SAE INTERNATIONAL®

Force and Moment Test Method

RATIONALE

Committee recommends to stabilize the document. Auto and tire manufacturers are running their own force and moment methods so there seem to be no users of the document. However, if the Committee determines in the future that by revising the method more users could be attracted to use it then the document can be brought out of stabilization for revision.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE Highway Tire Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

TO PLACE A DOCUMENT ORDER:	Tel:	877-606-7323 (inside USA and Canada)	**For more information on this standard, visit**
	Tel:	+1 724-776-4970 (outside USA)	https://www.sae.org/standards/content/J1987_202006
	Fax:	724-776-0790	
	Email:	CustomerService@sae.org	
SAE WEB ADDRESS:		http://www.sae.org	

1. *Scope*

1.1   This SAE Recommended Practice describes the determination of passenger car and light truck tire force and moment properties on a belt-type flat surface test machine. It is suitable for accurately determining five tire forces and moments in steady-state under free-rolling conditions as a function of slip angle and normal force which are incrementally changed in a given sequence.

1.2   Heavy-duty tires are not considered in this document, because the measuring system would have force and moment ranges too large to meet sensitivity requirements for passenger and light truck tire force and moment measurements.   A standard for heavy-duty truck tires would have many of the same features as this document, but the measuring system, would have to be extensively altered.

1.3   Inclination angle combined with slip angle, pull forces, and any combination with spindle torque are not considered in this document. Standards needed for these topics will be considered separately.

1.4   The test method described in this document is suitable for comparative evaluations of tires for research and development purposes.   The method is also suitable for use in manufacturing quality control and vehicle dynamics modeling.

1.5   The values of tire forces and moments obtained on the test machine defined in the procedure outlined can be correlated with similar test machines using the procedure defined in this document.

2. *References*

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

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

SAE J670—Vehicle Dynamic Terminology
SAE 760029—"Effects of Test Speed and Curvature on Cornering Properties of Tires", M.G. Pottinger, K.D. Marshall, E.A. Arnold
SAE 770870—"The Effect of Tire Break-In on Force and Moment Properties", K.D. Marshall, R.L. Phelps, M.G. Pottinger, W. Pelz
SAE 810006—"The Effect of Tire Aging on the Force and Moment Properties of Radial Tires", M.G. Pottinger, K.D. Marshall

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

Tire and Rim Association Yearbook

2.1.3   Other Publications

M.G. Pottinger, Tire/Vehicle Pull; "Ply Steer Effects", Clemson University Tire meeting, October 1988.

3.   *Definitions*—These terms follow the definitions given in [SAE J670] and in the [TRA Yearbook].

3.1   Aligning Stiffness—First derivative of aligning moment of a free-rolling tire with respect to slip angle, evaluated at zero slip angle. For practical purposes, aligning stiffness may be approximated by subtracting the –1 degree slip angle value of the aligning moment from the +1 degree slip angle of aligning moment and dividing by 2.

3.2   Aligning Stiffness Coefficient—Ratio of aligning stiffness to the absolute value of normal force.

3.3   Aligning Moment—Moment about the Z' axis acting on the tire by the road.   The aligning moment is shown in Figure 1. The aligning moment shown in Figure 1 is positive.
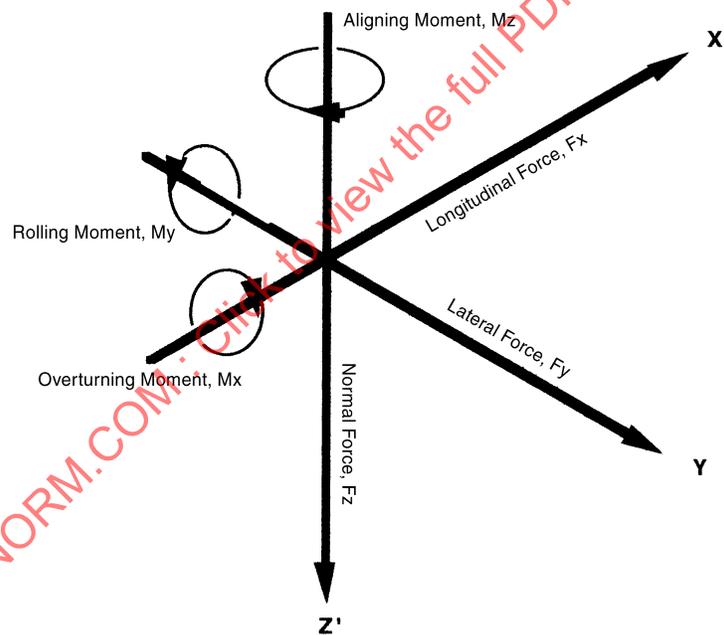
FIGURE 1—TIRE AXIS SYSTEM

3.4   Aligning Moment Offset—Average aligning moment of a free straight-rolling tire. The aligning moment offset is dependent on the direction of tire rotation.   It is different, generally speaking, in left and right tire rotation. [see 2.1.3.]

