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SURFACE VEHICLE RECOMMENDED PRACTICE

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Free-Rolling Cornering Test For Truck Tires

1. ***Scope***—This SAE Recommended Practice describes a test method for determination of steady-state heavy truck (Class VI, VII, and VIII) tire force and moment properties under free-rolling conditions. The properties are acquired as functions of incrementally changed slip angle and normal force using a sequence specified in this document. The data are suitable for use in vehicle dynamics modeling, comparative evaluations for research and development purposes, and manufacturing quality control.

1.1 **Truck Tires**—For the purposes of this document, truck tires are defined as being the tires mounted on all heavy commercial over-the-road trucks and buses. Examples of vehicles which use heavy truck tires include: tractor/semi-trailer combinations, dump trucks, school buses, etc. Tires mounted on other types of lighter GVWR vehicles are explicitly excluded from consideration in this document.

1.2 **Effects Not Considered**—The effects of inclination angle and spindle torque or any combination of inclination and spindle torque with slip angle and normal force are not considered in this document.

1.3 **Test Machines**—This document is test machine neutral. It may be applied using any type of test machine capable of fulfilling the requirements stated in this document. By way of example, specific data used in support of various parts of this document came from both an indoor flat-belt type machine and outdoor over-the-road dynamometer. This document does not require a machine to match the ideal machine, but does require that a test machine's performance be fully defined over its range of application. In this document, an ideal is a goal not a requirement.

1.3.1 IDEAL MACHINE—An ideal machine is a machine which is capable of fully matching every item in this document. Such a machine neither exits at the time this document was written nor is it certain that the technology to build such a machine exists at this time.

2. References

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated the latest revision of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

CRP-11—Truck Tire Characterization, December, 1995

SOW 1.2.1 Final Report, M. G. Pottinger, August 7, 1994.
Straight-Line Braking Test for Heavy Duty Truck tires, M. G. Pottinger, G. A. Tapia, C. B. Winkler, W. Pelz, ACS Mtg., 10/17-1995.
Recommended Test Sample Sizes (SOW 1.5) and The CALSPAN/UMTRI Comparison (SOW 3.0), SAE CRP-11, M. G. Pottinger, W. Pelz, July 30, 1994.

SAE J670e—Vehicle Dynamics Terminology
SAE 760029—Effects of Test Speed and Curvature on Cornering Properties of Tires, M. G. Pottinger, K. D. Marshall, and G. A. Arnold, 1976.
SAE 770870—The Effect of Tire Break-in on Force and Moment Properties, K. D. Marshall, R. L. Phelps, M. G. Pottinger, and W. Pelz, 1977.
SAE 810066—The Effect on Aging on Force and Moment Properties of Radial tires, M. G. Pottinger and K. D. Marshall
SAE 960180—A Model for Combined Cornering and Braking Forces, D. J. Schuring, W. Pelz, M. G. Pottinger.

2.1.2 TIRE AND RIM ASSOCIATION PUBLICATIONS—Available from the Tire and Rim Association, Copley, OH 44321-2793.

Tire and Rim Association Handbook

2.2 Other Publications

OSHA Standard 1910.77—Available in wall chart form as #TTMP-7/95 from the Rubber Manufacturers Association, 1400 K St., N.W., Washington, DC 20005.

3. Definitions—The definitions which follow are of special meaning in this document and are either not contained in other documents or are worded somewhat differently in this document.

3.1 Test—Execution of the procedure described in this document one time on one tire.

3.2 Test Program—A designed experiment involving a set of the tests described in this document.

4. ***Nomenclature*—**Table 1 lists the symbols used in this document.

TABLE 1—SYMBOLS DEFINED

Symbol	Defined Term
α	Slip Angle
C	Force and Moment Interaction Matrix
F_{ACT}	Force and Moment Corrected for Interactions
F_{SEN}	Force and Moment Sensed by Measuring System
F_X	Longitudinal Force
F_Y	Lateral Force
F_Z	Normal Force
γ	Inclination Angle
M_X	Overturning Moment
M_Z	Aligning Moment
p	Inflation Pressure
R_1	Loaded Radius
S	Test Speed
T_A	Ambient Temperature

5. *Apparatus*

5.1 Laboratory Machines—A laboratory machine for performing truck tire force and moment testing according to this document is comprised of three systems: a simulated roadway, a loading and positioning system, and a measuring system. Table 2 specifies the applicable setting accuracies with respect to test speed, loading, and positioning plus ideal control setting rates.

TABLE 2—LABORATORY MACHINE CONTROL SETTING ACCURACIES AND IDEAL RATES

Setting	Least Acceptable Setting Accuracy SI Units	Least Acceptable Setting Accuracy USC Units
Test Speed	±1.0 km/h	±0.6 mph
Normal Force	±1% of Full Scale	±1% of Full Scale
Slip Angle	±0.05 degree	±0.05 degree
Inclination Angle(1)	±0.05 degree	±0.05 degree
Rate	Ideal Maximum Rate	
Normal Force	≥ 8900 N/s	≥ 2000 lb/s
Slip Angle	≥ 5 degrees/s	≥ 5 degrees/s
Inclination Angle(1)	≥ 1 degree/s	≥ 1 degree/s

1. Inclination Angle (γ) is not required and is not used in this document. It is provided should anyone desire to build a machine for more general tests.

5.1.1 SIMULATED ROADWAY—The simulated roadway shall be a surface coated with an abrasive material. The abrasive material shall exhibit essentially stable frictional properties over a useful period of time as confirmed by a control tire testing procedure such as the example included in Section 7, Preparation of Apparatus. The roadway shall be maintained free of loose materials and deposits.

