

SURFACE VEHICLE RECOMMENDED PRACTICE

J2812™

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Road Load Tire Model Validation Procedures for Dynamic Behavior

RATIONALE

This SAE Recommended Practice was developed to provide a standard procedure to validate tire models that are used for calculating dynamic spindle loads from road surface profiles.

SAE J2812 has been reaffirmed to comply with the SAE Five-Year Review policy.

1. SCOPE

This SAE Recommended Practice describes an evaluation procedure for validating tire models for use in road load simulations and assesses the relevant dynamic behavior of tires.

The laboratory test utilized is a “cleat” test, where a rolling tire on a drum encounters a cleat and the resulting dynamic forces and moments are measured. This test is described in SAE J2730, “Dynamic Cleat Test with Perpendicular and Inclined Cleats”. The test is commonly used to identify tire model parameters.

In this recommended practice, requirements for the measurement of the tire’s response are described along with data processing techniques and calculations used to quantitatively compare the tire model’s calculated response to the tire’s response measured on test. This recommended practice addresses both the tire model structure and its parameters.

NOTE 1: In this recommended practice, validation procedures are proposed for assessing a single cleat test response, i.e., a tire’s dynamic response for one operating condition consisting of a combination of vertical load, forward velocity, cleat size, shape, and orientation, tire pressure, etc. However, it is insufficient to validate a tire model based on a single test. In practice, this assessment should be conducted over an entire set of operating conditions which are selected in such a way as to cover the range of road load simulation applications for which the tire model will be utilized.

NOTE 2: The procedures defined in this recommended practice aim to assess the relevant tire dynamic behavior for road load simulations. It is recommended that the following additional tire properties be determined separately:

- Normal force and rolling radius of the steady-state rolling tire (i.e., the rolling tire in the absence of vertical excitations such as cleats) at various loaded radii and forward velocities relevant for the application.
- Static tire footprint dimensions vs. normal force. (See SAE J2704.)
- Tire quasi-static longitudinal force vs. longitudinal displacement and quasi-static lateral force vs. lateral displacement. (See SAE J2718.)
- Steady-state force and moment characteristics. (See SAE J2047.)

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Documents

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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 724-776-4970 (outside USA), www.sae.org.

SAE J670 Vehicle Dynamics Terminology

SAE J2047 Tire Performance Terminology

SAE J2704 Tire Normal Force/Deflection and Gross Footprint Dimension Test

SAE J2718 Test for Tire Quasi-Static Longitudinal Force vs. Longitudinal Displacement and Quasi-Static Lateral Force vs. Lateral Displacement

SAE J2730 Dynamic Cleat Test with Perpendicular and Inclined Cleats

3. DEFINITIONS

Definitions are consistent with the standards listed in 2.1.1 SAE Publications except as defined herein.

3.1 WHEEL-SPIN AXIS

The axis of wheel rotation. (See SAE J670.)

3.2 WHEEL PLANE

A plane normal to the wheel-spin axis, which is located halfway between the rim flanges. (See SAE J670.)

3.3 ROAD PLANE

The plane tangent to the test machine test surface (without cleat) at the shortest distance from wheel center to the test surface measured in the wheel plane. This definition is only applicable for cleat testing where the cleat width is significantly smaller than the tire contact patch.

3.4 AXIS SYSTEM (X_w , Y_w , Z_w)

The coordinate system used in this recommended practice is the SAE J670 Wheel Axis System with Z-Up orientation. The axis system is illustrated in Figure 1. Specifically:

- The origin of the coordinate system is fixed in the wheel plane at the wheel-spin axis.
- The positive X_w axis lies in the wheel plane, parallel to the road plane, in the direction of the wheel heading.
- The positive Z_w axis lies in the wheel plane, pointing away from the road plane.
- The positive Y_w axis lies in the wheel-spin axis and is chosen to make the axis system right-handed.

NOTE 3: If the origin of the coordinate system of the measured data (i.e., wheel force transducer or spindle transducer data) is not the same as the origin of the axis system defined above (origin at the wheel center), then the measured data will need to be transformed to the axis system prior to performing further analysis.

