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14. ABSTRACT This TOP provides procedures for testing the electronic stability control system of wheeled vehicles over 4,536 kg (10,000 lb). Electronic stability control systems are employed on some vehicles to mitigate understeer (plow), oversteer (spin-out) and rollover. The test procedures include slowly increasing steer (SIS), sine with dwell (SWD), and J-Turn test maneuvers. Test procedures to assess the function of the ESC malfunction telltale are also included.								
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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 02-2-718A
DTIC AD No.

1 October 2018

ELECTRONIC STABILITY CONTROL

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This TOP supersedes TOP 02-2-718 Electronic Stability Control, dated 5 December 2013.

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1 SCOPE.

This Test Operations Procedure (TOP) provides standardized test procedures for evaluating the electronic stability control (ESC) system capabilities of wheeled vehicles over 4,536 kilograms (kg) (10,000 pounds (lb)) gross vehicle weight (GVW). The test procedures include slowly increasing steer (SIS), sine with dwell (SWD), and J-Turn test maneuvers. Test procedures to assess the function of the ESC malfunction telltale are also included.

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 stability, especially when taking avoidance actions during emergency maneuvers. ESC provides the capability to mitigate severe oversteer or understeer conditions that may lead to vehicle loss-of-control (LOC) by automatically and selectively applying brakes to generate a yawing moment to help the driver maintain directional control of the vehicle (Society of Automotive Engineers (SAE) J2564^{1**}). ESC systems for heavy vehicles also provide Roll Stability Control (RSC) to mitigate on-road, un-tripped truck rollovers by automatically decelerating the vehicle by applying the foundation brakes and reducing engine torque output (Federal Motor Vehicle Safety Standard (FMVSS) 136)².

b. An ESC system has the following attributes².

(1) It augments vehicle directional stability by having the means to apply and adjust the vehicle brake torques individually at each wheel position on at least one front and at least one rear axle of the truck, truck tractor, or bus to induce correcting yaw moment to limit vehicle oversteer and to limit vehicle understeer.

(2) It enhances rollover stability by having the means to apply and adjust the vehicle brake torques individually at each wheel position on at least one front and at least one rear axle of the truck tractor or bus to reduce lateral acceleration of a vehicle.

(3) It is computer-controlled with the computer using a closed-loop algorithm to induce correcting yaw moment and enhance rollover stability.

(4) It has a means to determine the vehicle's lateral acceleration.

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

(6) It has a means to estimate vehicle mass or, if applicable, combination vehicle mass.

(7) It has a means to monitor driver steering inputs.

** Superscript numbers correspond to Appendix C, References.

(8) It has a means to modify engine torque, as necessary, to assist the driver in maintaining control of the vehicle and/or combination vehicle.

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

(10) Is operational over all vehicle speeds above a low-speed threshold.

(11) Has a means to coordinate ESC activities with other brake-related or stability enhancement features such as anti-lock braking systems (ABS), traction control systems (TCS), dynamic brake proportioning, and auxiliary braking systems. Remains capable of actuation even if the other systems are actuated.

c. This TOP describes two dynamic ESC tests for two-axle or more, multi-axle trucks at GVW over 4,536 kg (10,000 lb). The full test (which includes SIS and SWD) is generally intended for single unit trucks. The simplified test (which includes J-turn only) is generally intended for truck tractors and buses with a gross vehicle weight rating (GVWR) over 11,793 kg (26,000 lb), per guidance in FMVSS 136. Both tests (full and simplified) assess rollover stability. The full test also assesses 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 maneuvers and performance criteria are presented in Table 1. These tests are for performance on standard, paved test courses. The Full Test uses “auto pilot” instrumentation to provide accurate and repetitive steering inputs. The Simplified Test uses a human driver and a defined test course. The TOP also describes means to assess the ESC malfunction telltale and symbols.

TABLE 1. ESC TESTS AND ASSOCIATED PERFORMANCE CRITERIA

TEST	MANEUVER	CRITERION
Full Test; Rollover and Directional Stability	Slowly Increasing Steer (SIS) Characterization	Engine Torque Output
	Sine-With-Dwell (SWD)	Lateral Acceleration Ratio (LAR)
		Yaw Rate Ratio (YRR)
Simplified Test; Rollover Stability Only	J-Turn	Lateral Displacement (LD)
		Engine Torque Output
		Speed Reduction

Note: Specific performance criteria for each maneuver are listed in the respective paragraphs below.

1.2 Limitations.

a. This TOP describes two ESC test procedures for wheeled vehicles 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 (generally the test vehicle

purchase description, contract requirement, or FMVSS 136). 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.

(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.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

<u>Item</u>	<u>Requirement</u>
Road Surface	The road test surface shall produce a peak frictional coefficient (PFC) of at least 0.9 (see paragraph 2.3.b). Uniform hard surface of concrete or asphalt with a gradient of no more than 1 percent in any direction.
Circular Steer Test Course	Area must be of sufficient size to allow for safe execution of the SIS and/or J-Turn maneuvers.
Straight Roadway	A straight asphalt or concrete roadway with a width of at least 60 meters (m) over a length of at least 150 m, with additional roadway leading to and from the test course to allow for entry at target test speeds and stopping after the SWD maneuver.

2.2 Instrumentation.

<u>Devices for Measuring</u>	<u>Permissible Measurement Uncertainty</u>
Road speed	1 percent
Steering wheel angle	0.25 degrees

<u>Devices for Measuring</u>	<u>Permissible Measurement Uncertainty</u>
Lateral, longitudinal, and vertical acceleration	0.01 g
Yaw rate, roll rate, and pitch rate	0.05 degrees per second
Roll angle (see Section 2.3)	0.1 degrees
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)	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
Brake lining temperature	1 degree Celcius (°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

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test weight, center of gravity (CG), and moment of inertia remain as unchanged as practical (objective: outrigger weight \leq 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) E1337-90³, using an ASTM E1136-10⁴ standard reference tire.

c. Auto-Pilot Device. For the full test, a steering auto-pilot (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. The peak torque capability of the steering auto-pilot shall be sufficient to achieve the full series of steering control required for SIS and SWD testing while meeting the angular position requirements of Section 2.2 (estimated peak torque capability 60-75 N-m).



Figure 1. Auto-pilot device.

*** 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.

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 of 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. If the vehicle J1939 communication data link (or equivalent) has a data channel for brake application, this channel may be used in lieu of the load cell.

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 data bus for control, or the data bus used to control engine torque cannot be monitored, other test instrumentation must be applied to the vehicle as appropriate.

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. Ultrasonic distance measuring system sensors should have 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. Pressure transducers to monitor individual wheel-end brake line pressures with a full-scale range appropriate and safe for the vehicle under test. While brake line pressure is explicitly required for determining vehicle compliance only during the J-Turn test, the pressure data are used to confirm the individual wheel brake application function during other tests.

h. Transmitter/receiver set for locating the vehicle on the J-turn test course, such as an infra-red light emitter placed at the start gate and infra-red light sensors placed on the vehicle.

i. The sensors are recorded by the data acquisition system and aligned to denote the time at which the center of the vehicle's front axle crosses the start gate.

j. Digital video camera to record all test events and observe wheel lift, 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. 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.

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

d. Static Rollover Threshold (Tilt Table) Test. In preparation for ESC testing, conduct the tilt table test in accordance with SAE Recommended Practice J2180⁵ to determine the test vehicle's simulated lateral acceleration threshold prior to rollover.

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

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

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

h. Identify the tire size, manufacturer, name, and tire identification number (TIN), and tread wear condition. Tires shall have at least 50% of their tread life remaining prior to ESC testing. 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.

i. 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, brake line pressure (for J-Turn), 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. For data collection, the lateral accelerometer shall be located as close as possible to the position of the vehicle's longitudinal, lateral, and vertical CG.

j. 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.

k. 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 U.S. Army Evaluation Center (AEC) prior to using military personnel as test participants.

3.2 Test Controls.

a. Test engineers and technicians should familiarize themselves with FMVSS 126⁶ (Electronic Stability Control Systems), and FMVSS 136⁷ (Electronic Stability Control Systems for Heavy Vehicles).

b. Prior to the initiation of testing, ensure that:

(1) 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.

(2) The vehicle has received the proper break-in operation.

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

(4) 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: ≤ 5 m/s (11 mph) average value.

b. Ambient temperature: 2 to 40 °C (35 to 104 °F).

c. Humidity: ≤ 95 percent.

