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SURFACE VEHICLE INFORMATION REPORT

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(R) Tire Performance Terminology

RATIONALE

SAE J2047 was originally developed to gather together existing tire and pertinent wheel terms and their definitions developed by different standards organizations so as to provide a convenient single source for technical terms related to tire performance. Since the original development of SAE J2047, there have been numerous changes within the literature from which the definitions in the original version of this Recommended Practice were drawn. In particular 2007 changes in SAE J670 have rendered the 1998 version of this terminology obsolete due to a change in the sense of positive spindle torque within the Z-down Tire Coordinate System, which is intended to replace the Tire Axis System found in SAE J670e and its predecessors. It is, therefore, necessary to revise SAE J2047 so that it once again achieves its intended purpose of providing a one document reference to tire performance terminology.

FOREWORD

This Terminology assembles existing tire terms and their definitions developed by different standards organizations into a lexicon of technical terms related to tire performance. Different aspects of tire performance mutually influence each other. To account for these real performance interactions, the terms and definitions pertaining to different aspects of tire performance are combined herein.

The terms and definitions herein have been collected from national and international standards (listed in Section 2). They have been carefully examined for their current relevance and technical accuracy, and then consolidated into this document. If a term carries more than one name, the one believed most descriptive is listed first, and the others are shown in parentheses. If more than one term has the same definition, the preferred term is listed first. Other terms are listed in parentheses. In some cases, existing definitions have been altered or new ones introduced to achieve consistency. Preference is given to terms that:

a. Are technically correct and in compliance with mathematical and engineering conventions

b. Were issued by an international rather than a national standards organization and

c. Have been widely used for a long time

In cases, when a term or a definition appears to be inadequate or questionable, it is replaced by a new one and an explanation is given in the Notes.

Many terms and definitions related to tire performance, but originated by other organizations such as ISO, US Government, Tire and Rim Association, etc., or other SAE technical committees not affiliated with the SAE Highway Tire Forum Committee, have been adopted in this document and incorporated into Sections 3, 4, 18, 19, 20, and 21. Adopted terms and conditions are written, where possible and advisable in current circumstances, using exactly the same wording used in the original documents.

TABLE OF CONTENTS

1. SCOPE

This terminology aims to encompass all terms and definitions pertaining to the road performance of pneumatic tires designed for over-the-highway use, such as passenger car, light truck, truck and bus, and motorcycle tires. Not included are terms specific to the performance of agricultural, aircraft, industrial, and other off-highway tires. However, many terms contained in this document also apply to non-highway tires.

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 J1269 Rolling Resistance Measurement Procedure for Passenger Car, Light Truck, and Highway Truck and Bus Tires

SAE J1270 Measurement of Passenger Car, Light Truck, and Highway Truck and Bus Tire Rolling Resistance

SAE J1982 Nomenclature - Wheels for Passenger Cars, Light Trucks, and Multiple Vehicles

SAE J2452 Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance

2.1.2 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO 3911-2004 (E) Wheels and rims for pneumatic tyres - vocabulary, designation, and marking.

ISO 8855-2011 Road vehicles - Vehicle dynamics and road holding ability - Vocabulary

ISO 13473 Characterization of pavement texture by use of surface profiles (Parts 1 through 5)

2.1.3 U.S. Federal Publications

Available from U.S. Government Printing Office, New Orders, P.O. Box 979050, St. Louis, MO, 63197-9000.

49CFR575.104 Uniform Tire Quality Grading

49CFR571.109 New Pneumatic Tires and Certain Specialty Tires - Passenger Cars

49CFR571.117 Retreaded Pneumatic Tires

49CFR571.119 New Pneumatic Tires for Motor Vehicles with GVWR of more than 4,536 kilograms (10,000 pounds) and Motorcycles

49CFR571.120 Tire Selection and Rims and Motor Home/Recreation Vehicle Trailer Load Carrying Capacity Information for Motor Vehicles with a GVWR of more than 4,536 kilograms (10,000 pounds)

49CFR571.129 New Non-Pneumatic Tires for Passenger Cars

49CFR571.138 Tire Pressure Monitoring Systems

49CFR571.139 New Pneumatic Radial Tires for Light Vehicles

NHTSA Tire Aging Project: Roadwheel Removal Codes v2.2 - 4/13/2006

2.1.4 Tire and Rim Association Publication

Available from Tire and Rim Association, 175 Montrose West Avenue, Suite 150, Copley, OH 44321. 330-666-8121, Tire and Rim Association Year Book

2.1.5 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 F1016-07 Standard Practice for Tire Linear Treadwear Data Analysis

ASTM F1046-01 (2008) Standard Guide for Preparing Artificially Worn Passenger and Light Truck Tires for Testing

ASTM F1426-11 Standard Practice for Identifying Tire Tread Surface Irregular Wear Patterns Resulting From Tire Use

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 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 J341a Truck and Bus Tire Performance Requirements and Test Procedures

SAE J918c 1970-05 Passenger Car Tire Performance Requirements and Test Procedures

SAE J966 Test Procedure for Measuring Passenger Car Tire Revolutions Per Mile

SAE J1025 Test Procedures for Measuring Truck Tire Revolutions Per Kilometer/Mile

SAE J1106 Laboratory Testing Machines and Procedures for Measuring the Steady-State Force and Moment Properties of Passenger Car Tires

SAE J1269 Rolling Resistance Measurement Procedure for Passenger Car, Light Truck, and Highway Truck and Bus Tires

SAE J2013 Military Tire Glossary

SAE R-101 Dictionary of Automotive Engineering, D. Goodsell, 1989

SAE SP750 Glossary of Automotive Terms, 1988

SAE Paper 960999 The Role of Steer and Sideslip in the Mechanism of Slip Angle, W. Bergman, Dirk Pelargus, 1996

T. R. Giapponi, Tire Forensic Investigation: Analyzing Tire Failure, 2008.

2.2.2 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 F408-99(2008) Standard Test Method for Tires for Wet Traction in Straight-Ahead Braking, Using a Towed Trailer

ASTM F421-07 Standard Test Method for Groove and Void Depth in Passenger Car Tires

ASTM F424-86 Standard Test Method for Tires for Wet Driving Traction in Straight-Ahead Motion Using Highway Vehicles

ASTM F435-86 Standard Test Method for Peak Wet Traction of Tires with Driving Torque Application Using Highway Vehicles

ASTM F538-09 Standard Terminology Relating to Characteristics and Performances of Tires

ASTM F724-94a (2004)Standard Practice for Outdoor Evaluation of Tire Sidewall Component Cracking Resistance

ASTM F762-08 Standard Practice for Determining Change in Groove (or Void) Depth with Distance Traveled for Passenger Car Tires

ASTM F870-94 (2005) Standard Method for Obtaining Tread Footprints of Passenger Car Tires for Calculation of Groove Area Fraction

2.2.3 American Chemical Society

Schuring, D. J. 1980. The Rolling Loss of Pneumatic Tires. *Rubber Chemistry and Technology,* Vol. 53, No. 3, pp. 600–727.

