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14. ABSTRACT
This TOP prescribes procedures for analyzing the steering performance of tactical wheeled vehicles at lateral accelerations below 0.2 *g* (i.e., the "On-Center" region). Test procedures are provided for a weave test and a transition test.

15. SUBJECT TERMS
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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 02-2-600 29 July 2015
DTIC AD No.

STEERING PERFORMANCE, TACTICAL VEHICLES

1. SCOPE.

a. The procedures in this Test Operations Procedure (TOP) describe standardized methods for analyzing the on-center steering performance of wheeled vehicles.

b. As the mean and top speed of tactical wheeled vehicles continue to increase, the on-center steering behavior has more pronounced effects on drivability (comfort and fatigue) and safety. Standardized means are required to characterize the on-center vehicle responses of military vehicles for the purposes of influencing vehicle design and ensuring military truck steering systems are well made and consistent with modern industry practices.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Weave test course	A straight asphalt or concrete roadway having a gradient of less than 1%. A course width of at least 15 meters (m) is recommended for a human driver and at least 30 m is recommended for robotic steering control. A course length of approximately 2 kilometers (km) is recommended.
Transition test course	A straight asphalt or concrete roadway having a gradient of less than 1%, a recommended width of at least 60 m, and a recommended length of approximately 1 km.
Roadway Simulator (RWS)	A dynamic vehicle-in-the-loop test machine that utilizes D'Alembert's principle and kinematic relationships to simulate the roadway velocity vectors beneath each tire during driving. It consists of a series of flat track units positioned beneath the vehicle tires, an instrumented vehicle restraint system, an autopilot robotic driver, a hydraulic power supply, and a system controller.

2.2 Instrumentation.

Devices for Measuring	Permissible Measurement Uncertainty
Vehicle speed	1%
Steering wheel angle	0.1 degree

Devices for Measuring	Permissible Measurement Uncertainty
Steering wheel torque	1%
Lateral acceleration	0.02 *g*
Yaw rate	0.1 degree per second (deg/s)
Tire pressure	1 pound per square inch (psi)
Meteorological data:	
Atmospheric pressure	1%
Ambient temperature	1 °Celsius (C)
Humidity	3%
Wind speed	5%
Wind direction	3 degrees

2.3 Data Acquisition.

An anti-aliasing filter should be selected with a cutoff frequency that is sufficient to avoid excessive lag in the data at the selected sample rate. The rate of digital sampling should be selected to provide adequate resolution. A sample rate of 200 Hertz (Hz) with a 50 Hz low-pass anti-aliasing filter is appropriate, but other values may be used.

2.4 Specialized Equipment.

2.4.1 Strain-Gaged Steering Wheel With Angle Encoder.

A mechanism attached to the test vehicle's steering wheel (or replaces the steering wheel) that is strain gaged and calibrated to measure the steering effort (torque) exerted on the steering wheel and the steering wheel turning angle. It is critical for this test that the instrumented steering wheel installation introduces minimum friction to the steering system.

2.4.2 Auto-Pilot Device.

A steering robot is used to analyze vehicle stability and handling characteristics during the performance of steering maneuvers. The U.S Army Aberdeen Test Center (ATC) currently uses an ATI Heitz Automotive Sprint3 Steering Machine** and the U.S. Army Yuma Test Center (YTC) currently uses an Anthony Best Dynamics (ABD) SR60**. The steering machines are programmable to perform objective steering sequences. The steering robot is often used for executing steer maneuvers where precise repetition of the vehicle input is necessary. The device operates in the "open-loop" mode where the machine performs the programmed steer inputs without vehicle position or heading feedback. It is critical for this test that the steering machine installation introduces minimum friction to the steering system.

**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.

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. Select the applicable test procedures to be used based on the requirement documents and purpose of the 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.

d. Ensure that all test personnel are familiar with the required technical and operational characteristics of the test item, test equipment such as the steering robot, and test procedures.

3.2 Test Controls.

Prior to test initiation, 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.

b. The vehicle is payloaded in accordance with the test plan and verify the center of gravity (CG) location, if appropriate.

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

d. The wheel toe, camber, and caster settings are within proper specifications for the test vehicle.

e. The steering and suspension components are in good serviceable condition. Pay particular attention to the state of tire wear and pressure. The vehicle should be able to be driven in a straight line without steer input (i.e., “hands free”). If the vehicle pulls in either direction, the alignment should be adjusted. Because the condition of the tires has a significant effect on the results of this test, excessively worn tires (less than 70% tread depth remaining) should be avoided.

f. Fluid levels and pressures are properly set, particularly for the power steering pump or any other system which pertains to the vehicle’s steering or suspension system.

g. Suspension components, tires, and power steering equipment have reached their normal operating temperature.

3.3 Restrictions.

a. 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, un-obstructed surfaces are used unless the test plan introduces a specific requirement. Local safety and operational procedures will be carefully followed. Desirable environmental conditions for test conduct are as follows:

(1) Wind speed: ≤ 3 meters per second (m/s) average value and ≤ 5 m/s gust.

(2) Ambient temperature greater than 0 °C.

(3) Humidity: ≤ 95%.

b. It is preferable to test the vehicle in a heading such that the ambient wind direction causes a tail wind. Because wind and road crown have a significant effect on the results, it is recommended that each test be repeated on the same road in the opposite direction.

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

4. TEST PROCEDURES.

4.1 General Vehicle and Test Characterization.

Specific test and vehicle identification characteristics, basic measurements, and condition of components of the suspension and steering systems should be recorded. Particular characteristics of interest are as follows:

a. Test location.

b. Vehicle mileage.

c. Camber, caster, and toe settings at each wheel.

d. Suspension type, front and rear (unequal A-arm, multi-link, Hotchkiss, etc.).

e. Spring type, front and rear (coil, leaf, material, etc.).

f. Anti-roll bar, front and rear (whether or not equipped, diameter, arm length).

g. Active or passive dampers front and rear.

h. Steering gear type (rack & pinion, recirculating ball, etc.).

i. Steering linkage type.

(1) Rack & pinion (end take-off or center take-off).

(2) Worm & sector (bell crank, cross steer, parallelogram, Haltenberger).

(3) Linkage location (forward of or behind wheel centerline).

j. Assist type (whether or not equipped, hydraulic, electric).

k. Steering damper (whether or not equipped).

l. Overall steer ratio, on center.

m. Steering wheel diameter.

n. Tires, front and rear:

(1) Mileage.

(2) Size.

(3) Construction (radial, bias ply, number of plies).

(4) Brand and model.

(5) Load range, maximum load carrying capacity.

(6) Maximum inflation pressure.

(7) Speed rating or symbol.

(8) Tread depth (inner, middle, outer, or a qualitative description at a minimum) prior to test.

o. Weight distribution.

p. Center of gravity location.

q. Ambient temperature.

4.2 Weave Test.

a. Quantify transducer offsets.

(1) Drive the vehicle for a short distance to verify that the steering wheel is pointed straight ahead. Coast the vehicle to a stop on a level surface (± 1% longitudinal gradient, ± 0.1% side slope) and record transducer values for at least 15 seconds. Use these data to calculate transducer offsets for the steering wheel torque and vehicle body accelerations and angular rates.

(2) At the start of each test trial maneuver, as the vehicle is traveling at speed, begin recording transducer signals at least 3 seconds prior to the start of the steer maneuver. If possible, at the completion of the maneuver, return the steering to straight ahead and drive the vehicle in a straight line for 3 seconds.

b. Execute the test maneuver.

(1) The weave test steering maneuver consists of a sine-wave input with a nominal frequency of 0.2 Hz ± 10%. The amplitude of the steer input should be such that the vehicle lateral acceleration reaches values of approximately ± 0.2 *g*. Vehicle speed shall be held at a constant 64 kilometers per hour (km/hr) (40 miles per hour (mph)) ± 3% by the test driver. For additional higher speed testing (if required), the nominal road speed may be increased in increments of 16 km/hr (10 mph) ± 3%, as defined by the test plan.