NOTE—The proper frictional characteristics for the simulated road surface and the change of the frictional characteristics with time (surface endurance) are not now defined. These are subjects which should be resolved through research prior to the 5-year renewal of this document.

5.1.1.1 The roadway shall be wide enough to support the entire tire footprint. Ideally, the active width would be 800 mm (31.5 in) to insure that the widest envisioned tire (605/70R20.5) could be tested.

5.1.1.2 The roadway and its supporting structure shall be sufficiently rigid so as to not change appreciably in either transverse or longitudinal curvature or angular orientation under the maximum test loads applied in this document.

5.1.1.3 The roadway shall preferably be flat or, if curved, have a very small curvature, large radius (radius > 1.52 m (60 in)), as roadway curvature distorts tire force and moment properties (SAE 760029).

5.1.1.4 The drive system shall be capable of operating the roadway at the test speed, S. An ideal drive system would permit speeds between 10 and 120 km/h (6 and 75 mph). Test speed affects tire force and moment data (SAE 760029). Therefore, it is desirable to specify test speed, S, as realistically as possible consistent with the test machine's capabilities.

5.1.1.5 Temperature shall be maintained within the allowable ambient temperature, T_A, range specified in Section 8, Selection and Preparation of Test Tire and Section 9, Test Procedure. Ambient temperature affects tire temperature and tire temperature affects tire force and moment data (SAE 770870).

5.1.2 LOADING AND POSITIONING SYSTEM—The system positions the tire with respect to the roadway and loads it against the roadway surface at the normal forces, F_z, specified in Section 9 of this document, Test Procedure. The system shall accommodate the tire sizes to be tested.

5.1.2.1 The loading and positioning system shall accommodate tire-wheel-assemblies with diameters and widths required by users. An ideal system would accommodate rims from 6.00X15 to 20.00X24.5 allowing testing of tires between 800 mm and 1350 mm (31.5 to 55.0 in) in outside diameter with section widths up to 635 mm (25.0 in).

5.1.2.2 The loading mechanism shall be able to exert the normal forces required by the Test Procedure, Section 9, for the tire sizes to be tested. An ideal loading system would be able exert normal forces magnitudes of up to 140 kN (31 500 lb).

5.1.2.3 The positioning system and its supporting structure shall provide a slip angle, α. It shall, as a minimum, permit incremental setting of slip angles from –7 degrees to +7 degrees. An ideal slip angle setting system would be able to continuously set slip angles from –15 degrees to +15 degrees at a minimum.

5.1.2.4 If inclination angle, γ, setting capability is provided, the positioning system and its supporting structure shall be as a minimum permit incremental setting of inclination angles from –5 degrees to +5 degrees. An ideal inclination angle setting system would be able to continuously set inclination angles from –15 degrees to +10 degrees.

5.1.3 MEASURING SYSTEM—The measuring system shall be capable of measuring these data at a minimum: aligning moment (M_z), lateral force ($F\gamma$), roadway speed (S), and slip angle (α). The individual results for all channels shall be corrected for tare. Interactions shall be corrected by a matrix method. Section 6, Calibration, provides a matrix correction example for a machine capable of measuring three forces and two moments.

The ideal measuring system should be capable of measuring these data: aligning moment (M_z), ambient temperature (T_A), inclination angle (γ), (if the positioning system permits tire inclination), inflation pressure (p), lateral force (F_y), loaded radius (R_1), longitudinal force (F_x), normal force (F_z), overturning moment (M), roadway speed (S), and slip angle (α). The individual results for all channels should be corrected for tare. Interaction should be corrected by a matrix method. Section 6, Calibration, provides a matrix correction example.

5.1.3.1 The range of measurement for each individual channel must include the expected result range for the test tire in questions when tested according to Section 9, Test Procedure. Table 3 provides a set of ranges consistent with the ideal capacities of the roadway and loading and positioning systems expressed in this document.

TABLE 3—MEASURING SYSTEM IDEAL RANGES

Measurement(1)	Full Scale Range SI Units	Full Scale Range USC Units
Aligning Moment	0 ± 11 kN·m	0 ± 8.100 ft-lb
Ambient Temperature(2)	10 to 35 °C	50 to 95 °F
Inclination Angle(2)	0 ± 10 degrees	0 ± 10 degrees
Inflation Pressure(2)	0 to 1050 kPa	0 to 150 psi
Lateral Force	0 ± 140 kN	0 ± 31 500 lb
Loaded Radius(2)	350 mm to 675 mm	14.5 in to 27.5 in
Longitudinal Force(2),(3)	0 ± 140 kN	0 ± 31 500 lb
Normal Force	0 to 140 kN	0 to 31 500 lb
Overturning Moment(2),(3)	0 ± 33 kN·m	0 ± 24 300 ft-lb
Slip Angle	0 ± 15 degrees	0 ± 15 degrees
Test Speed	0 to 120 kph	0 to 75 mph

1. Overturning Moment (M_g) is not required and is not specified in this document.
2. These measurements are recommended for an ideal machine.
3. These measurements are needed in a single machine built to perform all types of tests.

5.1.3.2 The measurement accuracy for each channel shall be equal to or better than that listed in Table 4.

TABLE 4—LABORATORY MACHINE MEASURING SYSTEM ACCURACIES

Measurement	Accuracy(1)
Aligning Moment	±0.5% of Full Scale
Ambient Temperature(2)	±0.5 °C (± 1.0 °F)
Inclination Angle(2)	±0.02 degree
Inflation Pressure(2)	±3.5 kPa (± 0.50 psi)
Lateral Force	±0.5% of Full Scale
Loaded Radius(2)	±0.5 mm (± 0.020 in)
Longitudinal Force(2),(3)	±0.5% of Full Scale
Normal Force	±0.5% of Full Scale
Overturning Moment(2), (3)	±0.5% of Full Scale
Slip Angle	±0.02 degree
Test Speed	±0.5% of Full Scale

1. This applies to a single sample with loading of only the measurement channel being examined.
2. These measurements are recommended for an ideal machine.
3. These measurements are needed in a single machine built to perform all types of tests.

