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Aberdeen Proving Ground, MD 21005

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14. ABSTRACT
This TOP prescribes procedures for testing the electronic stability control system of two-axle vehicles up to 11,793 kg (26,000 lb) for speeds up to 81 km/hr (50 mph). Major factors to be considered when testing the yaw and roll stability of wheeled vehicles are their capability and behavior during sudden obstacle avoidance actions. Electronic stability control systems are employed on some vehicles to mitigate oversteer (or spin-out) and rollover. The sine-with-dwell steering maneuver was developed as an objective test of vehicle stability and electronic stability control system performance.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 02-2-718 5 December 2013
DTIC AD No. ADA593590

ELECTRONIC STABILITY CONTROL

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1. SCOPE.

This Test Operations Procedure (TOP) provides standardized tests for evaluating the electronic stability control (ESC) system capabilities of two and three axle trucks over 4,536 kilograms (kg) (10,000 pounds (lb)) gross vehicle weight (GVW).

1.1 Purpose.

a. Stability and handling, as an element of automotive testing, is associated with personnel safety. Thorough testing and evaluation of vehicle ESC capabilities can help ensure satisfactory vehicle performance, especially when taking avoidance actions, cornering, and other emergency maneuvers. ESC provides the capability to mitigate severe oversteer or understeer conditions that can lead to vehicle loss-of-control (LOC) by automatically applying selective brakes to generate a yawing moment, which helps the driver maintain directional control of the vehicle[1**]. ESC systems for heavy vehicles also provide Roll Stability Control (RSC) to mitigate on-road, untripped truck rollovers by automatically decelerating the vehicle by applying the foundation brakes and reducing engine torque output (per National Highway Traffic Safety Administration (NHTSA),(reference 1)).

b. Under the current definition, an ESC system has the following attributes:

(1) Augments vehicle directional stability by applying and adjusting vehicle brake torques individually at each wheel position on at least one front and one rear axle of the vehicle to induce correcting yaw moment to limit vehicle oversteer and to limit vehicle understeer.

(2) Enhances rollover stability by applying and adjusting the vehicle brake torques individually at each wheel position on at least one front and at least one rear axle of the vehicle to reduce lateral acceleration of a vehicle.

(3) Is computer- controlled, using a closed-loop algorithm to induce correcting yaw moment and enhance rollover stability.

(4) Has a means to determine the vehicle lateral acceleration.

(5) Has a means to determine the vehicle yaw rate and to estimate its side slip or side slip derivative with respect to time.

(6) Has a means to estimate vehicle mass.

(7) Has a means to monitor driver steering input.

(8) Has a means to modify engine torque, as necessary, to assist the driver in maintaining control of the vehicle.

** Superscript numbers correspond to Appendix C, References.

(9) When installed on a truck tractor, has the means to provide brake pressure to automatically apply and modulate the brake torques of a towed semi-trailer.

c. This TOP describes two ESC tests for two and three axle trucks over 4,536 kg (10,000 lb) GVW. These tests ensure sufficient rollover stability and oversteer or understeer intervention to mitigate the tendency for the vehicle to spin out or plow out in a curve. The two compliance tests, and associated performance criteria, are presented in Table 1 (extracted from NHTSA, Preliminary Regulatory Impact Analysis of ESC Systems on Heavy Vehicles (reference 1)). These tests are for performance on standard, paved test courses, using "auto pilot" instrumentation to provide accurate and repetitive steering inputs.

TABLE 1. ESC TESTS AND ASSOCIATED PERFORMANCE CRITERIA

TEST	CRITERION
Slowly Increasing Steer (SIS) Characterization	Engine Torque Output
Sine-With-Dwell (SWD)	Lateral Acceleration Ratio (LAR)
	Yaw Rate Ratio (YRR)
	Lateral Displacement (LD)

d. This TOP will identify the pertinent procedures to evaluate vehicle ESC performance.

1.2 Limitations.

a. This TOP describes two ESC tests for two and three axle trucks over 4,536 kg (10,000 lb) GVW, generally at road speeds up to 72 to 80 kilometers per hour (km/hr) (45 to 50 miles per hour (mph)), for compliance with applicable requirements. These procedures may be used for both developmental and production vehicles. Vehicles designed specifically for off-highway operations that do not possess a maximum vehicle speed capability of at least 72 km/hr will be considered on an individual basis. These procedures can be applied to vehicles without ESC systems to assess stability characteristics of the vehicle alone. For these cases specific test parameters and criteria will be provided in the vehicle test plans.

b. Prior to testing, the test agency should review the following information to verify that the test vehicle ESC system meets operational requirements and to aid execution and completion of testing and evaluation (reference 1):

(1) A system diagram that identifies all ESC system hardware.

(2) A written explanation describing the basic operational characteristics of the vehicle ESC system.

(3) A discussion of the pertinent inputs to the vehicle computer and how its algorithm uses that information to mitigate rollover and limit oversteer and understeer.

(4) The test vehicle must be equipped with an ESC system with the following capabilities (per Society of Automotive Engineers (SAE) J2180[2]):

(a) Capability to apply brake torques individually to all four wheels and has a control algorithm that utilizes this capability.

(b) Is operational during all phases of driving including acceleration, coasting, and deceleration (including braking), except when the driver has disabled ESC, the vehicle speed is below 20 km/h (12.4 mph), the vehicle is being driven in reverse, or during system initialization.

(c) Remains capable of activation even if the antilock brake system or traction control system is also activated.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Circular Steer Test Course	Uniform hard surface of concrete or asphalt with a gradient of no more than 1 percent in any direction. Area must be of sufficient size to allow for safe execution of the SIS test maneuver.
Straight Roadway	A straight asphalt or concrete roadway with a width of at least 45 meters (m) over a length of a least 1500 m, with additional roadway leading to and from the test course to allow for entry at target test speeds and stopping after the maneuver.

2.2 Instrumentation.

Devices for Measuring	Permissible Measurement Uncertainty
Road speed	1 percent
Steering wheel angle	0.25 degrees
Lateral, longitudinal, and vertical accelerations	0.01 *g*
Yaw rate, roll rate, and pitch rates	0.05 degrees per second
Roll angle (see Section 2.3)	0.1 degrees

Devices for Measuring	Permissible Measurement Uncertainty
Body slip angle	0.1 degrees
Steering effort (torque)	1.4 Newton-meter (N-m) (1 pound-foot (lb-ft)
Commanded engine torque (see Section 2.3)	1 percent
Brake line pressure (see Section 2.3) - Optional	1 percent
Tire pressure	0.7 kilopascals (kPa) (0.1 pounds per square inch (psi))
Brake pedal application force (see Section 2.3)	1 percent
Distance measuring device	1 percent
Time	1 percent
Temperature	1 °Celsius (C)
Meteorological data:	
Atmospheric pressure	1 percent
Ambient temperature	1 °C
Humidity	3 percent
Wind speed	5 percent
Wind direction	1 degree

2.3 Specialized Equipment.

Specialized equipment and instrumentation required for vehicle preparation, test course set-up, and test observation are as follow:

a. Safety device with supporting structures on either side of the vehicle (outriggers) to prevent rollover. The outriggers must be designed and installed in such a manner that the vehicle test weight, center of gravity (CG), and moment of inertia remain as unchanged as practical (objective: outrigger weight ≤ 10-percent of combined vehicle weight).

b. When required, the peak friction coefficient (skid number) of the various test course surfaces will be measured in accordance with American Society for Testing and Materials (ASTM) E1337-90[3], using an ASTM E1136-10[4] standard reference tire.

c. Auto-Pilot Device. A steering robot (ATI Heitz Automotive Sprint3 Steering Machine*** or equivalent), as shown in Figure 1, will be used to control the steering maneuvers. The steering machine can be programmed to perform any desired steering sequence at target speeds using feedback signals of vehicle speed and roll rate.



Figure 1. Auto-pilot device.

d. Load cell to monitor brake pedal force with a range of 0 to 136 kg (0 to 300 lb) and accuracy + 1.0 percent full scale. While brake pedal force is not explicitly required for determining vehicle compliance, the load cell is used to confirm the driver has not unintentionally applied the brakes during execution of the maneuvers.

e. Vehicle J1939 communication data link (or equivalent) can be recorded to observe vehicle control signals for engine torque command and response. If the vehicle is not equipped with a databus for control, or the databus used to control engine torque cannot be monitored, other test instrumentation must be applied to the vehicle as appropriate for compression ignition or spark ignition applications.

*** The use of brand names does not constitute endorsement by the Army or any other agency of the Federal Government, nor does it imply that it is best suited for its intended application.

f. Vehicle roll angle can be measured by integration of the roll rate data from inertial measurement devices (Oxford Technical Solutions Model RT2002 or equivalent), if deemed accurate, or by means of two ultrasonic distance measuring system sensors. Two ultrasonic distance measuring system sensors, to determine vehicle displacements that can be used to calculate roll angle, with a range of 10 to 102 centimeters (cm) (4 to 40 inches), resolution 0.25 millimeters (mm) (0.01 inches) and accuracy + 0.25% of maximum distance (MASSA Model M-5000/220 or equivalent).

g. (Optional) Pressure transducers to monitor individual wheel-end brake line pressures with a full-scale range appropriate and safe for the vehicle under test. Alternatively, these data may be obtained from the vehicle J1939 communication data link (or equivalent); provided the brake apply pressure data are available on the databus. While brake line pressure is not explicitly required for determining vehicle compliance, the pressure data are used to confirm the individual wheel brake application function during.

h. Digital video camera to record all test events to observe wheel lift and overall vehicle behavior and any test failures.