(2) If the steering maneuver is to be executed by a steering robot, each steer profile/program to be used during the test must be verified prior to executing it at speed. Drive the vehicle at a speed no greater than 8 km/hr (5 mph) and execute each steering robot program while observing the behavior of the steering machine. Furthermore, the drivers should familiarize themselves with the programmed inputs and the resulting vehicle behavior prior to commencing the test. Due to the open-loop nature of the steering robot, the position and heading of the vehicle relative to the test course at the initiation of the maneuver are critical. Theoretically, each time the steering input completes one full period of the sine wave, the vehicle's course should be nearly parallel to its initial, straight-ahead course. Although the heading may be nearly the same, it will have traversed laterally in the direction of the first steer movement as shown in Example 1 of Figure 1. For the vehicle to stay on the road throughout the maneuver, the initial heading must be askew from the heading of the roadway, as shown in Example 2 of Figure 1.

(3) If the steer maneuver is to be executed by a driver, the driver should be given ample opportunity to practice the steer maneuver while being provided performance feedback. The steer profile should maintain consistent peak amplitudes, a 0.2 Hz frequency, and angular velocity through zero steer angle. For a 0.2 Hz sine wave steer profile, the steering wheel angular rate through zero steer angle should be $0.4*\pi*A$, where A is the amplitude of the sine wave. It may be beneficial to practice with several values for A in a static vehicle prior to attempting the test. The initial position and heading of the vehicle at the start of the maneuver are less critical with a human driver. A human driver can stray from the target steer profile at the start to establish the maneuver on a path that follows the road.

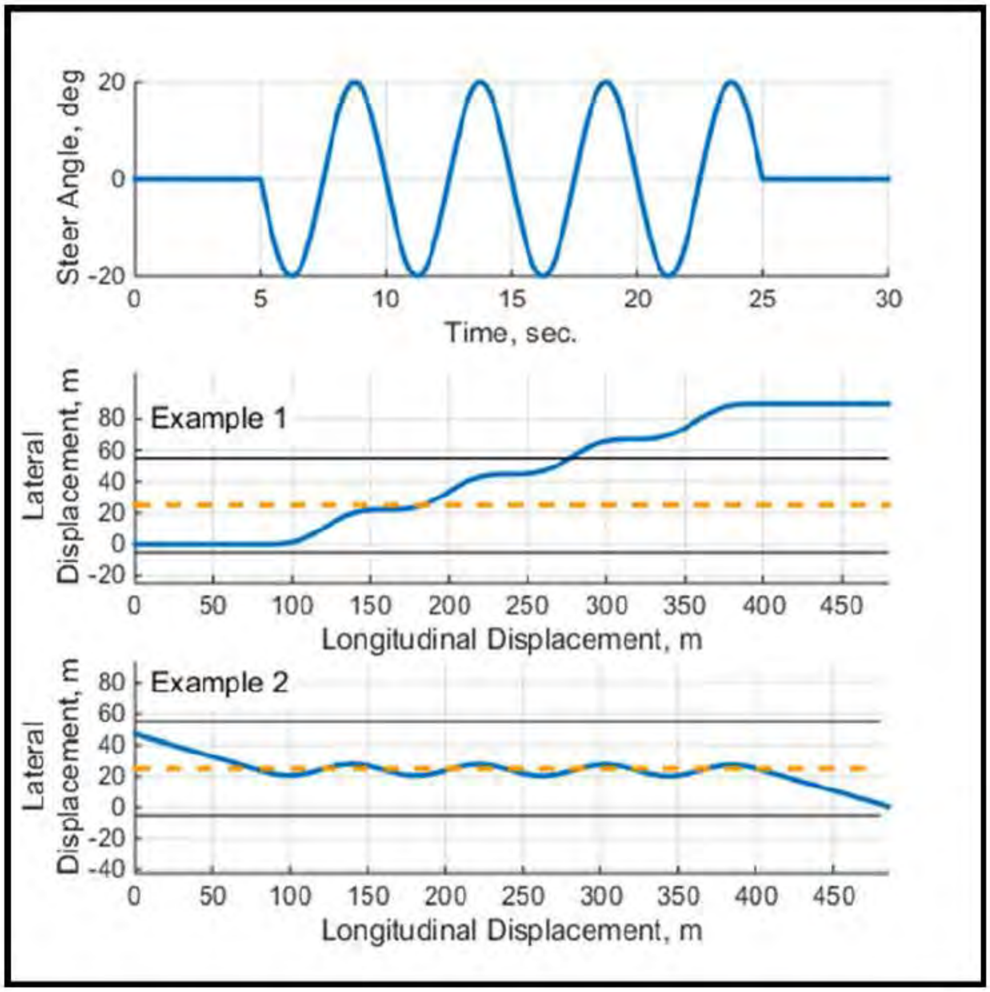

Figure 1. Steer profile and vehicle path, weave test.

(4) Using the steering robot produces extremely precise and repeatable steer inputs, but the path of the vehicle is difficult to control which may lead to more aborted test trials than using driver-controlled steer inputs. Using a driver reduces both the time required to prepare the vehicle and the probability of aborted trials. This allows more attempts to be made, but test results are likely to be less consistent and therefore more data may fail the validation criteria.

(5) At least 50 complete steer cycles should be measured if using a steering robot, not including the first steer cycle of each trial. The number of steering cycles required when using human-controlled steering is dependent on the skill of the driver, also excluding the first cycle of each trial.

c. Conduct in-field data validation. Validation shall be conducted for each half-cycle. A half-cycle is defined as the time at which the steer angle peaks in the left steer direction to the time at which it subsequently peaks in the right steer direction, and vice versa.

(1) Validate vehicle road speed. Vehicle road speed shall be held to within ± 3% of the target road speed. If road speed deviates from this threshold at any time, any half-cycle which includes the deviation shall be discarded.

(2) Validate steer frequency. For each data set, the frequency shall be 0.2 Hz ± 10%. Therefore, a half-period (not to be confused with a half cycle) shall be 2.5 sec ± 0.25 sec, as measured from when the steer angle passes through zero. If any half-period fails this criterion, that half period as well as one-quarter period before and after shall be discarded, as shown in Figure 2. This method invalidates any half-cycle which contains data within the invalid half-period.

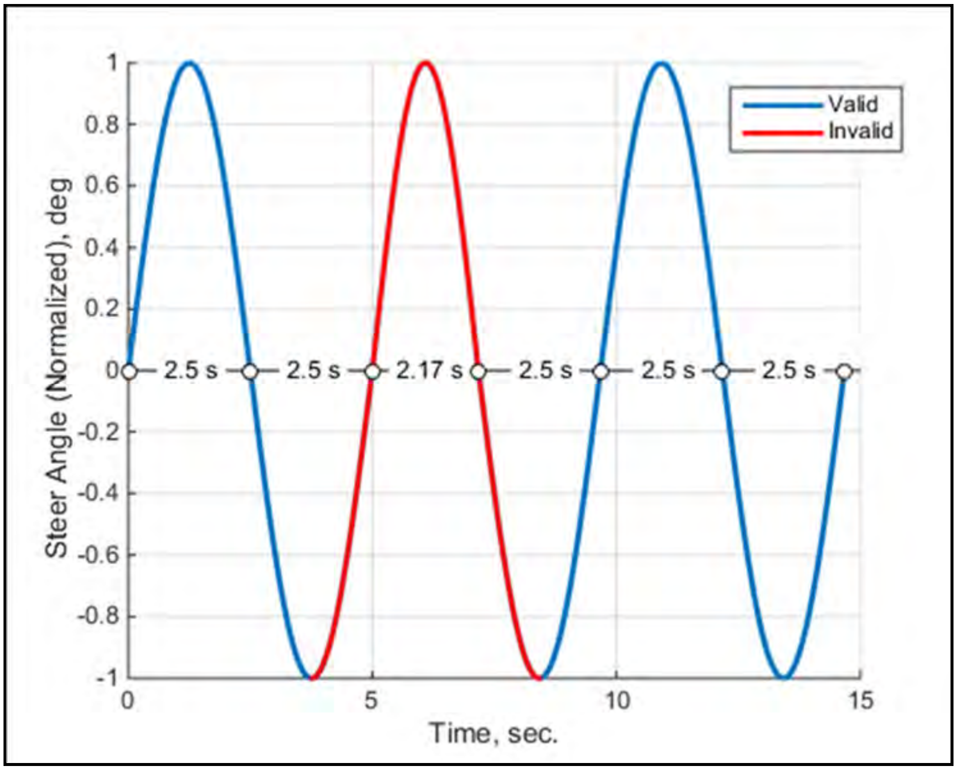

Figure 2. Steer frequency validation method.

