SURFACE VEHICLE RECOMMENDED PRACTICE

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Combined Cornering and Braking Test for Truck and Bus Tires

RATIONALE

The purpose of this revision is to correct minor errors in the existing document and to bring the document up to date in light of developments between 2010 and 2017. The original document referenced an over-the-road test machine that has since been decommissioned and is no longer available. The document has also been updated to include a new class of hybrid testing machines which test a tire while moving it over a paved surface in a controlled environment.

SAE J2675 has been reaffirmed to comply with the SAE Five-Year Review policy.

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 combined cornering and braking conditions. The properties are acquired as functions of slip angle, normal force, and slip ratio. Slip angle and normal force are changed incrementally using a sequence specified in this document. At each 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.

This document is intended to be a general guideline for testing on an ideal machine, and modifications to the protocols recommended within are expected depending on the requirements of each customer. Due care is necessary when modifying protocols to ensure that the integrity of the data is maintained.

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 (Class VI, VII, and VIII) and buses. Examples of vehicles which use heavy truck tires include tractor/semi-trailer combinations, dump trucks, and school buses. Tires mounted on classes of commercial vehicles other than Classes VI, VII, or VIII, and other types of lighter GVWR vehicles, are explicitly excluded from consideration in this document.

1.2 Effects Not Considered

The effects of non-zero inclination angle or any combination of non-zero inclination with non-zero slip angle, non-zero torque, and normal force are not considered in this document, but the accuracies of machines including inclination are referenced.

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, the CALSPAN Tire Research Facility (TIRF) (as it stood in 2004), and an outdoor over-the-road dynamometer, the University of Michigan Transportation Research Institute (UMTRI) Mobile Tire Dynamometer. This document does not require a machine to match the ideal machine defined in 1.3.1, but does require that a test machine's performance be fully defined over its range of application.

Note: **In this document, an ideal is a goal not a requirement.**

NOTE: The UMTRI Mobile Tire Dynamometer was decommissioned and is no longer available in response to an institute decision to no longer engage in testing. It is still mentioned in this revision because much of the backup data for SAE J2675 was taken with the UMTRI machine and experience with it shows the quality of information that can be obtained with a machine of this type.

1.3.1 Ideal Machine

This document references an ideal machine which is capable of fully matching every item in this document, SAE J2429, and SAE J2673. Such a machine neither exists currently nor is it certain that the technology to build such a machine exists. However, this recommended procedure does not depend on having an ideal machine. Useful data can be, and has been, gathered on existing machines. However, for repeatability and for situations when data from different machines might be compared, it is important to document the capability of each machine that contributes data.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE CRP-11 Truck Tire Characterization, December 1995

NOTE: CRP-11 is a book compiling the results of a very long and involved research study. It is indexed by the original statement of work (SOW) element numbers.

Contained within CRP-11 are:

M. G. Pottinger, W. Pelz, G. A. Tapia, and C. B. Winkler, "A Combined Cornering and Braking Test for Heavy Duty Truck Tires," 4th International Symposium on Heavy Vehicle Weights and Dimensions, University of Michigan, Ann Arbor, MI, June 25-29, 1995, pp. 583-592.

M. G. Pottinger, and W. Pelz, "Recommended Test Sample Sizes (SOW 1.5) and The CALSPAN/UMTRI Sample Sizes (SOW 1.5) and The CALSPAN/UMTRI Comparison (SOW 3.0) for SOW 1.2.3 Data," Smithers Scientific Services, Inc., April 12, 1995.

SAE J670 Vehicle Dynamics Terminology

SAE J2047 Tire Performance Technology

SAE J2429 Free-Rolling Cornering Test for Truck and Bus Tires

SAE J2673 Straight-Line Braking Test for Truck and Bus Tires

SAE 760029 Pottinger, M.G., Marshall, K.D., and Arnold, G.A., "Effects of Test Speed and Surface Curvature on Cornering Properties of Tires," SAE Technical Paper 760029, 1976, doi:10.4271/760029.

SAE 770870 Marshall, K.D., Phelps, R.L., Pottinger, M.G., and Pelz, W., "The Effect of Tire Break-In on Force and Moment Properties," SAE Technical Paper 770870, 1977, doi:10.4271/770870.

SAE 810066 Pottinger, M.G. and Marshall, K.D., "The Effect of Tire Aging on Force and Moment Properties of Radial Tires," SAE Technical Paper 810066, 1981, doi:10.4271/810066.