Schuring, D. J., and S. Futamura. 1990. Rolling Loss of Pneumatic Highway Tires in the Eighties. *Rubber Chemistry and Technology,* Vol. 62, No. 3, pp. 315–367.

2.2.4 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO 3877/1-1997 (E/F/R) Tyres, valves and tubes - List of equivalent terms - Part 1: Tyres

ISO 4223/1 – 2002 (E/F) Definitions of some terms used in the tire industry - Part 1: Pneumatic tyres

2.2.5 E.T.R.T.O Publication

Available from European Tyre and Rim Technical Organisation, Av. Brugmann, 32 - 1060 Brussels, Belgium, Tel: +32-2-344-40-59, info@etrto.org.

E.T.R.T.O. Standards Manual

2.2.6 ITEC Publications

M. G. Pottinger, “Pull: The Science of a Nuisance,” International Tire Exhibition and Conference, Cleveland, Ohio, 21-23 September 2010.

2.3 Other Publications

"Radial Tire Wear Conditions and Causes," American Trucking Association, The Maintenance Council, Alexandria, VA

C. L. Clover and J. E. Bernard, “Longitudinal Tire Dynamics,” Vehicle Systems Dynamics, Volume 29, Issue 4, 1998, pp. 231-260.

K. D. Marshall, “Tire Noise and Vibration,” Chapter 9, *The Pneumatic Tire*, Edited by J. D. Walter and A. N. Gent, National Highway Traffic Safety Administration, Washington, D.C., 2005.

T., Unrau, H. J., and El-Haji, M., “Experimental Determination of the Effect of the Surface Curvature on Rolling Resistance Measurements,” Tire Science and Technology, TSTCA, Vol. 37, No. 4, October – December 2009, pp. 254-278.

3. WHEEL TERMS

3.1 Wheel

A rotating load-carrying member between the tire and the hub, usually consisting of two major parts, the rim and the wheel disc*,* which may be: integral, permanently attached, or detachable. [ISO 3911, SAE J1982]

3.1.1 Wheel Offset

The measured distance from the attachment face of the wheel (Section 3.3.3) *to* the wheel plane (Section 3.5.1).

NOTE: Wheel offset is positive, if the mounted wheel increases the vehicle track (SAE J670) with respect to the hub face, and negative, if the mounted wheel decreases vehicle track with respect to the hub face.

3.1.1.1 Inset (Negative Offset) Wheel

A wheel so constructed that the wheel plane (Section 3.5.1) is located inboard of the attachment face. The inset, negative wheel offset [ISO 3911], is the distance from the attachment face to the wheel plane (see Figure 1A).

3.1.1.2 Zeroset Wheel

A wheel so constructed that the wheel plane is coincident with the attachment face (see Figure 1B). [ISO 3911]

3.1.1.3 Outset (Positive Offset) Wheel

A wheel so constructed that the wheel plane is located outboard of the attachment face. The outset, positive wheel offset [ISO 3911], is the distance from the attachment face to the wheel plane (see Figure 1C).

3.2 Rim (SAE J1982)

That part of the wheel on which the tire is mounted and supported. (See Figures 1 and 2.)

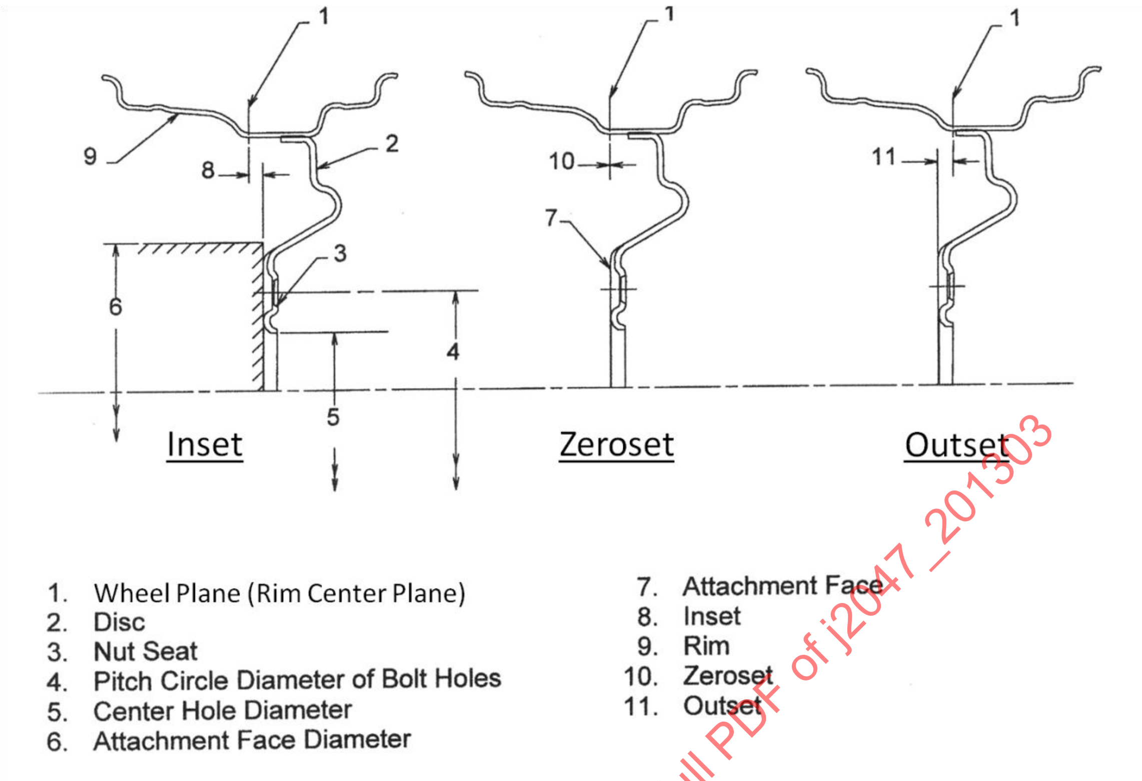
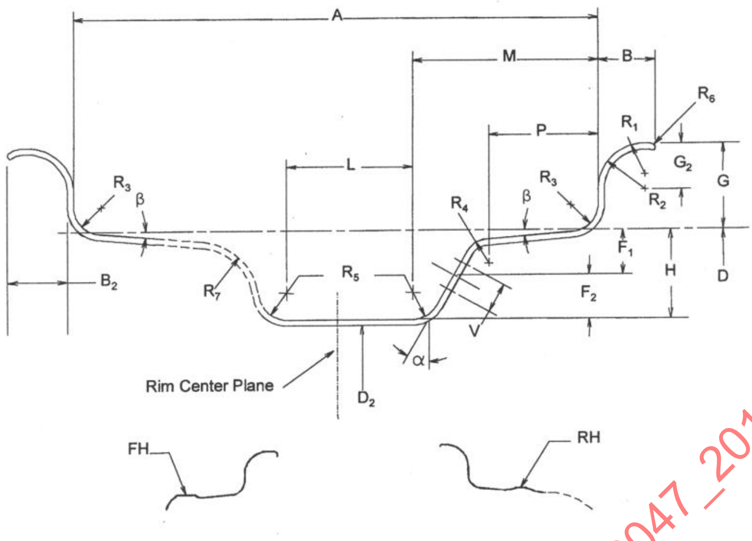


