for static zeroing of sensor channels during post processing.
- The steering controller is programmed to execute the sine with dwell maneuver using an initial counterclockwise steering direction and a steering wheel angle magnitude equal to 1.5 times the SIS steering angle.

Test Procedure Execution

Sine with Dwell Maneuver

- The vehicle is accelerated to 87±2 km/h (54±1 mph), the throttle is released and when the vehicle reaches the target speed of 80± 2km/h (50± 1mph) the steering controller executes the programmed maneuver.
- The driver reviews the collected data (steering wheel angle, vehicle speed, lateral acceleration and yaw rate). The driver confirms the maneuver entrance speed was within ±3 km/h (±1mph) of the desired speed, the steering wheel angle maximums approximately equal to the commanded steering wheel angle and both lateral acceleration and yaw rates seem reasonable.
- If all above data looks good, the test series is continued.

Test Procedure Execution

Sine with Dwell Maneuver

- Continue to execute the counterclockwise steering maneuvers, each time increasing the steering wheel magnitude by multiples of 0.5*SIS steering wheel angle.
- Continue maneuver execution until a steering wheel angle magnitude factor of 6.5* SIS steering wheel angle or 270 degrees is utilized, whichever is greater, provided the calculated magnitude of 6.5* SIS steering wheel angle is less than or equal to 300 degrees.
- Repeat the above procedure using an initial clockwise steering direction.
- Provide cool-down period between each test run of 90 seconds to 5 minutes, with the vehicle stationary.

Test Procedure Execution

Calculations of Performance Metrics

- Steps for MATLAB Routines Data Post Processing

Data Channel	1st Step	2nd Step	3rd Step	4th Step	5th Step	6th Step	7th Step	8th Step	9th Step	10th Step
	Filter Cutoff Freq. (Hz)	**Static Corrected Offset (1)**	**Calculate**	**Corrections and Filtering**	**Correct for Roll Angle**	**Dynamic Zero (3)**	**Integrate To Obtain**	**Zero (4)**	**Integrate To Obtain**	**Zero (4)**
Longitudinal Acceleration	6	YES	--	Correct Sensor Offset From C.G.	--	--	--	--	--	--
Lateral Acceleration	6	YES	--	Correct Sensor Offset From C.G.	YES	YES	Lateral Velocity	Lateral Velocity	Lateral Disp.	Lateral Disp.
Vertical Acceleration	6	YES	--	Correct Sensor Offset From C.G.	--	--	--	--	--	--
Roll Rate	6	YES	Roll Acceleration	--	--	--	--	--	--	--
Pitch Rate	6	YES	Pitch Acceleration	--	--	--	--	--	--	--
Yaw Rate	6	YES	Yaw Acceleration	--	--	YES	--	--	--	--
Steering Angle	10	YES	Steering Rate	Apply 100ms RAF To Steering Rate (2)	--	YES	--	--	--	--
Speed	2	--	--	--	--	--	--	--	--	--
Time	--	--	--	--	--	--	--	--	--	--
Left Side Ride Height	6	YES	Roll Angle	--	--	--	--	--	--	--
Right Side Ride Height	6	YES								

1. Offset is corrected using mean value from a static calibration file.
2. Running Average Filter (RAF)
3. Dynamic Zeroing refers to a zeroing range of 1 second prior to the point steering rate reaches 75 deg/sec. [Uses mean value]
4. Zeroing in this step should be performed at the point steering wheel angle first achieves 5 degrees. [Uses point value]

Test Procedure Execution

Calculations of Performance Metrics

- Coordinate Transformation Equations:

$$x''_{corrected} = x''_{accel} - (\Theta'^2 + \Psi'^2)x_{disp} + (\Theta'\Phi' - \Psi'')y_{disp} + (\Psi'\Phi' + \Theta'')z_{disp}$$

$$y''_{corrected} = y''_{accel} + (\Theta'\Phi' + \Psi'')x_{disp} - (\Phi'^2 + \Psi'^2)y_{disp} + (\Psi'\Theta' - \Phi'')z_{disp}$$

$$z''_{corrected} = z''_{accel} + (\Psi'\Phi' - \Theta'')x_{disp} + (\Psi'\Theta' + \Phi'')y_{disp} - (\Phi'^2 + \Theta'^2)z_{disp}$$