5.1.3.3 The A/D converters used must have a 12 bit or greater resolution.

5.2 Over-the-Road Machines—An over-the-road machine for performing truck tire force and moment testing according to this document is comprised of three systems: a mobility system, a loading and positioning system, and a measuring system. Table 5 specifies the applicable setting accuracies with respect to test speed, loading, and positioning, plus ideal control setting rates.

TABLE 5—OVER-THE-ROAD MACHINE CONTROL SETTING ACCURACIES AND IDEAL RATES

Setting	Least Acceptable Setting Accuracy USC Units	Least Acceptable Setting Accuracy SI Units
Test Speed	±10% of Full Speed	±10% of Full Speed
Normal Force	±3% of Full Scale	±3% of Full Scale
Slip Angle	±0.10 degree	±0.10 degree
Inclination Angle[1]	±0.10 degree	±0.10 degree
Rate	Ideal Maximum Rate	
Normal Force	≥ 8900 N/s	≥ 2000 lb/s
Slip Angle	≥ 5 degrees/s	≥ 5 degrees/s
Inclination Angle[1]	≥ 1 degree/s	≥ 1 degree/s

1. Inclination Angle (g) is not required and is not used in this document. It is provided should anyone desire to build a machine for more general tests.

NOTE— The road surface chosen to be the test surface is fundamental in this experiment. It is not discussed as a separate section as in the case of the laboratory test machine. However, test surface frictional characteristics should be defined within the context of the friction spectrum of highways. Further, the question of the change in the frictional characteristics with time (surface endurance) should be investigated. These are subjects which should be resolved through research prior to the 5-year renewal of this document.

5.2.1 MOBILITY SYSTEM—The mobility system shall be capable of moving the loading and positioning system over the test road at the test speed specified by the test engineer. An ideal mobility system would permit speeds between 10 and 120 km/h (6 and 75 mph). Test speed affects tire force and moment data (SAE 760029). Therefore, it is desirable to specify test speed as realistically as possible consistent with the test machine's capabilities.

5.2.2 LOADING AND POSITIONING SYSTEM—The system positioning the tire with respect to the road and loads it against the road surface at the normal forces specified in Section 9, Test Procedure. The system shall accommodate the tire sizes to be tested.

5.2.2.1 The loading and positioning system shall accommodate tire-wheel-assemblies with diameters and widths required by users. An ideal system would accommodate rims from 6.00X15 to 20.00X24.5 allowing testing of tires between 800 mm to 1350 mm (31.5 in to 55.0 in) in outside diameter with section widths up to 635 mm (25.0 in).

5.2.2.2 The loading mechanism shall be able to exert the normal forces required by the Test Procedure, Section 9, for the tire sizes to be tested. An ideal loading system would be able to exert normal force magnitudes of up to 140 kN (31 500 lb).

5.2.2.3 The positioning system and its supporting structure shall, as a minimum, permit incremental setting of slip angles from –7 degrees to +7 degrees. An ideal slip angle setting system would be able to continuously set slip angles from –15 degrees to +15 degrees at a minimum.

5.2.2.4 If inclination angle setting capability is provided, the positioning system and its supporting structure shall as a minimum permit incremental setting of inclination angles from –5 degrees to +5 degrees. An ideal inclination angle setting system would be able to continuously set inclination angles from –10 degrees to +10 degrees.

5.2.3 MEASURING SYSTEM—The measuring system shall be capable of measuring these data at a minimum: aligning moment (M_z), lateral force (Fγ), normal force, (F_z), test speed (S), and slip angle (α). The individual results for all channels shall be corrected for tare. Interactions shall be corrected by a matrix method. Section 6, Calibration, provides a matrix correction example for a machine capable of measuring three forces and two moments.

The ideal measuring system should be capable of measuring these data: aligning moment (M_z), ambient temperature (T_A), inclination angle (γ), (if the positioning system permits tire inclination), inflation pressure (p), lateral force (F_y), loaded radius (R_1), longitudinal force (F_x), normal force (F_z), overturning moment (M_x), test speed (S), and slip angle (α). The individual results for all channels should be corrected for tare. Interactions should be corrected by a matrix method. Section 6, Calibration, provides a matrix correction example for three forces and two moments.

5.2.3.1 The range of measurement for each individual channel must include the expected result range for the test tire in question when tested according to Section 9, Test Procedure. Table 3 provides a set of ranges consistent with the ideal capacities loading and positioning systems expressed in this document.

5.2.3.2 The measurement accuracy for each channel shall be equal to or better than that listed in Table 6.

TABLE 6—LABORATORY MACHINE MEASURING SYSTEM ACCURACIES

Measurement	Accuracy[1]
Aligning Moment	±1.0% of Full Scale
Ambient Temperature[2]	±0.5 °C (±1.0 °F)
Inclination Angle[2]	±0.05 degree
Inflation Pressure[2]	±3.5 kPa (±0.50 psi)
Lateral Force	±1.0% of Full Scale
Loaded Radius[2]	±1.0 mm (±0.040 in)
Longitudinal Force[2],[3]	±1.0% of Full Scale
Normal Force	±1.0% of Full Scale
Overturning Moment[2],[3]	±1.0% of Full Scale
Slip Angle	±0.05 degree
Test Speed	±0.5% of Full Scale

1. This applies to a single sample with loading of only the measurement channel being examined.
2. These measurements are recommended for an ideal machine.
3. These measurements are needed in a single machine built to perform all types of tests.

