SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Straight-Line 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 2020. 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 new classes of hybrid testing machines, one of which tests a tire while moving it over a paved surface in a controlled environment.

SAE J2673 has been reaffirmed to comply with the SAE Five-Year Review policy.

1. SCOPE

This SAE Recommended Practice (RP) 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.

This document is intended to be a general guideline for testing on an ideal machine. Users of this RP may modify the recommended protocols to satisfy the needs of specific use-cases; e.g., reducing the recommended number of test loads and/or pressures for benchmarking purposes. However, due care is necessary when modifying the protocols to maintain data integrity.

1.1 Truck Tires

For this RP, truck tires are defined as tires mounted on heavy commercial over-the-road trucks (Class VI, VII, VIII) and buses. Vehicles which use heavy truck tires include: tractor and semi-trailer combinations, rigid trucks (e.g., flat beds, dump trucks, refuse, and refrigerated vans), buses (e.g., school, city and coaches), heavy trailers (including semi-trailers, full trailers, platform trailers, and dollies), and special purpose vehicles (e.g., truck mounted concrete pumps, military trucks, and fire fighting appliances). Tires mounted on other types of vehicles with a GVWR of 8845 kg (19500 pounds) or less (Class I through V) are explicitly excluded from consideration in this document. However, when testing tires used on larger off-highway vehicles the protocols outlined in this RP may provide a useful reference provided the tire sizes and road surfaces are similar to on-highway conditions.

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1.2 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 in this document, but the accuracies of machines including inclination angle and slip angle are referenced.

1.3 Test Machines

This RP is test machine neutral. It may be applied to any type of test machine capable of fulfilling the specified requirements. For example, specific data used to develop this RP 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. The ideal machine defined in 1.3.1 is not required, but a test machine's performance must be fully defined over its operating range.

NOTE: The UMTRI Mobile Tire Dynamometer is decommissioned and no longer available to test tires. It is mentioned because much of the supporting data for SAE J2673, SAE J2429, and SAE J2675 was obtained from tires tested using the UMTRI machine and experience with it shows the quality of information that can be obtained with a machine of this type. Similar over-the-road test machines have since been commissioned like the TÜV measuring trailer II (Europe) and ARRB tyre-pavement test-trailer (Australia). These machines have increased vertical loading capacity (70 to 90 kN) compared to the UMTRI machine (45 kN) as well as hub braking (30 to 40 kNm) and slip angles up to ±25 degrees and ±10 degrees of camber in the case of the ARRB machine.

1.3.1 Ideal Machine

This RP references an ideal machine capable of fully matching every requirement of SAE J2673, SAE J2429, and SAE J2675. Such a machine neither exists currently, nor is it certain that the technology to build a machine to the desired accuracy exists. However, this RP does not require 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 and to provide a method for assessing performance; for example, through benchmarking machine performance using a Standard Reference Test Tyre (SRTT) such as the ASTM F2870, 315/70R22.5 154/150L Radial Truck SRTT or other specified procedure.

NOTE: The ideal machine, ideal test operating range, and ideal accuracies are goals, NOT requirements.

2. REFERENCES

2.1 Applicable Documents

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

2.1.1 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM F2870 Standard Specification for 315/70R22.5 154/150L Radial Truck Standard Reference Test Tire

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2.1.2 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:

Pottinger, M.G., Pelz, W., Tapia, G.A., and Winkler, C.B., "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.

Pottinger, M.G. and Pelz, W., "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 Terminology

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

SAE J2675 Combined Cornering and Braking Test for Truck and Bus Tires

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

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

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

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

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

2.1.3 Tire and Rim Association Publications

Available from The Tire and Rim Association, Inc., 4000 Embassy Parkway, Suite 390, Akron, OH 44333, www.us-tra.org.

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

NOTE: European Tyre and Rim Technical Organisation publications available from the European Tyre and Rim Technical Organisation, 78/80, rue Defacqz B-1060 Brussels, Belgium, Tel: 32-3-344-40-59, www.etrto.org.

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2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 OSHA Publications

Available from U.S. Department of Labor/OSHA, 200 Constitution Avenue, Washington, DC 20210, Tel: 800-321-6742, www.osha.gov/pls/publications/pubindex.list.

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.

2.2.2 NIST Publications

Available from NIST, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, Tel: 301-975-6478, www.nist.gov.

NIST Handbook 105-1 Specifications and Tolerances for Reference Standards and Field Standard Weights and Measures (NIST Class F)

2.2.3 Other Publications

Pottinger, M.G., Tapia, G.A., Winkler, C.B., and Pelz, W., “Straight-Line Braking Test for Heavy Duty Truck Tires,” Paper #45, American Chemical Society Mtg., October 17, 1995.

Trevorrow, N. and Wright, B., “Understanding the Impact of Pavement Surfaces from Next Generation Freight Vehicles - Literature Review,” Austroads 2011, ISBN 978-1-921709-63-0.

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), which is described in Appendix C of SAE J670e.

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.

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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
Fcal	Forces and moments applied during calibration
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_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 measuring truck tire forces and moments is comprised of three systems: a simulated roadway, a loading and positioning system, and a measuring system. Table 2 specifies accuracies for test speed, load, and position. Table 2 also specifies ideal control setting rates for machines capable of performing other related tests such as free-rolling cornering and combined cornering and braking.

NOTE: Torque control is not addressed in Table 2 because the test only involves slip ratio ramping and torque control is only practical for slip ratio magnitudes less than the slip ratio associated with peak friction. Furthermore, torque control requires the test machine to generate torque with a drive system.