SAE 960180 Schuring, D.J., Pelz, W., and Pottinger, M.G., "A Model for Combined Cornering and Braking Forces," SAE Technical Paper 960180, 1996, doi:10.4271/960180.

SAE 962153 Pottinger, M.G., Pelz, W., Pottinger, D.M., and Winkler, C.B., "Truck Tire Wet Traction: Effects of Water Depth, Speed, Tread Depth, Inflation, and Load," SAE Technical Paper 962153, 1996, doi:10.4271/962153.

2.1.2 Tire and Rim Association Publications

Available from The Tire and Rim Association, Inc., 175 Montrose West Avenue, Suite 150, Copley, OH 44321, Tel: 330-666-8121, www.us-tra.org .

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., NW, Suite 900, Washington, DC 20005, Tel: 202-682-4800, www.rma.org.

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.

NOTE: Definitions and symbols in this document employ the SAE J670 Superseded Tire Axis System (called the Historic SAE Tire Axis System in SAE J2047_201303), which is described in appendix C of SAE J670_200801.

3.1 TEST

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

3.2 TEST PROGRAM

A test program is 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_{CAL}	Forces and Moments Applied During Calibration
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	meter
M_X	Overturning Moment
M_Z	Aligning Moment
ω	Spin Angular Velocity about the Wheel Spindle
p	Inflation Pressure
R_1	Loaded Radius
S	Test Speed
SR	Slip Ratio
T_A	Ambient Temperature
T_S	Spindle Torque

5. APPARATUS

5.1 Conventional Laboratory Machines

A conventional 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. Table 2 also specifies ideal control setting rates for machines capable of performing not only this test, but also other related tests such as free-rolling cornering and straight-line braking.

NOTE: Torque control is not addressed in Table 2 because the test only involves slip ratio ramping; torque control is only practical for slip ratio magnitudes less than those associated with peak friction. Further, torque control places a requirement on the system that torque be generated by a motor system.

Table 2 - Laboratory machine control setting accuracies and ideal rates

	Largest Acceptable Tolerance and Rates For Setting Accuracy			
	SI Units		USC Units	
Setting	Tolerance	Ideal Max Rate	Tolerance	Ideal Max Rate
Test Speed	±1.0 km/h		±0.6 mph	
Normal Force	±1% of Full Scale	≥ 8900 N/s	±1% of Full Scale	≥ 2000 lb/s
Slip Angle	±0.05	≥ 5 degrees/s	±0.05	≥ 5 degrees/s
Inclination Angle(1)	±0.05	≥ 1 degree/s	±0.05	≥ 1 degree/s
Spin Angular Velocity(2)	±10 rpm	≥1200 rpm/s	±10 rpm	≥1200 rpm/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.
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 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. 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 which should be resolved through research.

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 ensure that the widest standardized or currently envisioned tire (e.g., 605/70R20.5, 24R20.5, etc.) 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, torques, and slip angles applied in this document.

5.1.1.3 The roadway shall be flat. Although combined cornering and braking data to support this requirement do 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). This implies the need for an impractically large round wheel machine to provide data indistinguishable from flat surface data. 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 1 and 160 km/h (0.6 and 100 mph). Test speed affects tire force and moment data (SAE 760029) and 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 Ambient Temperature, T_A, shall be maintained within the allowable 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, 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 15X6.00 to 24.5X16 allowing testing of tires between 800 mm and 1400 mm (31.5 in to 55.0 inch) in outside diameter with section widths up to 645 mm (25.4 inch).

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 to exert normal forces magnitudes of up to 140 kN (31500 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° to +7 . An ideal slip angle setting system would be able to continuously set slip angles from –20 to +20 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 inclination angle setting capability is provided 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 to +5 . An ideal inclination angle setting system would be able to continuously set inclination angles from -10 to +10 .