5.2.3.3 The A/D converters used must have a 12 bit or greater resolution.

6. Calibration

6.1 Transducer Calibration—Calibrate all transducers according to a standard written procedure specific to the test machine being calibrated. This procedure shall exercise the components of the measuring system, Table 3, over substantially the full measurement range possible on the test machine being calibrated. This procedure shall allow statistically valid examination of the calibration results.

6.1.1 CALIBRATION FIXTURES—Calibration fixtures are specific to the test machine being calibrated. The design and physical attachments of the fixtures shall be documented in writing supported by necessary drawing and photographs.

6.1.2 CALIBRATION REFERENCE STANDARDS—Standard reference load cells, dead weights, pressure transducers or gauges, height gauges, thermometers, speed sensors, and fundamental angle references shall be traceable to the National Institute of Standards and Technology. There shall be currently valid calibration certificates for all the calibration reference standards used on file within the testing laboratory's files at the time a calibration is conducted.

6.1.2.1 Reference load cells used for calibration of the force and moment components of the measuring systems specified in Table 3 shall be calibrated according to a dead weight procedure using Class F weights.

6.1.2.2 The height gauge used for calibrating the loaded radius transducers in Tables 3, 4, and 6 shall be accurate to ±0.025 mm (±0.0010 in) over the range of loaded radii measurable on the test machine.

6.1.2.3 Angle references used for calibrating slip angle transducers and inclination angle transducers, if fitted, shall have angular accuracies of ±0.01 degree or better.

6.1.3 CALIBRATION PROCEDURE

NOTE—The basic concept presented is to be used. However, the example matrices for load cell interactions are precisely applicable only to a three force and two moment system.

6.1.3.1 Simulated tire forces and moments shall be applied to the measuring system force and moment measuring components using reference load cells or optional deadweights traceable to NIST. Equation 1 represents the calibration process. The component gains, Table 7, and the inverse of the associated interaction matrix, C^{-1}, are developed. Inversion of C^{-1} yields the interaction matrix, C, Table 8. Equation 2 shows the practical use of the matrix. Table 9 gives the units for the components of the interaction matrix.

$$F_{SEN} = C^{-1}F_{CAL} \quad \text{(Eq. 1)}$$

$$F_{ACT} = CF_{SEN} \quad \text{(Eq. 2)}$$

TABLE 7—UNITS OF FORCE AND MOMENT GAINS

Type of Measurement	Gain(1) SI Units	Gain(1) USC Units
Force	N_{SEN}/N_{CAL}	$lb._{SEN}/lb._{CAL}$
Moment	$N{\cdot}m_{SEN}/N{\cdot}m_{CAL}$	$ft\text{-}lb_{SEN}/fg\text{-}lb_{CAL}$

1. Offsets are handled through tare readings.

TABLE 8—LAYOUT OF INTERACTION MATRIX C

ACTUAL	SENSED F_x	SENSED F_y	SENSED F_z	SENSED M_x	SENSED M_z
F_x	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
F_y	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}
F_z	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}
M_x	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}
M_z	C_{51}	C_{52}	C_{53}	C_{45}	C_{55}

TABLE 9—UNITS FOR INTERACTION MATRIX TERMS

Units SI	Units USC	Matrix Terms	Matrix Terms	Matrix Terms
N_{ACT}/N_{SEN}		C_{11} C_{21} C_{31}	C_{12} C_{22} C_{32}	C_{13} C_{23} C_{33}
$N{\cdot}m_{ACT}/N_{SEN}$	$ft\text{-}lb_{ACT}/lb_{SEN}$	C_{41} C_{51}	C_{42} C_{52}	C_{43} C_{53}
$N_{ACT}/N{\cdot}m_{SEN}$	$lb_{ACT}/ft\text{-}lb_{SEN}$	C_{14} C_{24} C_{34}	C_{15} C_{25} C_{35}	
$N{\cdot}m_{ACT}/N{\cdot}m_{SEN}$	$ft\text{-}lb_{ACT}/ft\text{-}lb_{SEN}$	C_{44} C_{54}	C_{45} C_{55}	

6.1.3.2 The pressure measuring system shall be calibrated using a hydrostatic calibrator to determine its gain, kPa_{SEN}/kPa_{CAL} (psi_{SEN}/psi_{CAL}), and offset, kPa (psi).

6.1.3.3 The loaded radius measuring system shall be calibrated using a height gauge to determine its gain, mm_{SEN}/mm_{CAL} ($in._{SEN}/in._{CAL}$), and offset, mm (in).

6.1.3.4 The slip angle measuring system shall be calibrated using an appropriate angle reference to determine its gain, $degrees_{SEN}/degrees_{CAL}$ and offset, degrees.

6.1.3.5 The inclination angle measuring system, if fitted, shall be calibrated using an appropriate angle reference to determine its gain, $degrees_{SEN}/degrees_{CAL}$ and offset, degrees.

6.1.3.6 The test speed sensing system shall be calibrated using an appropriate reference to determine its gain, $km/h_{SEN}/km/h_{CAL}$ (mph_{SEN}/mph_{CAL}) and offset, km/h (mph).

6.1.3.7 The individual, non-interacting, gains and offsets are used as illustrated in Equation 3. Where possible, the use of a tare procedure to suppress the offset is desirable as offsets are often not stable over long periods of time.

$$ACTUAL = (1/M) \bullet SENSED - (B/M) \quad \text{(Eq. 3)}$$

where:

ACTUAL is the real magnitude of the variable.
B is the offset.
M is the gain measured in calibration.
SENSED is the magnitude of the variable which the transducer measures.