Where;

x"corrected, y"corrected, and z"corrected = longitudinal, lateral, and vertical accelerations, respectively, at the vehicle's center of gravity

x"accel, y"accel, and z"accel = longitudinal, lateral, and vertical accelerations, respectively, at the accelerometer location

xdisp, ydisp, and zdisp = longitudinal, lateral, and vertical displacements, respectively, of the center of gravity with respect to the accelerometer location

Φ' and Φ'' = roll rate and roll acceleration, respectively

Θ' and Θ'' = pitch rate and pitch acceleration, respectively

Ψ' and Ψ'' = yaw rate and yaw acceleration, respectively

Test Procedure Execution

Calculations of Performance Metrics

- Correct lateral acceleration at the vehicle center of gravity by removing the effects caused by vehicle body roll.

$$a_{yc} = a_{ym}\cos\Phi - a_{zm}\sin\Phi$$

Where;

a_{yc}	is the corrected lateral acceleration (i.e., the vehicle's lateral acceleration in a plane horizontal to the test surface)
a_{ym}	is the measured lateral acceleration in the vehicle reference frame
a_{zm}	is the measured vertical acceleration in the vehicle reference frame
Φ	is the vehicle's roll angle

Note: The z-axis sign convention is positive in the downward direction for both the vehicle and test surface reference frames.

Test Procedure Execution

Calculations of Performance Metrics

- Determine dynamic "zeroing range" for zeroing lateral acceleration, yaw rate and steering wheel angle data channels as follows:
  - Using the steering wheel rate data identify the first instant steering wheel rate exceeds 75 deg/sec. From this point, steering wheel rate must remain greater than 75 deg/sec for at least 200 ms. If the second condition is not met, the next instant steering wheel rate exceeds 75 deg/sec is identified and the 200 ms validity check applied. This iterative process continues until both conditions are ultimately satisfied.
  - The "zeroing range" is identified as the 1.0 seconds time period prior to the instant the steering wheel rate exceeds 75 deg/sec (i.e., the instant the steering wheel velocity exceeds 75 deg/sec defines the end of the "zeroing range").

Test Procedure Execution

Calculations of Performance Metrics

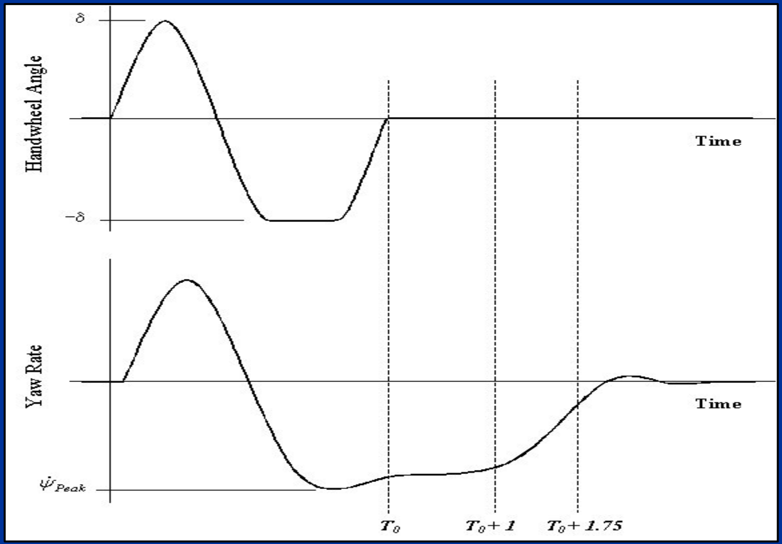
- Determine the "Beginning of Steer" (BOS) which is defined as the first instance filtered and zeroed steering wheel angle data reaches -5 degrees (when the initial steering input is counterclockwise) or +5 degrees (when the initial steering input is clockwise) after time defining the end of the "zeroing range." The value for time at the BOS is interpolated.