(3) Validate peak lateral acceleration for each half-cycle. Lateral acceleration shall be calculated by multiplying yaw rate by vehicle speed and applying appropriate unit conversions. Calculating lateral acceleration instead of using the directly-measured lateral acceleration provides a signal with less noise which is valid for quasi-steady-state maneuvers. The peak lateral acceleration at the end of each half cycle shall be at least 0.15 *g* after filtering, as defined in paragraph 5.1.a. If the peak lateral acceleration is not at least 0.15 *g*, the half-cycle preceding the peak shall be discarded.

(4) Validate steering wheel angular rate through zero steer angle. The ideal steer rate through zero steer angle was identified in paragraph 4.2.b(3) as $0.4*\pi*A$, where 'A' is the amplitude of the sine wave. The variable 'A' shall be determined from the sample set of half-cycles which have passed validation criteria 4.2.c(1) through 4.2.c(3). The variable 'A' is defined as the average of the sample of lateral acceleration peaks as measured at the end of each valid half-cycle. If multiple test scenarios were conducted, such as at several vehicle speeds, the variable 'A' shall be calculated separately for each scenario. For each half cycle, the steering rate through zero steer angle shall be $0.4*\pi*A \pm 0.15*\pi*A$ to provide adequate representation of an ideal sine wave. Also, for each half-cycle, the steering rate through zero steer angle shall be within 15% of the average steering rate through zero steer angle to provide adequate consistency.

(5) Data should be validated in the field using an automated process, particularly if using a human driver for steering control. At least 20 valid half-cycles in each steering direction for each direction of travel on course are needed for analysis, giving a total of 80 valid half cycles. If additional data are to be used, an equal number of half-cycles should be included for each steer direction for each direction of travel on the course.

4.3 Transition Test.

a. Quantify transducer offsets.

(1) Drive the vehicle for a short distance to verify that the steering wheel is pointed straight ahead. Coast the vehicle to a stop on a level surface (± 1% gradient) and record transducer values for at least 15 seconds. Use these data to calculate transducer offsets for the steering wheel angle and torque and vehicle body accelerations and angular rates.

(2) At the start of each test trial maneuver, as the vehicle is traveling at speed, begin recording transducer signals at least 3 seconds prior to the start of the steer maneuver while the vehicle is traveling in a straight line. No steer input should be used (i.e., "hands free"). If possible, at the completion of the maneuver, return the steering to straight ahead and drive the vehicle in a straight line for 3 seconds again, hands free.

b. Execute test maneuver.

(1) The transition test consists of a slowly increasing ramp-steer maneuver, starting from the straight-ahead position. Steer angle is increased in either steer direction at a target angular rate of no greater than 7 deg/s. If the steer ratio of the vehicle is less than 18:1, the maximum target steer rate should be reduced to 5 deg/s. The steer angle is increased for a minimum of three seconds and until the lateral acceleration of the vehicle reaches at least 0.15 *g*. Immediately before and after the maneuver, the steering is positioned straight ahead and the vehicle is driven without driver input, as described in paragraph 4.3.a(2). Vehicle speed shall be held at a constant 64 km/hr (40 mph) by the test driver throughout the maneuver. For additional higher speed testing (if required) the nominal road speed may be increased in increments of 16 km/hr (10 mph) ± 3%, as defined by the test plan.

(2) It is recommended that the transition test be performed by a human driver so that the steering wheel can be truly released (zero-torque) prior to and after the test maneuver.

c. Conduct in-field validation.

(1) Validate vehicle road speed. Vehicle road speed shall be held to within ± 3% of the target road speed. If road speed exceeds this threshold at any time, the test trial shall be discarded.

(2) Validate steering wheel angular rate. The steering wheel angular rate shall be held constant to within ± 20% of the target rate throughout each test trial. If the angular rate exceeds this threshold at any time, the test trial shall be discarded.

(3) Data should be validated in the field using an automated process. At least 20 trials in each steering direction are needed for analysis.

5. DATA REQUIRED.

5.1 Weave Test.

a. Prepare data for plotting and calculation of characteristic values. Prior to analysis, data shall be down-selected to include only valid half-cycles, as outlined in paragraph 4.2.c. Next, data are filtered to attenuate high-frequency signal interference. A 3 Hz, 12-pole, low-pass Butterworth filter is appropriate, but other filters may be used. Data should be filtered prior to resampling, if necessary. Finally, an average steer angle offset is calculated and subtracted from the steer angle. The steer angle is determined for each half-cycle at the time when the calculated lateral acceleration (see paragraph 4.2.c(3)) crosses 0 *g*, using linear interpolation between the positive and negative lateral acceleration values closest to 0 *g* at the last crossing. An average steer angle at 0 *g* is calculated for each steer direction. The left and right average steer angles at 0 *g* are then averaged and this steer offset is subtracted from all steer angle channel values. This procedure effectively “centers” the hysteresis loops on 0 *g* lateral acceleration.

b. Data channel values are plotted in pairs, one against the other. This creates hysteresis loops for three pairs of data which are used to calculate characteristic values. Characteristic values are calculated for each half-steer-cycle separately, creating a sample set of values to perform a statistical analysis. All gradients are calculated using linear regression over the specified range of x-values. Pairs of data and corresponding characteristic values include the following:

(1) Steering wheel angle (SWA) versus lateral acceleration (see Table 1).

(2) Steering wheel torque (SWT) versus lateral acceleration (see Table 2).

(3) SWT versus SWA (see Table 3).

TABLE 1. WEAVE TEST CHARACTERISTIC VALUES REQUIRED, SWA VERSUS LATERAL ACCELERATION

CHARACTERISTIC VALUE	DESCRIPTION
Steering sensitivity at 0 *g*, g/100 degrees	Average gradient over the range: 0 *g*, ± 0.02 *g*
Steering sensitivity at 0.1 *g*, *g*/100 degrees	Average gradient over the range: 0.1 *g*, ± 0.02 *g*
Minimum steering sensitivity, *g*/100 degrees	Minimum average gradient over a ± 0.02 *g* window moved across a range of ± 0.1 *g*.
Lateral acceleration at minimum steering sensitivity, *g*.	Lateral acceleration of the minimum steering sensitivity found above.
Steering sensitivity ratio, unit-less	Minimum steering sensitivity divided by steering sensitivity at 0.1 *g*
Steering hysteresis, degrees	Integral of SWA over the range ± 0.1 *g*, divided by 0.2 *g* (gives average angle over the range)

TABLE 2. WEAVE TEST CHARACTERISITIC VALUES REQUIRED, SWT VERSUS LATERAL ACCELERATION

CHARACTERISTIC VALUE	DESCRIPTION
Lateral acceleration at zero torque, *g*	Lateral acceleration value at 0 SWT
SWT at 0 *g*, Newton meter (N-m) (foot pound (ft-lb))	SWT value at 0 *g* lateral acceleration
SWT at 0.1 *g*, N-m (ft-lb)	SWT value at 0.1 *g* lateral acceleration
SWT gradient at 0 *g*, N-m/*g* (ft-lb/*g*)	Gradient analyzed at 0 *g* ± 0.02 *g* lateral acceleration
SWT gradient at 0.1 *g*, N-m/*g* (ft-lb/*g*)	Gradient anayzed at 0.1 *g* ± 0.02 *g* lateral acceleration

TABLE 3. WEAVE TEST CHARACTERISTIC VALUES REQUIRED, SWT VERSUS SWA

CHARACTERISTIC VALUE	DESCRIPTION
Steering stiffness, N-m/deg (ft-lb/deg)	Average gradient over the range ± x degree, where x = 10% of the peak SWA
Steering torque gradient at zero steer, N-m/deg (ft-lb/deg)	Gradient analyzed at 0 degree ± 10 degree SWA
Steering torque at zero steer, N-m (ft-lb)	SWT value at 0 SWA
Steering angle at zero torque, deg	SWA value at 0 SWT

c. For each characteristic value from paragraph 5.1.b, there is a value for each valid half-cycle. The values should be separated into left and right steering directions. Statistical methods should be used to determine the mean of each characteristic value in each steer direction. At a minimum, data which falls more than two standard deviations from the mean should be discarded from the sample. It may be helpful to plot histograms or 90% confidence intervals of the samples for each characteristic value in addition to presenting the means and standard deviations.