4. TEST PROCEDURES.

4.1 Background.

The first ESC tests on military wheeled vehicles were conducted using a procedure based on the National Highway Traffic Safety Administration (NHTSA) Laboratory Test Procedure for FMVSS No. 126⁸, which was limited to vehicles weighing no more than 4,536 kg (10,000 lb). Modifications to the FMVSS No. 126 SIS and SWD procedures were developed by the U.S. Army Test and Evaluation Command (ATEC) for testing two-axle vehicles weighing approximately 10,433 kg (23,000 lb). The modifications, known as the Annex S Modifications⁹, were established for the Joint Light Tactical Vehicle (JLTV) prototype test phases. Later, NHTSA published a Proposed Rule (PR)¹⁰ for heavy trucks with gross vehicle weight ratings greater than 11,793 kg (26,000 lb). This procedure was designated as FMVSS No. 136; Electronic stability control systems for heavy vehicles. The Final Rule (FR) for FMVSS No. 136 did not include SIS and SWD tests, but instead utilized a J-turn maneuver. However, further analysis of test results from ATEC highlighted the need for SWD testing to thoroughly evaluate military class vehicle ESC systems¹¹. The following procedures describe the most current states of the SIS, SWD and J-turn tests.

4.2 General Vehicle and Test Preparation.

The following items should be performed before proceeding with testing:

- a. Record the test and vehicle identification.
- b. 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 shall have a consistent slope between level and 1 percent^{6,7}.
- c. Document the test track peak friction coefficient (PFC) or skid number, as appropriate, for each test track^{3,4}.
- d. Power on the data acquisition system and verify all data channels are activated and observe for normal data drift. Verify the DAS is set up for a 200 hertz (Hz) data sampling rate, filtered using a two-pole low-pass Butterworth filter with nominal cut-off frequencies at 25 Hz to prevent aliasing. Select amplifier gains to maximize signal-to-noise ratio. Verify the DAS displays accurate calibrated sensor outputs.
- e. Compile calibration data prior to each maneuver test series to assist in resolving uncertain test data.
- f. Perform the Pre-Test Brake Conditioning procedures per Appendix A.
- g. Operate the test vehicle in a straight line on a level, uniform, solid-paved road surface with a vehicle speed of 97 km/hr (50 mph) and compile 5 to 15 seconds of data from all instrument channels to establish zero levels.

4.3 Slowly Increasing Steer (SIS) Test.

a. General.

(1) The SIS test (a type of constant speed skidpad test) is conducted as a precursor to SWD testing to determine the reference steering wheel angle amplitude, δ_{ref} , for the SWD test. The vehicle is driven in a straight line initially, and then the steering auto-pilot steers to the right or left at 13.5 degrees per second until approximately 0.4 g lateral acceleration is experienced. Linear regression of the data is used to estimate the steering angle producing 0.5 g. The resulting reference angle at 0.5 g, δ_{ref} , is needed to program the steering auto-pilot for the SWD test. The SIS test is also used to evaluate the engine torque-reducing capability of the ESC system.

(2) For historical purposes, a summary of the differences between the earlier procedures and TOP 02-2-718A is presented in Table 2.

TABLE 2. DIFFERENCES IN SIS TEST PROCEDURES

PARAMETER	PROCEDURE			
	FMVSS 126	ANNEX S MODS	FMVSS 136 PR	TOP 02-2-718A
Vehicle speed, mph	50	30	30	30
SIS Steering Wheel Angle (SWA) ramp rate, deg/s	13.5	13.5	13.5	13.5
SIS SWA maximum, first test	30 degree	SWA @ ~0.4g	270 degree	SWA @ ~0.4g
Maximum lateral acceleration target, g	0.55	0.4	ESC activation	0.4
Maximum lateral acceleration range, g	0.5-0.6	0.4-0.45	None	0.4-0.45
Lateral acceleration for determination of SWD reference SWA, g	0.3	0.5	0.5	0.5
Range for linear fit, g	0.1-0.375	0.1-0.375	0.05-0.30	0.05-0.30
Engine torque reduction criterion	None	None	10% in 1.5 seconds	10% in 1.5 seconds

b. Criteria. In the absence of specific SIS performance requirements provided by the test sponsor, the criterion listed in Table 3 shall apply. The procedure to calculate the associated performance metric is presented in paragraph 6.2.b. The SIS test is also used to establish the reference steering angle, δ_{ref} , for SWD testing, with no associated criteria.

TABLE 3. SIS TEST CRITERION

PERFORMANCE METRIC	CRITERION
Engine torque reduction	The engine torque reduction when measured 1.5 seconds after the activation of the electronic stability control system must be at least 10 percent less than the engine torque requested by the driver.

c. TOP 02-2-718A SIS Procedures.

(1) Measure and record ambient temperature and wind speed. Verify whether the wind speed and ambient temperature meet test condition requirements.

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

(3) Document the vehicle powertrain drive configuration and operating 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. The engine brake or transmission retarder, if equipped, shall be disabled. Subsequent tests may be executed under different drive configurations and modes, as directed in the detailed test plan.

(4) If equipped with an adjustable suspension, document the vehicle suspension configuration for testing. Generally, the first test will be executed with the suspension set to the manufacturer's standard or default setting for on-highway operation.

(5) Disable the ESC, if possible. In the event that the ESC cannot be disabled with a switch, a fuse or circuit breaker may have to be disabled to deactivate the ESC system. Consultation with the vehicle manufacturer may be required.

(6) 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, $\delta_{0.4g}$, at a rate of 13.5 degrees/second. A description of the SIS steering profile is shown in Figure 2. The maximum value, $\delta_{0.4g}$, is the steering wheel angle necessary to achieve 0.40-0.45 g lateral acceleration during a steady-state cornering maneuver at 48 km/hr (30 mph). Pre-test experimentation, or other analytical means, are used to determine the angle.

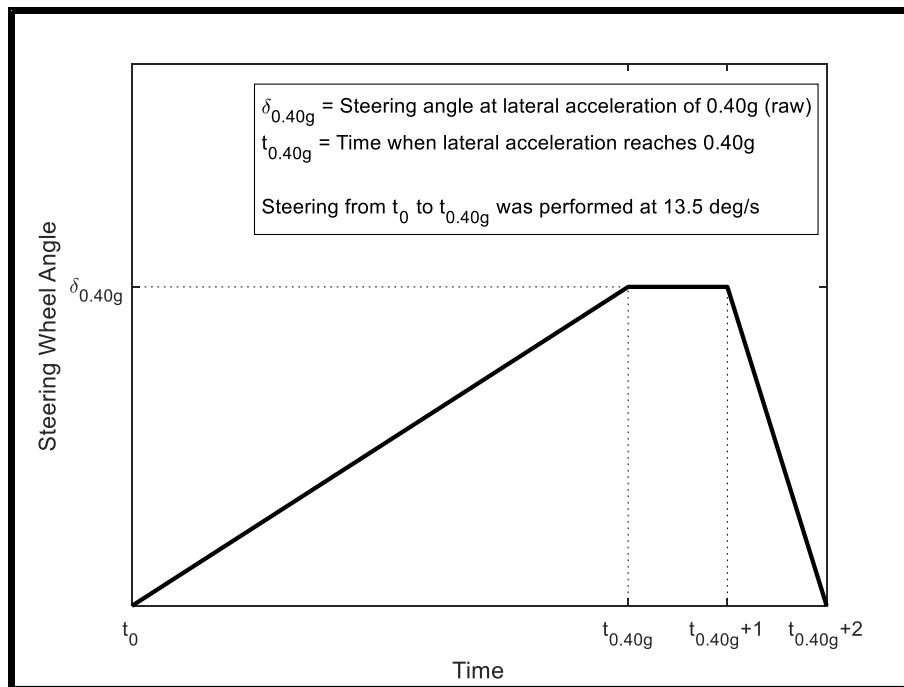


Figure 2. SIS steering profile.

(7) Position the test vehicle at the circular steer test course as needed to execute the SIS maneuvers. Record 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). The static data file will be used in post processing to establish a datum (zero level) for each instrument channel.

(8) Execute a SIS maneuver in the left steer direction using the SIS steer profile described in paragraph 4.3.6.c(6) and maintain a speed of 48 km/hr, ± 1.6 km/hr (30 mph, ± 1 mph). Record the steering wheel angle and lateral acceleration data. If the maximum lateral acceleration is below 0.40 g, then increase the maximum steering angle by 10 degrees and repeat. If the maximum lateral acceleration is above 0.45 g, then decrease the maximum steering angle by 10 degrees and repeat.

(9) Repeat the procedure in paragraph 4.3.c(8) until three SIS maneuvers to the left have been completed. It is recommended that the maximum time permitted between test run maneuvers is five minutes. For each of the three test runs, document the run time, steering wheel angle, and lateral acceleration.

(10) Enable the ESC system. Verify the ESC system is enabled by ensuring that the ESC malfunction and “ESC OFF” (if provided) telltale is not illuminated. If the vehicle data bus includes an ESC status channel, ensure that the status indicates the ESC is enabled.