3. REQUIRED TEST CONDITIONS.

3.1 Preparation for Test.

a. Review all instructional material issued with the test vehicle by the manufacturer, contractor, or government, as well as reports of previous similar tests on the same types of vehicles.

b. Obtain copies of and review relevant Federal Motor Vehicle Safety Standards (FMVSS) ESC test procedures applicable to the class of the vehicle under test.

c. Prepare data collection sheets to record all pre-test information, conditions of test, test results, observations, and measurements that would be valuable for analysis and assessment.

d. Conduct vehicle training to ensure that all test personnel are familiar with the required technical and operational characteristics of the item and with the required test procedures.

e. Static Rollover Threshold (Tilt Table) Test. In preparation for ESC testing, conduct the tilt table test in accordance with SAE Recommended Practice J2180 to determine the test vehicle's maximum side slope angle and simulated lateral acceleration prior to rollover.

f. Install safety outriggers on the test vehicle and proof load the outriggers as appropriate for the vehicle and outrigger arrangement.

g. If military personnel are required, ensure a Test Schedule and Review Committee (TSARC) request is submitted within one year from the start of testing or as early as possible. A Safety Release (SR) must be obtained from the US Army Evaluation Center (AEC) prior to using military personnel as test participants.

3.2 Test Controls.

Prior to the initiation of testing, ensure that:

a. The vehicle has been prepared and equipped in accordance with standard use and/or within the specifications presented in the test plan. Fill the fuel tank and other fluid reservoirs.

b. The vehicle has received the proper break-in operation.

c. The steering and suspension components are in good serviceable condition, with particular attention to proper wheel alignment.

d. Tire tread is in serviceable condition.

3.3 Restrictions.

Tests are not conducted at night, during inclement weather, or when the road surface may introduce a hazard to the test vehicle or other traffic on the road. Dry,unobstructed surfaces are used, unless the test plan introduces a specific requirement. Local safety and operational procedures will be followed. Desirable environmental conditions for test conduct are as follows:

a. Wind speed: $\leq$ 3 meters per second (m/s) average value.

b. Ambient temperature: 0 to 30 °C.

c. Humidity: $\leq$ 95 percent.

4. TEST PROCEDURES.

4.1 General Vehicle and Test Preparation.

The following items should be performed before proceeding with testing:

a. Record the test and vehicle identification.

b. Record the vehicle weight, weight distribution, and center-of-gravity characteristics, as tested.

c. Record the basic measurements and condition of the components of the suspension and steering systems (e.g., camber, caster, and wheel toe).

d. Identify the tire size, manufacturer, name, and tire identification number (TIN). Verify the tires are new. Examine the vehicle placard and/or any manuals or publications provided with the vehicle. Verify the tires are the same size and make as those provided with a new vehicle at the time of delivery. Inflate the tires to the recommended cold inflation pressure as specified on

the vehicle placard or optional tire inflation pressure label. Record the measured pressure for each tire.

e. Verify that the test track being used is dry and uniform with a solid-paved surface. Surfaces with irregularities and undulations, such as dips and large cracks, are unsuitable. The test surface must have a consistent slope between level and 1 percent[5].

f. Document the test track peak friction coefficient (PFC) (skid number) for each test track. The road test surface must produce a PFC of at least 0.9 when measured using an ASTM E1136-10 standard reference test tire (in accordance with ASTM E1337-90), at a speed of 64.4 km/h (40 mph), without water delivery (reference 5).

g. Instrument the vehicle to measure yaw rate, roll rate, roll angle, lateral acceleration, steering wheel angle and torque, vehicle speed and sideslip, brake pedal application force and document the manufacturer, identification (serial number, part number, etc.), calibration information, and transducer locations (including photographs). The location of inertial sensors (those used to measure yaw rate, roll rate, and lateral acceleration) must be accurately located relative to the vehicle center of gravity, using a coordinate measurement machine (CMM) when possible. For data collection, the lateral accelerometer shall be located as close as possible to the position of the vehicle's longitudinal and lateral CG.

h. Install the automatic steering controller, centered onto vehicle steering wheel. Verify calibration of steering controller encoder by confirming one full rotation of the steering controller wheel results in a reading of 360 degrees on the data acquisition system (DAS). Verify the steering controller triggers a steering maneuver at the correct vehicle speed by injecting a voltage into the speed sensor connection to simulate speed.

i. Power up the data acquisition system and verify all channels are activated and observe for normal data drift. Verify DAS is set up for 200 hertz (Hz) sampling rate, filtering using two-pole low-pass Butterworth filter with nominal cut-off frequencies at 25 Hz to prevent aliasing, and amplifier gains selected to maximize signal-to-noise ratio. Verify DAS displays accurate calibrated sensor outputs.

j. Compile calibration data prior to each maneuver test series to assist in resolving uncertain test data. At the beginning of each test day for each test vehicle, document the distance along a straight line between the end points of a surveyed linear roadway standard of 305 m (1000 ft) or more (observed and recorded manually from the speed sensor display). In addition, operate the test vehicle in a straight line on a level, uniform, solid-paved road surface with a vehicle speed of 97 km/h (50 mph) and compile 5 to 15 seconds of data from all instrument channels.

k. Perform the Pre-Test Brake Conditioning procedure per Appendix A.

4.2 Slowly Increasing Steer (SIS) Test.

The SIS (constant speed skidpad) test is conducted as a precursor to SWD testing to determine the steering input angle limits. The reference steering wheel angle determined during the SIS test is used to program the automated steering machine for the SWD test. Using the established steering wheel angle ensures that each vehicle is subjected to the same test severity and is likely to be subjected to the same instability condition. The SIS test is also used to evaluate the engine torque-reducing capability of the ESC system to characterize system capability to mitigate both rollover and understeer. The test procedure is adapted from the NHTSA Laboratory Test Procedure for FMVSS No. 126 (reference 5).

a. Measure and record ambient temperature and wind speed. Verify whether the wind speed and ambient temperature are within required test conditions.

b. Immediately prior to testing, perform the Mass Estimation and Tire Conditioning procedures per Appendix A.

c. Document vehicle drive configuration and mode for testing. Generally, the first test will be executed with the drive configuration and mode set to the manufacturer's standard or default settings. Typically for on-highway operation the default setting is two-wheel drive or all-wheel drive with axles unlocked and with the transmission in Drive. For vehicles with manual transmissions, testing is to be conducted in the highest gear associated with normal driving at the test speeds indicated. Subsequent tests may be executed under different drive configurations and modes as appropriate and directed in the detailed test plan. Care should be taken when testing on paved surfaces to avoid damage to driveline components by locking the final drives on individual axles.

d. Energize the data acquisition system and automatic steering controller. Program the steering controller so at time zero the steering wheel angle is linearly increased from zero to a maximum value, δ_{SIS}, at a rate of 13.5 °/second. The maximum value, δ_{SIS}, is the steering wheel angle necessary to achieve 0.4 g lateral acceleration during a steady-state cornering maneuver at 30 mph, based on pre-test experimentation or other analytical means to determine the angle.

e. Position the test vehicle at the circular steer test course facing the direction the SIS maneuvers will be executed. Collect 15 seconds of data from all instrument channels with the test vehicle at rest, the engine running, the transmission in "Park" (automatic transmission) or neutral with the parking brake applied (manual transmission), and the front of the test vehicle pointing in the direction of testing. The static data file will be used in post processing to establish a datum for each instrument channel.

f. Execute a SIS maneuver to the left using the SIS steer profile determined in paragraph 4.2.d, and record the steering wheel angle and lateral acceleration data. If the lateral acceleration is below 0.4 g, then increase the steering angle by 15 degrees. If the lateral acceleration is above 0.45 g, then decrease the steering angle by 15 degrees.

g. Repeat the procedure in paragraph 4.2.f until three SIS maneuvers to the left have been completed where the lateral acceleration falls within 0.40 *g* to 0.45 *g*, the vehicle speed was 48 + 2 km/h (30 + 1 mph), and the maximum steering angle was held constant for 1 second before the maneuver was concluded. The maximum time permitted between test run maneuvers is 5 minutes. A description of the SIS steering profile is presented in Figure 2. For each of the three test runs, document the run time, steering wheel angle, and lateral acceleration.

