SAE International™

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J2673

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Straight-Line Braking Test for Truck and Bus Tires

1. Scope

This SAE Recommended Practice describes a test method for determination of heavy truck (Class VI, VII, and VIII) tire force and moment properties under straight-line braking conditions. The properties are acquired as functions of normal force and slip ratio using a sequence specified in this practice. At each normal force increment, the slip ratio is continually changed by application of a braking torque ramp. 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 Control Modes and Effects Not Considered

The effects of non-zero inclination angle and non-zero slip angle or any combination of non-zero inclination angle, non-zero slip angle, and spindle torque with normal force are not considered.

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, SAE J2429, and SAE J2675. Such a machine neither exists at the time this document was written nor is it certain that the technology to build such a machine exists at this time.

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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 1.2.2 Final Report, M. G. Pottinger, September 20, 1994.
Straight-Line Braking Test for Heavy Duty Truck tires, M. G. Pottinger, G. A. Tapia, C. B. Winkler, W. Pelz, ACS Mtg., 10/17-19/1995.
Recommended Test Sample Sizes (SOW 1.5) and The CALSPAN/UMTRI Comparison (SOW 3.0) for SOW1.2.2 Data, SAE CRP-11, M. G. Pottinger, W. Pelz, September 9, 1994.
SAE J670e—Vehicle Dynamics Terminology
SAE J2047—Tire Performance Terminology
SAE J2429—Free-Rolling Cornering Test for Truck and Bus Tires
SAE J2675—Combined Cornering and Braking Test for Truck and Bus Tires
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 962153—Truck Tire Wet Traction: Effects of Water Depth, Speed, Tread Depth, Inflation, and Load, M. G. Pottinger, W. Pelz, D. M. Pottinger, and C. B. Winkler, 1996.
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 962153—Truck Tire Wet Traction: Effects of Water Depth, Speed, Tread Depth, Inflation, and Load, M. G. Pottinger, W. Pelz, D. M. Pottinger, and C. B. Winkler

2.1.2 Tire and Rim Association Publications

Available from the Tire and Rim Association, Inc., Copley, OH 44321-2793.

XXXX Yearbook, The Tire and Rim Association, Inc. (XXXX stands for the current year)

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.
NIST Handbook 105-1—Specifications and Tolerances for Reference Standards and Field Standard Weights and Measures (NIST Class F) – Available electronically at http://ts.nist.gov/ts/htdocs/230/235/105-1.pdf.

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
ω	Spin Angular Velocity About the Wheel Spindle
p	Inflation Pressure
R_l	Loaded Radius
S	Test Speed
SR	Slip Ratio
T_A	Ambient Temperature
T_S	Spindle Torque

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 for machines capable of performing not only this test, but also, other related tests such as free-rolling cornering and combined cornering and braking.

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
Spin Angular Velocity[2]	±10 rpm	±10 rpm
Rate	**Ideal Maximum Rate**	
Normal Force	≥ 8900 N/s	≥ 2000 lb/s
Slip Angle	≥ 5 degrees/s	≥ 5 degrees/s
Spin Angular Velocity	≥ 1200 rpm/s	≥ 1200 rpm/s
Inclination Angle[1]	≥ 1 degree/s	≥ 1 degree/s

[1] Slip Angle (α) and Inclination Angle (γ) are not required and are not used in this document. They are provided should anyone desire to build a machine for more general tests.

[2] Precise control of Spin Angular Velocity (ω) would only be possible in the case of an Ideal Machine using a motor to apply torque to the test tire. It is not necessary to set a given steady-state ω level within the test discussed in this Recommended Practice. In the case of this practice it is only necessary that the machine generate a braking ramp that sweeps through the required Slip Ratio (SR) range defined in Section 9, Test Procedure, within the specified test time.

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 defined. These are subjects that 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 be flat. Though straight-line braking data to support this requirement does not exist, the probable correctness of this requirement can be inferred from the distortion of free-rolling force and moment properties by roadway curvature (SAE 760029). It is certainly correct for a general-purpose machine.

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 in braking (SAE 962153). 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 Tires, 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 to be tested. An ideal loading system would be able to exert normal force magnitudes of up to 140 kN (31,500 lb).