(11) Execute an SIS maneuver again to the left using the SIS steer profile determined in paragraph 4.3.c(6). If ESC system activation does not occur during the maneuver, the maximum steering wheel angle, 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 controlled test operations as vehicle cornering limits are reached.

(12) Repeat the procedure in paragraph 4.3.c(11) until three SIS maneuvers to the left have been completed. It is recommended that the maximum time permitted between test run maneuvers is 5 minutes.

(13) Repeat the procedure in paragraphs 4.3.c(8) through 4.3.c(12) in the right steer direction.

(14) Examine the brake pedal force load cell data. If any application of brake force is indicated, the maneuver shall be eliminated from analysis.

(15) The reference steering wheel angle for SWD testing, i.e. δ_{ref} , (paragraph 4.4) is determined using linear regression by extrapolating the SIS test data to determine the steer angle that would produce 0.5 g of lateral acceleration at 48 km/hr (30 mph). To confirm ESC activation and evaluate the ESC engine torque reduction capability, engine torque output and driver-requested torque data are collected and analyzed.

(16) Post-test data processing and analysis procedures for SIS Test data are presented in paragraph 6.2.

4.4 Sine-With-Dwell (SWD) Test.

a. General.

(1) The SWD test subjects a vehicle to conditions known to produce roll and yaw instabilities. The goal is to verify ESC system performance for mitigating those instabilities. The procedures for testing are presented below. An illustration of the open-loop steer maneuver executed during the test is presented in Figure 3.

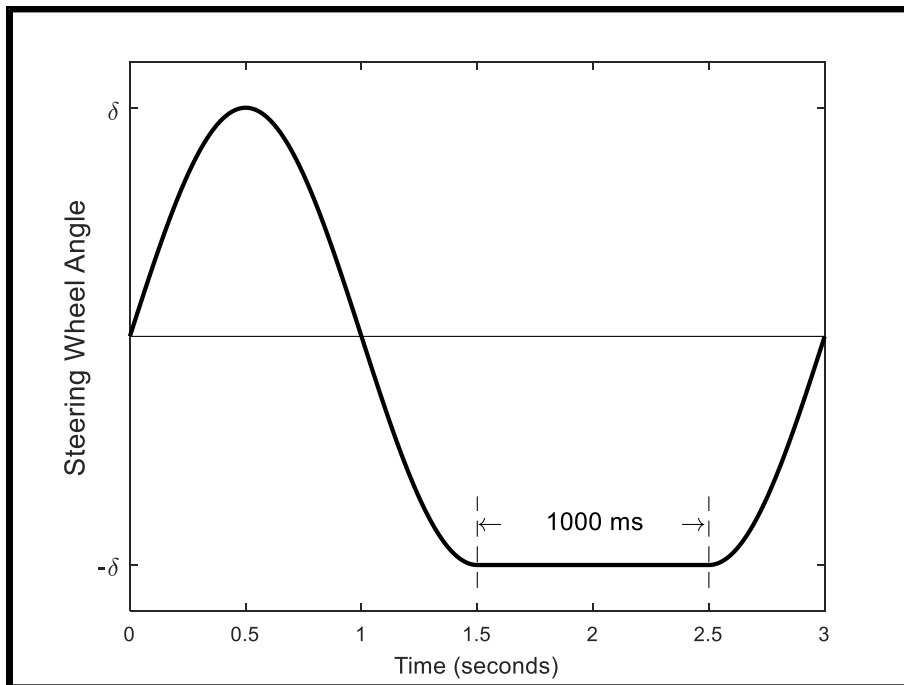


Figure 3. SWD steering wheel input.

(2) The evolution of the SWD test procedure for military vehicles was described in paragraph 4.1. A summary of the differences between the earlier procedures and TOP 02-2-718A is presented in Table 4, for historical purposes.

TABLE 4. COMPARISON OF VARIOUS SWD TEST PROCEDURES

PARAMETER	PROCEDURE			
	FMVSS 126	ANNEX S MODS	FMVSS 136 PR	TOP 02-2-718A
Vehicle Speed, mph	50	50	45	45
SWA frequency, Hz	0.7	0.5	0.5	0.5
Dwell (ms)	500	1000	1000	1000
SWA amplitudes (multiplied by δ_{ref})	1.5x to 6.5x, 0.5x steps	0.3x to 1.3x, 0.1x steps	0.3x to 1.3x, 0.1x steps	0.3x to 1.3x, 0.1x steps
Peak yaw rate	1st local peak resulting from steering reversal	1st local peak resulting from steering reversal	Greatest value recorded during second half of sine steer	Greatest value resulting from steering reversal
YRR criteria, % of peak, sec after COS	$\leq 35\%$ @ 1.00 s	$\leq 35\%$ @ 1.00 s	$\leq 40\%$ @ 0.75 s	$\leq 40\%$ @ 0.75 s
	$\leq 20\%$ @ 1.75 s	$\leq 20\%$ @ 1.75 s	$\leq 15\%$ @ 1.50 s	$\leq 15\%$ @ 1.50 s
Peak lateral acceleration	None	None	Greatest value recorded during second half of sine steer	Greatest value resulting from steering reversal
LAR criteria, % of peak, sec after COS	None	None	$\leq 30\%$ @ 0.75 s	$\leq 30\%$ @ 0.75 s
	None	None	$\leq 10\%$ @ 1.50 s	$\leq 10\%$ @ 1.50 s
Lateral Displacement assessed at	$\geq 5^* \delta_{ref}$,	$\geq 1.0^* \delta_{ref}$,	$\geq 0.7^* \delta_{ref}$,	$\geq 1.0^* \delta_{ref}$,
Lateral Displacement Time, s after BOS	1.07	1.5	1.5	1.5
Lateral Displacement (responsiveness) criteria, ft	$\leq 3,500$ kg: 6	10	Truck tractors: 7	10
	$> 3,500$ kg: 5		Busses: 5	
Additional responsiveness criteria	None	None	None	IYRR @ 1.50 s after BOS

BOS=Beginning of Steer
 COS=Completion of Steer
 IYRR=Initial Yaw Rate Ratio

b. Criteria. In the absence of specific SWD performance requirements provided by the test sponsor, the criteria listed in Table 5 shall apply. The procedures to calculate the associated performance metrics are presented in paragraph 6.3.

TABLE 5. SWD TEST CRITERIA

PERFORMANCE METRIC	CRITERIA
Roll stability	LAR \leq 30% @ 0.75 s after COS
	LAR \leq 10% @ 1.50 s after COS
Yaw stability	YRR \leq 40% @ 0.75 s after COS
	YRR \leq 15% @ 1.50 s after COS
Responsiveness	Lateral Displacement \geq 3 m (10 ft) @ 1.5 s after BOS
	IYRR \leq 40% @ 1.50 s after BOS

c. TOP 02-2-718A SWD Procedures.

(1) Initiate the first SWD test series within two hours after completing the SIS test, using the same tires.

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

(3) All tests shall be performed with the 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.

(4) Verify the vehicle powertrain drive configuration and operating mode for testing, as outlined in paragraphs 4.3.c(3) and 4.3.c(4).

(5) Ensure that the ESC system is operational, as outlined in paragraph 4.3.c(10).

(6) 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 as needed to execute the SWD maneuvers. Record 15 seconds of data from all instrument channels with the test vehicle at rest, the engine running, and the transmission in “Park” (automatic transmission) or neutral with the parking brake applied (manual transmission). The static data file will be used in post processing to establish a datum (zero level) for each instrument channel.

(7) Energize the steering controller. Program the controller to execute the SWD maneuver, shown in Figure 3, using an initial counterclockwise steering direction. The steering amplitude for the initial run of each test series is $0.3 * \delta_{ref}$, as determined from the SIS maneuver data. 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 72 km/hr (45 mph) with an allowable variation in initial speed of 1.6 km/hr (1.0 mph).

(8) Execute the first counterclockwise test trial at the initial steer amplitude and target vehicle speed. During the maneuver, observe the vehicle for loss of pavement contact of tires,

rim-to-pavement contact and tire de-beading. Rim-to-pavement contact will be verified by visual observation and identified by marks left on the pavement. De-beading 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.

(9) 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.

(10) Using the data from paragraph 4.4.c(8), plot the steering wheel angle, vehicle speed, lateral acceleration, and yaw rate. Confirm the maneuver entrance speed was within 1.6 km/hr (1.0 mph) of the desired speed, the steering wheel angle maximums were correct, and both lateral acceleration and yaw rate seemed reasonable. If any of the above conditions are not met, halt the test and correct the problem. If all conditions are met, continue the test series.