- Determine the "Completion of Steer" (COS) which is defined as the time the steering wheel angle returns to zero at the completion of the sine with dwell steering maneuver. The value for time at the zero degree steering wheel angle is interpolated.

Test Procedure Execution

Calculations of Performance Metrics (Yaw Rate Ratio)

- Determine the first peak value of yaw rate recorded after the steering wheel angle changes sign for each counterclockwise and clockwise steering maneuvers.
- Determine the yaw rates at 1.000 and 1.750 seconds after COS using interpolation for each counterclockwise and clockwise steering maneuvers.



Steering wheel position and yaw velocity information used to assess lateral stability.

Test Procedure Execution

Calculations of Performance Metrics (Yaw Rate Ratio)

- For each of the steering maneuvers calculate the yaw rate ratio (YRR) at 1.00 second. The yaw rate measured one second after COS must not exceed 35 percent of the second peak value of the yaw velocity recorded during the same test run. The YRR is expressed as a percentage as shown in below.
- Calculate yaw rate ratio (YRR) at 1.75 seconds for each of the steering maneuvers. The yaw rate measured 1.75 seconds after COS must not exceed 20 percent of the second peak value of the yaw velocity recorded during the same test run.

$$\mathrm{YRR} = 100 * \left(\frac{\dot{\psi}(\text{at time } t)}{\dot{\psi}_{Peak}} \right)$$

Test Procedure Execution

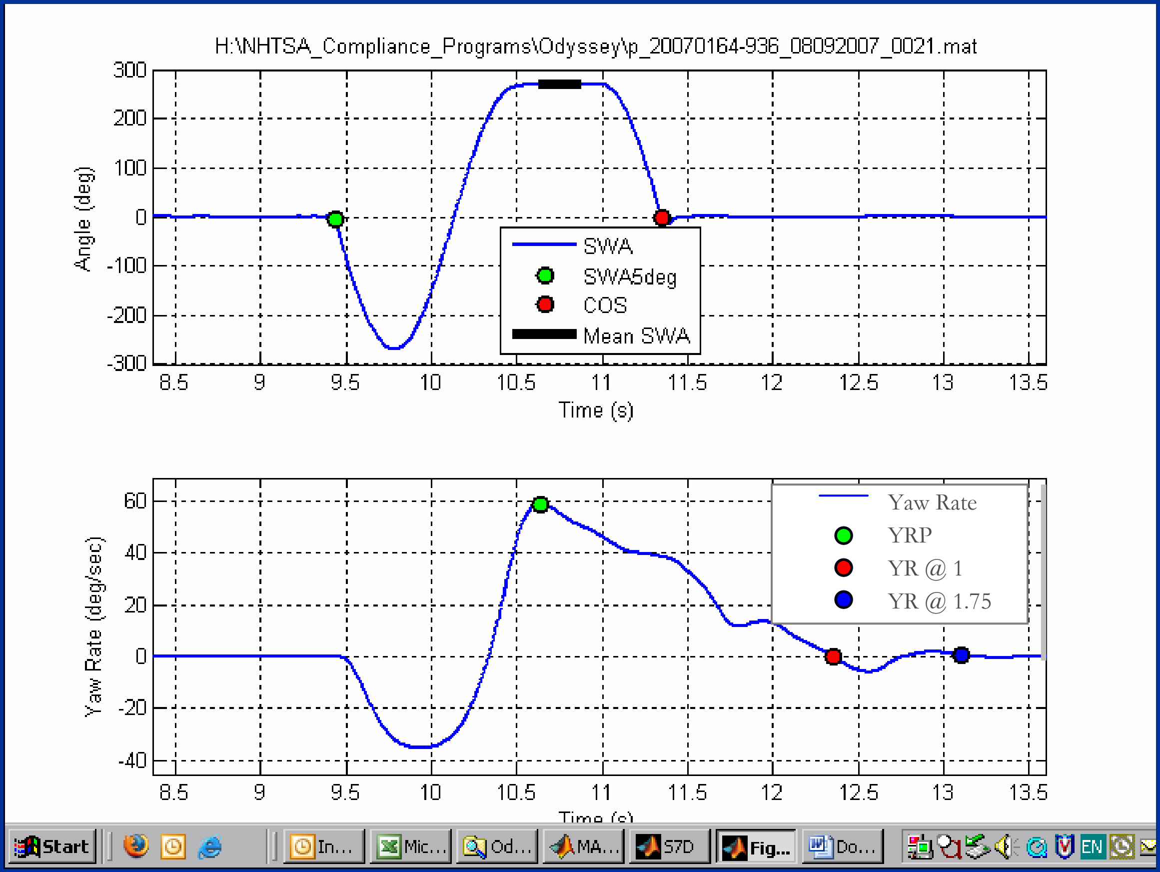
Calculations of Performance Metrics (Lateral Displacement)