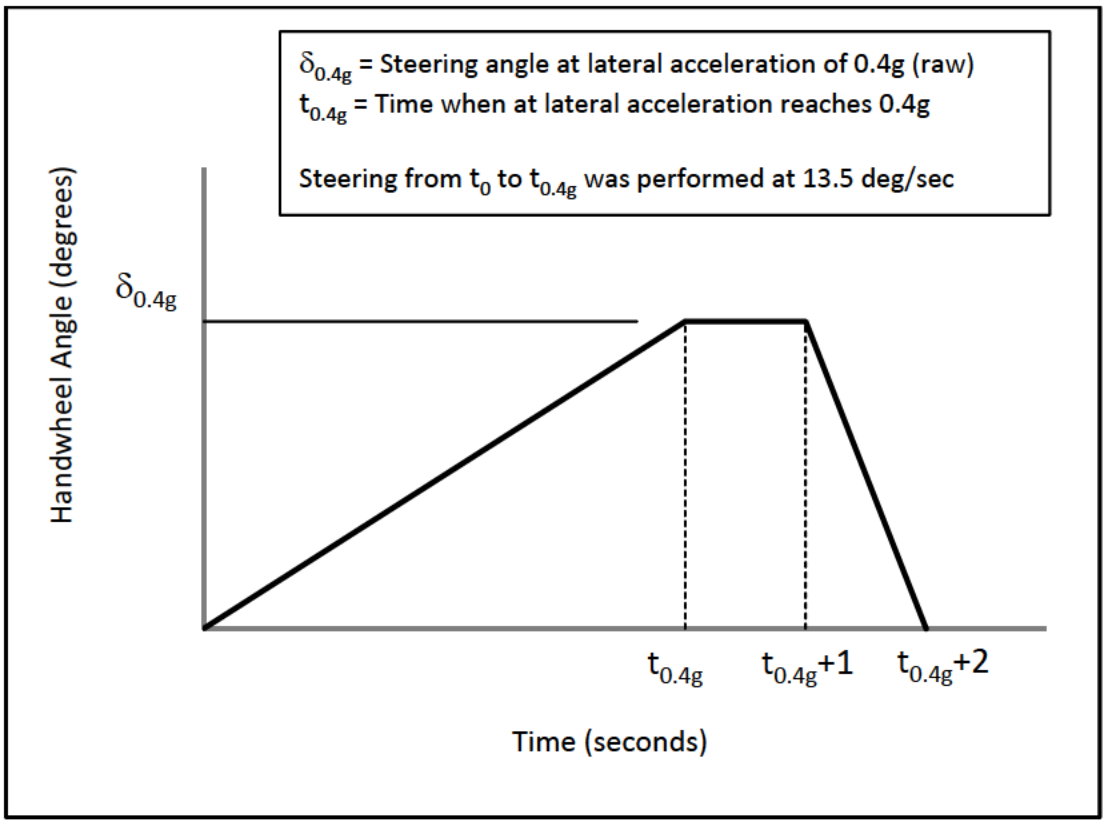


Figure 2. SIS steering profile.

h. Repeat the procedure in paragraphs 4.2.e through g until three SIS maneuvers to the right have been completed where the lateral acceleration falls within 0.40 *g* to 0.45 *g*, the vehicle speed was 48 + 2 km/h (30 + 1 mph), and the maximum steering angle was held constant for 1 second after which the maneuver was concluded. The maximum time permitted between each test run maneuver is 5 minutes. For each of the three test runs document the run time, steering wheel angle, and lateral acceleration.

i. For comparison, the tests described in paragraphs 4.2e through 4.2.h may be with the ESC system active and with the ESC disabled.

j. During each test run, ESC system activation should be confirmed (provided the ESC system was enabled). If the ESC system activation does not occur during the maneuver (with the

ESC system enabled), the maximum steering wheel angle, δ_{SIS}, should be increased appropriately until ESC activation is achieved, cornering limitations are reached, or the maximum steering angle is reached. Care should be taken to ensure safe and controllable test operations near vehicle cornering limits.

k. Examine brake the load cell data. If any application of brake force is indicated, the maneuver must be eliminated from analysis.

l. The reference steering wheel angle for SWD testing is the angle that would produce 0.5 *g* of lateral acceleration in the test vehicle at a constant speed of 30 mph. To confirm ESC activation and evaluate the ESC engine torque reduction capability, engine torque output and driver-requested torque are collected and analyzed. Post-test data processing and analysis are presented in paragraph 6.2.

4.3 Sine-With-Dwell (SWD) Test.

The SWD test subjects the test vehicle to roll and yaw instabilities to verify the performance of the ESC in mitigating those instabilities. The vehicle ESC must comply with lateral stability, yaw stability, and responsiveness criteria. The procedures for testing are presented below. The test procedure is adapted from the NHTSA Laboratory Test Procedure for FMVSS No. 126.

a. Initiate the first SWD test series within 2 hours after completing the SIS test, using the same tires.

b. Immediately prior to testing, perform the Mass Estimation, Brake Conditioning, and Tire Conditioning procedures, per Appendix A.

c. All tests must be performed with automatic transmission in Drive. If the test vehicle is equipped with a manual transmission, the highest gear capable of sustaining the desired test speeds shall be used. Manual transmission clutches are to remain engaged during all maneuvers.

d. Verify the vehicle drive configuration and mode selected, as determined for testing in paragraph 4.2.c.

e. Verify the ESC system is enabled by ensuring that the ESC malfunction and "ESC OFF" (if provided) telltale is not illuminated, provided testing is conducted with the ESC system enabled.

f. At the completion of the tire conditioning procedure and before the start of a test series, position the test vehicle at the straight roadway test course facing the direction in which the SWD maneuvers will be executed. Collect 15 seconds of data from all instrument channels with the test vehicle at rest, the engine running, the transmission in "Park" (automatic transmission) or neutral with the parking brake applied (manual transmission), and the front of the test vehicle pointing in the direction testing will occur. The static data file will be used in post processing to establish a datum for each instrument channel.

g. Energize the programmable steering controller. Program the controller to execute the SWD maneuver, as shown in Figure 3, using an initial counterclockwise steering direction. The steering amplitude for the initial run of each series is $0.3 * \delta_{0.5g,\text{overall}}$, as determined from the SIS maneuvers.

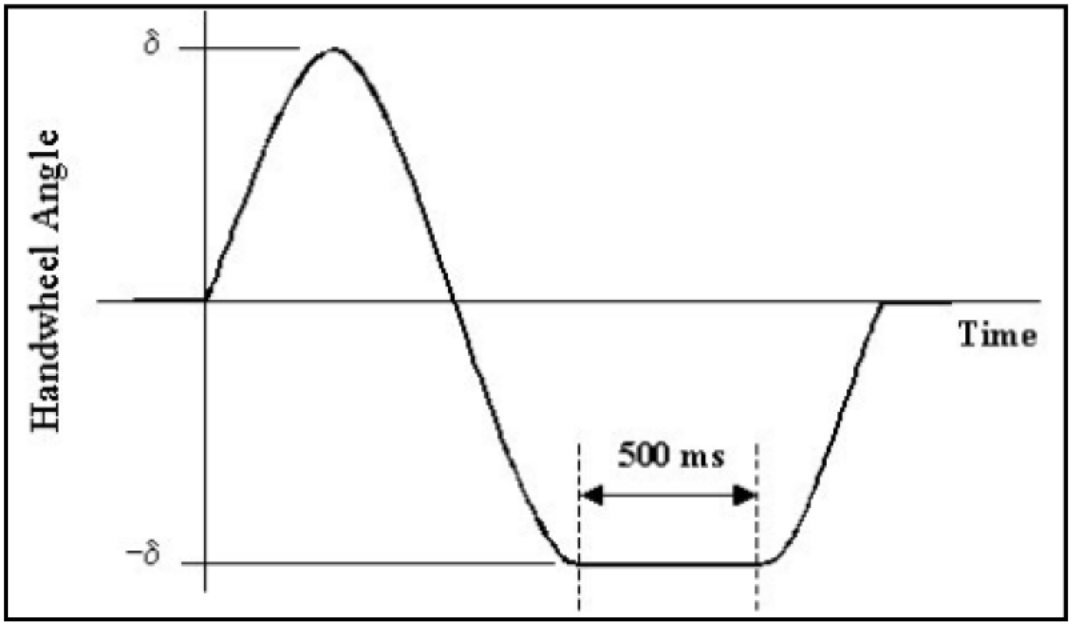


Figure 3. SWD by steering wheel angle inputs (from reference 1).

h. Program the steering controller to execute the SWD maneuver when the vehicle reaches the target test speed determined by specific vehicle requirements established in the test plan. Typically, the target speed is 64 km/hr (40 mph), 72 km/h (45 mph), or 80 km/hr (50 mph) with an allowable variation in initial speed of 2 km/h (1.0 mph). The vehicle will be subjected to a steering pattern of a sine wave at a frequency of 0.5 Hz, with a 1-second delay beginning at the second peak amplitude, as shown in Figure 3.

i. During the maneuver, observe the vehicle for loss of pavement contact of tires, rim-to-pavement contact and tire debeading. Rim-to-pavement contact will be verified by visual observation and identified by marks left on the pavement. Debeading will be verified by visual observation and a corresponding loss of tire inflation pressure. Loss of pavement contact of tires will be verified by visual observation and documented by video camera. If any of these events are observed, or if the test driver experiences a vehicle loss of control or spinout, the test will be halted for consultation with the test officer before proceeding. Generally, an undamped spinout or rollover condition determines the stopping point for the test series in a particular steer direction.

j. During a test series, if one or both safety outrigger skid pads contact the road surface during a test run where there is no spinout or wheel lift, raise the height of the affected outrigger(s) by one adjustment position, and repeat the test run.

k. Using the data from paragraph 4.3.h, plot the steering wheel angle, vehicle speed, lateral acceleration, and yaw rate. Confirm the maneuver entrance speed was within 2 km/h (1.0 mph) of the desired speed, the steering wheel angle maximums were accurate, and both lateral acceleration and yaw rate seem reasonable. If any of the above conditions are not met, halt the test and correct the problem. If all conditions are met, the test series will continue.

l. Between each test run, provide a cool-down period of 90 seconds to 5 minutes with the engine running, vehicle stationary, and positioned at the maneuver starting point.

m. Continue to execute the steering maneuvers, each time increasing the steering wheel angle magnitude by multiples of $0.1 * \delta_{0.5g,\text{overall}}$. Maneuver execution should continue until a steering wheel angle magnitude factor of $1.3 * \delta_{0.5g,\text{overall}}$ or 270 °, whichever is greater, provided the calculated magnitude of $1.3 * \delta_{0.5g,\text{overall}}$ is less than or equal to 300 °. If $1.3 * \delta_{0.5g,\text{overall}}$ is less than 270 °, maneuver execution should continue by increasing the steering wheel angle magnitude by multiples of $0.1 * \delta_{0.5g,\text{overall}}$without exceeding the 270 ° steering wheel angle. If any $0.1 * \delta_{0.5g,\text{overall}}$increment, up to $1.3 * \delta_{0.5g,\text{overall}}$, is greater than 300 °, the steering amplitude of the final run shall be 300 °.

n. Repeat the procedure m using an initial clockwise steering direction.

o. Examine data for brake force. If any application of brake force is indicated, the maneuver must be eliminated from analysis.

p. Post-test data processing and analysis are presented in paragraph 6.3.