FIGURE 1 - WHEEL OFFSET (RIM TO DISC OFFSET - SAE J1982)



A	Specified rim width
B	Flange width
B_2	Flange offset
D	Specified rim diameter
D_2	Rim inside diameter
F_1, F_2	Valve hole location
FH	Flat Hump
G	Flange height
G_2	Flange radius location
H	Well depth
L	Well width
M	Well position
P	Bead seat width
R_1	Flange compound radius
R_2	Flange radius
R_3	Bead seat radius
R_4	Well top radius
R_5	Well bottom radius
R_6	Flange edge radius
R_7	Well wall radius
RH	Round Hump
V	Valve hole
α	Well angle
β	Bead seat angle

FIGURE 2 – RIM (SAE J1982)

3.2.1 Rim Flange

That part of the rim which provides lateral support to the tire.

3.2.2 Bead Seat

That part of the rim which provides radial support to the tire and air pressure seal for tubeless tires.

3.2.3 Well

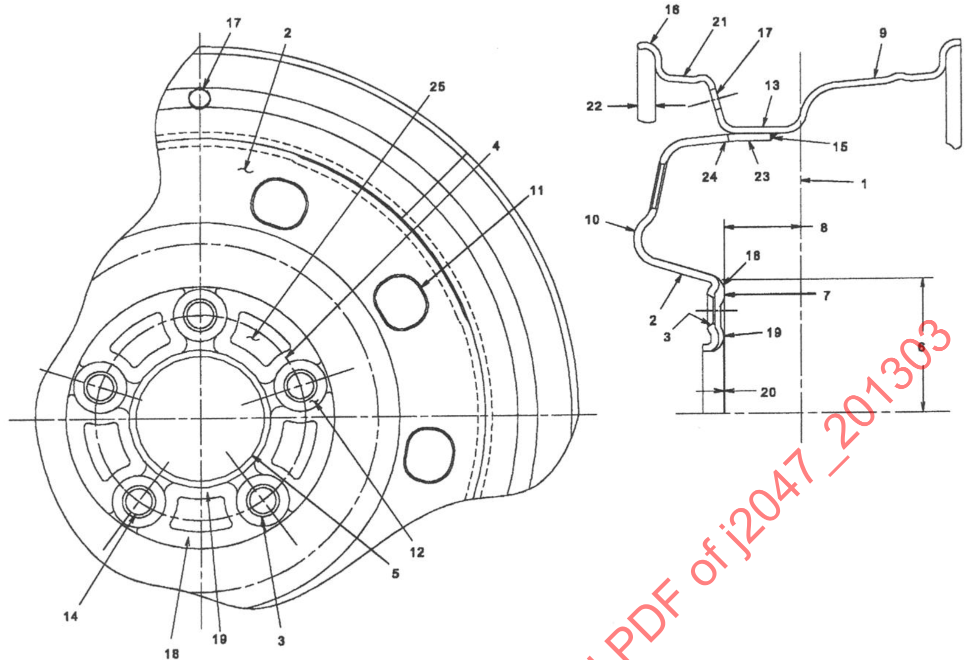
That part of the rim so located with sufficient depth and width to enable the tire beads to be mounted and demounted over the mounting side rim flange.

3.2.4 Valve Hole

The hole or slot in the rim which accommodates the valve for tire inflation.

3.3 Disc

That part of the wheel which is the supporting member between the hub (axle) and the rim. (See Figure 3.)



1. Rim Center Plane
2. Disc
3. Nut Seat
4. Pitch Circle Diameter of Bolt Holes
5. Center Hole Diameter
6. (See Figure 3)
7. Attachment Face
8. Inset
9. Rim
10. Hat
11. Window
12. Nut Boss
13. Well
14. Bolt Hole
15. Assembly Weld
16. Rim Flange
17. Valve Hole
18. Outer Mounting Pad
19. Inner Mounting Pad
20. Step
21. Bead Seat
22. Flange Offset
23. Disc Flange
24. Disc Scallop
25. Rib

FIGURE 3 - DISC WHEEL (J1982)

3.3.1 Disc Flange

The part of the disc that supports the rim.

3.3.2 Attachment Face

The surface of the disc that contacts the hub face. This surface is often considered the datum for axial rim measurements.

3.3.3 Bolt Hole

Mounting stud clearance hole.

3.3.4 Bolt Circle

A circle locating the centers of the bolt holes that are used to attach the wheel to the hub.

3.3.5 Center Hole

The clearance hole for the pilot of the hub.

3.4 Wheel Designations and Dimensions

3.4.1 Wheel Plane (Rim Center Plane)

A plane normal to the wheel-spin axis, which is located halfway between the rim flanges.