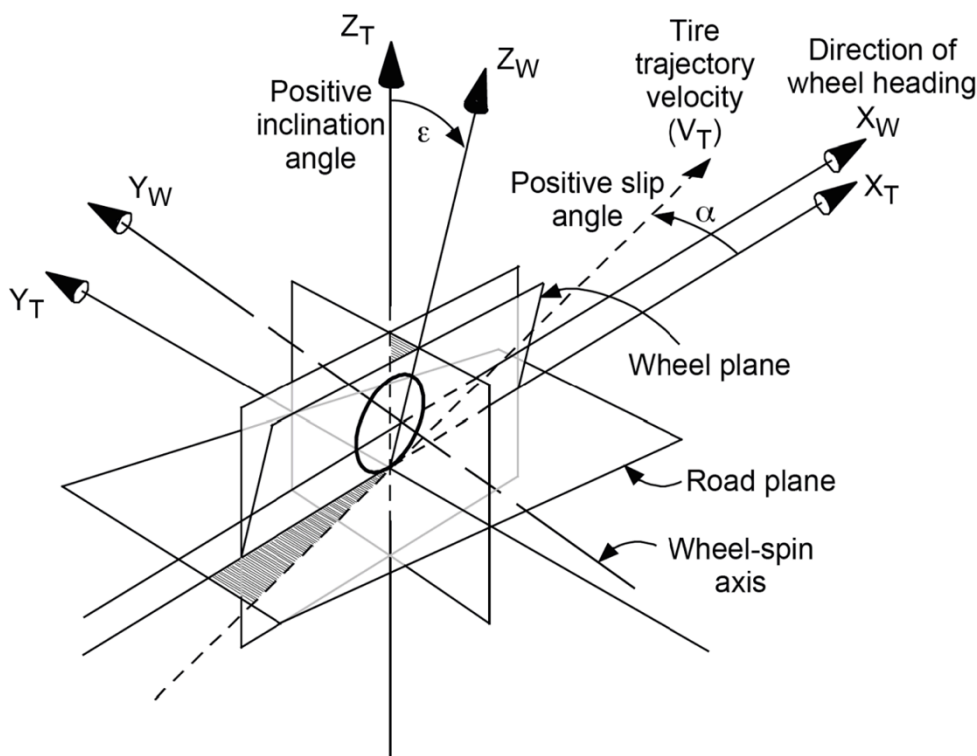


FIGURE 1 – AXIS SYSTEM (FROM SAE J670 WHEEL AXIS SYSTEM WITH Z-UP ORIENTATION)

4. NOMENCLATURE

Table 1 defines symbols used in the calculations in 5.4 of this document.

TABLE 1 – SYMBOLS DEFINED

Symbol	Defined Term
$F_{ZSS(EST)}$	Estimated steady-state vertical force (see 5.4.1)
$F_{XSS}, F_{YSS}, F_{ZSS}$	Calculated steady-state longitudinal, lateral, and vertical force ¹
M_{XSS}, M_{ZSS}	Calculated steady-state overturning and aligning moment ¹
t	Time
t_0, t_1, t_2, t_3	Specific times used to calculate steady-state vertical load
t_H, t_Q, t_M	Specific times used to identify the time of first cleat contact
t_{CC}	Time of first cleat contact ¹
Δt_0	Time interval for the on-cleat phase of a test ¹
t_{CLEAT}	Time when the tire is centered above the cleat
t_{CCR}	Estimated time at the end of cleat contact
Q_0	Quality measure for agreement between measurement and simulation during the on-cleat interval ²
W_0	Weighting function for composite quality measure, on-cleat interval ²
Q_A	Quality measure for agreement between measurement and simulation during the after-cleat interval ²
Q	Composite quality measure for agreement between measurement and simulation
A	Fitted amplitude ²
ω	Fitted frequency ²
δ	Fitted decay coefficient ²

1. These quantities represent, or are derived from, both measured and simulated signals. As needed, M and S are appended to their subscripts to indicate measured or simulated quantities, respectively.

2. These quantities are derived from force and moment time histories. As needed, FX, FY, FZ, MX, and MZ are appended to their subscripts for elucidation.

5. QUANTIFICATION OF DEVIATION BETWEEN A MEASURED AND A SIMULATED CLEAT TEST

The variables defined in 5.1, 5.2, and 5.3 characterize a single cleat test. Section 5.4 describes the calculation of the deviation between measurement and simulation for a single cleat test.

5.1 Cleat Test Primary Influence Factors

Table 2, Figure 2, and Figure 3 define the primary factors that characterize the cleat test. Together, these values classify a given cleat test and they appear in the calculations of quality measures for agreement.

Equation 1 and 2 define measures of cleat height and width, respectively.

$$\text{Normalized Cleat Height} = \frac{\text{Cleat Height}}{\text{Tire Section Height}} \times 100 \quad (\text{Eq. 1})$$

$$\text{Normalized Cleat Width} = \frac{\text{Cleat Width}}{\text{Tire Section Height}} \times 100 \quad (\text{Eq. 2})$$

The actual cleat height and width used during the measurement may differ by up to 2.5 mm from the values indicated, if exactly the same geometry is used in the simulation. This allows the use of standard cleats with dimensions in increments of no more than 5 mm.

The figures provide an example for a cleat with a rectangular cross section. The cleat's edges may be chamfered or rounded up to 25% of its height if exactly the same cross section is used in the simulation.