4.4 Electronic Stability Control (ESC) Malfunction Telltale and Symbol.

This test procedure confirms the system is equipped with a functioning ESC malfunction telltale. The procedure is adapted from the NHTSA Laboratory Test Procedure for FMVSS No. 126. According to current NHTSA ESC regulations, in the event of ESC malfunction, the system must display in front of the driver, and in clear view, the acronym “ESC” or the following yellow telltale symbol (Figure 4) (available in FMVSS No. 101[6] (Controls and Displays, Table 1)).



Figure 4. ESC telltale symbol.

a. Examine the vehicle to determine whether or not there is an on/off switch for the ESC.

b. With the vehicle off and ESC enabled, induce a malfunction in the ESC by disconnecting the power source to any ESC component or disconnecting any electrical connection between ESC components. The electrical connections for the telltale lamp(s), or the "ESC OFF" control, are not to be disconnected.

c. Turn the ignition to the "on" position (Run position) and observe the driver's display panel. The malfunction telltale is required to illuminate after one or more ESC malfunctions.

d. If the malfunction telltale did not illuminate when engine was started, put the vehicle in a forward gear and obtain a vehicle speed of 48 + 8 km/h (30 + 5 mph). Drive the vehicle for at least 2 minutes, including at least one left and one right turning maneuver, and at least one service brake application. Verify that within 2 minutes of obtaining this vehicle speed, the ESC malfunction telltale illuminates. Document any other telltales and/or warning messages activated upon simulating the subject ESC system malfunction.

e. Turn the ignition to the "off" position. After 5 minutes have elapsed, if the vehicle is so equipped, turn the ignition to a point between on (Run position) and Start, designated by the manufacturer as a check position. The telltale must illuminate. Otherwise, after 5 minutes have elapsed, turn the ignition to the "on" position and verify that the ESC malfunction telltale illuminates and remains illuminated for as long as the engine is running.

f. Stop the vehicle and turn the ignition to the "off" position. Restore the ESC to working condition, and restart the ignition. Turn the ignition to the "on" position (Run position). Repeat paragraph 4.4.c and observe to verify the ESC telltale has extinguished.

g. Post-test data presentation are presented in paragraph 6.4.

5. DATA REQUIRED.

5.1 General Vehicle and Test Preparation.

a. Date of test and test site.

b. Vehicle identification: manufacturer, type, identification number.

c. Measurements and condition of the suspension and steering systems.

d. Tire size, manufacturer, name, and TIN. Confirm whether the tires are new. Record any inconsistencies based on the vehicle placard and/or any manuals or publications provided with the vehicle, including whether the tires are the same size and make as those provided with a new vehicle at the time of delivery.

e. The recommended cold inflation pressure as specified on the vehicle placard or optional tire inflation pressure label and the measured pressure for each tire.

f. The recommended cold inflation pressure as specified on the vehicle placard or optional tire inflation pressure label and the measured pressure for each tire.

g. Test course peak friction coefficient (PFC) (skid number).

h. Instrumentation name/type, manufacturer, identification (serial number, part number, etc.), calibration information, and location on vehicle (including photographs).

i. Vehicle configuration: weight, load distribution, mileage, and condition.

j. Measurements for the coordinates of the inertial sensing system or yaw rate, roll rate, and lateral acceleration sensors.

k. Vehicle CG coordinates.

l. Results of tilt table test.

m. Locations of and distance between the ultrasonic distance measuring sensors, if used for roll angle measurements.

n. Test course identification, dimensions, and description of operating conditions.

o. Vehicle maximum side slope angle and simulated lateral acceleration prior to rollover.

5.2 Slowly Increasing Steer (SIS) Test.

a. Ambient temperature and wind speed at each test site.

b. Detailed record of Tire Conditioning procedure.

c. Immediately prior to test runs, compile 15 seconds of data from all instrument channels with the test vehicle at rest, the engine running.

d. Detailed record of steering controller setup and direction of steer (counterclockwise or clockwise).

e. Vehicle speed.

f. Vehicle drive configuration and mode for each test series.

g. Vehicle travel distance (gathered during calibration check of vehicle speed sensor).

h. Lateral acceleration data.

i. Steering angle and peak amplitude.

j. Yaw rate.

k. Roll angle and side slip.

l. Elapsed time of steer maneuver.

m. Confirmation of ESC system activation (including engine torque command).

n. Steering effort (torque or force).

o. Brake load cell data. If any application of brake force is indicated, the maneuver must be eliminated from analysis.

p. Observations of wheel lift, spinout, or outrigger contact if occurred and time of occurrence.

q. Meteorological data.

5.3 Sine-With-Dwell (SWD) Test.

a. Date of test and test site.

b. Time between completing the SIS test and initiating the SWD test.

c. Description of steer maneuver executed.

d. Vehicle travel distance.

e. Vehicle drive configuration and mode for each test series.

f. Vehicle speed.

g. Lateral acceleration and lateral acceleration decay time.

h. Steering angle and peak amplitude.

i. Yaw rate and yaw rate decay time.

j. Roll angle.

k. Lateral velocity.

l. Vehicle side slip.

m. Elapsed time of steer maneuver.

n. Observations of wheel lift, spinout, or outrigger contact if occurred and time of occurrence.

o. Meteorological data.

5.4 Electronic Stability Control (ESC) Malfunction Telltale and Symbol.

a. Details of procedure used to induce a controlled malfunction in the ESC.

b. Observations regarding the ESC telltale with the induced malfunction and after the ESC has been restored.

6. PRESENTATION OF DATA.

6.1 General Vehicle and Test Preparation.

Presented in narrative, tabular, graphical, pictorial, or other format as appropriate.

6.2 Slowly Increasing Steer (SIS) Test.

a. Reference Steering Wheel Angle. SIS testing is used to determine the steering wheel angle that would produce 0.5 *g* of lateral acceleration at a constant speed of 30 mph. At 0.5 *g* lateral acceleration, a heavy vehicle is highly likely to experience roll instability. The relationship between the steering wheel angle and lateral acceleration varies among vehicles because of differences in steering gear ratios, suspension systems, wheelbase, and other vehicle characteristics. Using the established steering wheel angle in the subsequent SWD tests ensures that each vehicle is subjected to the same test severity and is likely to experience the same instability condition. The following procedures for preparing and applying SIS test data are adapted from the NHTSA Laboratory Test Procedure for FMVSS No. 126.

(1) Filter the raw steering wheel angle data with a 12-pole phaseless Butterworth filter and a cutoff frequency of 10 Hz. Zero the filtered data to remove sensor offset using static pretest data.

(2) Filter the raw speed data with a 12-pole phaseless Butterworth filter and a cutoff frequency of 2 Hz.

(3) Filter the raw yaw, pitch, and roll rate data with a 12-pole phaseless Butterworth filter and a cutoff frequency of 6 Hz. Zero the filtered data to remove sensor offset utilizing static pretest data.

(4) If ultrasonic sensors are used to determine vehicle roll height, filter the left side and right side ride height data with a 12-pole phaseless Butterworth filter and a cutoff frequency of 6 Hz. Zero the filtered data to remove sensor offset utilizing static pretest data.

(5) If an inertial sensor system (Oxford Technical Solutions Model RT2002 or equivalent) is used to determine vehicle roll angle, filter the raw roll angle data with a 12-pole phaseless Butterworth filter and a cutoff frequency of 6 Hz. Zero the filtered data to remove sensor offset utilizing static pretest data.

(6) Filter the raw lateral, longitudinal, and vertical acceleration with a 12-pole phaseless Butterworth filter and a cutoff frequency of 6 Hz. Zero the filtered data to remove sensor offset utilizing static pretest data.

(7) Determine the roll, yaw and pitch accelerations by differentiating the filtered and zeroed roll and yaw rate data.

(8) The lateral acceleration data at the vehicle CG is determined by removing the effects caused by vehicle body roll and by correcting for sensor placement via use of coordinate transformation, as shown below.

