



SURFACE VEHICLE RECOMMENDED PRACTICE

J2675™

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Superseding J2675 NOV2017

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.

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Documents

Document Sharing Hub

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

Setting	Largest Acceptable Tolerance and Rates For Setting Accuracy			
	SI Units		USC Units	
	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 $+7^\circ$. An ideal slip angle setting system would be able to continuously set slip angles from -20° to $+20^\circ$ at a minimum.

5.1.2.4 For this test, the positioning system and its supporting structure shall provide an inclination angle of $\gamma = 0^\circ \pm 0.05^\circ$. 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 $+5^\circ$. An ideal inclination angle setting system would be able to continuously set inclination angles from -10° to $+10^\circ$.

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_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). 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⁾

Setting	Largest Acceptable Tolerance and Rates For Setting Accuracy			
	SI Units		USC Units	
	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 $+7^\circ$. An ideal slip angle setting system would be able to continuously set slip angles at least from -20° to $+20^\circ$.

- 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 $+5^\circ$. An ideal inclination angle setting system would be able to continuously set inclination angles from -10° to $+10^\circ$.

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	$\pm 1.0\%$ of Full Scale
Ambient Temperature ⁽²⁾	$\pm 0.5^\circ\text{C}$ ($\pm 1.0^\circ\text{F}$)
Inclination Angle ⁽²⁾	± 0.05
Inflation Pressure ⁽²⁾	$\pm 3.5\text{ kPa}$ ($\pm 0.50\text{ psi}$)
Lateral Force	$\pm 1.0\%$ of Full Scale
Loaded Radius ⁽²⁾	$\pm 1.0\text{ mm}$ ($\pm 0.040\text{ in}$)
Longitudinal Force	$\pm 1.0\%$ of Full Scale
Normal Force	$\pm 1.0\%$ of Full Scale
Overturning Moment ⁽²⁾	$\pm 1.0\%$ of Full Scale
Slip Angle	± 0.05
Spin Angular Velocity	$\pm 5\text{ rpm}$
Spindle Torque ⁽²⁾	$\pm 1.0\%$ of Full Scale
Test Speed	$\pm 0.5\%$ 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.