6.2 Frequency of Calibration—The test machine shall be calibrated at least once a year or more often should experience with a specific machine indicate that more frequent calibrations are warranted.

6.2.1 CALIBRATION TO RESOLVE A PROBLEM—Should routine operational checks conducted in accordance with Section 7, Preparation of Apparatus, reveal an apparent problem with some component of the measuring system and routine practices do not resolve the problem, that portion of the measuring system in question shall be recalibrated before testing continues. If the problem is a force and moment measurement problem indicating a need for recalibration, the entire force and moment measuring system must be recalibrated.

6.3 Maintenance of Calibration Records—The gains, offsets, and calibration matrix elements shall be kept as a permanent record along with any observations on measuring system performance made during calibration. The gains, offsets, and calibration matrix elements shall be plotted as a function of time so as to develop a statistical record usable in assessing the significance of small random changes in calibration or in detecting measuring system drift.

7. Preparation of Apparatus

7.1 Purpose—Preparation of apparatus is intended to insure that: (a) test equipment meets its calibration during a test program and from test program-to-test program and (b) the road or roadway surface exhibits an approximately stationary frictioon level during the test program and from test program-to-test program. The precise method of preparing the apparatus used at each site must be contained within the written procedures of an individual test site.

7.2 Measuring System Before the Start of a Test Program—Before the start of a test program, the following non-interacting transducer gain check procedure and a force platform, single point pull, or control tire check of the force measuring system shall be conducted. A full calibration of the measuring system performed before the start of a test program may be substituted for the procedures detailed under this heading.

7.2.1 NON-INTERACTING TRANSDUCER GAIN CHECKS—The performance of the transducers listed in Table 10, which are in use at given test site, shall be multi-point checked against a reference adequate to verify that they are still in calibration. If a transducer is no longer in calibration (the check result is deviant by twice the expected system accuracy or more), it shall be repaired and re-calibrated prior to the start of testing. The precise check method shall be a written procedure on file within the records of the testing company or agency. The method must specify a way to insure that the check method is itself valid. The results of the checks shall be retained by the test facility as a permanent time-sequenced record.

Non-Interacting Transducers to Check:

Ambient Temperature
Inclination Angle
Inflation Pressure
Loaded Radius
Slip Angle
Test Speed

NOTE—The remainder of this section lists a number of examples of what might be done to verify satisfactory load cell performance. None of the example methods represents a procedural requirement applying to any specific laboratory. However, each specific laboratory is required to have in use its own written procedure which will verify that load cell performance is satisfactory at the outset of a test program.

7.2.2 FORCE PLATFORM CHECK OF FORCE MEASURING SYSTEM—A check tire typical in size of the tires to be tested in the test program shall be statically loaded onto the force platform at the tire's rated normal force capacity for maximum rated inflation. This loading shall occur in steps of 33%, 67%, and 100% of F_{ZRATED}. This will allow a linear regression check of F_Z gain for the force measuring system. With F_{ZRATED} applied, the force-measuring platform shall be exercised through a displacement which will induce F_Y values from –50% to 50% of the magnitude of F_{ZRATED}. Enough values shall be obtained to allow a linear regression check of F_Y gain. With F_Y set to zero and $F_Z = F_{ZRATED}$, the footprint shall be twisted sufficiently to induce M_Z data over the range of ±0.015 m·F_{ZRATED} in Newtons. Enough values shall be obtained to allow a linear regression check of M_Z gain. If a channel of the force-measuring system is no longer in calibration (the check result is deviant by twice the expected system accuracy or more), the system shall be repaired and re-calibrated prior to the start of testing. The precise check method shall be a written procedure on file within the records of the testing company or agency. The method must specify a way to insure that the force platform is itself calibrated. The results of the checks shall be retained by the test facility as a permanent time-sequenced record.

7.2.2.1 A force-measuring platform shall be capable of supporting the entire check tire footprint under normal forces up to at least 75% of the maximum magnitude measurable by the force-measuring system and be capable of applying at least ±75% the force-measuring systems capacity for F_X, F_Y, and M_Z. Friction elements, such as bearings, shall not be interposed between the moving stage and the tire footprint. It shall have a verifiable and traceable calibration history.

7.2.3 SINGLE POINT PULL CHECK—A special spindle tip with cable system set at an angle plus offset to the machine axis system and a known weight may be substituted as a force and moment source in place of a force platform. Application of the known weight permits a quick check of system response.

7.2.4 CONTROL TIRE CHECK OF FORCE-MEASURING SYSTEM—A control tire typical in size to the tires to be tested in the test program shall be tested according to the following procedure. Control tire selection and pre-testing (SOW 1.2.1 Final Report) is discussed in Appendix A, Control Tire Selection, Pre-Testing, Storage, and Data analysis. It is good practice to leave a control tire mounted on a single rim during its use as a control.

7.2.4.1 The control tire shall be tested on a rim which is typical for general application of the control tire at an inflation regulated to the maximum rated for the control tire specification used.