5.1.3 Measuring System

The measuring system shall, at a minimum, be capable of measuring these data: aligning moment (M_Z), lateral force (F_Y), longitudinal force (F_X), normal force (F_Z), test speed (S), slip angle (α), ambient temperature (T_A) 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, for example 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_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 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	0 ± 11 kNm	0 ± 8100 ft-lb
Ambient Temperature(1)	10 to 35 °C	50 to 95 °F
Inclination Angle(1)	0 ± 10	0 ± 10
Inflation Pressure(1)	0 to 1,500 kPa	0 to 215 psi
Lateral Force	0 ± 140 kN	0 ± 31500 lb
Loaded Radius(1)	350 mm to 675 mm	14.5 in to 27.5 in
Longitudinal Force	0 ± 140 kN	0 ± 31,500 lb
Normal Force	0 to -140 kN	0 to -31,500 lb
Overturning Moment(1)	0 ± 33 kN·m	0 ± 24,300 ft-lb
Test Speed	0 to 160 km/hr	0 to 100 mph
Slip Angle	0 ± 20	0 ± 20
Spin Angular Velocity	0 ± 1200 rpm	0 ± 1200 rpm
Spindle Torque(1)	0 ± 94500 Nm	0 ± 70000 ft-lb

1. This measurement is recommended for an ideal machine, but not required for this test.

NOTE: Braking Force is the equivalent of negative longitudinal force (SAE 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(2)
Aligning Moment	±0.5% of Full Scale
Ambient Temperature(1)	±0.5 °C (± 1.0 °F)
Inclination Angle(1)	±0.02
Inflation Pressure(1)	±3.5 kPa (± 0.50 psi)
Lateral Force	±0.5% of Full Scale
Loaded Radius(1)	±0.5 mm (± 0.020 in)
Longitudinal Force	±0.5% of Full Scale
Normal Force	±0.5% of Full Scale
Overturning Moment(1)	±0.5% of Full Scale
Test Speed	±0.5% of Full Scale
Slip Angle	±0.02
Spin Angular Velocity	±5 rpm
Spindle Torque(1)	±0.5% of Full Scale

1. 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.
2. 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 16 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[(1)]

	Largest Acceptable Tolerance and Rates For Setting Accuracy			
	SI Units		USC Units	
Setting	Tolerance	Ideal Max Rate	Tolerance	Ideal Max Rate
Test Speed	±10% of Full Speed		±10% of Full Speed	
Normal Force	±3% of Full Scale	≥ 8900 N/s	±3% of Full Scale	≥ 2000 lb/s
Slip Angle	±0.10	≥ 5 degrees/s	±0.10	≥ 5 degrees/s
Inclination Angle[(2)]	±0.10	≥ 1 degree/s	±0.10	≥ 1 degree/s

1. 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 within the specified test time.
2. 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.

NOTE: The road surface chosen to be the test surface is fundamental in this experiment. The surface 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 frictional characteristics with time (surface endurance) should be investigated. These are subjects, which should be resolved through research.

NOTE: Torque control is not considered for the reason discussed in the note in 5.1.

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 1 km/h and 160 km/h (0.6 mph and 100 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 positions the tire with respect to the road and loads it against the road surface at the normal forces specified in Section 9. 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 15X6.00 to 24.5X16 allowing testing of tires between 800 mm to 1400 mm (31.5 inch to 55.0 inch) in outside diameter with section widths up to 645 mm (25.4 inch).

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 (31500 lb).

5.2.2.3 The positioning system and its supporting structure shall, as a minimum, permit incremental setting of slip angles from –7° to +7 . An ideal slip angle setting system would be able to continuously set slip angles at least from –20° to +20 .

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

5.2.3 Measuring System

The measuring system shall be capable of measuring at least these data: aligning moment (M_Z), lateral force (F_Y), longitudinal force (F_X), normal force, (F_Z), spin angular velocity (ω), slip angle (α), ambient temperature (T_A), spindle torque (T_S), and test speed (S). The individual results for all channels shall be corrected for tare. Interactions shall be systematically corrected by an established procedure (for example, using a matrix method or other 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_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 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. Table 3 provides a set of ranges consistent with the ideal capacities 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[(1)]
Aligning Moment	±1.0% of Full Scale
Ambient Temperature[(2)]	±0.5 °C (±1.0 °F)
Inclination Angle[(2)]	±0.05
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	±1.0% of Full Scale
Normal Force	±1.0% of Full Scale
Overturning Moment[(2)]	±1.0% of Full Scale
Slip Angle	±0.05
Spin Angular Velocity	±5 rpm
Spindle Torque[(2)]	±1.0% of Full Scale
Test Speed	±0.5% of Full Scale

1. This applies to a single sample with loading of only the measurement channel being examined.
2. 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.

5.2.3.3 The A/D converters used must have a 16 bit or greater resolution.

5.3 Hybrid - Laboratory Machines Over Pavement

The Hybrid system described in this section for performing truck tire force and moment testing according to this document is comprised of four systems: an automated mobility system, a loading and positioning system, a measuring system, and a paved road surface protected from the environment.