(11) Continue to execute the steering maneuvers, each time increasing the steering wheel angle magnitude by $0.1 * \delta_{ref}$. Additional intermediate maneuvers may be executed at steering wheel angle magnitudes between the target multiples of $0.1 * \delta_{ref}$ if deemed necessary for safe operation. Maneuver execution should continue until a steering wheel angle magnitude of $1.3 * \delta_{ref}$ is reached, provided the calculated magnitude of $1.3 * \delta_{ref}$ is less than or equal to 400 degrees, or vehicle roll or yaw instability is observed. If any $0.1 * \delta_{ref}$ increment, up to $1.3 * \delta_{ref}$, is greater than 400 degrees, the steering amplitude of the final run shall be 400 degrees.

(12) Repeat the above procedure using an initial clockwise steering direction.

(13) Examine data for brake force application. If any application of brake force is indicated, the maneuver shall be eliminated from analysis.

(14) Post-test data processing and analysis of SWD Test data are presented in paragraph 6.3.

4.5 J-Turn Test.

a. General. The J-Turn test subjects a vehicle to conditions known to produce roll instability. The goal is to verify ESC system performance for mitigating roll instability. The test is performed in accordance with the NHTSA Laboratory Test Procedure for FMVSS No. 136¹².

b. Criteria. In the absence of specific J-turn performance requirements provided by the test sponsor, the criteria listed in Table 6 shall apply.

TABLE 6. J-TURN TEST CRITERIA^a

PERFORMANCE METRIC	CRITERION OVERVIEW
Lane Keeping	The wheels of the truck tractor or bus must remain within the lane between the start gate and the end gate.
Engine Torque Reduction	The ESC system must reduce the driver-requested engine torque by at least 10 percent for a minimum continuous duration of 0.5 second during the time period from 1.5 seconds after the vehicle crosses the start gate to when it crosses the end gate ^b .
Roll stability Control	During roll stability control test series: <ul style="list-style-type: none"> a. The vehicle speed measured at 3.0 seconds after vehicle crosses the start gate must not exceed 47 km/hr (29 mph). b. The vehicle speed measured at 4.0 seconds after the vehicle crosses the start gate must not exceed 45 km/hr (28 mph). c. The wheels of the truck tractor or bus must remain within the lane between the start gate and the end gate. d. There must be ESC service brake activation.

^a Consult FMVSS 136 for more detailed criteria guidance.

^b The FMVSS 136 test procedure description for verification of engine torque reduction indicates that during the initial stages of each maneuver the two torque signals [the engine torque data output and the driver requested output (presumably from the data bus)] will parallel each other. Based on experience, this may not be the case as the data bus signals may be faulty. Test engineer expertise or additional instrumentation may be required to assess this component of the criteria.

c. Procedures.

(1) The J-turn test procedures are conducted in accordance with FMVSS No. 136, available through the Federal Register, and the NHTSA Laboratory Test Procedure for FMVSS No. 136¹². The J-turn test course is shown in Figure 4. FMVSS No. 136 may evolve periodically, so the detailed procedures are not summarized here. Test personnel shall obtain current copies of the FMVSS No. 136 and the associated NHTSA Laboratory Test Procedure for detailed guidance when test are to be conducted.

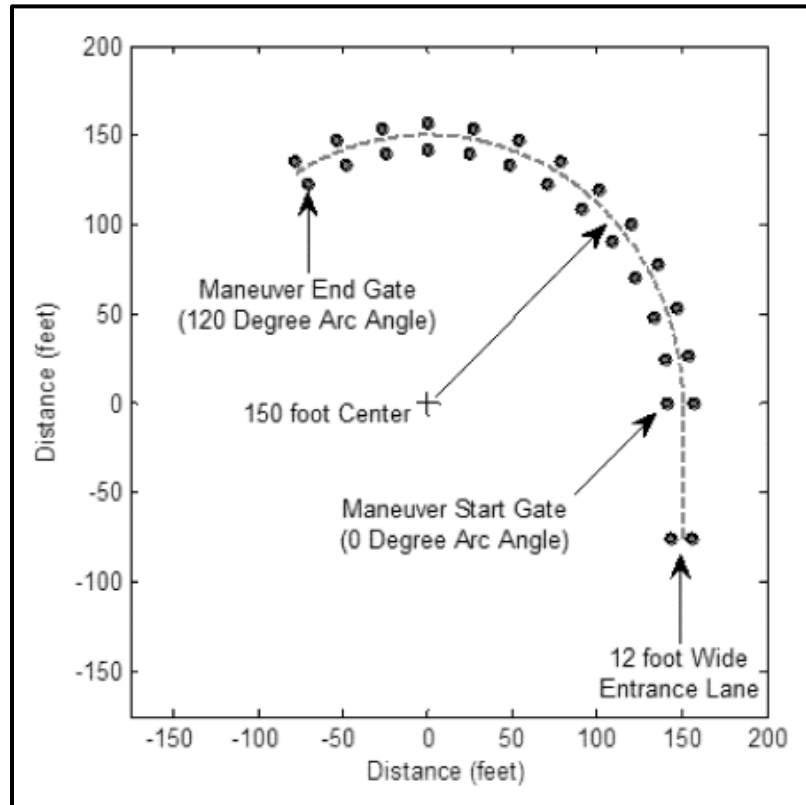


Figure 4. J-Turn Test Course.

(2) In addition to the test procedure requirements of FMVSS 136, supplemental data in lieu of engine torque output and driver requested torque output data from the J1939 data bus may be required. Anomalies may exist in the data bus results. Supplemental data may consist of throttle position and vehicle longitudinal acceleration. Test engineer expertise may be instrumental in the measurement of engine torque reduction.

(3) A brake pedal force transducer may be used in lieu of the FMVSS 136 required foot brake control treadle valve pressure gauge as an indication of inadvertent brake application during test maneuvers.

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

a. General. This test procedure confirms the ESC system is equipped with a functional ESC malfunction telltale. The procedure is adapted from the NHTSA Laboratory Test Procedures for FMVSS No. 126 and FMVSS 136.

b. Criteria. In the absence of specific ESC malfunction telltale requirements provided by the test sponsor, the following criteria shall apply. In the event of ESC malfunction, the system must display in front of and in clear view of the driver the malfunction telltale symbol shown in Figure 5 or the acronym “ESC,” as specified in Table 1 of FMVSS No. 101¹³.



Figure 5. ESC telltale symbol.

c. Procedures.

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

(2) 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.

(3) Turn the ignition to the “on” position (Run position) and observe the driver’s display panel for illumination of the ESC telltale after one or more ESC malfunctions.

(4) If the malfunction telltale does not illuminate when engine is started, put the vehicle in a forward gear and obtain a vehicle speed of $48 + 8$ km/hr ($30 + 5$ 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 two 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.

(5) Stop the vehicle and turn the starting system to the “off” position. After 5 minutes have elapsed, if the vehicle is so equipped, turn the starting system to a point between on (Run position) and Start, designated by the manufacturer as a check position. Verify that the ESC malfunction indicator again illuminates. Otherwise, after 5 minutes have elapsed, turn the starting system to the “on” position and verify that the ESC malfunction telltale illuminates and remains illuminated for as long as the engine is running.

(6) Stop the vehicle and turn the ignition to the “off” position. Restore the ESC to working condition, and restart the vehicle by turning the starting system to the “on” position (Run position). Verify that the ESC telltale has extinguished.

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. Vehicle configuration: weight, load distribution, mileage, and condition.
- d. Vehicle CG coordinates.
- e. Vehicle drive configuration and mode for each test series.
- f. Vehicle suspension and steering systems measurements (if available) and condition.
- g. Results of the tilt table test (i.e., vehicle maximum side slope angle and simulated lateral acceleration prior to rollover).
- h. Tire size, manufacturer, name, and TIN. Confirm whether the tires are new or used and record the tire wear condition. 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 manufacture.
- i. The recommended tire cold inflation pressure as specified on the vehicle placard or optional tire inflation pressure label and the measured pressure for each tire.
- j. Test course identification, dimensions, and description of operating conditions.
- k. Test course peak friction coefficient (PFC) (skid number).
- l. Instrumentation name/type, manufacturer, identification (serial number, part number, etc.), calibration information, and location on vehicle (including photographs).
- m. Measurements for the coordinates of the inertial sensing system or yaw rate, roll rate, and lateral acceleration sensors.
- n. Locations of and distance between the ultrasonic distance measuring sensors, if used for roll angle measurements.