7.2.4.2 Prior to the control test, the tire shall be conditioned as indicated in Table 10.

TABLE 10—CONTROL TIRE CONDITIONING FOR FORCE-MEASURING SYSTEM CHECK

Time min.	Speed km/h	Speed mph	F_Z N	F_Z lb	α degrees	γ degrees
5	16	10	Rated	Rated	0	0

7.2.4.3 Test the control tire as indicated in Table 11.

TABLE 11—CONTROL TIRE TEST FOR FORCE MEASURING SYSTEM CHECK

Speed km/h	Speed mph	γ degrees	F_Z N	F_Z lb	α degrees	α degrees	α degrees	α degrees	α degrees	α degrees	α degrees
16	10	0	Rated	Rated	0	0.5	1	–0.5	–1	–4	–4

7.2.4.4 Data analysis shall begin with correction of the $F_Y(\alpha)$ and $M_Z(\alpha)$ data for any F_Z error using Equations 4 and 5. The F_Z corrected to 0.0 degree, 0.5 degree, 1.0 degree, –0.5 degree, and –1.0 $F_Y(\alpha)$ and $M_Z(\alpha)$ data shall each be fit with a regression line and the Aligning Stiffness, Cornering Stiffness, F_Y(0 degree), and M_Z(0 degree) for the control tire shall be obtained. The F_Z corrected –4.0 degrees and 4.0 degrees $F_Y(\alpha)$ and $M_Z(\alpha)$ data shall be mirrored using Equations 6 and 7. Aligning Stiffness, cornering Stiffness, F_Y(0 degree), M_Z(0 degree), F_{YM}(4 degrees) and M_{ZM}(4 degrees) shall be plotted on control charts showing lines for the mean value and 2.5 σ from the mean based on the data from control tire pretesting. If the values of Aligning Stiffness, Cornering Stiffness, F_Y(0 degree), M_Z(0 degree), F_{YM}(4 degrees), and M_{ZM}(4 degrees) lie within 2.5 σ, standard deviations, as determined in the control tire pretesting, the force-measuring system is assumed to be in calibration. If any of the values lie outside of 2.5 σ, repeat the control tire check. If the check is again failed, repair and re-calibrate the force measuring system.[1]

$$F_{Y@Rated} = (F_{ZRated}/F_{ZMeasured}) \bullet F_{YMeasured} \quad \text{(Eq. 4)}$$

$$M_{Z@Rated} = (F_{ZRated}/F_{ZMeaured}) \bullet M_{ZMeasured} \quad \text{(Eq. 5)}$$

$$F_{YM}(4°) = 0.5 \bullet [F_Y(-4°) + F_Y(4°)] \quad \text{(Eq. 6)}$$

$$M_{ZM}(4°) = 0.5 \bullet [M_Z(4°) + M_Z(-4°)] \quad \text{(Eq. 7)}$$

7.3 Roadway Friction Before the Start of a Test Program—Before the start of a test program, a check of roadway surface friction shall be conducted.

NOTE—The remained of this section is an example of what might be done to verify satisfactory roadway surface friction. The example method requires the presence of torque capability on the test machine and could not be run by a facility without torque capability. It is not a procedural requirement applying to any laboratory. However, each specific laboratory is required to have in use its own written procedure which will verify that roadway surface friction is satisfactory at the outset of a test program.

Development of a valid method of tracking roadway surface friction applicable to any machine capable of only free-rolling testing should be pursued through research prior to the 5-year renewal of this document. It is possible, based on work to date, that the level of M_Z(4 degrees) might be a valid indicator.

7.3.1 CONTROL TIRE CHECK OF ROADWAY SURFACE FRICTION—A control tire typical in size to the tires to be tested in the test program shall be tested according to the following procedure. Control tire selection and pre-testing (SOW 1.2.1 Final Report) is discussed in Appendix A Control Tire Selection, Pre-Testing, Storage, and Data Analysis.

7.3.1.1 The control tire shall be tested on a rim which is typical for general application of the control tire at an inflation regulated to the maximum rated for the control tire specification used.

1. The Aligning and Cornering Stiffness will very slowly increase with time due to tire aging. If a control tire is used for a very long time this effect can become significant (SAE 810066).

7.3.1.2 Prior to the roadway surface friction control test, the tire shall be conditioned as indicated in Table 13.

TABLE 12—CONTROL TIRE CONDITIONING FOR SURFACE FRICTION CHECK

Time min.	Speed km/h	Speed mph	F_Z N	F_Z lb	α degrees	γ degrees
15	48	30	Rated	Rated	0	0

7.3.1.3 Test the control tire as indicated in Table 13.

TABLE 13—CONTROL TIRE TEST FOR SURFACE FRICTION CHECK

Speed km/h	Speed mph	α degrees	γ degrees	F_Z N	F_Z lb	Slip Ratio Start, %	Slip Ratio End, %	Slip Ratio Rate, %/s
48	30	0	0	Rated	Rated	0	–80	–80

7.3.1.4 Data analysis shall begin with correction of the F_X(SR) data corrected for any F_Z errors using Equation 8. The F_{XCORR}(SR) shall be plotted versus the reference value of F_X(SR) for the control tire used slip ratio by slip ratio.

$$F_{X@Rated} = (F_{AZRated} / F_{ZMeasured}) \bullet F_{XMeasure} \quad \text{(Eq. 8)}$$

7.3.1.5 Testing may begin if the regression line slope of F_{XCORR}(sr) versus F_{XREF}(SR) is between 0.95 and 1.05 and there is no appreciable nonlinearity (see Figures 5 and 6, A Straight-Line Braking Test for Heavy-Duty Truck tires: SAE CRP-11). In this case, the surface exhibits an approximately stationary friction level and there is a reasonable probability that surface friction will not lead to results divergent from previous results on the same surface.

7.3.1.6 Testing may not begin if the regression line slope of F_{XCORR}(SR) versus F_{XREF}(SR) is not between 0.95 and 1.50 and/or there is appreciable nonlinearity (see Figures 5 and 6, A Straight-Line Braking test for Heavy-Duty Truck Tires: SAE CRP-11). In this case, the surface exhibits a non-stationary friction level and there is a reasonable probability that surface friction differences will lead to results divergent from previous results on the same surface. The following actions shall be taken:

a. On an indoor machine, the surface shall be replaced with a duplicate sample of the original abrasive surface which shall be broken in according to the standard written procedure for surface break-in in use at the test facility in question. Then, the procedure of 7.3.1 shall be repeated to verify that surface friction is now properly bounded.

b. Outdoors other locations on the test surface shall be tried using the method of 7.3.1 until an area with friction similar to the original friction is found. Should this prove impossible, the friction achieved shall be documented by a graph of the type discussed in 7.3.1.4 and through preservation of the data as a computer file. Testing may resume under the warning that the results obtained may not be usefully comparable to previous results.