(9) The following coordinate transformation equations are used to correct the accelerometer data in post-processing to remove roll, pitch, and yaw rate and acceleration effects (reference 5).

$$x''_{corrected} = x_{accel} - \left(\Theta'^2 + \varphi'^2\right)x_{disp} + \left(\Theta'\Phi' - \varphi''\right)y_{disp} + \left(\varphi'\Phi' + \Theta''\right)z_{disp} \quad \text{Equation 1}$$

$$y''_{corrected} = y_{accel} + \left(\Theta'\Phi' + \varphi''\right)x_{disp} - \left(\Phi'^2 + \varphi'^2\right)y_{disp} + \left(\varphi'\Theta' - \Phi''\right)z_{disp} \quad \text{Equation 2}$$

$$z''_{corrected} = z_{accel} + \left(\varphi'\Phi' - \Theta''\right)x_{disp} + \left(\varphi'\Theta' + \Phi''\right)y_{disp} - \left(\Phi'^2 + \Theta'^2\right)z_{disp} \quad \text{Equation 3}$$

where,

$x''_{corrected}$, $y''_{corrected}$, and $z''_{corrected}$ = longitudinal, lateral, and vertical accelerations, respectively, at the vehicle CG.

x''_{accel}, y''_{accel}, and z''_{accel} = longitudinal, lateral, and vertical accelerations, respectively, at the accelerometer location.

x''_{disp}, y''_{disp}, and z''_{disp} = longitudinal, lateral, and vertical displacements, respectively, of the CG with respect to the accelerometer location.

$\Phi'$and Φ'' = roll rate and roll acceleration, respectively.

$\Theta'$and Θ'' = pitch rate and pitch acceleration, respectively.

$\Psi'$and Ψ'' = yaw rate and yaw acceleration, respectively.

(10) Correct lateral acceleration at the vehicle CG by removing the effects caused by vehicle body roll. Roll angle is determined using two ultrasonic distance measurement sensors or by integrating the roll rate sensor data, if deemed accurate. The corrected lateral acceleration value is given by Equation 4.

$$a_{yc} = a_{ym}cos\Phi - a_{zm}sin\Phi \qquad \text{Equation 4}$$

where;

a_{yc} = the corrected lateral acceleration (i.e., the vehicle's lateral acceleration in a plane horizontal to the test surface)

a_{ym} = the measured lateral acceleration in the vehicle reference frame

a_{zm} = the measured vertical acceleration in the vehicle reference frame

Φ = 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.

(11) Plot steering wheel angle data versus corrected lateral acceleration data for each test run. Using linear regression techniques from 0.1 to 0.375 *g*, determine the "best-fit" line (slope = deg/*g*) for each of the six completed SIS maneuvers.

(12) Using the best-fit line equation for each of the six SIS maneuvers, determine the steering wheel angle, to the nearest 0.1 degree, at 0.5 *g* by linear extrapolation for each respective maneuver. Using Equation 5, calculate the average overall steering wheel angle, rounded to the nearest 0.1 degree, at 0.5 *g* using the absolute value data from each of the six SIS maneuvers.

$$\delta_{0.3\ g,\text{overall}} = (|\delta_{0.3\ g,left\ (1)}| + |\delta_{0.3\ g,left\ (2)}| + |\delta_{0.3\ g,left\ (3)}| + \delta_{0.3\ g,right\ (1)} + \delta_{0.3\ g,right\ (2)} + \delta_{0.3\ g,right\ (3)})/6$$

Equation 5

b. Engine Torque Reduction. To confirm ESC activation and evaluate the ESC engine torque reduction capability, collect the engine torque output and driver-requested torque from the vehicle J1939 communication data link (or equivalent) and compare. During the initial stages of an SIS test, the rate of change over a period of time for engine torque output and driver requested torque will be consistent. If ESC is activated, engine torque will be reduced, and the rate of change for engine torque output and driver-requested torque will diverge over time.

c. An example SIS results data table is shown as Table 2 and an example SIS plot is shown as Figure 5.

TABLE 2. SAMPLE SIS DATA TABLE

Vehicle XX, 30 mph SIS results

RUN NUMBER	STEER DIRECTION	AVG. SPEED	.3g STEERING WHEEL ANGLE	.5g STEERING WHEEL ANGLE
		mph	deg	deg
ESC OFF - SIS				
1	Right	29.8	100.3	175.8
2	Right	30.1	98.5	180.1
3	Right	29.9	102.1	177.6
4	Left	30.4	-99.9	-182.1
5	Left	29.9	-103.2	-184.5
6	Left	30.8	-101.1	-180.9
		Average	**100.9**	**180.2**

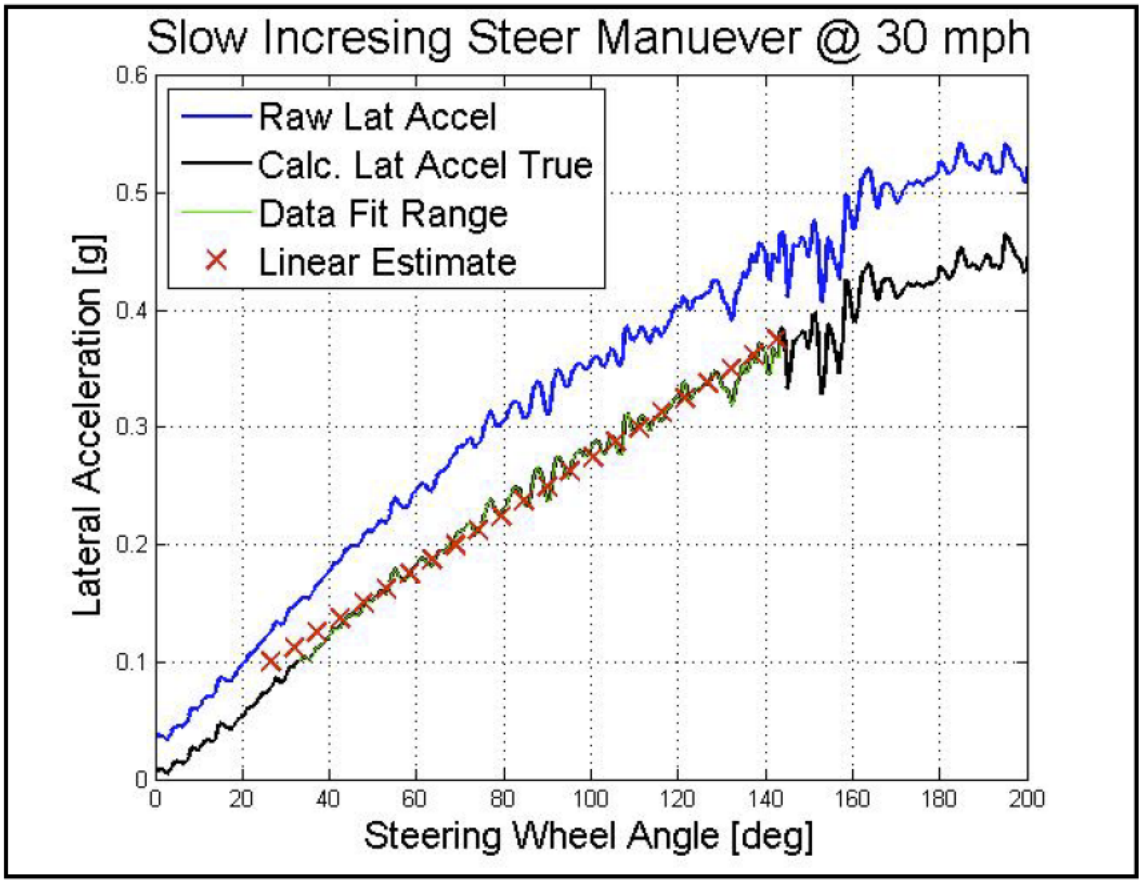


Figure 5. Sample SIS data plot.

6.3 Sine-With-Dwell (SWD) Test.

a. Yaw rate, lateral acceleration, and lateral displacement measurements and calculations are processed utilizing the following techniques. The procedures for preparing and applying SWD test data are adapted from the NHTSA Laboratory Test Procedure for FMVSS No. 126.

(1) Prepare vehicle speed, steering wheel angle, yaw, roll, and pitch rate, lateral, longitudinal, vertical acceleration, roll angle, roll, yaw, and pitch acceleration, and corrected lateral acceleration data for analysis using the techniques described in paragraphs 6.2.a(1) through 6.2.a(10).

(2) Determine steering wheel velocity by differentiating the filtered and corrected steering wheel angle data. Filter the steering wheel velocity data using a moving 0.1-second running average filter.

(3) Zero lateral acceleration, yaw rate, and steering wheel angle data channels using a defined zeroing range. The methods used to establish the zeroing range are as follows:

(a) Using the steering wheel velocity data (paragraph 6.3.a(11)), the first instance the steering wheel rate exceeds 75 °/second is identified. From this point, the steering wheel rate must remain greater than 75 °/second for at least 200 milliseconds (ms). If the second condition is not met, the next instance the steering wheel rate exceeds 75 °/second is identified, and the 200-ms validity check is applied. This iterative process continues until both conditions are ultimately satisfied.

(b) The zeroing range is identified as the 1.0-second time period prior to the time at which the steering wheel rate exceeds 75 °/second (i.e., the instant the steering wheel velocity exceeds 75 °/second defines the end of the zeroing range).

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

(5) Determine the Completion of Steer (COS), which is defined as the time the steering wheel angle returns to zero at the completion of the SWD steering maneuver. The value for time at the 0 ° steering wheel angle is interpolated.

(6) Determine the second peak yaw rate ($\dot{\Psi}_{Peak}$), which is defined as the first local yaw rate peak produced by the reversal of the steering wheel. Refer to Figure 6 (reference 5).