5.2 General Test Maneuvers.

- a. Ambient temperature and wind speed at each test site.
- b. Detailed record of tire and brake conditioning procedures, as appropriate.

c. Fifteen seconds of static vehicle data prior to a test event to establish a datum (zero level) for each instrument channel.

d. Description of steer maneuver executed and steer direction (counterclockwise or clockwise). If an Auto-Pilot Device is used, provide a detailed record of steering controller setup.

e. Steering angle and peak amplitude.

f. Vehicle speed.

g. Vehicle travel distance.

h. Lateral acceleration.

i. Yaw rate.

j. Roll angle and side slip.

k. Steering effort (torque or force).

l. Elapsed time of steer maneuver.

m. ESC system activation state (activated or not activated). This is generally accomplished by observing and recording pertinent vehicle data bus channels.

n. Engine torque state (percent) and driver torque command state (percent). This is generally accomplished by observing and recording pertinent vehicle data bus channels.

o. Brake pedal force, including observations of inadvertent brake pedal force activation during the test trial.

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

5.3 Sine-With-Dwell (SWD) Test.

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

b. Lateral acceleration decay.

c. Yaw rate decay.

d. Lateral displacement.

5.4 J-Turn Test.

In addition to the data requirements of FMVSS 136, supplemental data in lieu of engine torque output and driver requested torque output data from the J1939 data bus may be required. Anomalies may exist in the data bus results. Supplemental data may consist of throttle position and vehicle longitudinal acceleration.

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

- a. Details of procedure used to induce a controlled malfunction in the ESC system.
- b. Observations regarding the ESC telltale with the induced malfunction and condition after the ESC has been restored.

6. PRESENTATION OF DATA.

6.1 General Vehicle and Test Preparation.

Data are to be presented in narrative, tabular, graphical, pictorial, or other format as appropriate.

6.2 Slowly Increasing Steer (SIS) Test.

a. Reference Steering Wheel Angle. The following procedures shall be used for preparing and applying SIS test data, and 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 angle, 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 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.

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

(8) The longitudinal, lateral, and vertical accelerations at the vehicle CG are determined by removing the effects caused by vehicle body roll and by correcting for sensor placement via the use of coordinate transformations⁶, as shown below in Equations 1 - 3.

$$x''_{corrected} = x_{accel} - (\theta'^2 + \psi'^2)x_{disp} + (\theta'\phi' - \psi'')y_{disp} + (\psi'\phi' + \theta'')z_{disp} \quad \text{Equation 1}$$

$$y''_{corrected} = y_{accel} + (\theta'\phi' + \psi'')x_{disp} - (\phi'^2 + \psi'^2)y_{disp} + (\psi'\theta' - \phi'')z_{disp} \quad \text{Equation 2}$$

$$z''_{corrected} = z_{accel} + (\psi'\phi' - \theta'')x_{disp} + (\psi'\theta' + \phi'')y_{disp} - (\phi'^2 + \theta'^2)z_{disp} \quad \text{Equation 3}$$

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 locations

x_{disp} , y_{disp} , and z_{disp} = longitudinal, lateral, and vertical displacements, respectively, of the CG with respect to the accelerometer locations

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

(9) 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.

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

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 at the vehicle CG, corrected by Equation 2

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.

(10) Plot steering wheel angle data versus corrected lateral acceleration data for each test run. Using linear regression techniques from 0.05 to 0.3 g, determine the “best-fit” line (slope = deg/g) for each of the six completed SIS maneuvers.

(11) 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 and the absolute value data from each of the six SIS maneuvers, calculate δ_{ref} , the average overall steering wheel angle at 0.5 g rounded to the nearest 0.1 degree.

$$\delta_{ref} = (|\delta_{0.5\ g, left\ (1)}| + |\delta_{0.5\ g, left\ (2)}| + |\delta_{0.5\ g, left\ (3)}| + \delta_{0.5\ g, right\ (1)} + \delta_{0.5\ g, right\ (2)} + \delta_{0.5\ g, right\ (3)})/6$$

Equation 5

b. Engine Torque Reduction. Confirm ESC activation and evaluate the ESC engine torque reduction capability by assessing engine torque output and driver-requested torque data from the vehicle J1939 communication data link (or equivalent). As noted in Section 4.5, test engineer expertise and other test instrumentation may be required to assess engine torque reduction if anomalies are observed in the J1939 data bus results. Compare the engine torque reduction test results graphically to the appropriate criterion, indicating compliance or non-compliance.

c. An example SIS results data table for determination of the reference steering angle is shown in Table 7 and an example SIS plot is shown in Figure 6.

TABLE 7. SAMPLE SIS DATA TABLE, VEHICLE XX, 30-MPH, SIS RESULTS

RUN NUMBER	STEER DIRECTION	AVG. SPEED mph	0.3g STEERING WHEEL ANGLE degree	0.5g STEERING WHEEL ANGLE degree
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

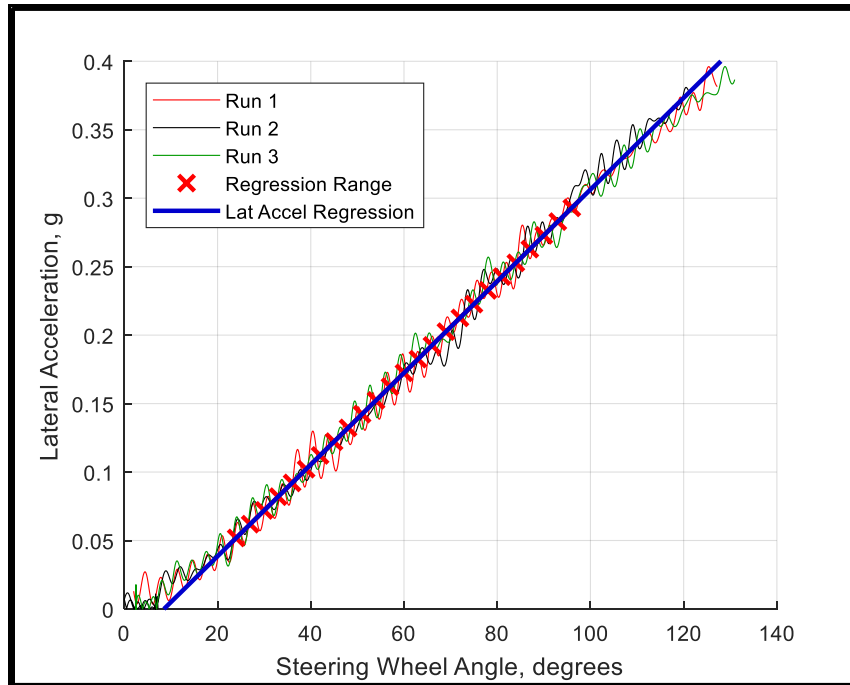


Figure 6. Sample SIS data plot.

6.3 Sine-With-Dwell (SWD) Test.

a. Yaw rate, lateral acceleration, and lateral displacement measurements and calculations are processed utilizing the following techniques for each steering maneuver. 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, and 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 (9). For lateral acceleration, yaw rate, and steering wheel angle use the zeroing steps discussed in paragraph 6.3.a(3).

(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 0), the first instance when the steering wheel rate exceeds 75 degrees/second is identified. From this point, the steering wheel rate must remain greater than 75 degrees/second for at least 200 ms. If the second condition is not met, the next instance the steering wheel rate exceeds 75 degrees/second is identified, and the 200-ms validity check is applied. This iterative process continues until both conditions are satisfied.

(b) The zeroing range is identified as the 1.0-sec time period prior to the instant the steering wheel rate exceeds 75 degrees/second (i.e., the instant the steering wheel velocity exceeds 75 degrees/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 reaches -5 degrees (when the initial steering input is counterclockwise) or +5 degrees (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-degree steering wheel angle is interpolated.

(6) Determine the peak yaw rate due to the initial steer ($\dot{\Psi}_{Peak,initial}$), which is defined as the maximum yaw rate produced by the initial steer, as shown in Figure 7. More specifically, the peak yaw rate is the yaw rate with the greatest magnitude from the subset of yaw rate values which occur from the BOS to 1 second after the BOS during the same test run and are signed consistently with the direction of the initial steer.