3.5   Center-of-Tire-Contact—Intersection of the wheel plane and the normal projection of the spin axis onto the road plane.   The center-of-tire contact is the origin of the tire axis system shown in Figure 1.

3.6   Cornering Stiffness—Absolute value for the first derivative of the lateral force of the free-rolling tire with respect to slip angle, evaluated at zero slip angle.   For practical purposes, cornering stiffness may be approximated by taking the absolute value of the quantity yielded by subtracting the +1 degree slip angle value of the lateral force from the −1 degree slip angle value of the lateral force and dividing by 2.

3.7   Cornering Stiffness Coefficient—Ratio of cornering stiffness to the absolute value of normal force.

3.8   Free-Rolling Tire—Loaded rolling tire operating without application of driving or braking torque.

3.9   Inclination Angle—Angle between the X'—Z' plane and the wheel plane. Figure 2 shows a positive inclination angle.   The X' axis is into the paper.

FIGURE 2—INCLINATION ANGLE

3.10   Lateral Force—Component of the tire force vector in the Y' direction acting on the tire by the road. Lateral force is shown in Figure 1.   The lateral force shown in Figure 1 is positive.

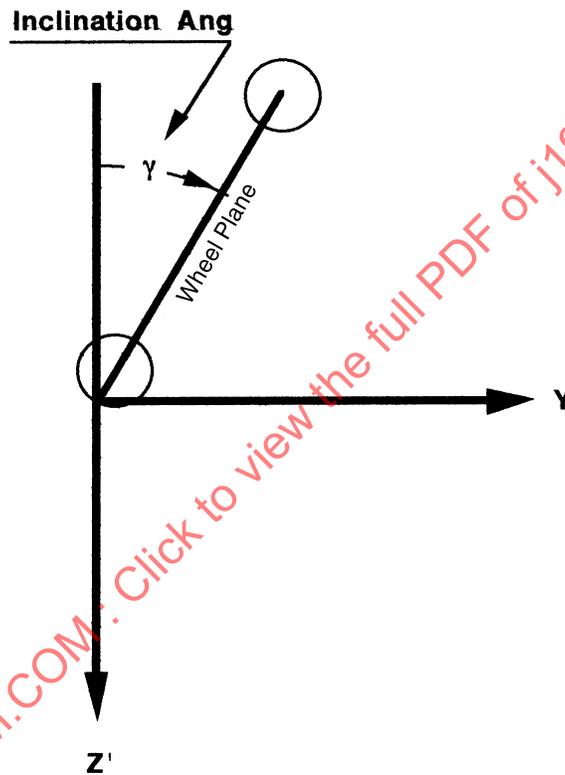**3.11   Lateral Force Offset**—Average lateral force of a free straight-rolling tire. The lateral force offset is dependent on the direction of tire rotation.   The direction of tire rotation may be taken as either left or right. [2.1.3]

3.12   Left Rotation—Operation of the tire on the left side of the vehicle moving forward, with the tire face to the left.

3.13   Loaded Radius—Distance from the wheel center to the center-of-tire contact measured in the wheel plane.

3.14   Longitudinal Force—Component of the force vector in the X' direction acting on the tire by the road. Positive longitudinal force is shown in Figure 1.

3.15 **Normal Force**—Normal component of force between the tire and the road acting on the tire by the road and directed into the road plane. The positive direction of normal force is shown in Figure 1. It is common practice to normalize the force and moment properties of tires with respect to normal force. When this is done, the 100% level of normal force is the absolute value of the tire design load with the tire design load expressed in force, not mass terms.

3.16 **Overturning Moment**—Moment about the X' axis acting on the tire by the road. Positive overturning moment is shown in Figure 1.

3.17 **Right Rotation**—Operation of the tire on the right side of the vehicle moving forward, with the tire face to the right.

3.18 **Rolling Moment**—Moment about Y' axis acting on the tire by the road. Positive rolling moment is shown in Figure 1.

3.19 **Slip Angle**—Angle between the X' axis and the direction of travel of the center-of-tire contact. Figure 3 shows slip angle. The slip angle shown in Figure 3 is positive.

Slip Angle

Note: The direction of travel is rotated relative to the X' axis.