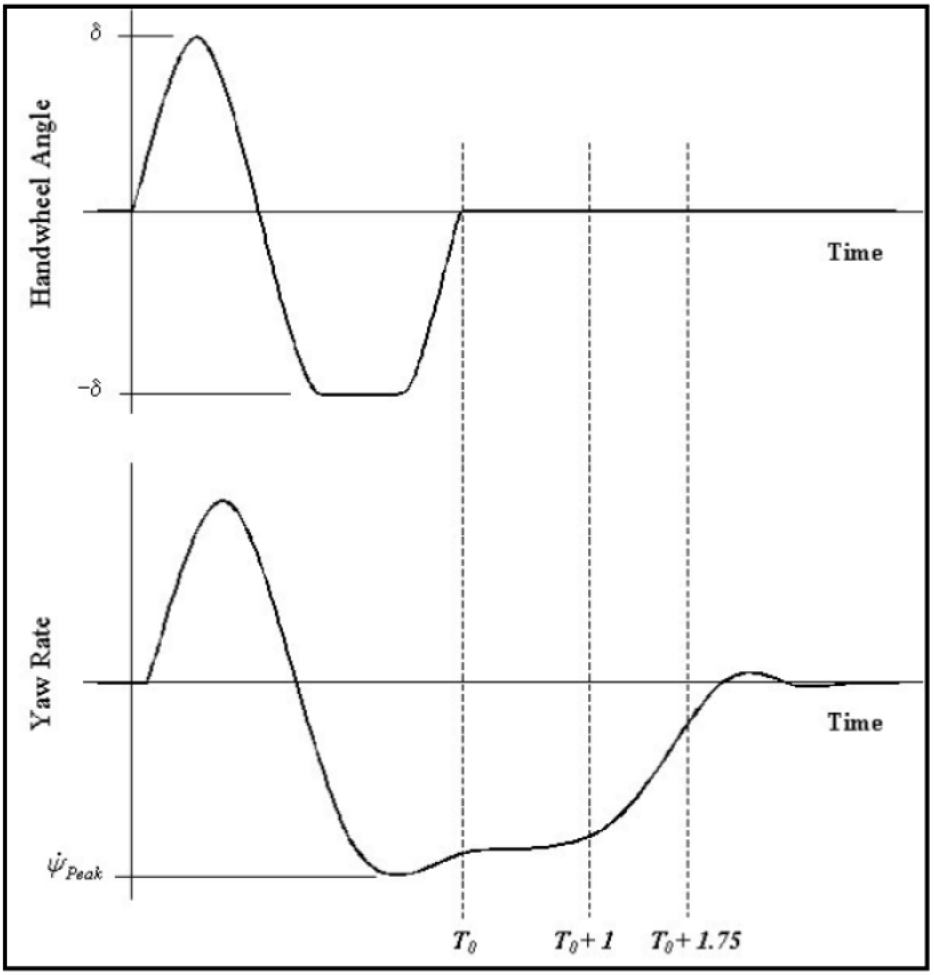


Figure 6. Steering wheel position and yaw velocity information used to assess lateral stability.

Note: In Figure 6, $\dot{\Psi}_{Peak}$ is the first local peak yaw rate resulting from the SWD steering reversal. In some situations, the yaw rate produced by the steering reversal may reach a peak ($\dot{\Psi}_{Peak}$), decay slightly, and then increase to a level beyond a $\dot{\Psi}_{Peak}$. Even though the overall peak magnitude of the yaw rate response may exceed $\dot{\Psi}_{Peak}$, only $\dot{\Psi}_{Peak}$ is used in the calculation process.

(7) The yaw rates at 1.000 and 1.750 seconds after COS are determined by interpolation for each counterclockwise and clockwise steering maneuver.

(8) For each of the steering maneuvers calculate the yaw rate ratio (YRR) at 1.00 and 1.75 seconds after COS. The YRR is expressed as a percentage, as shown in Equation 6.

$$\text{YRR} = 100 * \left(\frac{\Psi \text{ at time } t)}{\Psi_{Peak}}\right) \qquad \text{Equation 6}$$

(9) For each of the steering maneuvers calculate the lateral acceleration rate ratio (LAR) at 1.00 and 1.75 seconds after COS. The LAR is expressed as a percentage, as shown in Equation 7.

$$\text{LAR} = 100 * \left(\frac{a_{yc}\, at\ time\ t)}{a_{yc\ Peak}}\right) \qquad \text{Equation 7}$$

(10) Present a table showing yaw rate decay time (indicated by YYR and LAR at 1.0 and 1.75 seconds after COS) for each steering maneuver conducted. Present graphically the vehicle yaw rate versus time for each steering maneuver that generates yaw rate decay (time after end of steer maneuver) for each configuration tested.

(11) For each of the SWD steering maneuvers in procedure 4.3, with a steering wheel angle of $1 * \delta_{0.5g,\text{overall}}$ or greater, determine lateral velocity by integrating corrected, filtered, and zeroed lateral acceleration data. Zero lateral velocity at BOS event.

(12) Determine lateral displacement by integrating the zeroed lateral velocity. Zero lateral displacement at the BOS event.

(13) Determine lateral displacement of the vehicle CG with respect to its initial straight path at 1.5 seconds from BOS event using interpolation.

(14) Present a table showing lateral displacement at 1.5 seconds from BOS for each steering maneuver conducted with a steering wheel angle of $1 * \delta_{0.5g,\text{overall}}$ or greater.

(15) Compare the observed YYR, LAR, and lateral displacement results to vehicle requirements as stated in the vehicle test plan.

b. A sample SWD data table is provided as Table 3. Sample SWD data plots are provided as Figures 7 through 12.

TABLE 3. SAMPLE SWD DATA TABLE

Vehicle XX, 50 mph 0.7Hz, 0.5sec Dwell SWD Results

SWA	MAX YAW RATE	YRR @1 sec	YRR @1.75 sec	MAX LAT. ACCEL.	LAR 1S	LAR 1.75S	LAT. DISP.
[deg]	[deg/s]	% of peak	% of peak	[g]	%	%	[ft]
60	16.8	12.7	0.4	0.45	6.9	-2.8	-2.66
90	24.8	0.9	5.8	0.54	23.9	5.2	-3.81
120	33.9	21.9	15.7	0.57	***101.6***	***117.3***	-4.88
135	38.5	24.3	-4.3	0.66	***102.9***	***42.6***	-5.13
60	-14.8	8.8	-1.0	-0.43	0.3	-2.9	2.89
90	-25.6	4.4	2.3	-0.56	14.2	5.3	3.64
150	-42.8	33.4	1.7	-0.61	***100.3***	4.0	5.76

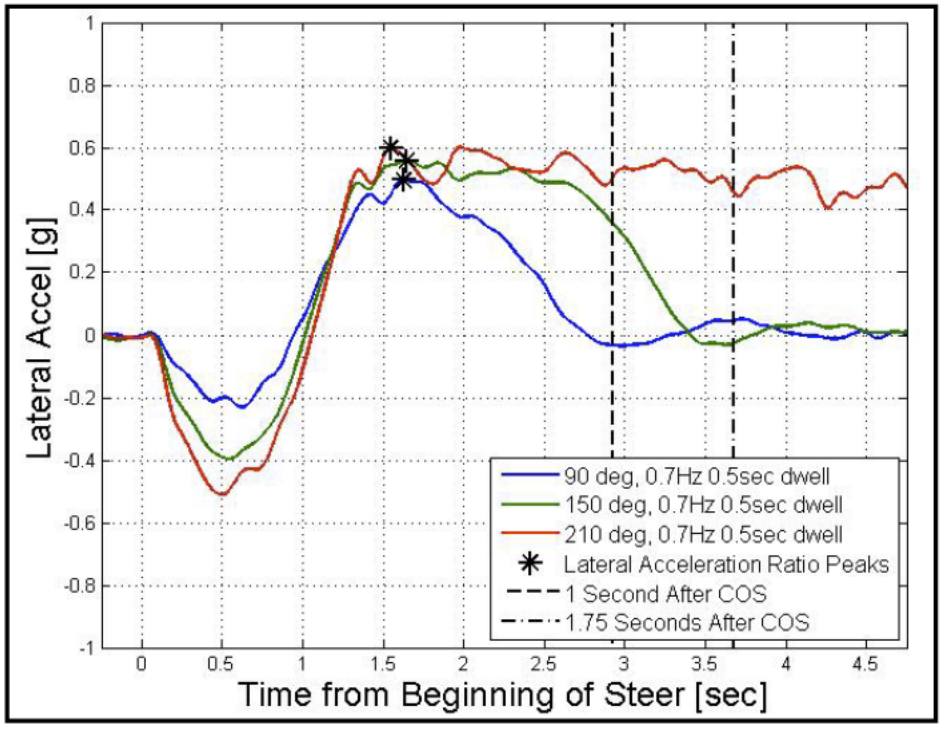


Figure 7. Sample SWD lateral acceleration plot.