5.1.2.3 For this test, the positioning system and its supporting structure shall provide a slip angle of $\alpha = 0° \pm 0.05°$. If setting capability is provided for slip angle, as part of a general machine, 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.

5.1.2.4 For this test, the positioning system and its supporting structure shall provide an inclination angle of $\gamma = 0° \pm 0.05°$. If setting capability is provided for inclination angle, as part of a general machine, 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.

5.1.3 MEASURING SYSTEM

The measuring system shall at a minimum be capable of measuring these data: longitudinal force (F_x), normal force (F_z), test speed (S), and spin angular velocity about the wheel spindle (ω). The individual results for all channels shall be corrected for tare. Force and moment interactions shall be corrected by a matrix method.

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_l), longitudinal force (F_x), normal force (F_z), overturning moment (M_x), test speed (S), slip angle (α), spin angular velocity about the wheel spindle (ω), and spindle torque (T_s). The individual results for all channels shall be corrected for tare. Section 6, Calibration, provides a matrix correction example for an ideal machine capable of measuring three forces and three moments.

5.1.3.1 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 of the roadway and loading and positioning systems expressed in this document. An ideal machine would have the ability to perform all the measurements for which system ranges are provided in Table 3.

TABLE 3 – MEASURING SYSTEM IDEAL RANGES

Measurement	Full Scale Range SI Units	Full Scale Range USC Units
Aligning Moment[3]	0 ± 11 kN·m	0 ± 8.100 ft-lb
Ambient Temperature[3]	10 to 35 °C	50 to 95 °F
Inclination Angle[3]	0 ± 10 degrees	0 ± 10 degrees
Inflation Pressure[3]	0 to 1050 kPa	0 to 150 psi
Lateral Force[3]	0 ± 140 kN	0 ± 31,500 lb
Loaded Radius[3]	350 mm to 675 mm	14.5 in to 27.5 in
Longitudinal Force	0 ± 140 kN	0 ± 31,500 lb
Normal Force	0 ± 140 kN	0 ± 31,500 lb
Overturning Moment[3]	0 ± 33 kN·m	0 ± 24,300 ft-lb
Test Speed	0 to 120 km/hr	0 to 75 mph
Slip Angle[3]	0 ± 15 degrees	0 ± 15 degrees
Spin Angular Velocity	0 ± 2000 rpm	0 ± 2000 rpm
Spindle Torque[3]	0 ± 94,500 N-m	0 ± 70,000 ft-lb

[3] This measurement is not required or used in this document. Information is provided should anyone desire to build a machine suitable for more general testing.

NOTE—Braking Force is equivalent to negative longitudinal force (J2047).

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[4]
Aligning Moment[3]	±0.5% of Full Scale
Ambient Temperature[3]	±0.5 °C (± 1.0 °F)
Inclination Angle[3]	±0.02 degree
Inflation Pressure[3]	±3.5 kPa (± 0.50 psi)
Lateral Force[3]	±0.5% of Full Scale
Loaded Radius[3]	±0.5 mm (± 0.020 in)
Longitudinal Force	±0.5% of Full Scale
Normal Force	±0.5% of Full Scale
Overturning Moment[3]	±0.5% of Full Scale
Test Speed	±0.5% of Full Scale
Slip Angle[3]	±0.02 degree
Spin Angular Velocity	±5 rpm
Spindle Torque[3]	±0.5% of Full Scale

[3] This measurement is not required or used in this document. Information is provided should anyone desire to build a machine suitable for more general testing.
[4] This applies to a single sample with loading of only the measurement channel being examined.

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[5]

Setting	Least Acceptable Setting Accuracy SI Units	Least Acceptable Setting Accuracy USC 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[5]	±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[5]	≥ 1 degree/s	≥ 1 degree/s

[5] Precise control of Spin Angular Velocity (ω) would require impractically bulky equipment in the case of an over-the-road machine. Therefore, control of ω is ignored as a feature of an Ideal Over-the-Road Machine. For the purposes of this practice, it is only necessary that the machine generate a braking ramp that sweeps through the required Slip Ratio (SR) range defined in Section 9, Test Procedure, within the specified test time.