X'

α

Direction of Travel

Y'
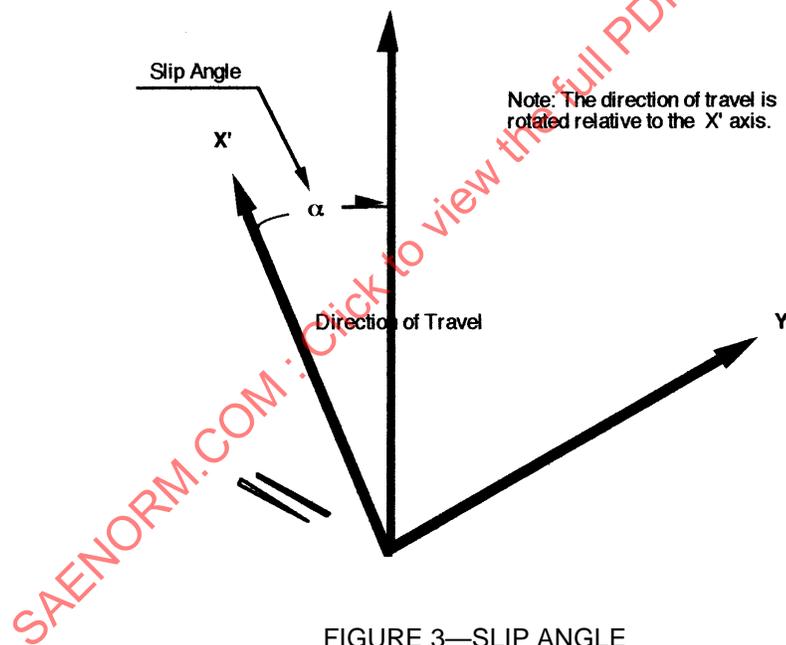
FIGURE 3—SLIP ANGLE

3.20 **Spin Axis**—Axis of rotation of the wheel.

3.21 **Target Normal Load**—A normal force chosen to represent 100%. The normal force test range is 20% to 160% of the target normal load.

3.22 **Tire Design Load**—Tire design load is the base or reference load assigned to a tire at a specific inflation pressure and service condition. Other load/pressure relationships applicable to the tire are based upon that base or reference load. [TRA Yearbook]

3.23 **Tire Face**—Outward side of a tire mounted on a vehicle according to the vehicle manufacturer's specification or general practice. Currently in the United States, the tire face is usually the side without the serial number. Other examples commonly used to define the tire face are the side of the tire with the white sidewall or other decoration (e.g., large raised letters), or the side with the curb strip. In doubtful cases, the tire face selected should be marked and recorded as such.

3.24 **Tire Axis System**—Right-hand orthogonal system fixed in the road plane with the origin in the center-of-tire contact. The X' and Y' axes are located in the road plane and the Z' axis is perpendicular to the road plane, with its positive direction into the road plane. The X' axis is the line of intersection of the wheel plane with the road plane with its positive direction forward. The Y' axis is perpendicular to the line of intersection of the wheel plane and the road plane, with its positive direction to the right when viewed in the positive X' direction. (See Figure 1.)

3.25 **Wheel Center**—The point at which the spin axis of the wheel intersects the wheel plane.

3.26 **Wheel Plane**—Central plane of the tire normal to the spin axis.

4. *Apparatus*

4.1 The laboratory tire test machine shall consist of three basic components: a belt-type flat surface simulated roadway with a drive mechanism, a loading and positioning system, and a measuring system.

4.2 **Simulated Roadway**—The simulated roadway shall be a continuous flat surface and coated with a stable nonpolishing material like "Safety Walk, or 3-Mite."[1] The roadway surface shall be maintained free from loose material or deposit.

4.2.1 The roadway support area shall be wide enough to support the entire tire footprint.

4.2.2 The supporting structure shall be sufficiently rigid to ensure that the specifications for angular accuracy in 4.3.3 are met.

4.2.3 The surface shall be periodically checked for friction characteristics and flatness. Until a valid check can be devised, we must rely on a visual check. If the surface is cracked, torn, dimpled, contaminated, or has some other defect that changes the friction and/or flatness, then the simulated roadway surface should be changed.