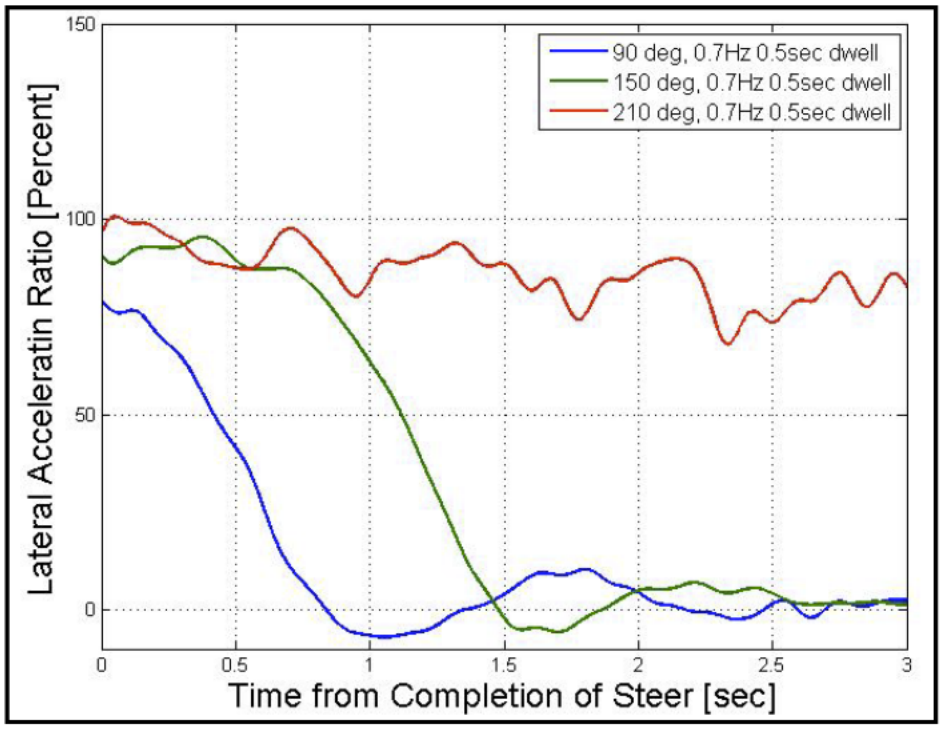


Figure 8. Sample SWD lateral acceleration ratio plot.

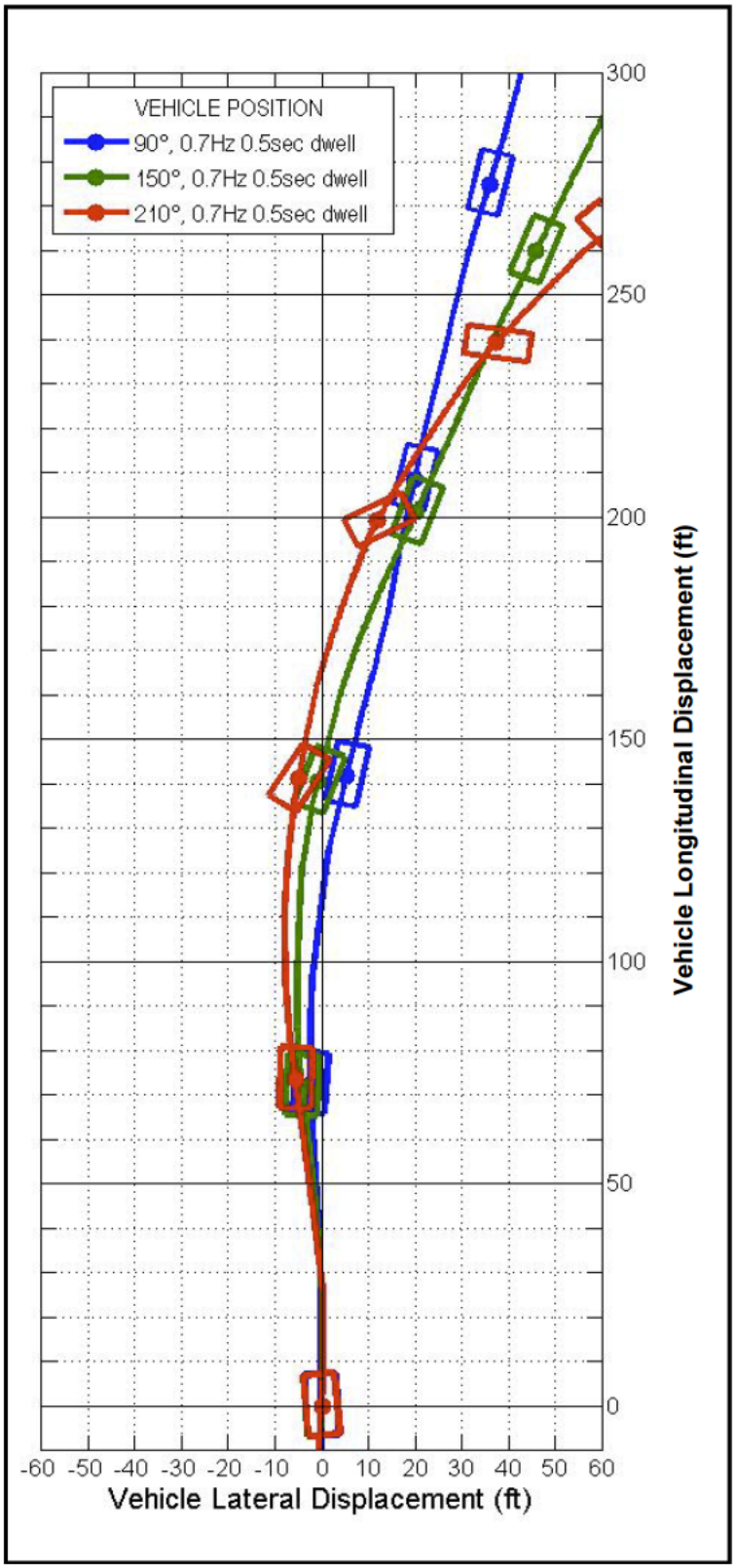


Figure 9. Sample SWD position plot.

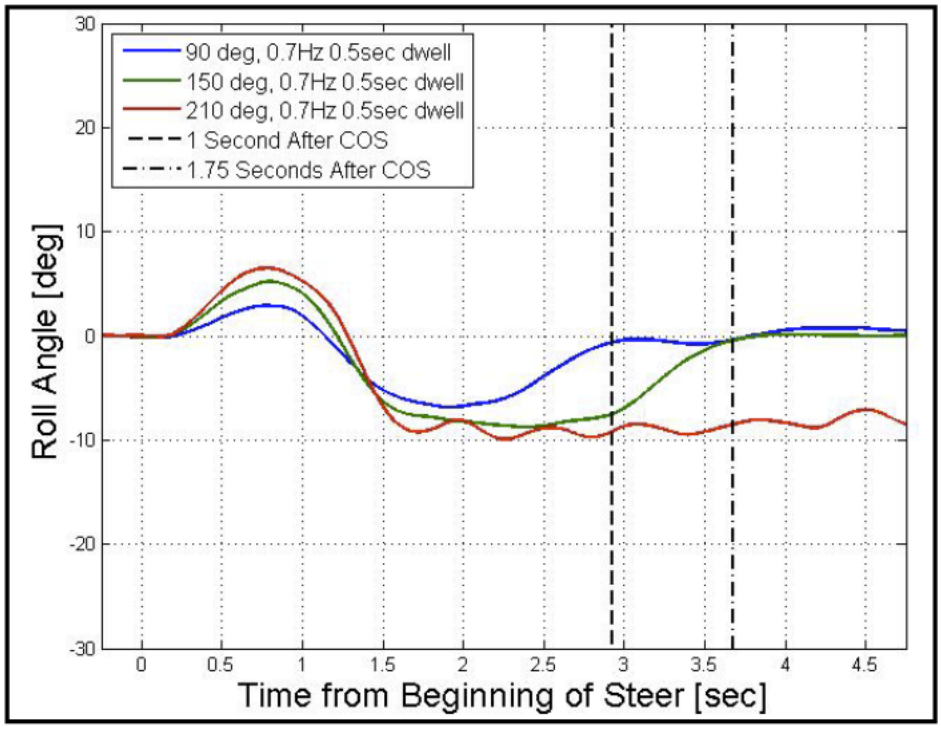


Figure 10. Sample SWD roll angle plot.

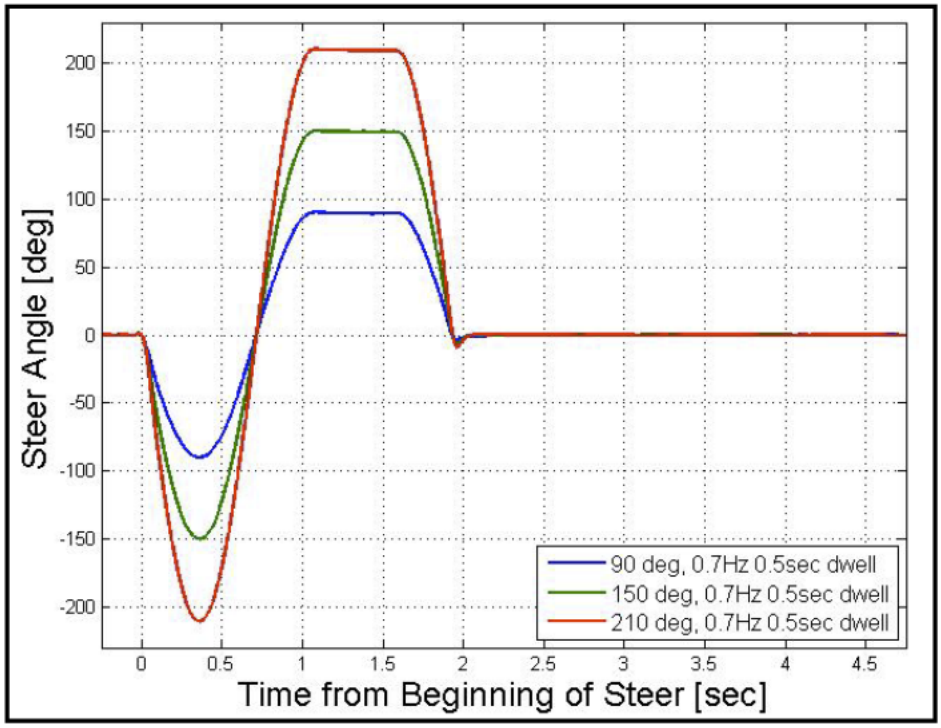


Figure 11. Sample SWD steering angle plot.