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 in braking (SAE 962153). 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 and 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 For this test, the positioning system and its supporting structure shall provide a slip angle of $\alpha = 0° \pm 0.10°$. If setting capability is provided for slip angle, as part of a general machine, 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 For this test, the positioning system and its supporting structure shall provide an inclination angle of $\gamma = 0° \pm 0.10°$. If setting capability is provided for inclination angle, as part of a general machine, 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 at a minimum be capable of measuring these data: longitudinal force (F_x), normal force, (F_z), test speed (S), and spin angular velocity about the wheel spindle (ω). The individual results for all channels shall be corrected for tare. Force and moment interactions shall be corrected by a matrix method.

The ideal measuring system should be capable of measuring these data: aligning moment (M_z), ambient temperature (TA), 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), slip angle (α), spin angular velocity about the wheel spindle (ω), and spindle torque (T_S). Section 6, Calibration, provides a matrix correction example for an ideal machine, which measures three forces and three 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 of the loading and positioning systems expressed in this document. An ideal machine would have the ability to perform all the measurements for which system ranges are provided in Table 3.

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

TABLE 6 – OVER-THE-ROAD MACHINE MEASURING SYSTEM ACCURACIES

Measurement	Accuracy[4]
Aligning Moment[3]	±1.0% of Full Scale
Ambient Temperature[3]	±0.5 °C (±1.0 °F)
Inclination Angle[3]	±0.05 degree
Inflation Pressure[3]	±3.5 kPa (±0.50 psi)
Lateral Force[3]	±1.0% of Full Scale
Loaded Radius[3]	±1.0 mm (±0.040 in)
Longitudinal Force	±1.0% of Full Scale
Normal Force	±1.0% of Full Scale
Overturning Moment[3]	±1.0% of Full Scale
Slip Angle[3]	±0.05 degree
Spin Angular Velocity	±5 rpm
Spindle Torque[3]	±1.0% of Full Scale
Test Speed	±0.5% of Full Scale

[3] This measurement is not required or used in this document. Information is provided should anyone desire to build a machine suitable for more general testing.
[4] This applies to a single sample with loading of only the measurement channel being examined.

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 drawings 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 (NIST). There shall be current 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 (NIST HB 105-1).

6.1.2.2 Reference pressure transducers used for calibrating the pressure measuring system shall be calibrated using a hydrostatic calibrator.

6.1.2.3 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.

6.1.2.4 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 is presented here. However, the example matrices for load cell interactions are precisely applicable only to an ideal three-force and three-moment system.

6.1.3.1 Simulated tire forces and moments shall be applied to the measuring system force and moment measuring components using fixtures involving 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, $\mathbf{C}^{-1}$, are developed. Inversion of $\mathbf{C}^{-1}$ 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.

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

$$\mathbf{F}_{ACT} = \mathbf{C}\mathbf{F}_{SEN} \quad \text{(Eq. 2)}$$

TABLE 7 – UNITS OF FORCE AND MOMENT GAINS

Type of Measurement	Gain[6] SI Units	Gain[6] USC Units
Force	N_{SEN}/N_{CAL}	lb_{SEN}/lb_{CAL}
Moment	$N{\cdot}m_{SEN}/N{\cdot}m_{CAL}$	$ft\text{-}lb_{SEN}/ft\text{-}lb_{CAL}$

[6] 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 T_s	SENSED M_z
F_x	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}
F_y	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}
F_z	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{36}
M_x	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}
T_s	C_{51}	C_{52}	C_{53}	C_{54}	C_{55}	C_{56}
M_z	C_{61}	C_{62}	C_{63}	C_{64}	C_{65}	C_{66}