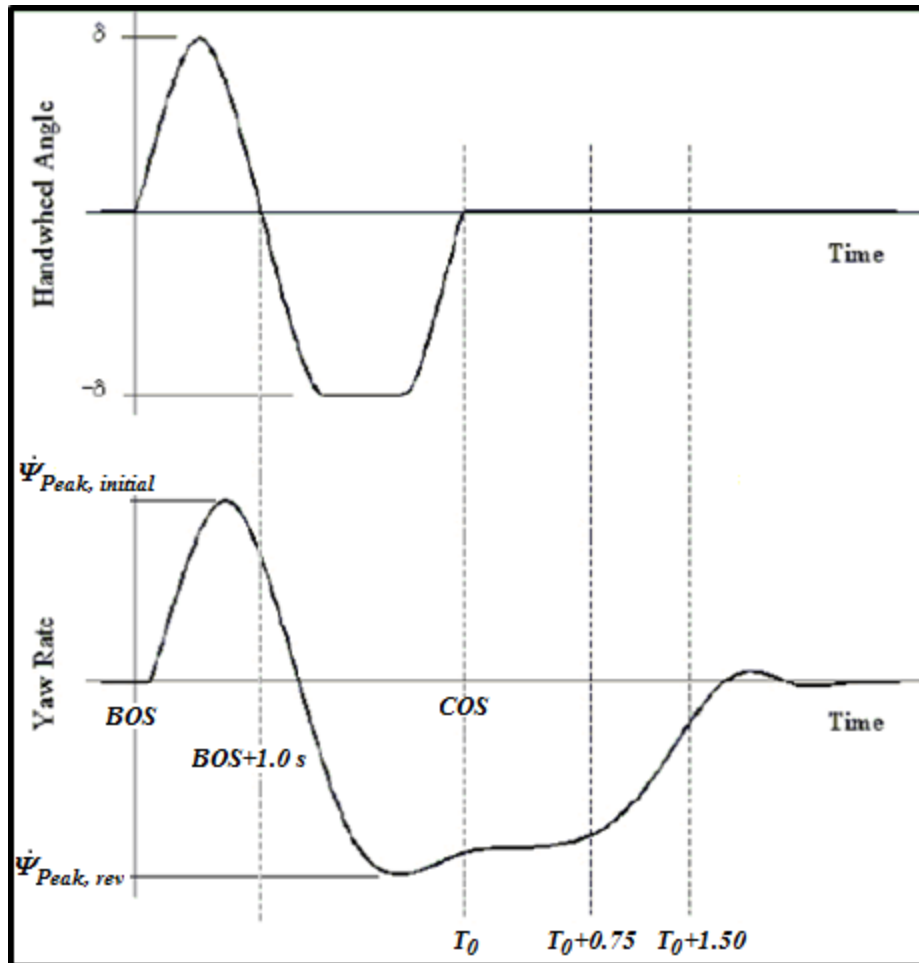


Figure 7. Steering wheel position and yaw rate information used to assess directional stability.

(7) The yaw rate at 1.50 second after BOS is determined by interpolation.

(8) Calculate initial yaw rate ratio (IYRR) at 1.50 second after BOS. The IYRR is expressed as a percentage, as shown in Equation 6.

$$IYRR = 100\% * \left(\frac{\dot{\Psi}_{1.5 \text{ s after BOS}}}{\dot{\Psi}_{Peak, initial}} \right) \quad \text{Equation 6}$$

(9) Determine the steer reversal peak yaw rate ($\dot{\Psi}_{Peak, rev}$), which is defined as the maximum yaw rate produced by the reversal of the steering wheel, as shown in Figure 7. More specifically, the peak yaw rate is the yaw rate with the greatest magnitude from the subset of yaw rate values which occur from the time 1 sec after the BOS to the COS during the same test run and are signed consistently with the direction of the steer reversal.

(10) The yaw rates at 0.75 and 1.50 seconds after COS are determined by interpolation.

(11) Calculate (Equation 7) the yaw rate ratio (YRR) at 0.75 and 1.50 seconds after COS. The YRR is expressed as a percentage, as shown in Equation 7, where ‘time t’ is 0.75 and 1.50 seconds after COS.

$$YRR = 100\% * \left(\frac{\dot{\psi}_{at\ time\ t}}{\dot{\psi}_{Peak,rev}} \right) \quad \text{Equation 7}$$

(12) Determine the steer reversal peak lateral acceleration ($a_{yc,Peak}$), which is defined as the maximum lateral acceleration produced by the reversal of the steering wheel. The determination of the peak lateral acceleration is consistent with the determination of the peak yaw rate, as in paragraph 6.3.a(9).

(13) Calculate the lateral acceleration ratio (LAR) at 0.75 and 1.50 seconds after COS. The LAR is expressed as a percentage, as shown in Equation 8, where ‘time t’ is 0.75 and 1.50 seconds after COS.

$$LAR = 100\% * \left(\frac{a_{yc,at\ time\ t}}{a_{yc,Peak}} \right) \quad \text{Equation 8}$$

(14) For each of the SWD steering maneuvers in procedure 4.4, with a steering wheel angle of $1.0 * \delta_{ref}$, or greater, determine lateral velocity by integrating corrected, filtered, and zeroed lateral acceleration data. Zero lateral velocity data using the value at the BOS event.

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

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

(17) Present a table showing lateral displacement at 1.5 seconds after BOS for each steering maneuver conducted with a steering wheel angle of $1.0 * \delta_{ref}$, or greater.

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

b. Present a table showing yaw rate and lateral acceleration decay (indicated by IYRR at 1.50 seconds after BOS and YRR and LAR each at 0.75 and 1.50 seconds after COS) for each

steering maneuver conducted. Include lateral displacement results in the table. A sample SWD data table is provided as TABLE 8.

TABLE 8. SAMPLE SWD DATA TABLE, VEHICLE XX, SWD RESULTS

SWA	IYRR @ 1.50 seconds after BOS	MAX YAW RATE, REVERSAL	YRR @0.75 seconds after COS	YRR @1.50 seconds after COS	MAX LAT. ACCEL., REVERSAL	LAR @0.75 seconds after COS	LAR @ 1.50 seconds after COS	LAT. DISP.
[degree]	% of peak	[degree/s]	% of peak	% of peak	[g]	% of peak	% of peak	[ft]
Left Initial Steer								
60	10.8	16.8	12.7	0.4	0.45	6.9	-2.8	-2.66
90	0.8	24.8	0.9	5.8	0.54	23.9	5.2	-3.81
120	18.6	33.9	21.9	15.7	0.57	101.6	117.3	-4.88
135	20.7	38.5	24.3	-4.3	0.66	102.9	42.6	-5.13
Right Initial Steer								
60	7.5	-14.8	8.8	-1.0	-0.43	0.3	-2.9	2.89
90	3.7	-25.6	4.4	2.3	-0.56	14.2	5.3	3.64
150	28.4	-42.8	33.4	1.7	-0.61	100.3	4.0	5.76

SWA = steering wheel angle

IYRR = initial yaw rate ratio

BOS = beginning of steer

YRR = yaw rate ratio

COS = completion of steer

LAT = lateral

LAR = lateral acceleration ratio

c. Graphically present the vehicle yaw rate versus time and lateral acceleration versus time for each steering maneuver and for each configuration tested. Additional plots may be presented to show metrics such as roll rate, lateral displacement, vehicle side slip at points of interest such as the vehicle CG or axles, and brake application pressures, as desired. Sample SWD data plots are provided as Figure 8 through Figure 10.

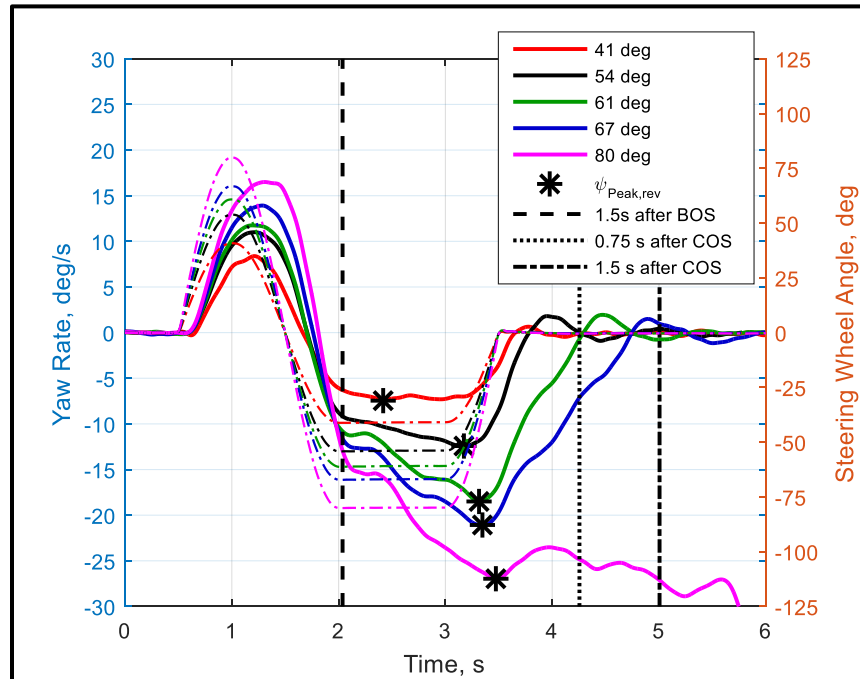


Figure 8. Sample SWD yaw rate plot.