5.2 Transition Test.

a. Prepare data for plotting and calculation of characteristic values. Prior to analysis, data shall be down-selected to include only valid trials, as outlined in paragraph 4.3.c. Next, data are filtered to attenuate high-frequency signal interference. A 3 Hz, 12-pole, low-pass Butterworth filter is appropriate, but other filters may be used. Data should be filtered prior to resampling, if necessary. An average steer angle offset is calculated and subtracted from the steer angle. The average steer angle offset is determined from the initial and ending steering conditions of each test trial. One steer angle offset should be calculated and subtracted from all data for a given test scenario.

b. Data channel values are plotted in pairs, one against the other. This creates a series of traces for three pairs of data which are used to calculate characteristic values. Each trace starts at the last occurrence where the y-value crosses zero on the y-axis. Data prior to this point are discarded for each trace. The data must be fit with a mathematical model to calculate each characteristic value. The arithmetic fit may be comprised of one or two models. An example fit is shown in Figure 3.

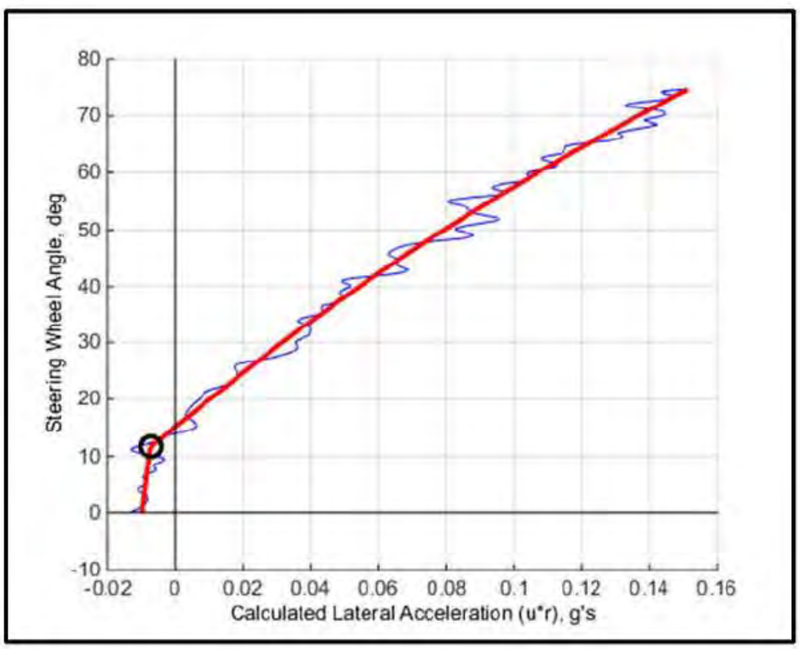

Figure 3. SWA versus lateral acceleration, mathematic fit to data, linear on lower range and spline fit on upper range.

(1) To determine the intersection point between two models, many models are calculated and tested for goodness of fit. This is accomplished by varying the x-value of the transition point, thus affecting the limits used for the calculations of the models over the two resulting regimes. The transition point sets the upper limit for the fit of the first model and the lower limit for the fit on the second model.

(2) For each transition point tested, a fit is calculated for each resulting range of data and the R^2 value of the entire model is calculated. The location of the transition point which creates an R^2 value closest to 1.0 defines the overall model used to analyze the characteristic values. The R^2 calculation is presented in Equation 1.

$$R^2 = 1 - (SS_{res} - SS_{tot}) \qquad \text{Equation 1}$$

$$SS_{res} = \sum\left(y_{meas} - y_{fit}\right)^2$$

$$SS_{tot} = \sum(y_{meas} - \overline{y}_{meas})^2$$

where:

SS_{res} = residual sum of squares
SS_{tot} = total sum of squares
y_{meas} = y values, measured
$\overline{y}_{meas}$ = mean of measured y values
y_{fit} = y values, mathematic model

c. Characteristic values are calculated for each test trial separately, creating a sample set of values to perform a statistical analysis. Pairs of data and corresponding characteristic values include the following:

(1) SWA versus lateral acceleration (see Table 4).

TABLE 4. TRANSITION TEST CHARACTERISTIC VALUES REQUIRED, SWA VERSUS LATERAL ACCELERATION

CHARACTERISTIC VALUE	DESCRIPTION
Steering sensitivity, *g*/100 degrees SWA	Gradient of data fit for each turn direction, reported at 0.02, 0.06, and 0.10 *g*
SWA deadband, degree	SWA at ± 0.06 *g* lateral acceleration

(2) SWT versus lateral acceleration (see Table 5).

TABLE 5. TRANSITION TEST CHARACTERISTIC VALUES REQUIRED, SWT VERSUS LATERAL ACCELERATION

CHARACTERISTIC VALUE	DESCRIPTION
SWT gradient, N-m/*g* (ft-lb/*g*)	Gradient of data fit for each turn direction, reported at 0.02, 0.06, and 0.10 *g*
SWT values, N-m (ft-lb)	SWT values at reference lateral acceleration values, reported at breakaway (transition point in model), 0.02, 0.06, and 0.10 *g*

(3) SWT versus SWA (SEE Table 6).

TABLE 6. TRANSITION TEST CHARACTERISTIC VALUES REQUIRED, SWT VERSUS SWA

CHARACTERISTIC VALUE	DESCRIPTION
Breakaway friction	SWT at breakaway (SWT at transition point in model), SWA at breakaway (SWA at transition point in model), and work to breakaway, N-mm (in-lb) (equivalent to SWA at breakaway times SWT at breakaway times steering wheel radius)
SWT gradient, N-m/degree SWA (ft-lb/degree SWA)	Gradient of data fit for each turn direction, reported at 0.02, 0.06, and 0.10 *g*

d. For each characteristic value from paragraph 5.2.c, there is a value for each valid trial. The values should be separated into left and right steering directions. Statistical methods should be used to determine the mean of each characteristic value in each steer direction. At a minimum, data which falls more than two standard deviations from the mean should be discarded from the sample. It may be helpful to plot histograms or 90% confidence intervals of the samples for each characteristic value in addition to presenting the means and standard deviations.

6. PRESENTATION OF DATA.

6.1 Weave Test.

a. Present overlaid plots for each of the three pairs of data.

(1) SWA versus lateral acceleration (see Figure 4).