NOTE: The term "wheel plane" has been adopted from the ISO 8855 and SAE J670 terminologies. The term "rim center plane" has been adopted from the SAE J1982 nomenclature.

3.4.2 Rim Width

The distance between the inside surfaces of the rim flanges.

3.4.3 Measuring Rim Width (Design Rim Width)

The specific rim width assigned to each tire size designation to determine basic tire dimensions.

3.4.4 Specified Rim Diameter

The diameter at the intersection of the bead seat and the projection of the vertical portion of the rim flange. See Figure 2.

3.4.5 Rim Diameter Code (Rim Diameter Designation/Nominal Rim Diameter)

The nominal rim diameter assigned for tire/rim matching.

NOTE: The term "nominal" implies a convenient figure designating or approximating an actual dimension. Nominal exists in name only, and it is not real, true, actual, or measured. Nominal is used primarily for identification rather than for measurement.

3.4.6 Rim Profile (Rim Contour)

The radial cross-sectional shape of a rim.

3.4.7 Rim Contour Designation

A code comprised of numbers and/or letters to show the designated width and contour of the rim. Example: 6 J.

3.4.8 Rim Size Designation

Rim diameter designation x rim contour designation. Example: 17 x 6.5 J, which denotes a 17 inch nominal rim diameter, 6.5 inch nominal rim width, and J rim profile.

3.4.9 Test Rim (Model Rim Assembly)

A rim on which the tire is mounted for testing that is approved by a standardizing body and used for the determination of tire dimensions or performance characteristics.

4. GENERAL TIRE TERMS

4.1 Pneumatic Tire

A flexible, hollow semi-toroid mounted on the rim and which becomes load bearing when filled with compressed gas (usually air).

4.1.1 Inner Tube

A low-diffusion hollow section rubber torus which retains compressed air within a tube-type tire and thus allows maintenance of a prestressed state in the tire structure.

4.2 Tire Designation (for Some Metric Size Tires)

The numbers or letters indicating tire size designation and service description.

4.2.1 Tire Size Designation (for Metric Passenger Car and Light Truck Tires)

The numbers or letters indicating intended tire application, nominal section width, nominal aspect ratio, construction, and nominal rim diameter, such as P205/60R17.

4.2.2 Service Description (Load/Speed Index)

A code consisting of load index and speed symbol, which is not part of the tire size designation. Example: 90 H.

4.2.2.1 Load Index

A numerical code associated with the maximum load a tire can carry at the speed indicated by its speed symbol under specified service conditions.

4.2.2.2 Speed Symbol

A symbol indicating the speed category at which the tire can carry a load corresponding to its load index under specified service conditions.

COMPLETE DESIGNATION EXAMPLE: Based on the Tire and Rim Association Year Book: P205/60R17 90H denotes a passenger car tire (P) with nominal section width of 205 mm, nominal aspect ratio 60, radial ply construction (R), with nominal rim diameter of 17 in, load index 90, and speed symbol H.

4.2.3 Tire Structure (Construction)

The generic type of tire structure is identified by a letter code. The letter "D" is used for diagonal tire, letter "B" for bias belted tire, and letter "R" for radial tire.

4.2.3.1 Diagonal Tire (Bias Tire, Cross Ply Tire)

A pneumatic tire structure in which the ply cords extend to the beads and are laid at alternate angles substantially less than 90 degrees to the circumferential centerline of the tread, Figure 4A.

4.2.3.2 Bias Belted Tire (Belted Tire)

A pneumatic tire structure of the diagonal (bias ply) type in which the carcass is topped by a belt comprised of two or more layers, Figure 4B.

4.2.3.3 Radial Ply Tire

A pneumatic tire structure in which the ply cords extend to the beads and are laid substantially at 90 degrees to the circumferential centerline of the tread, the carcass being topped by a belt, Figure 4C.

4.2.3.4 Tube-Type Tire

A pneumatic tire which requires an inner tube for air retention.

4.2.3.5 Tubeless Tire

A pneumatic tire which does not require an inner tube, inflation pressure is retained by the tire innerliner, the rim, and the valve.

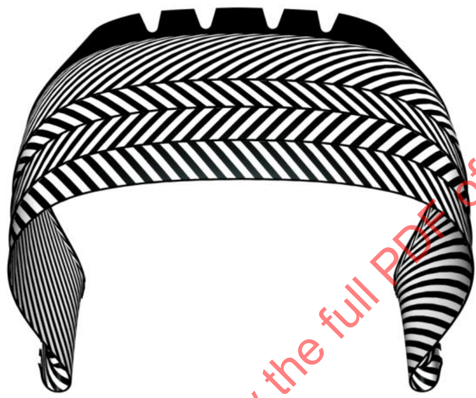


FIGURE 4A – DIAGONAL (BIAS) TIRE

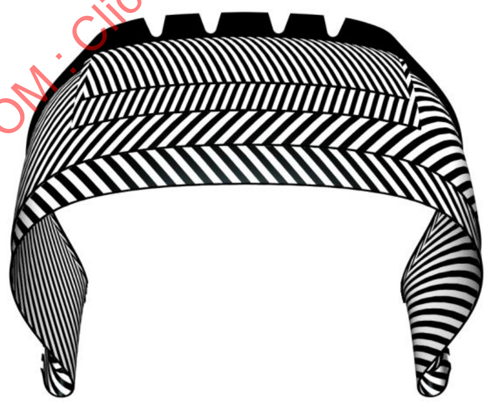


FIGURE 4B – BIAS BELTED TIRE

FIGURE 4C – RADIAL TIRE

4.2.3.6 Retreaded Tire

A tire to which a new tread has been affixed to an existing carcass or casing in place of the initial tread.

4.2.3.7 Unidirectional Tire

A tire with a tread pattern intended to rotate in a single direction during use. It is sometimes referred to as a directional tire.

4.2.4 Tire Condition

4.2.4.1 New Tire

A tire, whose chemical and physical state is essentially equivalent to that existing immediately after manufacturing and which is being mounted on a vehicle rim for the first time after leaving the factory.

4.2.4.2 Broken-in Tire

A tire which has experienced one or more periods of initial operation, resulting in a physical state in which the tire will exhibit consistent, repeatable performance properties, and generally does not have a significant tread depth reduction.