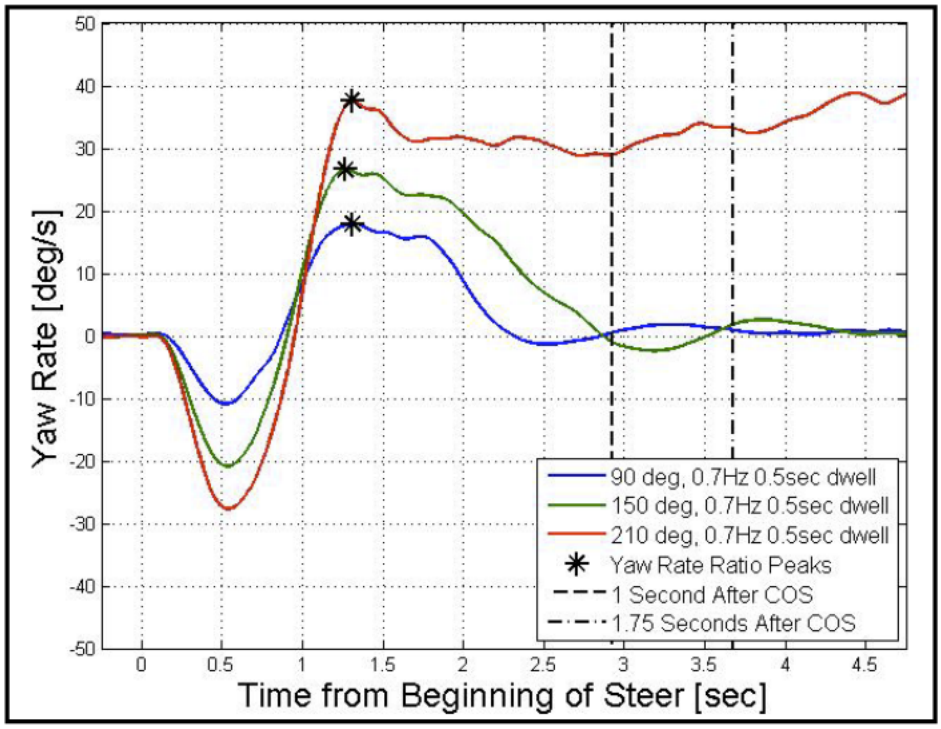


Figure 12. Sample SWD yaw rate plot.

6.4 Electronic Stability Control (ESC) Malfunction Telltale and Symbol.

Present observations in narrative and tabular, as appropriate.

APPENDIX A. PRE-TEST PROCEEDURES.

The Pre-Test Brake Conditioning procedure is performed prior to any road tests. Mass Estimation and Tire Conditioning procedures are performed prior to initiating the SIS test. Mass Estimation, Brake Conditioning, and Tire Conditioning procedures are performed prior to initiating the SWD test.

A-1. PRE-TEST BRAKE CONDITIONING.

Brake performance of light, medium, and heavy trucks affects ESC capability. To ensure brakes are operating as effectively as possible, the FMVSS No. 121[7] brake burnish procedure should be performed on the test vehicle prior to SIS and SWD testing, consisting of 500 brake snubs from 40-20 mph at a deceleration of 10 ft/s/s. If the burnish procedure was performed for other brake testing prior to ESC testing using the same brake linings and components, the burnish procedure does not need to be repeated.

A-2. MASS ESTIMATION.

Some truck ESC systems require a mass estimation procedure be conducted to compensate for payload conditions. If available, follow the manufacturer recommended process prior to SIS and SWD testing. If a manufacturer process is not provided, accelerate the vehicle to 40 mph and decelerate at 0.3-0.4 *g* to a full stop. Repeat the process two more times. If the vehicle engine is shut down at any point, the mass estimation procedure must be repeated prior to testing.

A-3. BRAKE CONDITIONING (IMMEDIATELY PRIOR TO SWD TESTING).

a. Verify and if necessary inflate tires to the vehicle manufacturer's recommended cold inflation pressures. Record the measured pressure in each tire.

b. Energize the data acquisition system. Set data acquisition system so vehicle longitudinal acceleration can be observed on the system's display by the test driver.

c. Condition brakes using successive 40-20 mph (0.3 *g* deceleration) brake snubs until the vehicle brake temperatures are within a range of 150-200 degrees.

A-4 TIRE CONDITIONING (IMMEDIATELY PRIOR TO SIS SWD TESTING).

Tire conditioning is required to wear away mold sheen and achieve tire operating temperatures immediately before executing the SIS and SWD test maneuvers.

a. Verify and if necessary inflate tires to the vehicle manufacturer's recommended cold inflation pressures. Record the measured pressure in each tire.

b. Energize the data acquisition system. Configure the data acquisition system so the vehicle's measured lateral acceleration can be observed on the system's display by the test driver.

c. Drive two (2) complete circles to the left and two (2) complete circles to the right at a speed that results in 0.1 *g* lateral acceleration (approximate 200 ft radius at 20 mph).

APPENDIX B. ABBREVIATIONS.

AEC	US Army Evaluation Center
ASTM	American Society for Testing and Materials
AVTP	Allied Vehicle Test Publication
BOS	beginning of steer
C	Celsius
CFR	Code of Federal Regulations
CG	center of gravity
cm	centimeter
CMM	coordinate measurement machine
COS	completion of steer
DAS	data acquisition system
ESC	electronic stability control
FMVSS	Federal Motor Vehicle Safety Standards
GVW	gross vehicle weight
Hz	hertz
kg	kilogram
km/hr	kilometers per hour
kPa	kilopascal
LAR	lateral acceleration ratio
lb	pound
lb-ft	pound-foot
LD	lateral displacement
LOC	loss-of-control
m	meter
m/s	meters per second
mm	millimeter
mph	miles per hour
ms	millisecond
NHTSA	National Highway Traffic Safety Administration
N-m	Newton-meter

APPENDIX B. ABBREVIATIONS.

PFC	peak friction coefficient
psi	pounds per square inch
RSC	roll stability control
SAE	Society of Automotive Engineers
SIS	Slowly Increasing Steer
SR	Safety Release
SWD	Sine-With-Dwell
TIN	tire identification number
TOP	Test Operations Procedure
TP	Test Procedure
TSARC	Test Schedule and Review Committee
YRR	yaw rate ratio

APPENDIX C. REFERENCES.

1. US Department Of Transportation, National Highway Traffic Safety Administration, Preliminary Regulatory Impact Analysis, FMVSS No. 136 Electronic Stability Control Systems On Heavy Vehicles, May 2012.

2. SAE J2180, A Tilt Table Procedure for Measuring the Static Rollover Threshold for Heavy Trucks, 17 May 2011.

3. ASTM E 1337-90(2012), Standard Test Method for Determining Longitudinal Peak Braking Coefficient of Paved Surfaces Using Standard Reference Tire, 2012.

4. ASTM E 1136-10, Standard Specification for P195/75R14 Standard Reference Test Tire, 2010.

5. Test Procedure (TP)-126-03, US Department of Transportation, National Highway Traffic Safety Administration, Laboratory Test Procedure for FMVSS No. 126, Electronic Stability Control Systems, 9 September 2011.

6. FMVSS No. 101, Controls and Displays, February 2005.

7. FMVSS No. 121, Air Brake Systems - Trucks, Buses, and Trailers, February 2005.

For information only (related publications).

a. Allied Vehicle Test Publication (AVTP) 03-160W, Dynamic Stability, September 1991.

b. AVTP 03-30, Steering and Maneuverability, September 1991.

c. Code of Federal Regulations (annual edition), 49 CFR Ch. V (10-1-11 Edition).

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APPENDIX D. APPROVAL AUTHORITY.

CSTE-TM 5 December 2013

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 02-2-718, Electronic Stability Control, Approved for Publication

1. TOP 02-2-718, Electronic Stability Control, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP prescribes procedures for testing the electronic stability control system of two-axle vehicles up to 11,793 kilograms (26,000 pounds) for speeds up to 81 kilometers per hour (50 miles per hour). Major factors to be considered when testing the yaw and roll stability of wheeled vehicles are their capability and behavior during sudden obstacle avoidance actions. Electronic stability control systems are employed on some vehicles to mitigate oversteer (or spin-out) and rollover. The sine-with-dwell steering maneuver was developed as an objective test of vehicle stability and electronic stability control system performance.

2. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

ZWIEBEL.MICHAEL.J.1229197289

MICHAEL J. ZWIEBEL
Director, Test Management Directorate (G9)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), US Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Automotive Directorate (TEDT-AT-AD), US Army Aberdeen Test Center, 400 Colleran Road, Aberdeen Proving Ground, Maryland 21005.. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.