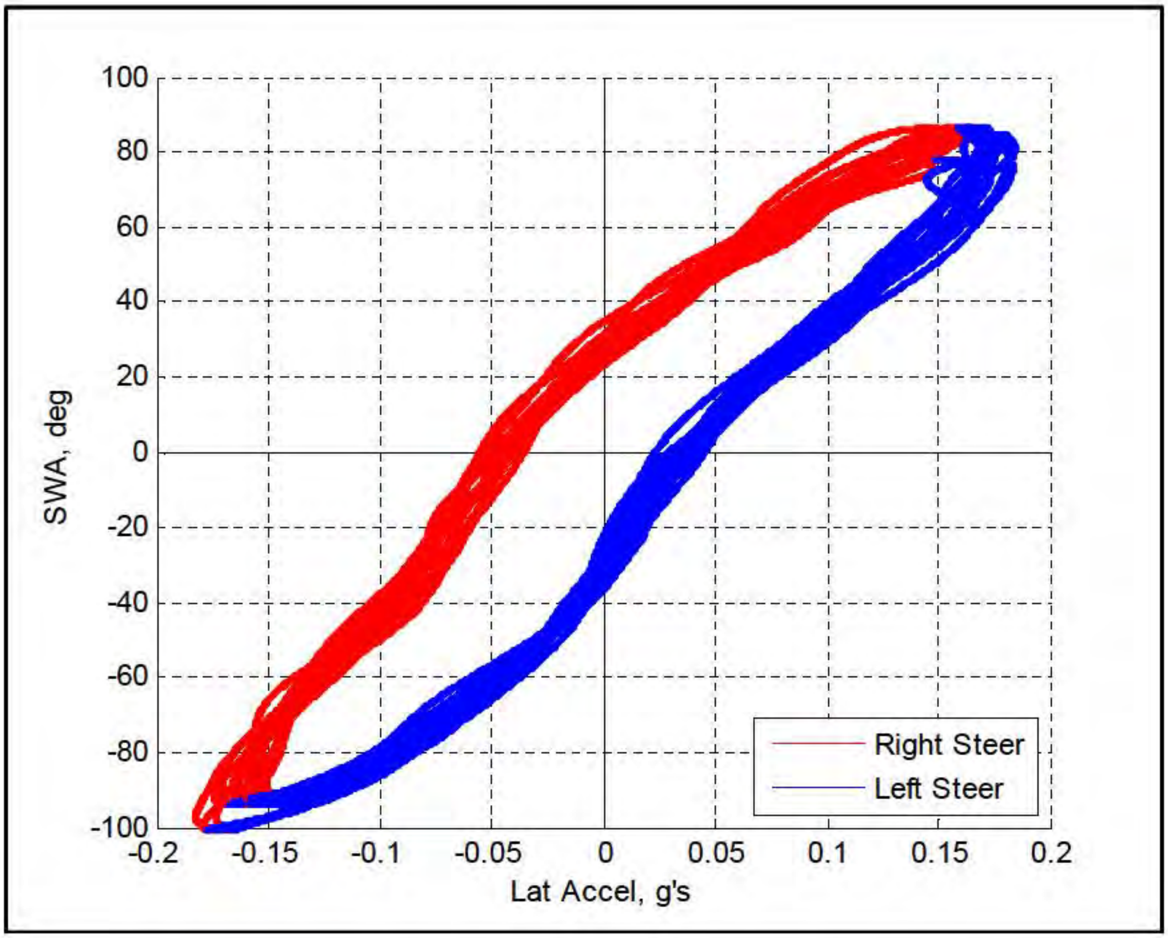

Figure 4. Steering wheel angle versus lateral acceleration, weave test.

(2) SWT versus lateral acceleration (see Figure 5).

(3) SWT versus SWA (see Figure 6).

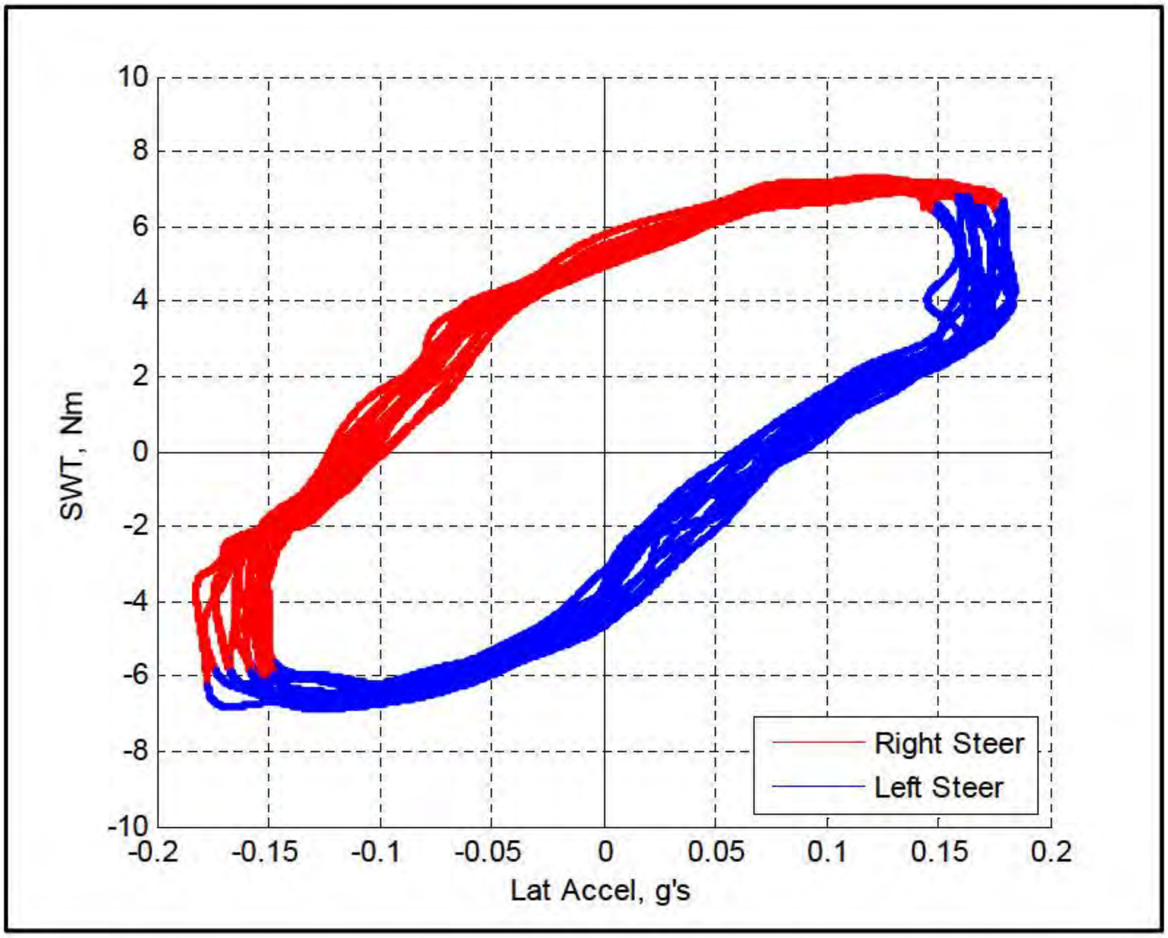

Figure 5. Steering wheel torque versus lateral acceleration, weave test.