4.2.4.3 Worn Tire

A tire which has experienced use resulting in a measureable reduction in tread depth.

4.2.4.4 Aged Tire

A tire which has experienced a modification of the material properties within one or more components. The material properties modifications can either occur naturally in storage, in normal use, or under specific controlled conditions.

4.2.4.5 Grown Tire

A tire which has changed in size due to use in service and inflation.

4.2.5 DOT Code

The DOT code is comprised of the symbol DOT and the Tire Identification Number (TIN). The TIN is comprised of letters and numbers molded or branded into or onto the sidewall of the tire. An example DOT code: DOT YY XX ZZZZ DDDD. YY indicates the tire plant, XX indicates the tire size, ZZZZ is an optional code and DDDD represents the week and year of manufacture. (4007 would indicate the 40th week of 2007). See 49 Code of Federal Regulations part 574 for details.

4.2.6 Uniform Tire Quality Grading

UTQG, a DOT required system of passenger car tire grading that assigns grades to tires and indicates that the tire is certified by the manufacturer to comply with DOT requirements as determined in standardized tests for treadwear, traction, and temperature resistance. (Reference 49CFR Part 575.104.)

4.3 Tire Design Dimensions

The dimensions of a tire mounted on its measuring rim as specified by a tire and rim standards organization such as the Tire and Rim Association (T&RA).

4.3.1 Section Width

The width of an unloaded, new tire inflated to the recommended pressure 24 hours prior to measurement thus taking account inflation growth (see, for example, the T&RA Year Book). Molded on sidewall elements such as curb ribs, lettering, and decorations are excluded.

4.3.2 Overall Width

The width of an unloaded new tire inflated to recommended pressure 24 hours prior to measurement thus taking account inflation growth (see, for example, the T&RA Year Book). Molded on sidewall elements such as curb ribs, lettering, and decorations are included.

4.3.2.1 Tire Maximum Overall (Grown) Tire Width

The overall width including allowances for as manufactured size, growth, and growth in-service.

4.3.3 Section Height

The height of radial cross section of a tire including 24-hour inflation growth. It is calculated as half the difference between the tire overall diameter and the nominal rim diameter.

4.3.4 Aspect Ratio

Ratio of section height to section width of a tire times 100.

4.3.5 Overall (Outside) Diameter

The diameter of the largest part of the unloaded new tire mounted on the test rim and inflated to the recommended pressure including 24-hour inflation growth (see, for example, the T&RA Year Book).

4.3.5.1 Overall (Grown) Diameter in Service (Gross Service Diameter - Static)

The tire overall diameter after an appreciable amount of time in service. When referenced by a standardizing body, the grown tire diameter is based on the new tire design diameter plus allowances for manufacturing variations and growth in service.

4.3.5.2 Maximum Overall (Grown) Diameter in Service Motorcycle (Gross Service Diameter - Dynamic)

The tire overall diameter plus tolerances for manufacturing and service, plus allowance for dimensional changes due to centrifugal forces.

4.3.6 Size Factor

The sum of section width and overall diameter of a tire.

4.4 Tire Components and Elements

See Figure 5 an illustration based on a radial tire.

4.4.1 Sidewall

The portion of the tire between the bead and the tread.

4.4.1.1 Curb Rib (Sidewall Rib)

A raised circumferential protective rib located on the sidewall.

4.4.1.2 Rim Protector

A feature (for example: a protruding circumferential rubber rib) incorporated into the lower sidewall area of the tire intended to help protect the rim from damage.

4.4.1.3 Sidewall Rubber

The layer of rubber compound on the outside of the sidewall; it may include molded on sidewall elements such as curb ribs, lettering, and decorations.

4.4.1.4 White Sidewall

A sidewall containing white or light-colored compounds used for decoration or lettering.

4.4.1.5 Black Sidewall

A sidewall without light-colored compounds.

4.4.1.6 Cover Strip (Cover Gum Strip)

A thin layer of compound (usually black) covering part of the white sidewall surface of the finished tire.

4.4.1.7 Veneer

An extended cover strip.

4.4.1.8 Upper Sidewall

The upper sidewall is the sidewall region between the point of mid-section height and the tread.

4.4.1.9 Lower Sidewall

The lower sidewall is the sidewall region between the point of mid-section height and the bead.