4.2.4 The bearing supporting the simulated roadway shall be maintained flat to less than 0.5 mm (0.020 in) of wear.[2]

4.2.5 The hydrostatic water bearing supporting the simulated roadway shall be maintained at 24 °C ± 2.5 °C (75 °F ± 5 °F). The expected deviation induced by the temperature variation allowed in this specification is ±1.0%. [SAE 770870]

4.2.6 The drive system shall be capable of operating the simulated roadway at the speed specified within an accuracy of ±1 km/h. At 3.5 km/h, the recommended test speed in this procedure and a 1 degree slip angle, reference [SAE 760029] shows that there is an expected speed induced deviation in lateral force and aligning moment of ±1.3% and ±0.5% respectively. Reference [SAE 760029] demonstrates that the speed effects become statistically uncertain as slip angle is changed above 4 degrees.

---

1. At present, there is no valid way of checking the surface. Most testers look at the appearance of the surface and replace it if it is torn, obviously contaminated, or subjectively judged to be worn smooth as compared to a recently broken-in new surface

2. At present there is no data showing the effect of bearing flatness on force and moment measurements. It is known that more than 0.5 mm of wear in a hydrostatic bearing can lead to rapid bearing failure

4.3 Loading and Positioning System—A fixture is provided for positioning the tire with respect to the track surface and loading it against the simulated roadway at specified normal forces. It shall accommodate all sizes of tires to be tested.

4.3.1 The machine shall accommodate rims with diameters and widths required by the user.

4.3.2 The loading mechanism shall have provision for changing the normal force on the test tire from zero to 160% of the target normal load.

4.3.2.1 The loading mechanism shall have a setting accuracy of ±1% of the maximum normal force as defined in 4.4.1.

4.3.3 The structure supporting the loading and positioning mechanism shall be sufficiently rigid to ensure that angular accuracies of at least ±0.05 degree can be maintained.

4.3.3.1 The accuracy of slip angle setting shall be ±0.05 degree.

4.3.3.2 The accuracy of inclination angle setting shall be ±0.05 degree.

4.4 Measuring System—The measuring system shall be capable of measuring these data for a free-rolling tire: Aligning moment, lateral force, longitudinal force, normal force, overturning moment, slip angle, inclination angle, and loaded radius. Individual load cell values shall be corrected for tare and interactions shall be corrected by a matrix method. Quoted ranges are advisory minimums.

4.4.1 LOAD CELL ACCURACY—The accuracy of any single measurement after the tare and interaction effects have been removed shall be 1% of full-scale range or better. This accuracy is a system accuracy and includes all system errors, such as alignments, computer data acquisition, and signal conditioning. Table 1 lists the typical measurement accuracy.

4.4.2 LOAD CELL MEASUREMENT RANGES—For the best precision, it is important to choose the lowest full-scale range that exceeds the largest measured datum value for each measurement channel. Listed in Table 1 are the typical full-scale ranges for force and moment measurement.

TABLE 1—LOAD CELL RANGES AND ACCURACY

Measurement	Full Scale Range		Accuracy	
Longitudinal Force	0 to ±1 kN	(0 to ±225 lb)	±10 N	(± 2.3 lb)
Lateral Force	0 to ±15 kN	(0 to ±3370 lb)	±150 N	(± 33.7 lb)
Normal Force	0 to –24 kN	(0 to –5395 lb)	±240 N	(± 54 lb)
Overturning Moment	0 to ±10 kNm	(0 to ±7375 ft-lb)	±100 Nm	(± 73.5 ft-lb)
Rolling Moment	not measured			
Aligning Torque	0 to ±1 kNm	(0 to ±737.5 ft-lb)	±10 Nm	(± 7.4 ft-lb)

4.4.3 The slip angle measuring system shall meet the following requirements:

4.4.3.1 Full-Scale Range— ±15 degrees.

4.4.3.2 Accuracy— ±0.05 degree.

4.4.4 The loaded radius measuring system shall meet the following requirements:

4.4.4.1 Full-Scale Range—200 to 450 mm (8.0 to 18 in).

4.4.4.2 Accuracy— ±1.0 mm (±0.04 in)

5.   *Calibration*

5.1   Calibrate all transducers using the appropriate calibration fixtures along with standard reference load cells, dead weights, and fundamental angle references traceable to the National Institute of Standards and Technology.

5.1.1   The reference load cells used for calibration of the transducers specified in Table 1 shall be calibrated according to a dead weight procedure using Class F weights, the calibration of which is traceable to the National Institute of Standards and Technology.

5.1.2   Calibrate the transducers for measuring slip and inclination angles using measuring devices such that calibration angular resolution is ±0.01 degree or better.

5.1.3   Calibrate the slip angle and inclination angle transducers by incremental changes of angles by clockwise and counterclockwise rotation of the wheel spindle respectively about the Z' and X' axes, recording the values of the angles and recording outputs of the transducer.