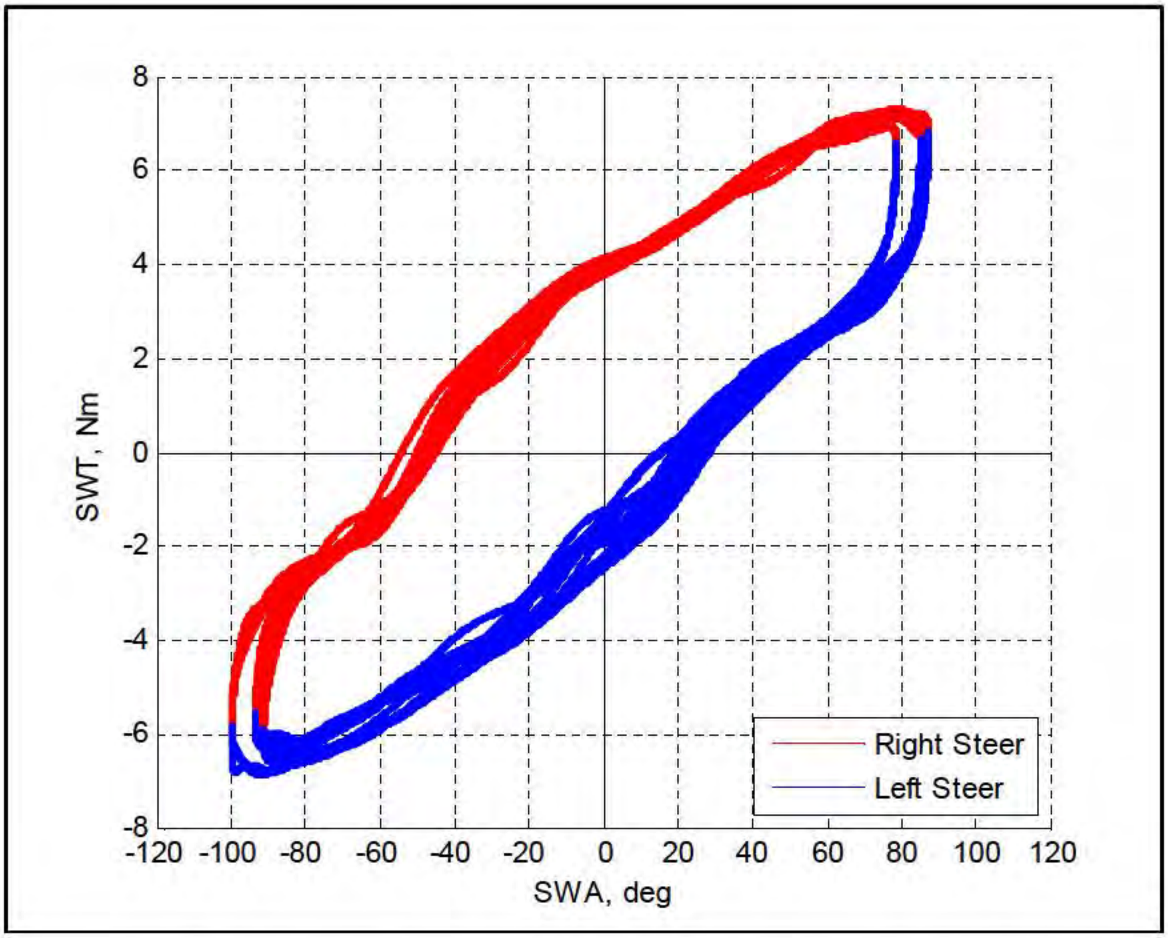

Figure 6. Steering wheel torque versus steering wheel angle, weave test.

b. Present characteristic values in tabular format (see Tables 7, 8, and 9).

TABLE 7. WEAVE TEST RESULTS, SWA VS LATERAL ACCELERATION CHARACTERISTIC VALUES

Segment	SWA versus Lateral Acceleration											
	Steering Sensitivity				Minimum Steering Sensitivity		Lateral Acceleration at Minimum Steering Sensitivity		Minimum Steering Sensitivity Ratio		Steering Hysteresis	
	At 0 g		At 0.1 g									
	g/100 degree SWA						g		(Unitless)		deg	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
1	0.18	0.13	0.26	0.33	0.09	0.12	-0.15	0.18	0.37	0.37	20.84	-26.63
2	0.21	0.11	0.36	0.25	0.09	0.11	-0.15	0.17	0.25	0.45	18.79	-27.72
3	0.22	0.08	0.35	0.30	0.10	0.08	-0.16	0.18	0.29	0.26	18.57	-26.17
4	0.17	0.11	0.38	0.34	0.11	0.11	-0.17	0.17	0.29	0.31	21.01	-25.31
5	0.25	0.09	0.36	0.46[b]	0.12	0.09	-0.17	0.18	0.33	0.19	20.76	-25.85
6	0.22	0.13	0.28	0.28	0.10	0.10	-0.15	0.16	0.37	0.36	22.88	-26.83
7	0.16	0.15	0.25	0.28	0.09	0.11	-0.15	0.17	0.35	0.41	26.25	-26.59
8	0.20	0.13	0.33	0.21	0.08	0.11	-0.15	0.16	0.25	0.51[b]	25.24	-23.89
9	0.24	0.12	0.20	0.25	0.09	0.10	-0.16	0.16	0.45	0.38	24.14	-24.19
10	0.24	0.09	0.27	0.30	0.09	0.08	-0.16	0.16	0.34	0.28	28.05	-21.93
etc…	…	…	…	…	…	…	…	…	…	…	…	…
Mean	0.19	0.12	0.29	0.30	0.10	0.10	-0.15	0.17	0.33	0.32	22.49	-25.33
STD	0.04	0.03	0.05	0.04	0.01	0.01	0.02	0.01	0.06	0.07	2.71	2.12
UprLim[a]	0.25	0.17	0.38	0.37	0.11	0.12	-0.12	0.18	0.43	0.43	26.97	-21.83
LwrLim[a]	0.13	0.08	0.21	0.23	0.08	0.08	-0.18	0.15	0.23	0.21	18.01	-28.83

[a] The upper and lower limit refer to the 90% confidence interval of the mean.

[b] These values were considered outliers and were not considered in the calculation of the mean and standard deviation

TABLE 8. WEAVE TEST RESULTS, SWT VS LATERAL ACCELERATION CHARACTERISTIC VALUES

Segment	SWT versus Lateral Acceleration									
	Lateral Acceleration at 0 SWT		SWT				SWT Gradient			
			At 0 *g*		At 0.1 *g*		At 0 *g*		At 0.1 *g*	
	g		Nm				Nm/g			
	Right	Left	Right	Left	Right	Length	Right	Left	Right	Left
1	-0.10	0.08	5.15	-3.67	6.82	-6.16	23.83	60.02	3.85	6.44
2	-0.10	0.07	4.97	-3.87	6.94	-6.15	23.10	59.64	7.13	3.69
3	-0.10	0.06	5.34	-3.52	6.69	-6.26	27.55	88.92[b]	6.60	5.96
4	-0.11	0.06	5.08	-3.57	6.97	-6.18	30.94	68.17	0.54	-0.59
5	-0.11	0.06	5.13	-3.15	7.15	-6.31	25.18	59.28	7.04	11.00
6	-0.11	0.08	5.24	-4.61	7.16	-6.48	23.90	41.88	3.69	3.44
7	-0.12	0.08	5.40	-4.45	7.21	-6.39	23.38	31.52	2.25	8.87
8	-0.11	0.07	5.33	-4.39	7.21	-6.38	22.72	38.57	8.49	9.36
9	-0.10	0.10	5.01	-4.64	7.24	-6.30	42.00	42.59	-1.77	-15.96[b]
10	-0.08	0.09	4.96	-4.72	7.24	-6.55	38.50	28.54	15.50	-15.49[b]
etc…	…	…	…	…	…	…	…	…	…	…
Mean	-0.10	0.08	5.20	-4.13	7.05	-6.42	28.29	45.86	5.59	7.31
STD	0.01	0.01	0.30	0.51	0.17	0.17	6.50	15.95	5.57	4.45
UprLim[a]	-0.08	0.10	5.78	-3.12	7.39	-6.08	41.04	77.12	16.51	16.02
LwrLim[a]	-0.13	0.06	4.61	-5.13	6.72	-6.76	15.54	14.60	-5.34	-1.40

[a] The upper and lower limit refer to the 90% confidence interval of the mean.