7.4 Measuring System Check During a Test Program—At the beginning of each operating day the measuring system shall be checked to insure that the system has not deviated from its calibration. This check may be done by repeating 7.2 or by a standard daily check routine which shall be a written procedure on file within the records of the testing company or agency and which has been shown to yield a valid daily check of the particular measuring system being used. The results of each daily check shall be retained by the test facility as a permanent time sequenced record. Should the measuring system not pass a daily check, it is mandatory that the system be repaired and subjected to a check by the method of 7.2 or to a full calibration which ever is more appropriate.

7.5 Roadway Friction Test During a Test Program—The roadway friction check of 7.3 shall be repeated:

1. Each time an indoor facility must replace its roadway surface due to a failure which necessitates replacement of the roadway surface
2. If the surface has reached the end of its documented usable life and the intent is to continue using the surface,
3. Daily if an indoor facility has no documented usable life information within its files or is using a surface beyond its documented usable life,
4. Each time a test track is subject to unusual weather events, or
5. The test track surface has been disused for a substantial time period, two weeks or more.

The results of each check shall be retained by the test facility as a permanent time-sequenced record. Should the surface friction check reveal that requirements of 7.3.1.5 are not met then the requirements of 7.3.1.6 become mandatory before testing can resume.

7.5.1 DOCUMENTED USABLE LIFE—Documented usable life is the usage life for which it has been experimentally established that there is a 5% or less change in friction coefficient. The data and analysis on which the documented usable life is based shall be part of the permanent written records of the testing facility using a particular documented usable life along with test time and severity tracking to establish use life of artificial roadway surfaces.

7.6 Measuring System at the End of a Test Program—7.2 shall be repeated as written at the end of testing.

7.7 Roadway Friction at the End of a Test Program—7.3 shall be repeated as written at the end of testing.

7.8 Reporting of Appratus and Surface Status During a Test Program—If the system and roadway friction remain controlled throughout the test program, a statement certifying control is the only required report on control. Should a loss of control occur, the testing company or agency shall issue a summary report of the problems and an estimation of the effect of the problems on use of the data.

It is advised that any deviation from control be promptly brought to the attention of the test purchaser rather than to wait for the formal report before informing the customer.

8. Selection and Preparation of Test Tires

8.1 Selecting Tire for Good Comparability—The purpose of the test must be carefully borne in mind when selecting test tires since tire properties depend on numerous factors besides the tire design and materials. It is especially important to properly account for storage history (SAE 810066) and previous work history (SAE 770870). Due to the many complex questions that the test defined in this document may be used to address, specific tire selection recommendations can only be made for the case in which different tires are to be compared for pure design or materials effects. In this case, all test tires should be of approximately the same age, have been stored under essentially the identical conditions, have experienced approximately the same exercise history, and have been sampled from production lots with similar statistical characteristics.

8.2 Inflation Pressure—The inflation pressure used in the test is a regulated inflation pressure. The test inflation pressure may be pre-specified by the test requester. In the absence of such a specification, the method of this section allows determination of a realistic tire inflation pressure for use in the force and moment test. Operating tire inflation may be tire specification dependent as individual tire specifications may exhibit different operating temperatures and, therefore, different operating inflation pressures in spite of having been inflated to the same cold inflation pressure prior to operation.

8.2.1 TIRE PREPARATION FOR DETERMINING TEST INFLATION—Mount an experimental tire for the specification to be tested on the tire and rim standards organization specified rim. Inflate the tire to the target cold inflation pressure specified by the test requester and cap the valve. Mounting and demounting shall be done in accordance with the practices specified in (OSHA 1910.177). The rim used shall meet or exceed OE specifications.

8.2.2 TEST INFLATION DETERMINATION EXPERIMENT—Run the tire at inclination angle (γ) = 0 degree slip angle (α) = 0 degree, normal force (F_Z) = –(Rated Load for the target cold inflation), and test speed (S) for 1 h. At the end of 1 h stop the test and measure the pressure in the test tire. The pressure measured is the test inflation pressure (p) which will be used during the tire conditioning and test.

8.2.3 COMMENT ON EXPERIMENTAL EFFICIENCY—The test inflation determination experiment corresponds to the first step of pre-test conditioning. Therefore, if the tester proceeds immediately with testing of the tire used in the inflation determination experiment, there is little extra cost associated with this step.

8.3 Pre-Test Conditioning—The purpose of this step is to raise the tire to the operating temperature associated with use at the test speed (S) and to lightly scuff the tread in a way representative of a few miles of Interstate Highway travel.

8.3.1 TIRE PREPARATION—Mount the test tire on the tire and rim standards organization specified rim. Mounting and demounting shall be done in accordance with the practices specified in (OSHA 1910.177). The rim used shall meet or exceed OE specifications. Inflate the test tire to the test inflation pressure (p) using a pressure regulator.

8.3.2 CONDITIONING—Condition the test tire in accordance with the operating sequence in Table 14.

TABLE 14—TIRE CONDITIONING SEQUENCE

Distance Kilometers (mile)	Speed km/h (mph)	Load, % Rated	Pressure psi	α degrees	γ degrees
S X 1 h	S	100	P	0	0
0.80 (0.5)	S	100	P	1	0
0.80 (0.5)	S	100	P	–1	0

8.4 Ambient Temperature Limits—During pre-test conditioning, the ambient temperature, T_A, shall be between 15 °C (59 °F) and 27 °C (81 °F) so as to limit temperature induced variance in the lateral force results to ±1% or less (SAE 770870).