Hybrid systems are designed to provide the repeatability of a laboratory machine combined with the accuracy of a paved road surface protected from extreme changes in environmental conditions. Unlike Mobile systems described in the previous section, hybrid machines may be automated to remove variability in speeds and test locations and positions, may utilize rail systems to constrain vehicle motion, and are protected from external environmental conditions.

NOTE: The test surface is fundamental in this experiment. The surface 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 frictional characteristics with time (surface endurance) should be investigated. These are subjects, which should be resolved through research.

NOTE: Torque control is not considered for the reason discussed in the note in 5.1.

5.3.1 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 1 km/h and 160 km/h (0.6 mph and 100 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.

5.3.2 Loading and Positioning System

The system positions the tire with respect to the road and loads it against the road surface at the normal forces specified in Section 9. The system shall accommodate the tire sizes to be tested.

5.3.2.1 The loading and positioning system shall accommodate tire-wheel-assemblies with diameters and widths required by users. An ideal system would accommodate rims from 15X6.00 to 24.5X16 allowing testing of tires between 800 mm to 1400 mm (31.5 inch to 55.0 inch) in outside diameter with section widths up to 645 mm (25.4 inch).

5.3.2.2 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 (31500 lb).

5.3.2.3 The positioning system and its supporting structure shall, as a minimum, permit incremental setting of slip angles from –7° to +7 . An ideal slip angle setting system would be able to continuously set slip angles at least from –20° to +20 .

5.3.2.4 If inclination angle setting capability is provided, the positioning system and its supporting structure shall permit incremental setting of inclination angles from at least –5 to +5 . An ideal inclination angle setting system would be able to continuously set inclination angles from –10° to +10 .

5.3.3 Measuring System

The measuring system shall be capable of measuring at least these data: aligning moment (M_Z), lateral force (F_Y), longitudinal force (F_X), normal force, (F_Z), spin angular velocity (ω), slip angle (α), ambient temperature (T_A), spindle torque (T_S), and test speed (S). The individual results for all channels shall be corrected for tare. Interactions shall be systematically corrected by an established procedure (for example, using a matrix method or other 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_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). As described in 5.2, the data are processed similarly to the example in Section 6.

5.3.3.1 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. Table 3 provides a set of ranges consistent with the ideal capacities 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.

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

5.3.3.3 The A/D converters used must have a 16 bit or greater resolution.

6. CALIBRATION

6.1 Transducer Calibration

All transducers should be calibrated 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 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 and 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, if fitted, shall be calibrated using a hydrostatic calibrator.

6.1.2.3 The height gauge used for calibrating the loaded radius transducer in Tables 3, 4, and 6, if fitted, shall be accurate to ±0.025 mm (±0.0010 inch) 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 a 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 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.

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

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

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	$N{\cdot}m_{SEN}/N{\cdot}m_{CAL}$	$ft\text{-}lb_{SEN}/ft\text{-}lb_{CAL}$

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 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
		C_{11}	C_{12}	C_{13}
N_{ACT}/N_{SEN}	Lb_{ACT}/lb_{SEN}	C_{21}	C_{22}	C_{23}
		C_{31}	C_{32}	C_{33}
		C_{41}	C_{42}	C_{43}
$N{\cdot}m_{ACT}/N_{SEN}$	$ft\text{-}lb_{ACT}/lb_{SEN}$	C_{51}	C_{52}	C_{53}
		C_{61}	C_{62}	C_{63}
		C_{14}	C_{15}	C_{16}
$N_{ACT}/N{\cdot}m_{SEN}$	$lb_{ACT}/ft\text{-}lb_{SEN}$	C_{24}	C_{25}	C_{26}
		C_{34}	C_{35}	C_{36}
		C_{44}	C_{45}	C_{46}
$N{\cdot}m_{ACT}/N{\cdot}m_{SEN}$	$ft\text{-}lb_{ACT}/ft\text{-}lb_{SEN}$	C_{54}	C_{55}	C_{56}
		C_{64}	C_{65}	C_{66}

6.1.3.2 The pressure measuring system, if fitted, shall be calibrated using a hydrostatic calibrator or similar device 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, if fitted, shall be calibrated using a height gauge or similar device to determine its gain, mm_{SEN}/mm_{CAL} (in_{SEN}/in_{CAL}), and offset, mm (inch).