[b] These values were considered outliers and were not considered in the calculation of the mean and standard deviation

TABLE 9. WEAVE TEST RESULTS, SWT VS SWA CHARACTERISTIC VALUES

Segment	SWT versus SWA							
	Steering Stiffness		SWT Gradient at 0 degree SWA		SWT at 0 degree SWA		SWA at 0 SWT	
	Nm/deg				Nm		deg	
	Right	Left	Right	Left	Right	Left	Right	Left
1	0.04	0.04	0.05	0.04	3.99	-1.22	-48.65	22.34
2	0.04	0.04	0.04	0.04	3.92	-1.82	-46.32	20.10
3	0.04	0.05	0.04	0.05	3.95	-1.72	-49.08	17.91
4	0.04	0.09	0.04	0.09	4.07	-1.29	-45.46	15.04
5	0.03	0.11	0.03	0.11	4.01	-1.35	-47.94	14.09
6	0.04	0.07	0.04	0.08	3.81	-2.35	-49.15	26.01
7	0.04	0.06	0.04	0.06	4.04	-2.31	-49.82	27.85
8	0.05	0.07	0.05	0.07	3.98	-2.44	-47.55	26.44
9	0.05	0.06	0.05	0.07	3.93	-2.39	-47.58	26.21
10	0.07	0.08	0.07	0.08	3.69	-3.25	-44.00	45.09[b]
etc…	…	…	…	…	…	…	…	…
Mean	0.05	0.07	0.05	0.07	3.84	-2.14	-46.24	24.66
STD	0.02	0.03	0.02	0.02	0.34	0.66	5.79	6.94
UprLim[a]	0.08	0.11	0.08	0.11	4.40	-1.04	-36.69	36.11
LwrLim[a]	0.02	0.03	0.02	0.03	3.29	-3.24	-55.79	13.22

[a] The upper and lower limit refer to the 90% confidence interval of the mean.

[b] These values were considered outliers and were not considered in the calculation of the mean and standard deviation

6.2 Transition Test.

a. Present sample plots for each of the three pairs of data.

(1) SWA versus lateral acceleration (see Figure 7).

(2) SWT versus lateral acceleration (see Figure 8).

(3) SWT versus SWA (see Figure 9).

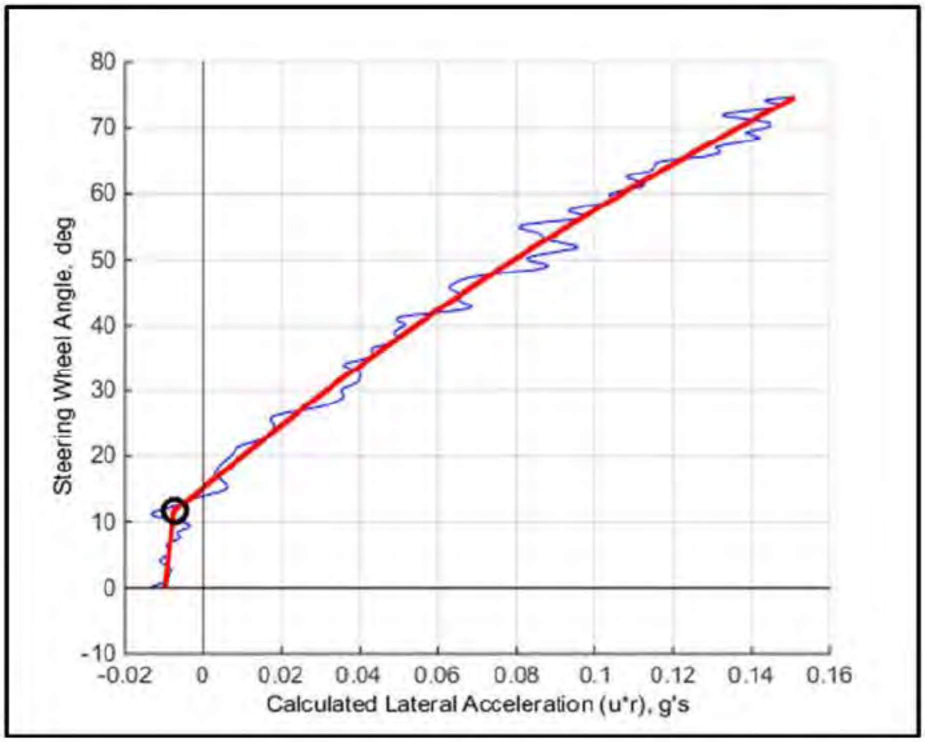

Figure 7. Steering wheel angle versus lateral acceleration, transition test.

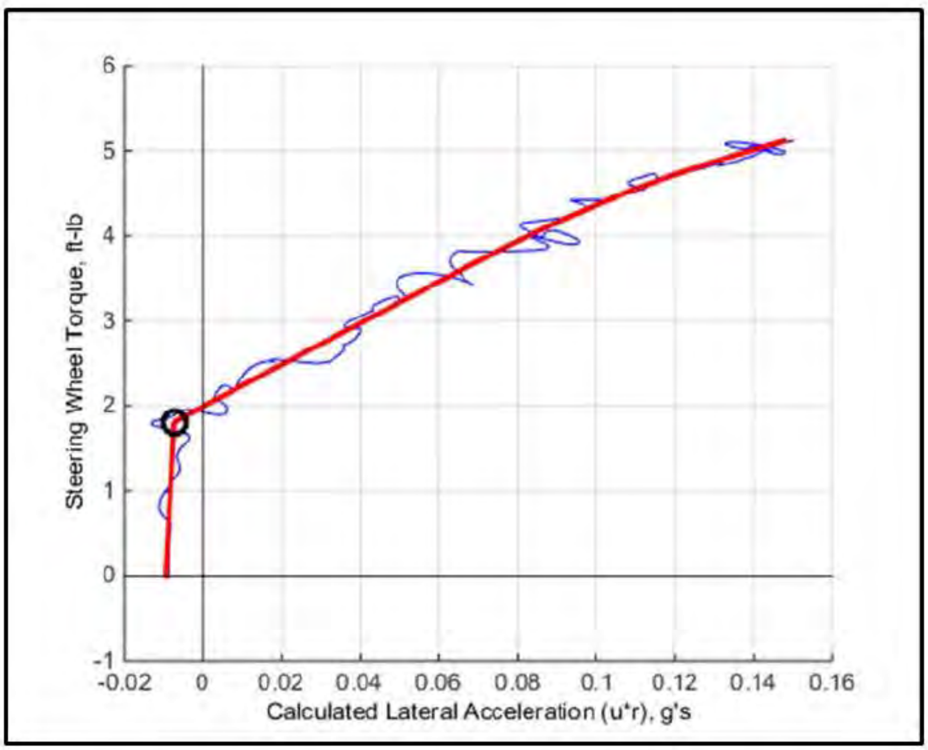

Figure 8. Steering wheel torque versus lateral acceleration, transition test.

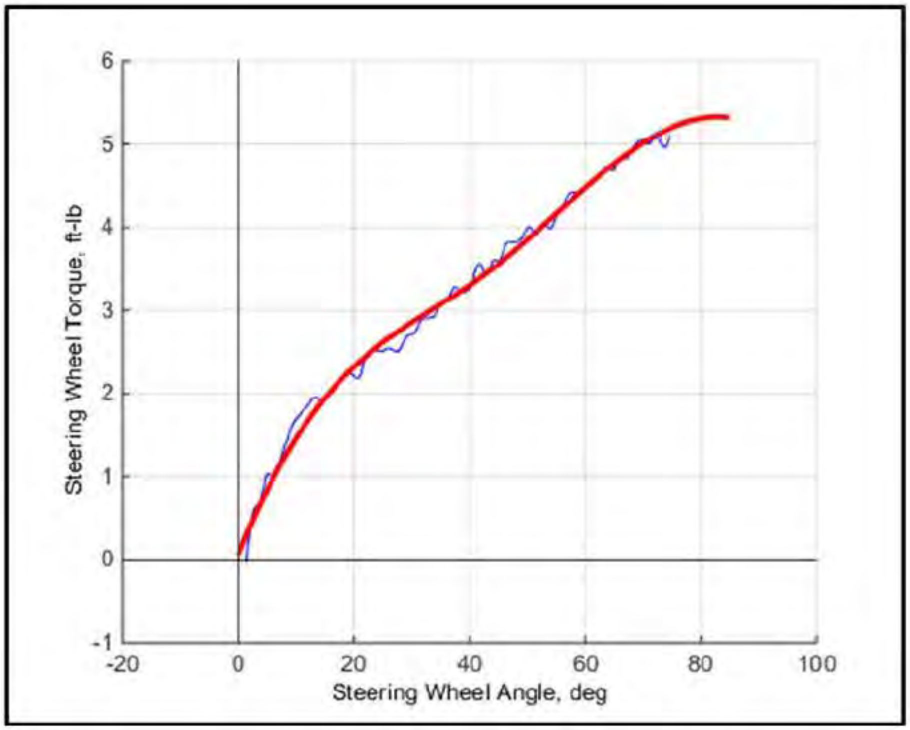

Figure 9. Steering wheel torque versus steering wheel angle, transition test

b. Present characteristic values in tabular format (see Tables 10, 11, and 12).