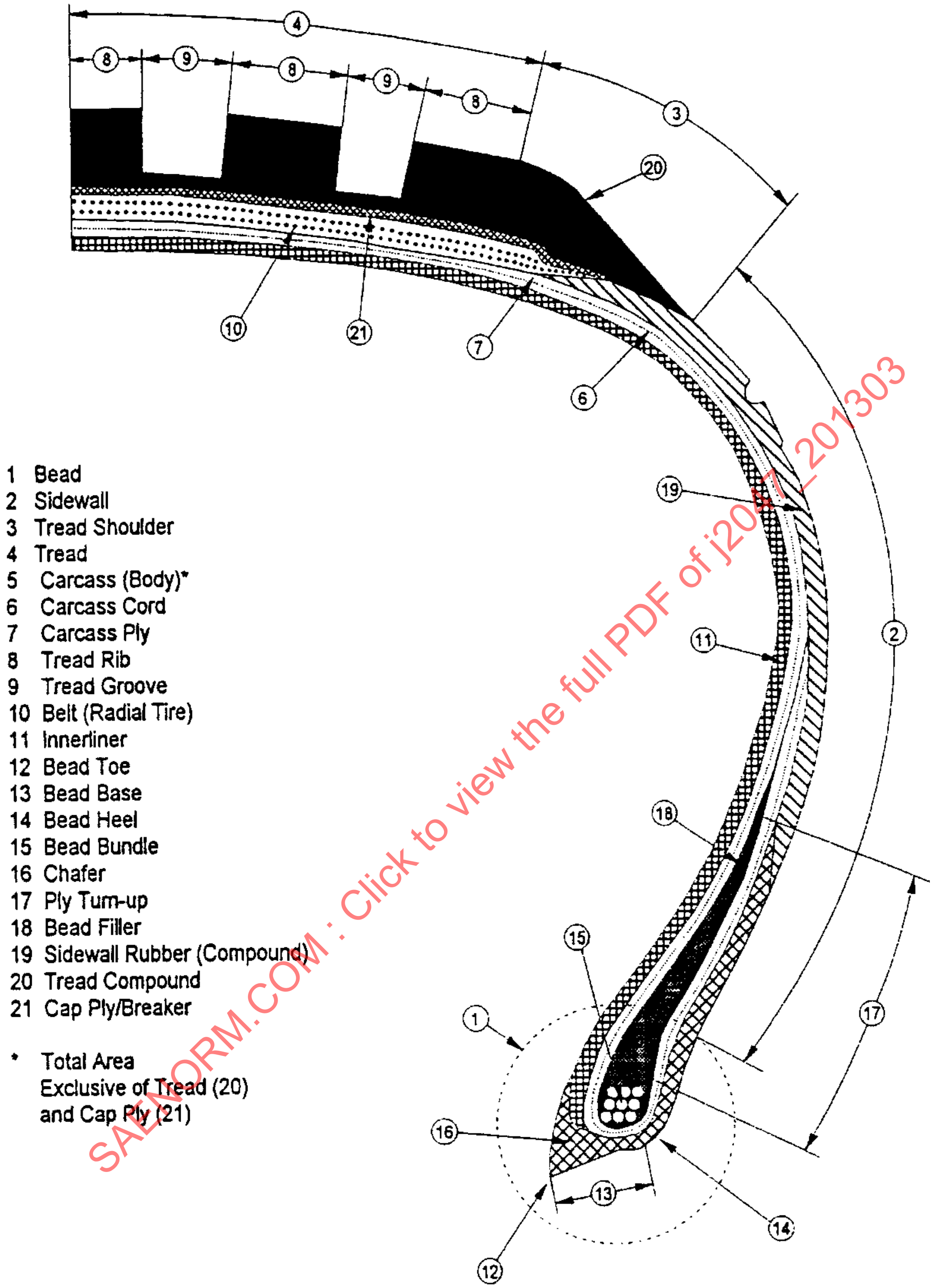


FIGURE 5 - TIRE COMPONENTS AND TIRE ELEMENTS USING A RADIAL TIRE AS AN EXAMPLE

4.4.2 Bead

The part of a tire that comes into contact with the rim and is shaped to secure the tire to the rim. (See figure 5.)

4.4.2.1 Bead Base

Inner portion of the bead that is seated on the bead seat.

4.4.2.2 Bead Toe

Inner portion of the bead base.

4.4.2.3 Bead Heel

Outer portion of the bead base.

4.4.2.4 Bead Bundle (Bead Coils, Bead Cord)

A circumferentially stiff hoop made of steel wires embedded in the bead which resists the inflation pressure generated forces.

4.4.2.5 Bead Filler (Apex)

A rubber compound fillet between the bead bundle and adjacent ply cords.

4.4.2.6 Bead Face

The portion of the bead above the bead heel that interfaces with the rim flange.

4.4.2.7 Chafer (Rim Strip; Clinch Strip)

A layer of rubber compound, with or without fabric reinforcement, applied to the bead for resisting damage caused by movement relative to the bead seat and rim flange.

4.4.2.8 Flipper

A partial ply wrapped around the bead bundle but not extending the full height of the sidewall.

4.4.3 Tread

The portion of the tire designed to contact the road surface in normal service.

4.4.3.1 Tread Band

An annular volume of rubber that includes the outer pavement contacting periphery of a tire.

4.4.3.2 Tread Shoulder

The outermost portion of the tread adjacent to the sidewall.

4.4.3.3 Shoulder Rib

A rib at or near the outer edge of the tread band.

4.4.3.4 Shoulder Row

A row located at or near the tread shoulder

4.4.3.5 Tread Contour

The surface contour across the tread of an inflated, unloaded tire without consideration of grooves, sipes, etc.

4.4.3.6 Tread Crown

The crown is the region between the tread shoulders of the tire when looking from the inside center of the tire to the tire's outside.

4.4.3.7 Tread Arc Width

The peripheral distance between the two tread shoulders measured along the tread contour.

4.4.3.8 Tread Chord Width

The distance between the two tread shoulders measured parallel to the spin axis of an inflated, unloaded tire.

4.4.3.9 Tread Pattern

The molded geometric configuration on the peripheral tread face, generally composed of tread elements and voids.

4.4.3.10 Tread Element (Projection)

A raised portion of the tread pattern, contacting the road surface when passing through the footprint.

4.4.3.11 Tread Rib

An essentially continuous, circumferential tread element.

4.4.3.12 Lug or Block

A discontinuous tread element.

4.4.3.13 Row

A sequence of tread elements along a circumferential line.

4.4.3.14 Groove

A void that is molded or cut into the tread rubber and is relatively narrow compared to its length. Sipes and Kerfs (Section 4.4.3.18) are not grooves.

4.4.3.15 Void

An open space between tread elements or ribs. Sometimes used to describe the volume of the open space.

4.4.3.16 Groove Depth (Groove Depth, Tread Depth)

The depth of a groove or void measured perpendicular to the reference plane defined by the edges of adjacent tread elements.

4.4.3.17 Tread Wear Indicator (Wear Bar)

Raised bottom portions of a groove or void, spaced regularly around the tire across the tread to provide a visual indication of wear-out.

4.4.3.18 Sipe (Kerf)

A narrow slot usually less than 1 mm wide. Typically molded into a tread element.

4.4.3.19 Notch

A slot with a closed end, wider than a sipe, but in most cases, narrower than a groove.

4.4.4 Carcass (Body; Casing)

The rubber-bonded cord structure that provides the tire's stiffness when prestressed by the inflation pressure.

NOTE: Sometimes casing is used to describe a used or treadless tire. Thus, it is necessary to distinguish between meaning when using the term casing.

4.4.5 Cord

An assembly formed by twisting together textile or non-textile filaments that is the structural reinforcing element for plies.

4.4.5.1 Cord Angle

The angle between a cord in a ply and the tread circumferential center line.

4.4.6 Ply

A sheet of rubber-coated cords.

4.4.6.1 Carcass Ply

The ply extending from bead to bead.

4.4.6.2 Ply Turn-Up

The portion of the ply passed around the bead bundle (see Figure 5).

4.4.6.3 Belt (Breaker)

An assembly of plies located under the tread that does not extend into the sidewalls.

NOTE: It provides additional tread area stiffness/strength. For radial ply constructions, it restrains the overall diameter, provides circumferential tread stiffness and is the source of cornering forces.