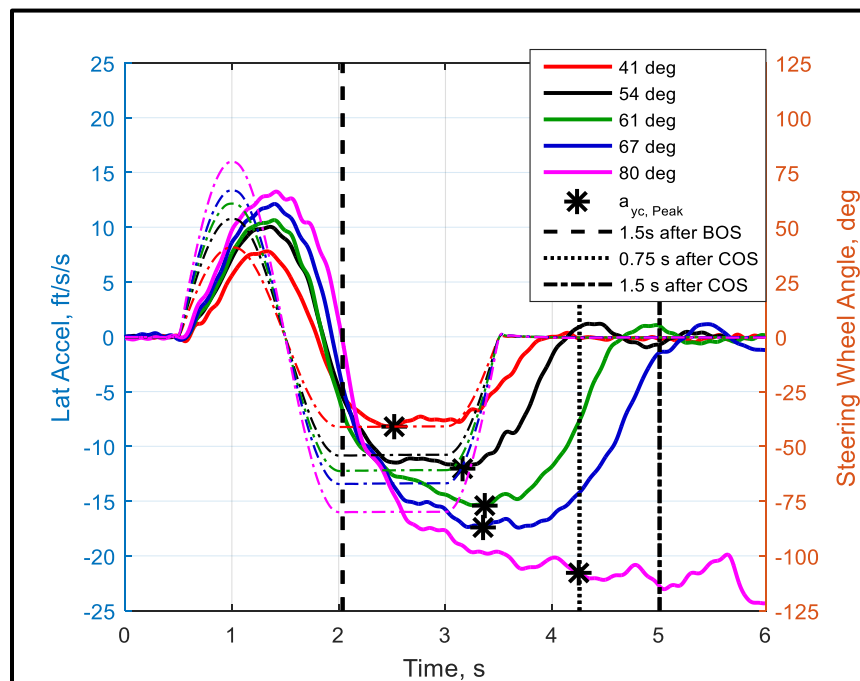


Figure 9. Sample SWD lateral acceleration plot.

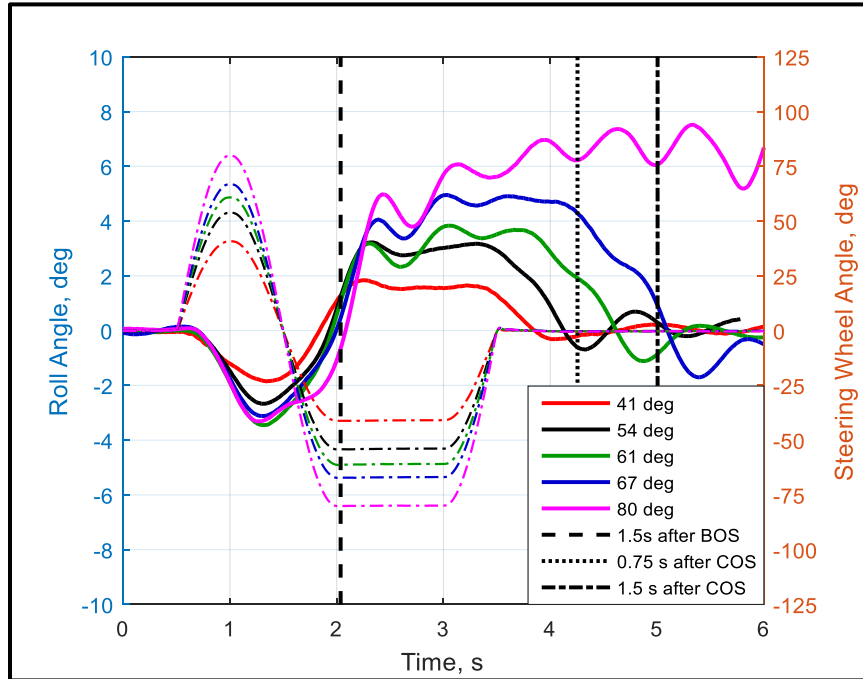


Figure 10. Sample SWD roll angle plot.

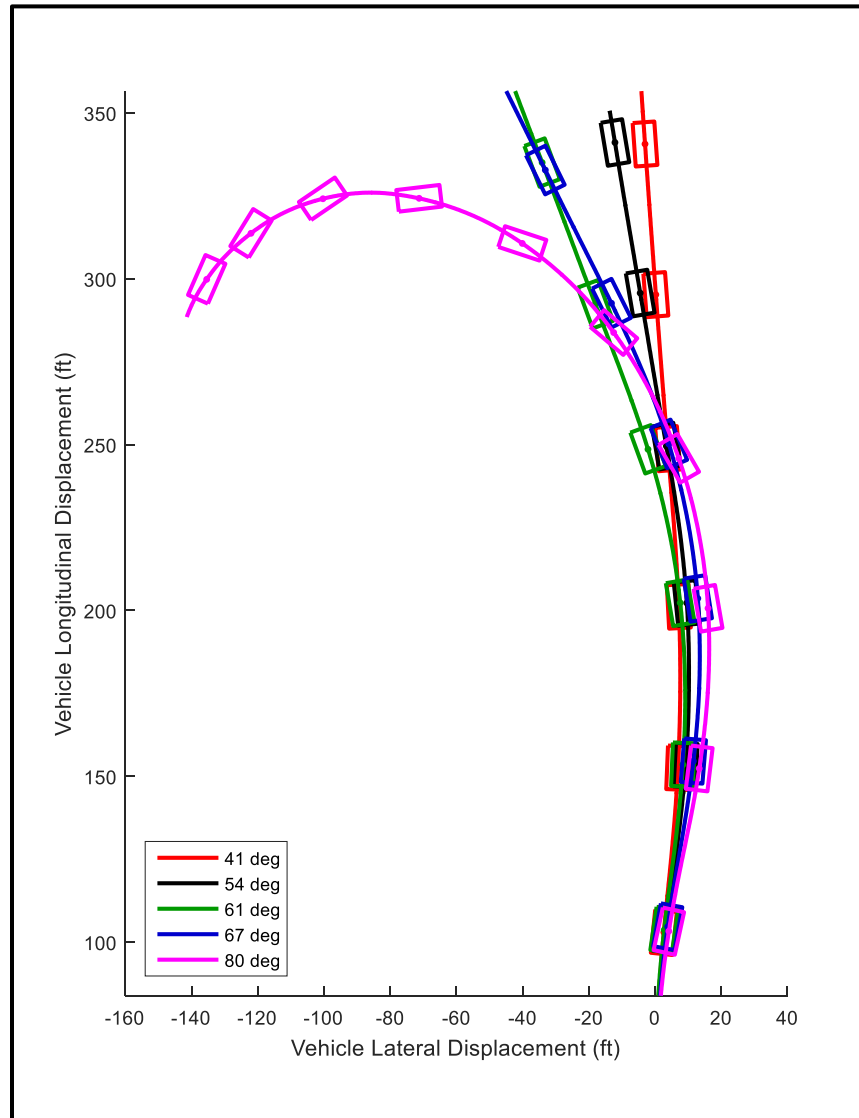


Figure 11. Sample SWD position plot.

6.4 J-Turn Test.

The J-turn data post-processing and presentation procedures are conducted in accordance with FMVSS No. 136, available through the Federal Register, and the NHTSA Laboratory Test Procedure for FMVSS No. 136. Supplemental data in lieu of engine torque output and driver requested torque output data from the J1939 data bus may be required. Anomalies may exist in the data bus results. Supplemental data may consist of throttle position and vehicle longitudinal acceleration. Test engineer expertise may be instrumental in the post processing and presentation of engine torque reduction data. A sample J-turn results table is presented in TABLE9 and sample J-Turn plots are shown in Figure 12 and Figure 13.

TABLE 9. SAMPLE J-TURN DATA TABLE

Run	Speed at 3 s		Speed at 4 s	
	km/hr	mph	km/hr	mph
Right Steer				
1	34.1	21.2	33.9	21.1
2	34.1	21.2	33.7	20.9
3	27.7	17.2	27.4	17.0
4	30.8	19.2	30.2	18.8
5	30.6	19.0	30.7	19.1
6	35.8	22.2	34.7	21.6
7	33.8	21.0	33.6	20.9
8	32.5	20.2	32.8	20.4
Left Steer				
1	36.6	22.7	36.5	22.7
2	35.0	21.8	32.8	20.4
3	35.4	22.0	34.9	21.7
4	31.6	19.6	31.0	19.3
5	32.9	20.5	31.7	19.7
6	36.0	22.4	35.1	21.8
7	33.3	20.7	33.0	20.5
8	33.6	20.9	33.3	20.7