TABLE 10. TRANSITION TEST RESULTS, SWA VERSUS LATERAL ACCELERATION CHARACTERISTIC VALUES

File	SWA vs Lateral Acceleration			
	Steering Sensitivity			SWA
	At 0.02 *g*	At 0.06 *g*	At 0.10 *g*	Dead-band
	g/100 degree SWA			degree
Right Steer				
1	0.22	0.24	0.29	41.54
2	0.21	0.24	0.28	42.39
3	0.21	0.24	0.31	43.14
4	0.22	0.24	0.28	43.82
5	0.21	0.26	0.29	44.94
6	Infinity[b]	0.25	0.26	44.17
7	Infinity[b]	0.21[b]	0.24[b]	42.82
8	0.22	0.24	0.29	41.54
9	0.21	0.24	0.28	42.39
10	0.21	0.24	0.31	43.14
etc…	…	…	…	…
Mean	0.22	0.24	0.29	43.02
STD	0.01	0.01	0.02	1.07
Upper Limit[a]	0.23	0.26	0.32	45.12
Lower Limit[a]	0.20	0.22	0.26	40.92

[a] The upper and lower limit refer to the 90% confidence interval of the mean.

[b] These values were considered outliers and were not considered in the calculation of the mean and standard deviation.

TABLE 11. TRANSITION TEST RESULTS, SWT VERSUS LATERAL ACCELERATION CHARACTERISTIC VALUES

File	SWT vs Lateral Acceleration						
	Steering Wheel Torque Gradient			Steering Wheel Torque			
	At 0.02 *g*	At 0.06 *g*	At 0.10 *g*	Break-away	At 0.02 *g*	At 0.06 *g*	At 0.10 *g*
	ft-lb/g			ft-lb			
Right Steer							
1	22.38	21.11	17.61	1.14	2.65	3.47	4.26
2	24.49	24.50	18.71	1.81	2.55	3.54	4.43
3	21.54	28.63	16.53	1.25	1.75	2.91	3.72
4	25.24	25.93	19.97	1.83	2.74	3.71	4.71
5	22.61	20.83	17.84	1.72	2.93	3.51	4.42
6	0.00[b]	23.63	19.84	1.97	0.00[b]	3.64	4.58
7	0.00[b]	25.20	21.62[b]	1.66	-0.01[b]	3.44	4.20
8	22.38	21.11	17.61	1.14	2.65	3.47	4.26
9	24.49	24.50	18.71	1.81	2.55	3.54	4.43
10	21.54	28.63	16.53	1.25	1.75	2.91	3.72
etc…	…	…	…	…	…	…	…
Mean	20.99	24.56	18.42	1.56	2.23	3.43	4.31
STD	7.31	2.81	1.45	0.31	0.86	0.28	0.34
Upper Limit[a]	35.33	30.07	21.26	2.17	3.91	3.99	4.97
Lower Limit[a]	6.65	19.04	15.58	0.94	0.55	2.87	3.64

[a] The upper and lower limit refer to the 90% confidence interval of the mean.

[b] These values were considered outliers and were not considered in the calculation of the mean and standard deviation.

TABLE 12. TRANSITION TEST RESULTS, SWT VERSUS SWA CHARACTERISTIC VALUES

File	SWT vs SWA					
	SWT	SWA	Work	SWT Gradient		
	Breakaway			At 0.02g	At 0.06g	At 0.10g
	ft-lb	degree	in-lb	ft-lb/degree SWA		
Right Steer						
1	1.14	4.66	12.21	0.06	0.04	0.05
2	1.81	13.44	56.03	0.06	0.05	0.06
3	1.25	12.46	35.84	0.06	0.05	0.06
4	1.83	12.99	54.89	0.07	0.05	0.06
5	1.72	10.02	39.70	0.05	0.04	0.06
6	1.97	14.69	66.86	0.00[b]	0.05	0.06
7	1.68	13.15	50.82	0.00[b]	0.04	0.06
8	1.14	4.66	12.21	0.06	0.04	0.05
9	1.81	13.44	56.03	0.06	0.05	0.06
10	1.25	12.46	35.84	0.06	0.05	0.06
etc…	…	…	…	…	…	…
Mean	1.56	11.10	41.65	0.06	0.05	0.06
STD	0.32	3.47	17.56	0.02	0.01	0.00
Upper Limit[a]	2.18	17.91	76.06	0.09	0.06	0.07
Lower Limit[a]	0.94	4.30	7.24	0.02	0.04	0.05

[a] The upper and lower limit refer to the 90% confidence interval of the mean.

[b] These values were considered outliers and were not considered in the calculation of the mean and standard deviation.

APPENDIX A. GLOSSARY.

Term	Definition
Anti-aliasing filter	A filter used before a signal sampler to restrict the frequency bandwidth of a signal.
Camber	The inclination of a wheel outward from the body in the lateral plane.
Caster	The inclination of the steer rotation axis in the longitudinal plane.
Gradient	A change in the quantity of one variable as a result of, and normalized by, a change in the quantity of another. When a dependent variable is plotted against an independent variable, the gradient at any given point on the plot is equal to the slope of the trace at that point.
Toe	The symmetrical angle about the steer rotation axis of the front wheels, inward from parallel.
Transducer offset	A value applied to transducer measurements to account for scalar error.

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APPENDIX B. ABBREVIATIONS.

A	amplitude
AEC	U.S. Army Evaluation Center
ATC	U.S. Army Aberdeen Test Center
C	Celsius
CG	center of gravity
deg/s	degree per second
ft-lb	foot pound
HRPP	Human Resource Protection Plan
Hz	Hertz
ISO	International Organization for Standardization
km	kilometer
km/hr	kilometers per hour
m	meter
m/s	meters per second
mph	miles per hour
N-m	Newton meter
psi	pounds per square inch
RWS	Roadway Simulator
SAE	Society of Automotive Engineers
SR	Safety Release
SWA	steering wheel angle
SWT	steering wheel torque
TOP	Test Operations Procedure
TSARC	Test Schedule and Review Committee
YTC	U.S. Army Yuma Test Center

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APPENDIX C. REFERENCES.

For information only (related publications).

a. International Organization for Standardization (ISO) 13674-1, Road vehicles - Test method for the quantification of on centre handling - Part 1: Weave test, 15 May 2010.

b. ISO 13674-2, Road vehicles - Test method for the quantification of on centre handling - Part 2: Transition test, 1 December 2006.

c. Society of Automotive Engineers (SAE) J670, Vehicle Dynamics Terminology, January 2008.

d. “Fundamentals of Vehicle Dynamics”, Thomas D. Gillespie, SAE International, February 1992.

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APPENDIX D. APPROVAL AUTHORITY.

CSTE-TM 29 July 2015

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) 02-2-600, Steering Performance, Tactical Vehicles, Approved for Publication

1. TOP 02-2-600, Steering Performance, Tactical Vehicles, 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:

The procedures in this TOP describe standardized methods for analyzing the on-center steering performance of wheeled vehicles. Standardized means are required to characterize the on-center vehicle responses of military vehicles for the purposes of influencing vehicle design and ensuring military truck steering systems are well made and consistent with modern industry practices.

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.

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RAYMOND G. FONTAINE
Associate Director, Test Management Directorate (G9)

FOR

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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), U.S. Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Automotive Instrumentation Division (TEDT-AT-AD-I), U.S. Army Aberdeen Test Center, 400 Colleran Road, Aberdeen Proving Ground, Maryland 21005-5059. Additional copies can be requested through the following website: http://www.atec.army.mil/publications/topsindex.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.