- For each of the steering maneuvers executed, with a steering wheel angle of 5*SIS steering wheel angle or greater, determine lateral displacement at 1.07 seconds from BOS event using interpolation.
- Lateral displacement must be at least 1.83 m (6 ft) for vehicles w/GVWR of 3,500 kg (7,716 lb) or less,
- Lateral displacement must be at least 1.52 m (5 ft) for vehicles w/GVWR greater than 3,500 kg (7,716 lb).

Test Procedure Execution

Calculations of Performance Metrics

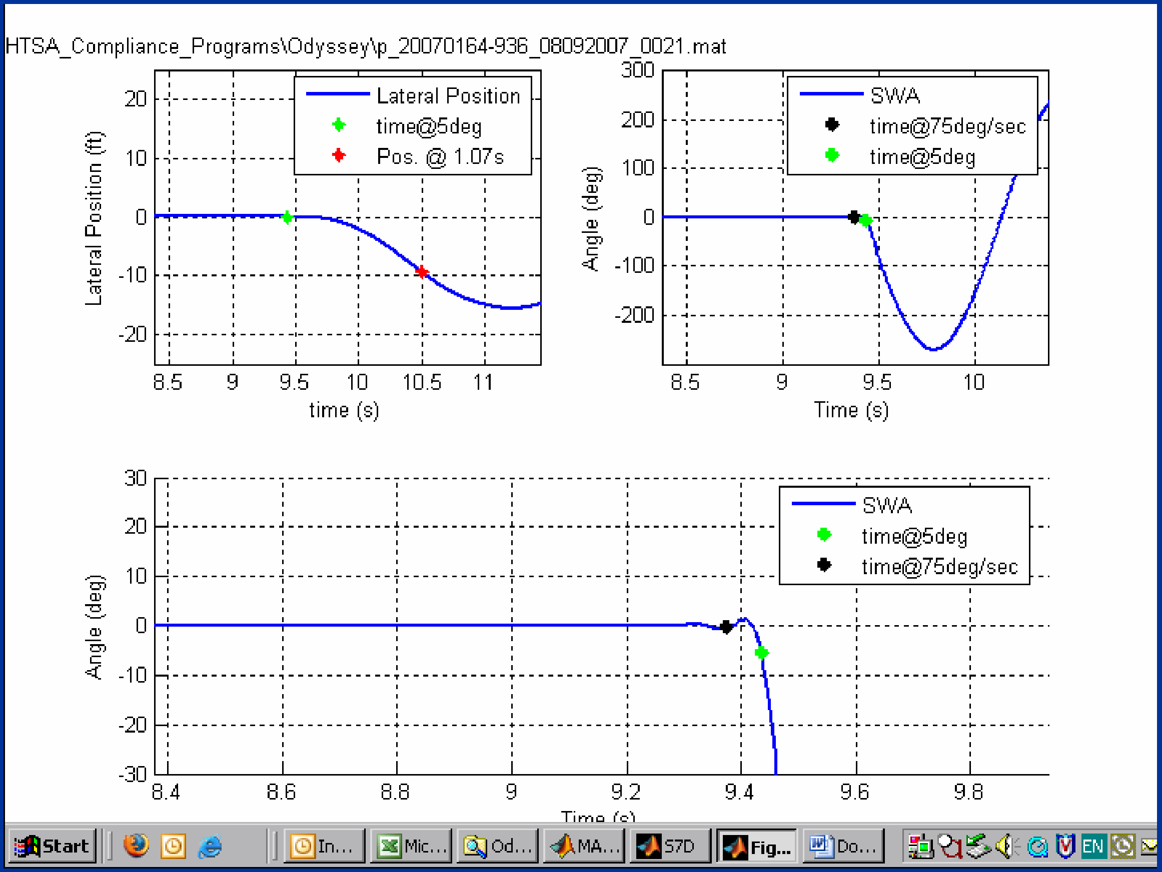
- MatLab Routine Plots



Test Procedure Execution

Calculations of Performance Metrics

- MatLab Routine Plots



Test Procedure Execution

Calculations of Performance Metrics

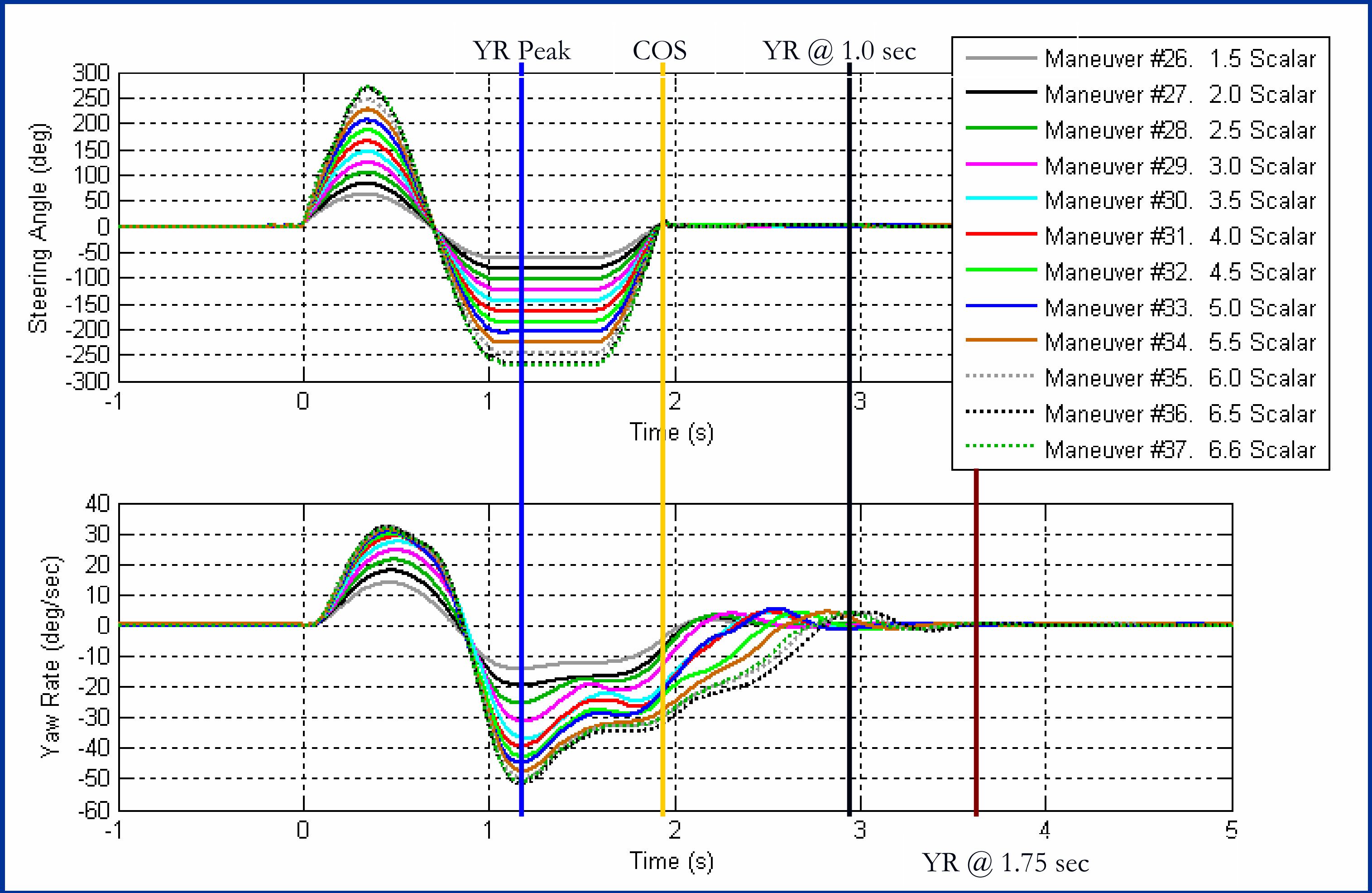
- Sample of MATLAB Performance Metric Calculations