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 offsets is desirable as offsets are often not stable over long periods of time.

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

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.

Routine "checks" of proper machine performance should be conducted on a regular basis as described in Section 7.

6.2.1 Calibration to Resolve a Problem

Should routine operational checks conducted in accordance with Section 7 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 ensure 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 the specific laboratory or 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 ensure 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[1]
Inclination Angle[2]
Inflation Pressure[1]
Loaded Radius[2]
Slip Angle
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[3] Check of Force Measuring System

Performance of the Force Measuring System will be verified via a reduced set of check points conducted using a Force Platform or other device whereby repeatable and verifiable loads can be quickly and efficiently applied. This verification should be done frequently - for example at the beginning of each day – to identify any gross errors in machine performance prior to the collection of data.

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[1] 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.

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

[3] In the case of this practice, it is only necessary that the force and moment measuring platform allow checking of F_X, F_Y, F_Z, and M_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.

7.2.2.1 An example of the proper use of a Force Platform is as follows. The platform would include a frictionless platform with calibrated load cells and a reliable method for actuating the platform in a defined direction. 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 and both F_Y and M_Z set to zero, 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. With F_{ZRATED} applied and both F_X and M_Z set to zero, the force-measuring platform shall be exercised through a Y-displacement, which will induce an F_Y value equal to approximately 50% of the magnitude of F_{ZRATED}. This checks F_Y gain. With F_Y and F_X set to zero and $F_Z = F_{ZRATED}$, the footprint shall be twisted sufficiently to induce M_Z data approximately equal to $0.015\text{m} \bullet F_{ZRATED}$, where F_{ZRATED} is expressed in Newtons. This checks 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 ensure 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. 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% of 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 repeatable load is applied to the force measurement system at a fixed point and direction. This may be done either of two ways. (1) A special spindle tip with a 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. Or, (2) The calibration force can be applied using a long tie rod with a load cell on the rod axis. Application of the known force permits a quick check of system response.

7.2.4 Example Control Tire Check of Force-Measuring System

A control tire typically similar in size to the tires to be used in the test program shall be tested according to the following procedure to check the F_Y and M_Z system responses. It is not feasible to check the F_X response of the force measuring system with a control tire due to confounding of the result with surface friction. 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 inflation 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 at each angle (α_1 to α_7).

Table 11 - Control tire test for force measuring system check

Speed km/h	Speed mph	γ degrees	F_Z N	F_Z lb	α_1 degrees	α_2 degrees	α_3 degrees	α_4 degrees	α_5 degrees	α_6 degrees	α_7 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 control tire $F_Y(\alpha)$ and $M_Z(\alpha)$ data for any F_Z error using Equations 4 and 5. Fit the F_Z corrected $F_Y(\alpha)$ and $M_Z(\alpha)$ data at slip angles of 0.0°, 0.5°, 1.0°, –0.5°, and –1.0° with regression lines. Compute the Aligning Stiffness, Cornering Stiffness, $F_Y(0°)$, and $M_Z(0°)$. The F_Z corrected $F_Y(\alpha)$ and $M_Z(\alpha)$ data at –4.0° and 4.0° shall be mirrored using Equations 6 and 7. Aligning Stiffness, Cornering Stiffness, $F_Y(0°)$, $M_Z(0°)$, $F_{YM}(4°)$ and $M_{ZM}(4°)$ shall be plotted on control charts showing lines for the mean value and $\pm 2.5\ \sigma$, standard deviations, from the mean based on the data from control tire pre-testing, Appendix A. If the values of Aligning Stiffness, Cornering Stiffness, $F_Y(0°)$, $M_Z(0°)$, $F_{YM}(4°)$, and $M_{ZM}(4°)$ lie within the $\pm 2.5\ \sigma$ band, 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 fails once again, repair and re-calibrate the force measuring system[4].

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

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

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

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

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

7.3.1 Control Tire Check of Roadway Surface Friction

A control tire similar in size to the program tires 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.

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 12.

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

[4] 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).

7.3.1.3 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 for any F_Z errors using Equation 8. The F_{XCORR}(SR) shall be plotted versus F_{XREF}, the reference value of F_X(SR).

$$F_{XCORR} = (F_{ZRated}/F_{ZMeasured}) \cdot F_{Xmeasured} \quad \text{(Eq. 8)}$$

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 (Figures 5 and 6, from “A Straight-Line Braking Test for Heavy-Duty Truck Tires” in 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.