8.5 Sample Size—The precise sample size to test in order to determine F_Y and M_Z differences between two tire specifications at a stated level of accuracy depends on the variance of the tire samples chosen and on the testing variability of the test machine used. Consequently, the procedure referenced in the following paragraphs may not be completely accurate in every case. However, the method can be considered to be useful as a first approximation.

8.5.1 ESTIMATING SAMPLE SIZE—Using either the CALSPAN or UMTRI test machine and assuming a test sample variance identical to that in the samples used in compiling SAE CRP-11, an estimate of test sample size can be made (see, Figures C/U1.2.1-1 and C/U1.2.1-2, Recommended Test Sample Sizes (SOW 1.5) and The CALSPAN/UMTRI Comparison (SOW 3.0), SAE CRP-11).

9. Test Procedure

9.1 The Test—Without stopping at the end of conditioning, test according to the sequence in Table 15. The sequence is to set the first normal force, do the slip angles in order, set the second normal force, do the slip angles in order, etc. until Table 15 has been completed.

TABLE 15—THE FREE-ROLLING CORNERING TEST
g = 0 degree; P is as determined in 8.2; S is at the engineering user's choice.

F_X, % Rated Load	α, deg	α, deg	α, deg	α, deg	α, deg	α, deg	α, deg	α, deg	α, deg
–25	0	1	–1	–2	2	4	–4	–6	6
–50	0	1	–1	–2	2	4	–4	–6	6
–75	0	1	–1	–2	2	4	–4	–6	6
–100	0	1	–1	–2	2	4	–4	–6	6
–125	0	1	–1	–2	2	4	–4	–6	6
–150	0	1	–1	–2	2	4	–4	–6	6
–200	0	1	–1	–2	2	4	–4	–6	6

9.2 Ambient Temperature Limits—During the test, the ambient temperature, T_A, shall be between 15 °C (59 °F) and 27 °C (81 °F) so as to limit temperature induced variance in the lateral force results to ±1% or less (SAE 7700870).

9.3 Test Speed—The choice of test speed should reflect the intended use of the model and the capabilities of the test machine being used. S is constant throughout the test.

9.4 Extension—Should there be a desire to use this test in modeling the combined cornering and braking behavior of a tire (SAE 960180), the test developed in this document must be extended to higher slip angles (SAE 960180). If the test is extended, any lateral force or aligning moment comparisons produced in the background work underlying this document are not to be extrapolated (SAE CRP-11).

NOTE—There are two possible modifications to the procedure which should be examined through research prior to the 5-year renewal of this document: a high-to-low (Fz) sequence and a swept slip angle test in place of the current incremental slip angle test.

10. Data Processing and Presentation

10.1 Data to Acquire—The data to acquire at a minimum are: F_Y, F_Z, M_Z, and α. Should the machine have the capability acquire: F_X, F_Y, F_Z, M_X, M_Z, R_1, α and γ.

10.2 Data Acquisition Rates and Filtering—Each reported data value shall be the average of data sampled 32 times per revolution over two revolutions so that tire uniformity variations are suppressed.

10.3 Tire Axis System—All data shall be reported using the SAE Tire and Axis System (SAE J670e).

10.4 Data Correction or Adjustment—If modest normal force (F_Z) errors exist, the F_Y and M_Z data may be corrected by use of Equations 9 and 10. Correction for slip angle errors is not considered. Depending on the tire modeling software used, neither correction may be necessary.

$$F_{Y@Rated} = (F_{ZRated} / F_{ZMeasured}) * F_{YMeasured} \quad \text{(Eq. 9)}$$

$$M_{Z@Rated} = (F_{ZRated} / F_{ZMeasured}) * M_{ZMeasured} \quad \text{(Eq. 10)}$$

10.5 Data File Format—The operating system used to format any media used to transmit data files must be specified in the letter of transmittal accompanying data files.

The data files shall be ASCII files whose character must be spelled out within the written procedures of the laboratory providing the data.

NOTE—The remainder of this section provides an example of what might be done and is not a requirement of this document.

The data files shall be ASCII files with the following suggested characteristics. Lines are to be terminated by an ASCII carriage return (decimal character 13) and an ASCII line feed character (decimal character 10). Multiple entries are assumed to be delimited by a space (ASCII decimal character 32).

Numbers are to be represented in ASCII decimal notation using a period (ASCII decimal character 46) as a decimal point. No commas or exponents are to be present in numbers.

An example of the suggested file format follows. This format is a general format for transmission of tire force and moment data and is not specific to free-rolling cornering data.

In the example (following Section 11), exclamation Points (!) denote comment lines. Lines initiated by asterisks (*) denote terminators for file sections. Alphabetical lines of the form XXX_YYY are keywords and transmit information for the use of modeling programs. The number or numbers which follow immediately are the values applicable to the variable signified by the keyword for the test specified in this document.

10.6 Record Keeping and Retention—Data files are to be retained on magnetic media in the format specified in this document for a period of time mutually agreed on between the testing organization and the customer. At the end of this reserve period, the testing agency may erase overage data files without further notification to the customer.

11. Data Repeatability and Reproducibility

11.1 Restrictions on the Available Data—The available data (SAE CRP-11) do not strictly represent either repeatability or reproducibility, but rather represent a combination of machine testing and tire-to-tire variance for different samples of a single tire specification tested at two sites (CALSPAN and UMTRI) at a single time at each site. However, the data do give a picture of variances that is useful for production of the sample size estimation referenced in 8.5.1.