TABLE 2 – CLEAT TEST CHARACTERISTICS

Name	Definition	Units
normalized cleat height	Maximum cleat height, relative to tire's nominal section height	%
normalized cleat width	Maximum cleat width relative to tire's nominal section height	%
cleat orientation angle (CO)	Cleat orientation angle relative to longitudinal direction, measured counter-clockwise. CO is negative if the right cleat end reaches the tire later than the left cleat end, 90 degrees if the cleat is oriented in the transverse direction, and positive if the right cleat end reaches the tire sooner than the left cleat end	deg
surface speed indicator	Test surface speed as seen from the wheel center, relative to the tire's rated maximum speed at the tested conditions	%
wheel load indicator	Estimated steady-state vertical spindle load relative to the tire's rated maximum load at the tested conditions	%

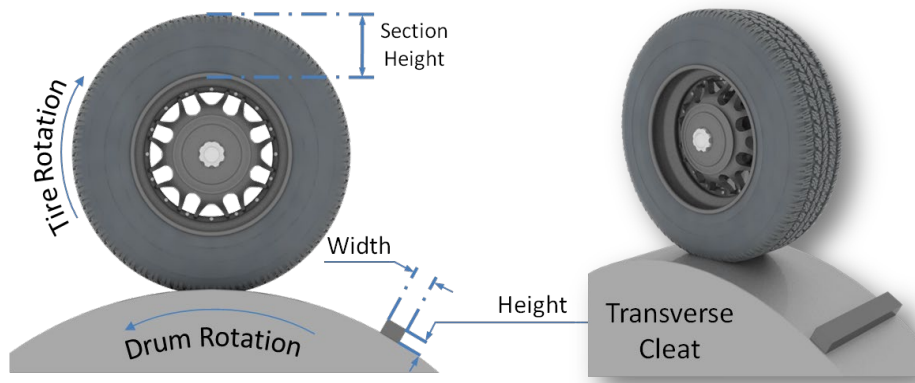


FIGURE 2 – CLEAT HEIGHT AND WIDTH, AND TIRE SECTION HEIGHT

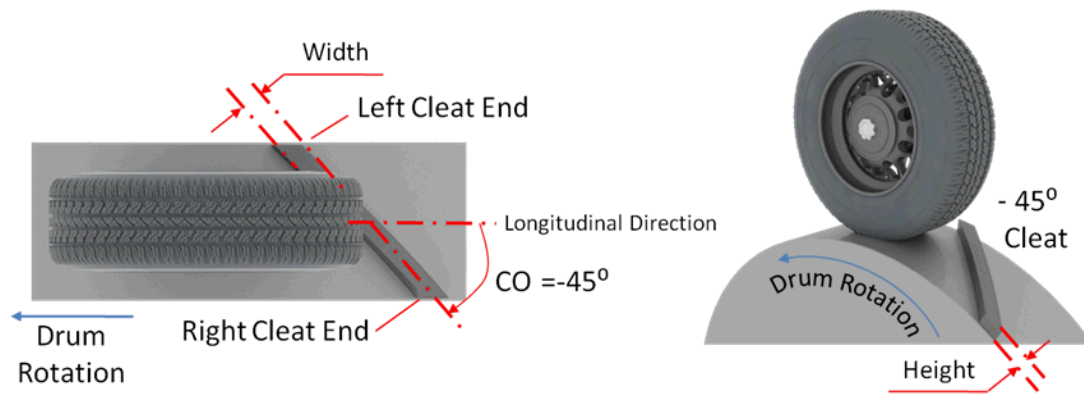


FIGURE 3 – CLEAT ORIENTATION ANGLE (CO), SHOWN IMMEDIATELY BEFORE IMPACT

5.2 Cleat Test Secondary Influence Factors

Tables 3 and 4 define secondary factors that influence the cleat test. These quantities do not appear in subsequent calculations, but they must be reported with the results of each comparison.

5.2.1 Test Rig Characterization

TABLE 3 – TEST RIG PROPERTIES

Name	Definition/notes	Units
test rig type	0: flat surface, 1: outer drum, 2: inner drum	-
drum diameter	Only required for drum-type rigs	m
wheel moment of inertia	Moment of inertia of the wheel used for testing (not including the tire), about the wheel spin axis	kg-m ²
hub moment of inertia	Moment of inertia of all parts rotating about the wheel spin axis excluding the inertia of the test tire and wheel about the spin axis	kg-m ²
rotating drum moment of inertia (optional)	Rotating drum moment of inertia about the drum spin axis	kg-m ²
longitudinal compliance (optional)	Longitudinal displacement of the wheel center per longitudinal force applied to the wheel center under non-rolling (static) conditions	m/N
lateral compliance (optional)	Lateral displacement of the wheel center per lateral force applied to the wheel center under non-rolling (static) conditions	m/N
vertical compliance	Vertical displacement of the wheel center per vertical force applied to the wheel center under non-rolling (static) conditions	m/N
inclination compliance (optional)	Rotation of the rim about the longitudinal axis per moment about the longitudinal axis under non-rolling (static) conditions	
drum (rig) surface type	Type of surface on the drum (rig) that makes contact with the tire, i.e. polished steel, 80 or 120 grit safety tread, etc.	deg/N-m
drum (rig) surface sliding friction coefficient (optional)	Friction coefficient for the tire sliding on the drum (rig) surface; at 0.1 m/s at 50% rated load when the wheel is locked. Handbook or estimated values may be used and shall be noted as such.	-
cleat surface sliding friction coefficient (optional)	Friction coefficient for the tire sliding on a flat surface made of the same material as the cleat surface; at 0.1 m/s at 50% rated load when the wheel is locked.	-