5.1.4   Calibrate the load cells using the standard reference load cell and/or optional dead weights. Individually load each load cell and record each load cell's value. The load cell interaction matrix generated is used to remove the load cell interactions from the data measurements.

6.   *Preparation of Apparatus*

6.1   Daily checks for machine readiness are important. At a minimum, a shunt calibration should be performed to assure the electronics and computer program are working correctly under a no-load condition. It is further recommended that a daily [3] control tire check of the machine be performed.

Control tires[4] and the test procedure are the responsibility of the test engineer. The following is a recommended procedure:

6.1.1   CONTROL TIRE TEST

6.1.1.1   No break-in shall be used with the test of a control tire.

6.1.1.2   The control tire shall have been temperature conditioned in accordance with the procedure specified in 7.1 of this document.

6.1.1.3   The control tire shall be inflated to the maximum allowable inflation for the tire size as specified in the Tire and Rim Association Yearbook

6.1.1.4   The control shall be tested according to the following sequence:

In sequence, obtain test data for the listed slip angles at the listed normal forces. Normal forces are applied incrementally with the tire being off the surface only during slip angle changes.

Slip Angle Sequence: 0.0 degree, +1.0 degree, –1.0 degree, –4.0 degrees, +4.0 degrees

Normal Force Sequence: 20%, 40%, 60%, 80%, 100%, 120%, 140%, 160% of the target normal load at each test angle.

---

3.   Control tire check frequency is dependent on the test machine and the types of tests being conducted on the machine. A frequency of once per day is recommended, but may be unnecessary for some machines

4.   The control tires, their maintenance, storage, test procedure, and data analysis used are the responsibility of the test engineer.

The tire shall complete two and one-half revolutions after each load change before beginning data acquisition. Data acquisition shall last for one revolution with 32 or more equally spaced data points being taken per tire revolution. Reported data for a load and slip angle shall be an average of the data points taken at that condition.

6.1.1.5   The data at 0.0 degree and ±1.0 degree slip angle shall be fitted with a cubic vs. normal force. The data at ±4.0 degrees slip angle shall be used as is.

6.2   The data from a control tire test can be analyzed in the following manner:

The lateral force and aligning moment data at 25%, 50%, 75%, 100%, 125% and 150% of the normalizing force shall be tabulated at 0.0 degree, +1.0 degree, and –1.0 degree slip angle. The lateral force and aligning moment at 100% of the normalizing target normal load shall be tabulated at ±4.0 degrees slip angle. The data should be plotted on control charts. If the data from the control tire deviates from the average value by more than 2.5 standard deviations (see 6.2.2 for a description of the determination of standard deviation), then the test results are suspect and testing of an additional control tire is needed. If this additional control tire reveals a potential problem with the behavior of the machine, then a full calibration of the machine including control tire checking according to the procedure, may be necessary. Further investigation is certainly required.

The set of control tires should be tested completely following recalibration to give a measure of how the machine has changed between calibrations.

6.2.1   Control tires can be selected and their properties standardized in the following manner: Control tires shall be smooth tread radial tires, of a size such that 160% of their design load at the maximum Tire and Rim inflation pressure shall equal three-fourths or more of the total load capability of the force and moment machine.

6.2.2   Twenty (20) tires suitable for control tire use shall be obtained in a group from a single build from a single manufacturer. The tires are to be tested according to the control tire test in 6.1.1. The data is to be tabulated and analyzed to yield the average lateral force and normal force values at each of the normal force increments and slip angles specified in 6.1.1. The standard deviations are also to be obtained. The 10 tires that form the most nearly equal set of tires are to be set aside for control tires. A control chart should be prepared for each control tire.

6.2.2.1   The control tire charts are expected to show long-term drift in spite of the precautions taken. When the basic average of the set has shown a drift of 0.5 standard deviations, a new set of control tires is to be obtained and begun. A control chart should be maintained with a point added at completion of a control tire record as specified in 6.4.

6.3   Between uses, control tires are to be stored to limit aging. [SAE 810006].

6.4   The control tire set is to be used in this sequence: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 1, 2, 3, ... to minimize drift.

7.   Selection and Preparation of Test Tires

7.1   In tests comparing tire design structures and materials, all test tires should be approximately the same age and shall have been stored at essentially the same conditions. The test tire shall have been stored at the test room temperature for at least 3 h before the test. [SAE 810006]

7.2   Mount the test tires on the rims recommended by the Tire and Rim Association using conventional mounting methods. Assure proper bead seating using a suitable lubricant on the beads. Excessive use of lubricant is to be avoided to prevent slipping of the beads along the wheel/rim during operation of the tire.

7.2.1   The rims shall meet or exceed OE standards.