File	Vehicle	MES	YRR1(%)	YR1 (deg/sec)	YRR175(%)	YR175 (deg/sec)	2nd Yaw Peak	Lat Disp (ft)	Scalar
0014.	2007 Chevrolet Avalanche	50.22631	-0.73689	-0.105759265	-0.3406684	-0.048893093	14.35210879	-3.9856763	1.5
0015.	2007 Chevrolet Avalanche	50.14498	-0.73945	-0.140998709	-0.8405674	-0.160280871	19.06817556	-5.1256741	2
0016.	2007 Chevrolet Avalanche	50.12923	-0.38204	-0.094239056	-0.7936234	-0.195765671	24.66732667	-6.1944702	2.5
0017.	2007 Chevrolet Avalanche	50.20021	1.862981	0.559204568	-0.3825053	-0.11481527	30.01665024	-7.0881552	3
0018.	2007 Chevrolet Avalanche	50.27794	2.124788	0.757428016	-0.097266	-0.034672625	35.64722894	-7.6400042	3.5
0019.	2007 Chevrolet Avalanche	50.20547	2.221153	0.874475826	-0.1354432	-0.053324476	39.37035609	-7.9472764	4
0020.	2007 Chevrolet Avalanche	50.14032	-7.21378	-3.0396973	-1.3679921	-0.576435878	42.13737037	-8.0900534	4.5
0021.	2007 Chevrolet Avalanche	50.22721	-8.26371	-3.679493335	-1.808386	-0.805200316	44.52590854	-8.2394604	5
0022.	2007 Chevrolet Avalanche	50.35561	-10.7342	-5.012401264	-1.0749958	-0.501976193	46.69564329	-8.3149326	5.5
0023.	2007 Chevrolet Avalanche	50.17747	-13.7256	-6.618077158	-1.5467287	-0.745786695	48.21703293	-8.3369131	6
0024.	2007 Chevrolet Avalanche	50.27539	-10.2688	-5.099126165	-1.02076	-0.50687143	49.65628082	-8.3189122	6.5
0025.	2007 Chevrolet Avalanche	50.21154	-0.13785	-0.067835676	0.68254347	0.335874557	49.20925502	-8.3293271	6.6
0026.	2007 Chevrolet Avalanche	50.16389	-0.79775	0.114717213	0.51987324	-0.074758591	-14.3801574	3.9834668	1.5
0027.	2007 Chevrolet Avalanche	50.14354	-0.28428	0.056291092	-0.6794116	0.134530986	-19.8011028	5.1483198	2
0028.	2007 Chevrolet Avalanche	50.31866	-0.92319	0.233955312	-0.820882	0.208029472	-25.3421891	6.1976082	2.5
0029.	2007 Chevrolet Avalanche	50.24844	0.023383	-0.007263315	-0.3482628	0.108179317	-31.0625502	6.8798061	3
0030.	2007 Chevrolet Avalanche	50.31531	2.832236	-1.044100578	0.03358235	-0.012380096	-36.8648867	7.4561744	3.5
0031.	2007 Chevrolet Avalanche	50.22227	2.940309	-1.155378921	-0.1695317	0.066616597	-39.2944765	7.794759	4
0032.	2007 Chevrolet Avalanche	50.18292	0.884461	-0.377714722	0.59919239	-0.255888827	-42.7056204	7.9959436	4.5
0033.	2007 Chevrolet Avalanche	50.16686	2.61917	-1.16783145	-0.2039412	0.090932994	-44.5878524	8.1958427	5
0034.	2007 Chevrolet Avalanche	50.3665	-5.89703	2.812125615	-0.060872	0.029028149	-47.6871892	8.1481675	5.5
0035.	2007 Chevrolet Avalanche	50.2095	-7.34182	3.665651545	-0.8144086	0.406621144	-49.9283968	8.3475805	6
0036.	2007 Chevrolet Avalanche	50.1383	-5.45659	2.823778884	-0.8405563	0.43498722	-51.7499232	8.3835971	6.5
0037.	2007 Chevrolet Avalanche	50.25156	-8.05284	4.120491468	-0.9725576	0.497639987	-51.1681758	8.3717951	6.6