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Table 2 - Laboratory machine control setting accuracies and ideal rates

	Least Acceptable Setting Accuracy	
Setting	**SI Units**	**USC Units**
Test Speed	±1.0 km/h	±0.6 mph
Normal Force	±1% of full scale	±1% of full scale
Slip Angle[1]	±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 nor used in this RP. They are provided for reference should anyone wish 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 drive system to apply torque to the test tire. It is not necessary to set a given steady-state ω level in this RP; 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. Efforts should be made to ensure the stability of the frictional properties of the abrasive material through a control tire testing procedure such as the example included in Section 7 or similar quality control procedure. The roadway shall be maintained free of loose materials and deposits.

NOTE: Frictional characteristics for the simulated road surface including acceptible changes in friction characteristics during testing (surface endurance) are not defined. However, simulated road surface friction properties should align to expected on-highway road surface conditions for the tire being characterised.

5.1.1.1 The roadway shall be wide enough to support the entire tire footprint at all slip angles. Ideally, the active width would be 800 mm (31.5 inches) to ensure that the widest standardized or currently envisioned tire (605/70R20.5, 24R20.5, etc.) could be tested.

5.1.1.2 The roadway and its supporting structure shall be sufficiently rigid so that it does not change appreciably in either transverse or longitudinal curvature or angular orientation under the maximum test loads and torques applied in this RP.

5.1.1.3 The simulated roadway shall be flat.

NOTE: Straight-line braking data to support this requirement does not exist. However, it is certainly correct for a general-purpose machine. The correctness of this requirement is inferred from the distortion of free-rolling force and moment properties by roadway curvature (SAE 760029). Available test data imply the need for an impractically large round wheel machine to provide data indistinguishable from flat surface data.

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 km/h and 120 km/h (6 mph 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 Ambient Temperature, T_A, shall be maintained within the allowable range specified in Sections 8 and 9. Ambient temperature affects tire temperature and tire temperature affects tire force and moment data (SAE 770870).

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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. 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 to 55.0 inches) in outside diameter with section widths up to 645 mm (25.4 inches).

5.1.2.2 The loading mechanism shall be able to exert the normal forces required by 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 pounds).

5.1.2.3 For this test, the positioning system and its supporting structure shall provide a slip angle of $\alpha = 0$ degrees ± 0.05 degree. 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 to +7 degrees. An ideal system would be able to continuously set slip angles between ±20 degrees.

5.1.2.4 For this test, the positioning system and its supporting structure shall provide an inclination angle of $\gamma = 0$ degrees ± 0.1 degrees. If, as part of a general machine, inclination angle setting capability is provided, the positioning system and its supporting structure shall permit incremental setting of inclination angles from -8 to +8 degrees.

5.1.3 Measuring System

The measuring system shall, at a minimum, be capable of measuring: longitudinal force (F_X), normal force (F_Z), test speed (S), and spin angular velocity about the wheel spindle (ω). Individual measurements for all channels shall be corrected for tare weight. 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: 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). Individual measurements for all channels shall be corrected for tare weight. 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. Table 3 provides a set of ranges consistent with the ideal capacities of the roadway and loading and positioning systems expressed in this RP. 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[1]	0 kNm ± 11 kNm	0 ft-lb ± 8.100 ft-lb
Ambient Temperature[1]	-40 to 50 °C	-40 to 122 °F
Inclination Angle[1]	0 degrees ± 10 degrees	0 degrees ± 10 degrees
Inflation Pressure[1]	0 to 1500kPa	0 to 215 psi
Lateral Force[1]	0 kN ± 140 kN	0 pounds ± 31500 pounds
Loaded Radius[1]	350 to 675 mm	14.5 to 27.5 inches
Longitudinal Force	0 kN ± 140 kN	0 pounds ± 31500 pounds
Normal Force	0 to -140 kN	0 to -31500 pounds
Overturning Moment[1]	0 kNm ± 33 kNm	0 ft-lb ± 24300 ft-lb
Test Speed	0 to 160 km/h	0 to 100 mph
Slip Angle[1]	0 degrees ± 20 degrees	0 degrees ± 20 degrees
Spin Angular Velocity	0 rpm ± 1200 rpm	0 rpm ± 1200 rpm
Spindle Torque[1]	0 Nm ± 94500 Nm	0 ft-lb ± 70000 ft-lb

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

NOTE: Braking force is equivalent to negative longitudinal force (SAE J2047).

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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[1]	±0.5% of full scale
Ambient Temperature[1]	±0.5 °C (±1.0 °F)
Inclination Angle[1]	±0.01 degree
Inflation Pressure[1]	±3.5 kPa (±0.50 psi)
Lateral Force[1]	±0.5% of full scale
Loaded Radius[1]	±0.5 mm (±0.020 inch)
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[1]	±0.01 degree
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 at least 16 bit resolution.

5.2 Over-the-Road Machines

An over-the-road machine for performing truck tire force and moment testing according to this RP is comprised of three systems: a mobility system, a loading and positioning system, and a measuring system. Table 5 specifies the applicable setting accuracies for test speed, load, and position, plus ideal control setting rates.

Table 5 - Over-the-road machine control setting accuracies and ideal rates[1]

	Least Acceptable Setting Accuracy	
Setting	**SI Units**	**USC Units**
Test Speed	±5% of test speed S	±5% of test speed S
Normal Force	±3% of test requirement S	±3% of full scale S
Slip Angle	±0.50 degree	±0.50 degree
Inclination Angle[2]	±0.50 degree	±0.50 degree
Rate	**Ideal Maximum Rate**	
Normal Force	≥8900 N/s	≥2000 lb/s
Slip Angle	≥5 degrees/s	≥5 degrees/s
Inclination Angle[2]	≥1 degree/s	≥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. 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 and that should be in line with the requirements of the objectives of the test data being collected.

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

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