TABLE 9 – UNITS FOR INTERACTION MATRIX TERMS

Units SI	Units USC	Matrix Terms	Matrix Terms	Matrix Terms
N_{ACT}/N_{SEN}	lb_{ACT}/lb_{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_{61}	C_{42} C_{52} C_{62}	C_{43} C_{53} C_{63}
$N_{ACT}/N{\cdot}m_{SEN}$	$lb_{ACT}/ft\text{-}lb_{SEN}$	C_{14} C_{24} C_{34}	C_{15} C_{25} C_{35}	C_{16} C_{26} C_{36}
$N{\cdot}m_{ACT}/N{\cdot}m_{SEN}$	$ft\text{-}lb_{ACT}/ft\text{-}lb_{SEN}$	C_{44} C_{54} C_{64}	C_{45} C_{55} C_{65}	C_{46} C_{56} C_{66}

6.1.3.2 The pressure measuring system shall be calibrated using a hydrostatic calibrator or a reference pressure transducer 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, if fitted, 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 spin angular velocity measuring system shall be calibrated using an appropriate angular velocity reference to determine its gain, rpm_{SEN}/rpm_{CAL} and offset, rpm.

6.1.3.7 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).

6.1.3.8 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.

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

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 the 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 friction 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 immediately after this paragraph, 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[7]
- Inclination Angle[8]
- Inflation Pressure[7]
- Loaded Radius[8]
- Slip Angle[8]
- Spin Angular Velocity
- 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[9] CHECK OF FORCE MEASURING SYSTEM

A tire typical in size of the tires to be tested in the test program shall be statically loaded onto the un-displaced force platform at the tire's rated normal force capacity for maximum rated inflation. This will allow a check of F_z gain for the force measuring system. With F_{ZRATED} applied, the force-measuring platform shall be exercised through an X-displacement, which will induce an F_x value equal to approximately 50% of the magnitude of F_{ZRATED}. This checks F_x 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 has itself been 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. 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.

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[7] These data need not be sampled simultaneously with the basic data specified in this procedure. However, good practice demands minimally that this measurement be made at the beginning and end of a test and an appropriate value entered within the data set so that the user knows the tire operational state. For example, in the non-sampled case, the header information in the data file would contain values for Ambient Temperature and Inflation Pressure typical of the conditions existing at the time of the test.

[8] This measurement is not used in this document. It would only be checked in the case of a machine with this transducer.

[9] In the case of this practice, it is only necessary that the force and moment measuring platform allow checking of F_x and F_z. However, if the machine is a generalized (ideal) machine, the platform and/or other equipment should allow verification testing of all forces and moments.

7.2.4 CONTROL TIRE CHECK OF FORCE-MEASURING SYSTEM

This is not feasible for longitudinal force as the result confounds the behavior of the force measuring system with the test surface-to-tire friction. In this practice, a control tire is used as described in the next section to assess test surface-to-tire friction after either the force platform or single point pull procedure has been applied to verify measurement system performance.

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 remainder of this section is an example procedure showing what might be done to verify satisfactory roadway surface friction. The example procedure 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.

7.3.1 EXAMPLE 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, Surface Friction Control Tire Selection, Pre-Testing, Storage, and Data Analysis.

7.3.1.1 The control tire shall be tested at its maximum rated inflation on a rim, which is typically used for general application of the control tire.

7.3.1.2 Prior to the roadway surface friction control test, the tire shall be conditioned as indicated in Table 10.

TABLE 10 – CONTROL TIRE CONDITIONING FOR EXAMPLE 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 11.

TABLE 11 – CONTROL TIRE TEST FOR EXAMPLE 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 for any F_z errors using Equation 4. The F_{XCORR}(SR) shall be plotted versus the reference value of F_x(SR) for the control tire.

$$F_{XCORR} = (F_{ZRated}/F_{Zmeasured}) \bullet F_{Xmeasured} \quad \text{(Eq. 4)}$$

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 (Figures 5 and 6, A Straight-Line Braking Test for Heavy-Duty Truck tires: SAE CRP-11 are examples of unsatisfactory behavior). A surface meeting the criteria in the previous sentence 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 1.05 and/or there is appreciable nonlinearity (as seen in Figures 5 and 6, from "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. For tests run 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 usable 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 Apparatus 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 ideally 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 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 degrees, slip angle (α) = 0 degrees, 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 very 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 12.

TABLE 12 – 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

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 measured longitudinal force. The limits are based on temperatures that would restrict lateral force results to a ±1% band or less (SAE 770870).