Test Procedure Execution

Calculations of Performance Metrics

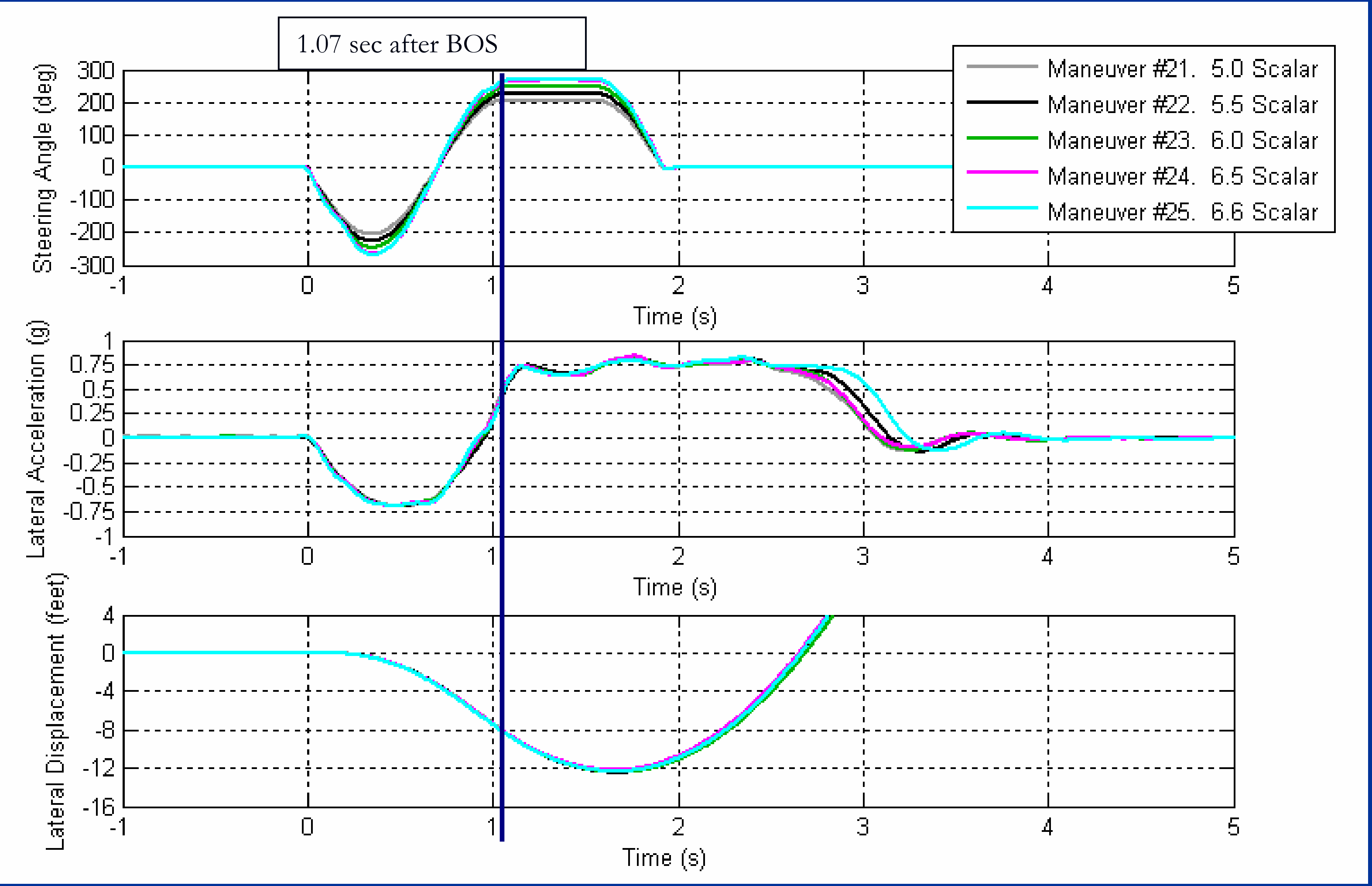
- Steering Wheel Angle & Yaw Rate



Test Procedure Execution

Calculations of Performance Metrics

- Steering Wheel Angle & Lateral Displacement



Test Procedure Execution

Test Execution - Malfunction Detection

Malfunction – Problem affecting the generation or transmission of control or response signals.

- Execute bulb check.
- Simulate an ESC system malfunction by disconnecting power source to any ESC component or disconnecting electrical connections between components.
- Activate the ignition locking system and start the engine.
- Verify the malfunction telltale illuminates.
- If necessary, place the vehicle in a forward gear and obtain a vehicle speed of 48 $\pm$ 8 km/h (30 $\pm$ 5 mph). Drive the vehicle for at least two minutes including at least one left and one right turning maneuver. Verify that within two minutes of obtaining this vehicle speed the ESC malfunction indicator illuminates.

Test Procedure Execution

Test Execution - Malfunction Detection

- Stop the vehicle, deactivate the ignition locking system to the "Off" or "Lock" position. After a five-minute period, activate the vehicle's ignition locking system and start the engine. Verify that the ESC malfunction indicator again illuminates to signal a malfunction and remains illuminated as long as the engine is running or until the fault is corrected.
- Deactivate the ignition locking system to the "Off" or "Lock" position. Restore the ESC system to normal operation and repeat above process. Verify that the malfunction telltale extinguishes.

Test Demonstration and Data Post Processing

- Test Vehicle Inspection
- Tire Conditioning
- Slowly Increasing Steer Maneuver
- Sine With Dwell Maneuver
- MATLAB Data Post Processing

Test Procedure Issues
and
Discussion of Comments

ESC NHTSA Points-of-Contact

- **Rulemaking Issues**
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- **Legal Issues**
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  (202)366-4332 rebecca.schade@dot.gov

Available Information

- For a copy of this ESC Technical Workshop and Demonstration presentation go to http://www.regulations.gov (under "Search for Dockets" enter docket# 29244)
- To view the latest revision of the OVSC Laboratory Test procedure, go to http://www.nhtsa.dot.gov (under "Test Procedures" on the Vehicles and Equipment page)
- MATLAB Routines will be made available by following directions provided in posted Laboratory Test Procedure