4.4.6.4 Cap Ply

An additional ply, under the tread and over the belt assembly of a radial ply tire, with cords oriented at approximately zero degrees to the circumferential line. It provides additional circumferential stiffness.

4.4.7 Innerliner

A low air diffusion layer covering the inside of the carcass of a tubeless tire.

4.4.8 Juncture

The interface between two different tire components, or different compounds (materials) within the same components.

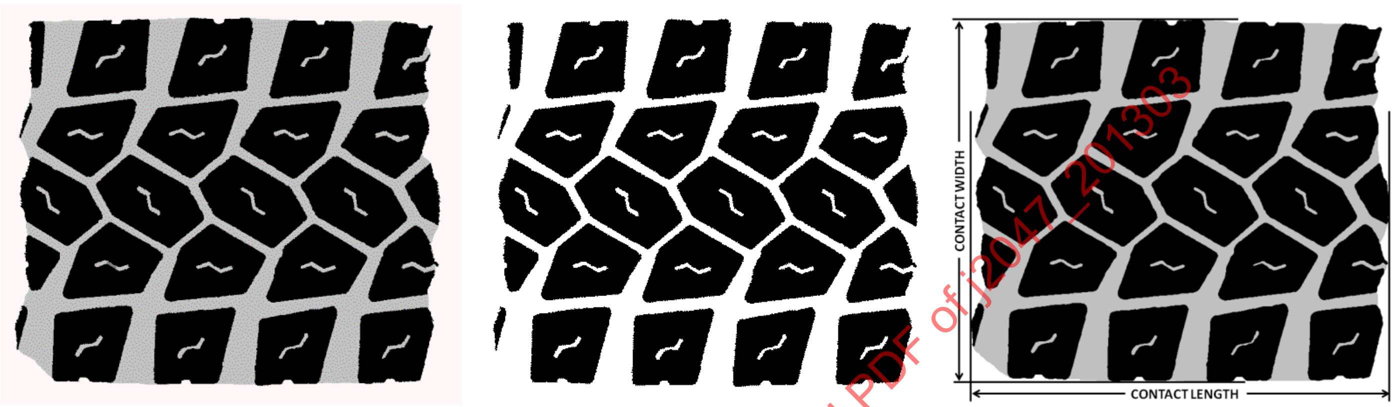
4.4.9 Splice

The joint formed by overlapping or butting the ends of a tire component during tire building.

4.4.10 Footprint (Contact Patch)

The contact area of a tire loaded against a flat or curved surface, Figure 6.

NOTE: A flat surface should be assumed in mathematical analysis of tire forces and moments for simulating vehicle control.



(A) – GROSS CONTACT AREA (B) – NET CONTACT AREA (C) – CONTACT LENGTH AND WIDTH

FIGURE 6 – CONTACT AREAS AND DIMENSIONS

4.4.10.1 Gross Contact Area

The area of the footprint in Figure 6A as described by the size and shape of the footprint including grooves and voids in the tread pattern.

NOTE: The grooves and voids are shown in gray in Figures 6A and 6C. Tread compound in contact in Figure 6 is shown in black.

4.4.10.2 Net Contact Area

The area of the footprint, area of tread compound in contact, as described by the size and shape of the footprint excluding grooves and voids in the tread pattern.

4.4.10.3 Contact Width

The distance between the extreme edges of the footprint measured in the plane perpendicular to the wheel plane of the straight free-rolling tire.

4.4.10.4 Contact Length

The distance between the extreme points of the front and back edges of the footprint measured parallel to the wheel plane of the straight free-rolling tire.

4.4.10.5 Footprint Aspect Ratio

The tire footprint contact width divided by the tire footprint contact length times 100.

4.5 Special Tire Outer Surfaces

4.5.1 Tire Face

The intended outboard sidewall of the tire when mounted on a vehicle.

4.6 Tire Inflation Pressure

The gage pressure of the filling gas within a tire under usage conditions.

4.6.1 Cold Tire Inflation Pressure

The gage pressure of the inflating gas within the tire with the tire, rim, and gas in thermal equilibrium at prevailing atmospheric temperature.
NOTE:ISO and TRA accepted pressure equivalencies appear in TABLE 1 in APPENDIX A – TABLES.

4.6.1.1 Maximum Cold Inflation Pressure

The highest permissible cold inflation pressure for a given tire.

5. WHEEL PLANE GEOMETRY AND ROAD SURFACE

5.1 Wheel (Tire-Wheel Assembly)

An assembly consisting of the wheel disc, rim, an inflated tire, nuts, bolts, valve, and balance weights capable of: (a) rotating about an axle, (b) carrying the load supported by the axle, (c) generating tire shear (tractive) forces between the tire tread surface and the road surface, necessary for control of vehicle motion, and (d) transmitting disturbance forces due to road surface irregularities.

NOTE: The term "wheel" used in this section and following sections of this document indicates the "tire-wheel-assembly". The usage of the term "wheel" is completely different from the usage in Section 3 where "wheel" indicates the "wheel rim - disc assembly". The usage of "wheel" instead of "tire-wheel assembly" in performance terms is common. Some examples are: wheel load, wheel torque, locked wheel, spinning wheel, etc. The term "tire" is also commonly used in performance definitions. Examples include: tire noise, tire wear, tire-road friction, tire power loss, etc. In some instances the use of the terms "tire" and "wheel" in performance definitions appears to be interchangeable. The forces and moments generated by the tire are called wheel forces and moments in ISO 8855 and tire forces and moments in SAE J670 (2008). This terminology uses the terms "tire" and "wheel" selectively in accordance with common usage.

5.2 Wheel Plane Geometry

5.2.1 Wheel Plane

Defined in 3.5.1.

5.2.2 Wheel Center

The point at which the wheel-spin axis intersects the wheel plane.

5.2.3 Wheel-Spin Axis

The axis of wheel rotation coincident with the Y_W axis (Section 6.5.4).

5.2.4 Contact Line

The intersection of the wheel plane and the road plane.

5.2.5 Contact Center (Center-of-tire Contact, Tire Coordinate System Origin)

This is the Tire Coordinate System Origin. It is defined by the geometry of the wheel mounted on the spindle, and is the intersection of the contact line and the normal projection of the wheel-spin axis onto the road plane.