NOTE: F_{XCORR}(SR) and F_{XREF}(SR) are data tabulated at the same slip ratios, for example, at slip ratio increments of 0.01. The forces are cross plotted slip ratio by slip ratio. F_{XREF}(SR) is the data taken on the test surface, which is the target surface, for example, on an indoor machine whose roadway is coated with its first abrasive application.

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, 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.

c. For tests run on an indoor, stationary surface, 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, or the surface may be treated to restore a desirable friction characteristic. 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 ensure 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, whichever 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 fixed machine 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 a fixed machine facility has no documented usable life information within its files or is using a surface beyond its documented usable life,

4. Each time an outdoor test track is subject to unusual weather events,

or

5. The test track surface has been disused for a substantial time period of, for example, 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

The procedure in 7.2 shall be repeated as written at the end of testing.

7.7 Roadway Friction at the End of a Test Program

The procedure in 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 considered 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 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 , normal force (F_Z) = – (Rated Load for the target cold inflation), and test speed (S) for 1 hour. At the end of 1 hour, stop the test and measure the pressure in the test tire. The pressure measured is the test inflation pressure (p), which shall 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 in Table 14. 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 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 hour	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 useful as a first approximation.

8.5.1 Estimating Sample Size

Using the CALSPAN 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. For F_X, see Figures C/U1.2.3-4 and C/U1.2.3-5, Recommended Test Sample Sizes (SOW 1.5) and the CALSPAN/UMTRI Comparison (SOW 3.0) for SOW 1.2.3 Data, SAE CRP-11. Sample size estimates for F_Y can be obtained from Figures C/U1.2.3-6 and C/U1.2.3-7 found in the same reference. Unfortunately, no M_Z sample size estimate was possible for CALSPAN data due to M_Z data quality problems.

NOTE: Sample size estimates for the UMTRI machine are no longer directly relevant due to it being decommissioned and no longer available for testing. However, the UMTRI sample sizes in the references illustrate the accuracy possible using a properly constructed over-the-road force and moment tester.

9. TEST PROCEDURE

9.1 The Test

Without stopping at the end of conditioning, test according to the sequence in Table 15. The procedure is to set the first normal force, set the first slip angle (α_1), do the braking ramp, set the second slip angle (α_2), do the braking ramp, and so forth in order until Table 15 has been completed.

Table 15 - Cornering and braking test

γ = 0°; p is as determined in 8.2; S is at the engineering user's choice.

-0.80 ≤ SR ≤ 0.00; dSR/dt = -0.80/s									
F_Z, % Rated Load	α_1 deg	α_2 deg	α_3 deg	α_4 deg	α_5 deg	α_6 deg	α_7 deg	α_8 deg	α_9 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

9.1.1 Braking Ramp

The braking ramp defined in Table 15 is as near a linear change of slip ratio from 0.00 in to –0.80 in 1 second as is feasible given the equipment existing at the test facility.

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 (S) 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_Y, F_Z, M_Z, ω, S, T_A, and α. Should the machine have the capability, acquire: F_X, F_Y, F_Z, M_X, M_Z, p, R_1, ω, S, T_A, T_S, α and γ.

Tire temperatures (surface, carcass, etc.) are recognized to have a significant impact on test results, and should be considered when conducting testing.

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 average smoothing and interpolating functions.

10.3 Tire Coordinate System

All data shall be reported using one of the tire coordinate systems in SAE J670_200801. As noted near the beginning of Section 3, this document is written in terms of the Historical SAE Coordinate System defined in J2047_201303.

10.4 Data Correction or Adjustment

If modest normal force (F_Z) errors (±5% or less) exist, the F_X, F_Y, and M_Z data may be corrected by use of Equations 9, 10, and 11. Correction for slip angle errors is not considered. Depending on the tire modeling software used, neither correction may be necessary.

$$F_{X@target} = (F_{Ztarget} / F_{ZMeasured}) \cdot F_{XMeasured} \quad \text{(Eq. 9)}$$

$$F_{Y@target} = (F_{Ztarget} / F_{ZMeasured}) \cdot F_{YMeasured} \quad \text{(Eq. 10)}$$

$$M_{Z@target} = (F_{Ztarget} / F_{ZMeasured}) \cdot M_{Zmeasured} \quad \text{(Eq. 11)}$$