8.5 Sample Size

The precise sample size to test in order to determine F_x 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, Figure C/U1.2.2-1, Recommended Test Sample Sizes (SOW 1.5) and The CALSPAN/UMTRI Comparison (SOW 3.0) for SOW 1.2.2 Data, SAE CRP-11).

9. Test Procedure

9.1 The Test

Without stopping at the end of conditioning, test according to the sequence in Table 13. The sequence is to set the first normal force, do the braking ramp, release to free-rolling, load to the second normal force, do the braking ramp, release to free rolling, etc. until the sequence is completed.

TABLE 13 – THE STRAIGHT-LINE BRAKING TEST
inflation pressure "p" is as determined in 8.2; S is at the engineering user's choice.

$-0.80 \le SR \le 0.00$; dSR/dt = -0.80/sec.				
$-F_z$, % Rated Load	p, pressure	S, speed	α, Slip Angle (°)	γ, Inclination Angle (°)
25	p	S	0.00	0.00
50	p	S	0.00	0.00
75	p	S	0.00	0.00
100	p	S	0.00	0.00
125	p	S	0.00	0.00
150	p	S	0.00	0.00
200	p	S	0.00	0.00

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 measured longitudinal force. The limits are based on temperatures that would restrict lateral force results to a ±1% band or less (SAE 770870).

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.

10. Data Processing and Presentation

10.1 Data to Acquire

The data to acquire at a minimum are: F_x, F_z, S, and ω. Should the machine have ideal capability acquire: F_X, F_Y, F_Z, M_X, M_Z, p, R_1, ω, S, T_A, T_S, α and γ.

10.2 Data Acquisition Rates and Filtering

Simultaneously sampled and held data shall be acquired at a rate of 200 samples per second or faster for all channels. The data shall be filtered to suppress aliasing and where possible uniformity variations. In this case, the force and moment data may still contain appreciable mechanical noise after filtering. Should this be true, other adjustments to suppress noise may be required such as application of moving smoothing and interpolating functions.

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_x data may be corrected by use of Equation 4.

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 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 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 Straight-line braking 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.

In the case of this example, the data are assumed to have been smoothed and interpolated to yield 81 values evenly spaced over the range of spin angular velocity for each load-slip angle condition.

10.6 Record Keeping and Retention

Data files are retained on magnetic or optical 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 should give a picture of variances that is useful for production of the sample size estimation referenced in 8.5.1.

—— EXAMPLE ——

Within the Example comments are in italics.

! FILE DATA: mm/dd/yy

! TEST NUMBER: An Alphanumeric Combination

! TIRE MANUFACTURER: A Descriptive Label

! TIRE NAME: A Descriptive Label

! TIRE SIZE: An Alphanumeric Combination

! RIM SIZE: An Alphanumeric Combination

! INFLATION PRESSURE: P, An Alphanumeric Combination (Example: 910 kPa)

! AMBIENT TEMPERATURE: Ta, An Alphanumeric Combination (Example: 24°C)

! RATED NORMAL FORCE: (-Rated Load)

! TEST SPEED: S, An Alphanumeric Combination (Example: 90.0 km/hr)

***** HEADING TERMINATOR

ANGLE_CHOICE
DEGREES *(Degrees are it for now, but allowing for the keyword allows a generalization to include RADIANS.)*
! SI = INTERNATIONAL SYSTEM, USC - ENGLISH: SIGNIFIES UNITS IN DATA
! IN SI - FORCE: N; MOMENTS: N·m; PRESSURE: kPa; LENGTH: mm
! IN USC - FORCE: lb; MOMENTS: ft-lb; PRESSURE: psi; LENGTH: in
UNIT_CHOICE
SI

! SLIP RATIO IS UNITLESS AND EXPRESSED AS A DECIMAL FRACTION.
! GIVES THE MAXIMUM AND MINIMUM SLIP RATIO COVERED IN THE DATA.
SLIP_RATIO
0.00, -0.80 *(Straight-line Braking test.)*

! MINIMUM AND MAXIMUM SLIP ANGLE IN THE DATA.
SLIP_ANGLE_RANGE
0.0, 0.0 *(Cornering is not considered in this test.)*