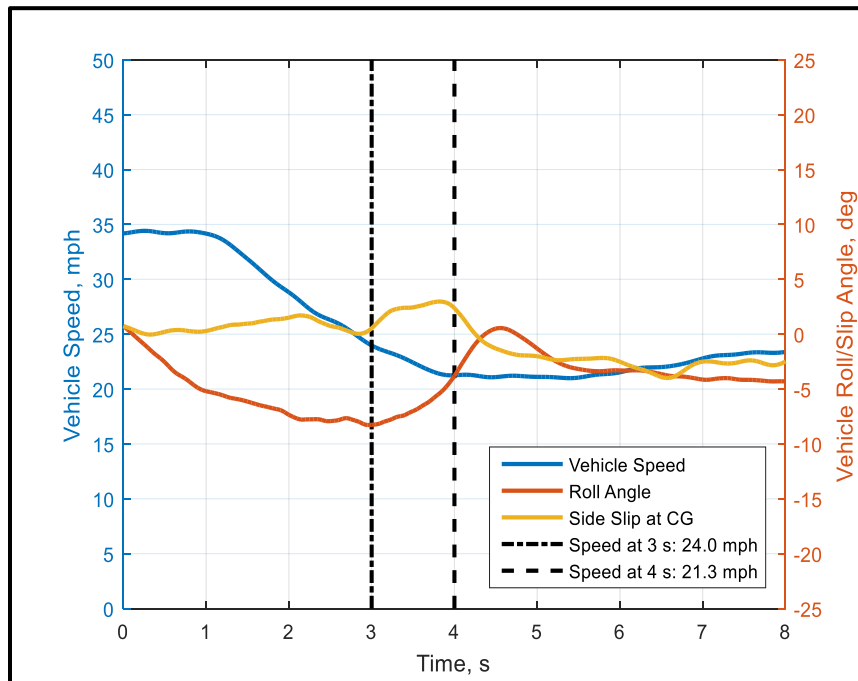


Figure 12. Sample J-Turn roll stability test plot.

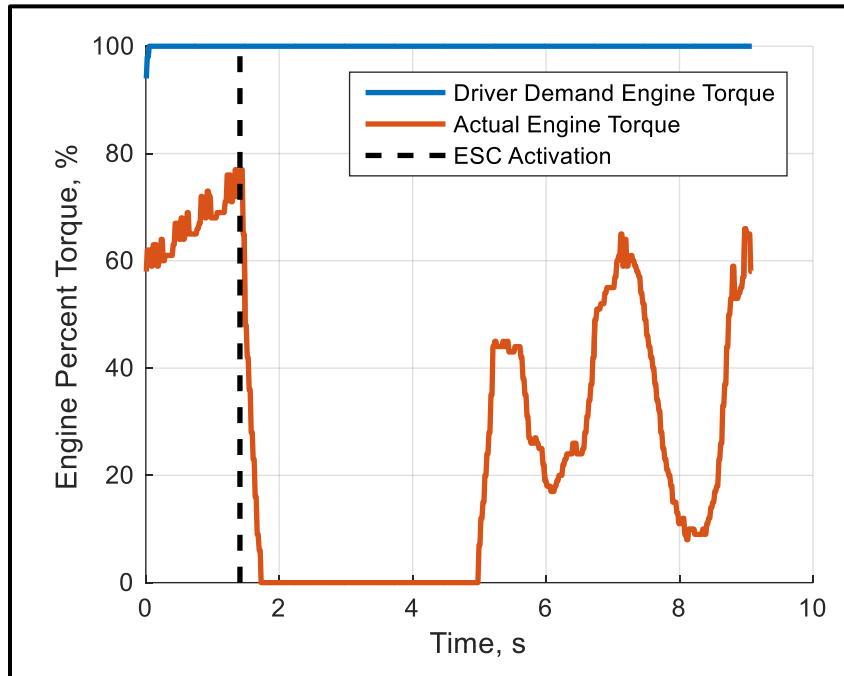


Figure 13. Sample J-Turn throttle reduction test plot.

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

Present observations in narrative and tabular form, as appropriate.

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APPENDIX A. PRE-TEST PROCEDURES.

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 and J-Turn 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. 121¹⁴ brake burnish procedure should be performed, 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 the tires to the vehicle manufacturer's recommended cold inflation pressures. Record the measured pressure in each tire.
- b. Energize the data acquisition system. Set the data acquisition system so that 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 AND 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 the 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.

APPENDIX A. PRE-TEST PROCEDURES.

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.

ABS	anti-lock braking system
AEC	U.S. Army Evaluation Center
ASTM	American Society for Testing and Materials
ATEC	U.S. Army Test and Evaluation Command
BOS	beginning of steer
°C	degrees Celsius
CG	center of gravity
cm	centimeter
COS	completion of steer
DAS	data acquisition system
ESC	electronic stability control
FMVSS	Federal Motor Vehicle Safety Standard
FR	Final Rule
GVW	gross vehicle weight
Hz	hertz
ISTVS	International Society of Terrain Vehicle Systems
IYRR	initial yaw rate ratio
JLTV	Joint Light Tactical Vehicle
kg	kilogram
km/hr	kilometers per hour
kPa	kilopascals
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

APPENDIX B. ABBREVIATIONS.

N-m	Newton-meter
NHTSA	National Highway Traffic Safety Administration
PFC	peak friction coefficient
PR	Proposed Rule
psi	pounds per square inch
RSC	roll stability control
SAE	Society of Automotive Engineers
SIS	Slowly Increasing Steer
SR	Safety Release
SWA	steering wheel angle
SWD	Sine-With-Dwell
TCS	traction control system
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. SAE International Surface Vehicle Recommended Practice J2564, Automotive Stability Enhancement Systems, Nov 2017.
2. Preliminary Regulatory Impact Analysis, FMVSS No. 136 Electronic Stability Control Systems on Heavy Vehicles, U.S. Department of Transportation, National Highway Traffic Safety Administration, May 2012.
3. ASTM E1337-90 (2012), Standard Test Method for Determining Longitudinal Peak Braking Coefficient of Paved Surfaces Using Standard Reference Tire, ASTM International, 2012.
4. ASTM E 1136-10, Standard Specification for P195/75R14 Standard Reference Test Tire, ASTM International, 2010.
5. SAE International Surface Vehicle Recommended Practice J2180, A Tilt Table Procedure for Measuring the Static Rollover Threshold for Heavy Trucks, 17 May 2011.
6. FMVSS No. 126, Electronic stability control systems. Code of Federal Regulations, Title 49, Subtitle B, Chapter 5, Part 571, Subpart B, Section 571.126.
7. FMVSS No. 136, Electronic stability control systems for heavy vehicles. Code of Federal Regulations, Title 49, Subtitle B, Chapter 5, Part 571, Subpart B, Section 571.136.
8. TP-126-03, Laboratory Test Procedure for FMVSS No. 126, Electronic Stability Control Systems, U.S. Department of Transportation, National Highway Traffic Safety Administration, Sept 2011.
9. Annex S, Modification to DOT-TP-126-3 to Purchase Description for Joint Light Tactical Vehicle, Version 3.0.3, November 9, 2012.
10. Section 571.136, Electronic stability control systems for heavy vehicles. Standard No. 136, Federal Register / Vol. 77, No. 100 / Wednesday, May 23, 2012 / Proposed Rules.
11. *Electronic Stability Control Testing of Military Wheeled Vehicles*, Duplan, B., Schultz, G., International Society of Terrain Vehicle Systems (ISTVS), 8th Americas Regional Conference Proceedings, Sept. 2016.
12. TP-136-00, Laboratory Test Procedure for FMVSS No. 136, Electronic Stability Control Systems for Heavy Vehicles, U.S. Department of Transportation, National Highway Traffic Safety Administration, Dec 2015.

APPENDIX C. REFERENCES.

13. FMVSS No. 101, Controls and Displays. Code of Federal Regulations, Title 49, Subtitle B, Chapter 5, Part 571, Subpart B, Section 571.101.

14. FMVSS No. 121, Air Brake Systems. Code of Federal Regulations, Title 49, Subtitle B, Chapter 5, Part 571, Subpart B, Section 571.121.

APPENDIX D. APPROVAL AUTHORITY.

CSTE-TM

1 October 2018

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) 02-2-718A Electronic Stability Control,
Approved for Publication

1. TOP 02-2-718A 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 provides standardized test procedures for evaluating the electronic stability control system capabilities of wheeled vehicles over 4,536 kilograms (10,000 pounds) gross vehicle weight. The test procedures include slowly increasing steer, sine with dwell, and J-Turn test maneuvers. Test procedures to assess the function of the electronic stability control malfunction telltale are also included.

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

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atc.mbx.atc-standards@mail.mil.

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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: Policy and Standardization Division (CSTE-TM), U.S. Army Test and Evaluation Command, 6617 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Automotive Directorate (TEDT-AT-AD), U.S. Army Aberdeen Test Center, 400 Collieran Road, Aberdeen Proving Ground, Maryland 21005. Additional copies can be requested through the following website:

<https://www.atec.army.mil/publications/documents.html>, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 220606218. This document is identified by the accession number (AD No.) printed on the first page.