5.2.6 Circumferential Line

A circle of intersection of the tread surface of an unloaded tire with any plane parallel to the wheel plane.

5.2.7 Equatorial Line

The circle of intersection of the tread surface of an unloaded tire with the wheel plane.

5.2.8 Loaded Radius (Wheel Center Height), R_L

The distance between wheel center and the center of contact in the wheel plane at a specified operating condition (load, speed, etc.). R_L is reported as an absolute value. (See Figure 7.)

NOTE: In equations it is necessary to assign proper signs to terms containing loaded radius.

NOTE: On a flat road surface, loaded radius is equal to the moment arm of the shear force or its longitudinal or lateral components with respect to the wheel center. However, on a curved road surface, loaded radius is not equal to the moment arm of the shear force or its components. On a curved surface the effective moment arm is ρ as shown in Figure 7.

5.2.8.1 Static Loaded Radius, R_{STAT}

The radius measured by placing a non-rolling tire onto a test surface under the appropriate load using the definition of loaded radius.

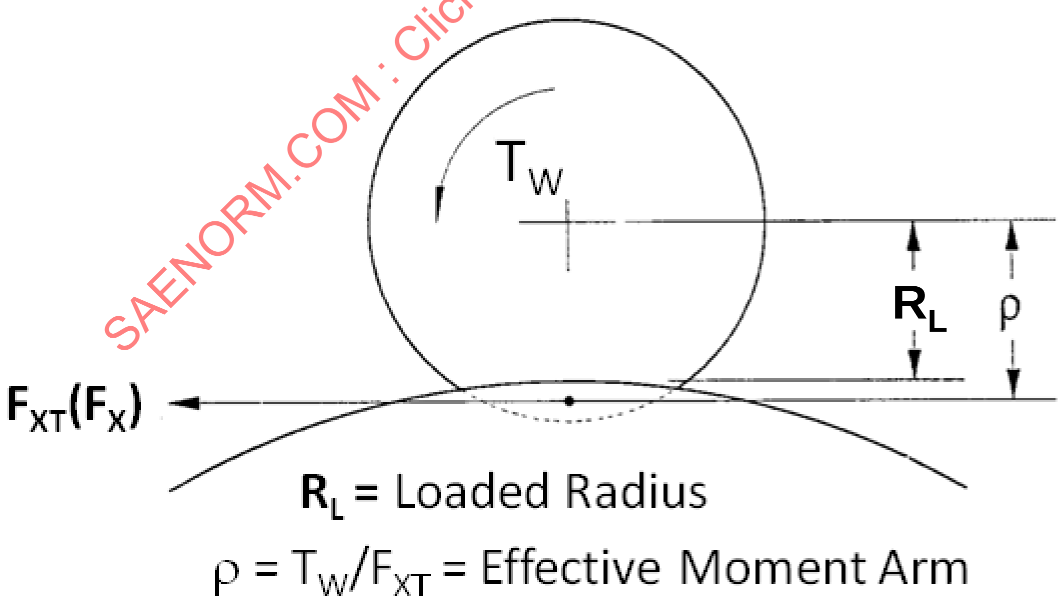


FIGURE 7 - WHEEL CENTER HEIGHT AND EFFECTIVE MOMENT ARM FOR A CURVED ROAD SURFACE

5.2.8.2 Rolling Loaded Radius (Dynamic Loaded Radius), R_{ROL}

The radius measured by placing a rolling tire onto a test surface under the appropriate load using the definition of loaded radius.

5.3 Road Surface

The surface, flat, curved, undulated, or other shape, supporting the wheel (tire) and providing the friction necessary to generate tire shear forces in the road plane.

NOTE: The road surface at any point may have general curvature in the direction of the X_T-axis and the direction of the Y_T-axis of a tire axis system (see 6.2) and be inclined so that the road plane (Section 5.3.1), the plane tangent to the road surface, is inclined in the direction of both the X_T-axis and Y_T-axis. The road plane generally is not horizontal as is implied in the SAE terminology prior to J670 (2008), and it is not identical with the ground plane employed in ISO 8855 terminology. In this terminology, SAE J2047, tire forces and moments are defined with respect to the road plane.

5.3.1 Road Plane

A plane representing the road surface within each tire contact patch. For an uneven road a different road plane may exist at each tire contact patch.

NOTE: For a typical road surface changing with a wavelength greater than several times the dimensions of the tire contact patch, a plane tangent to the road surface at the center of contact is an adequate representation of the road plane. When the individual road planes at each tire contact patch are essentially coplanar, the average plane can be taken to be the road plane. However, in the case of road surfaces with a wavelength similar to or less than the size of the contact patch, an equivalent road plane must be determined. This equivalent plane may not be coincident with the road surface at the tire contact center. This happens in the case of many ride events and the determination depends on the requirements of the analysis being performed. Very small wavelength, small amplitude, road surface undulations such as the pebbles forming the road surface macrotexture may be ignored in detail.

5.3.1.1 Road Plane Pitch Angle, θ_T

The angle from the normal projection of the X_T-axis onto the ground plane to the X_T-axis. The angle is positive for clockwise rotation about the positive branch of the Y_T-axis (See Figures 8A & 8B.)

5.3.1.2 Road Plane Roll Angle, ϕ_T

The angle from the normal projection of the Y_T-axis onto the ground plane to the Y_T-axis. The angle is positive for clockwise rotation about the positive branch of the X_T-axis. (See Figure 8A & 8B.)

5.3.2 Ground Plane

A horizontal plane in the inertial reference, normal to the gravitational vector.

NOTE: A positive Road Plane Pitch Angle, θ_T, in the Z-Up system signifies a road plane tipped downward in the X_T^+ **d**irection, but upward in X_T^+ direction in the Z-Down System. Correspondingly, a positive Road Plane Roll Angle, ϕ_T in the Z-Up system signifies a road plane tipped upward in the Y_T^+ direction, but downward in Y_T^+ direction in the Z-Down System. Positive Road Surface Curvature about the Y-Axis, K_X, in the Z-Up system signifies a road surface that is concave downward along X. Positive K_X in the Z-Down system signifies a road surface that is convex upward along X. Positive Road Surface Curvature about the X-Axis, K_Y, in the Z-Up system signifies a road surface that is concave upward along Y. Positive K_Y in the Z-Down system signifies a road surface that is convex downward along Y.

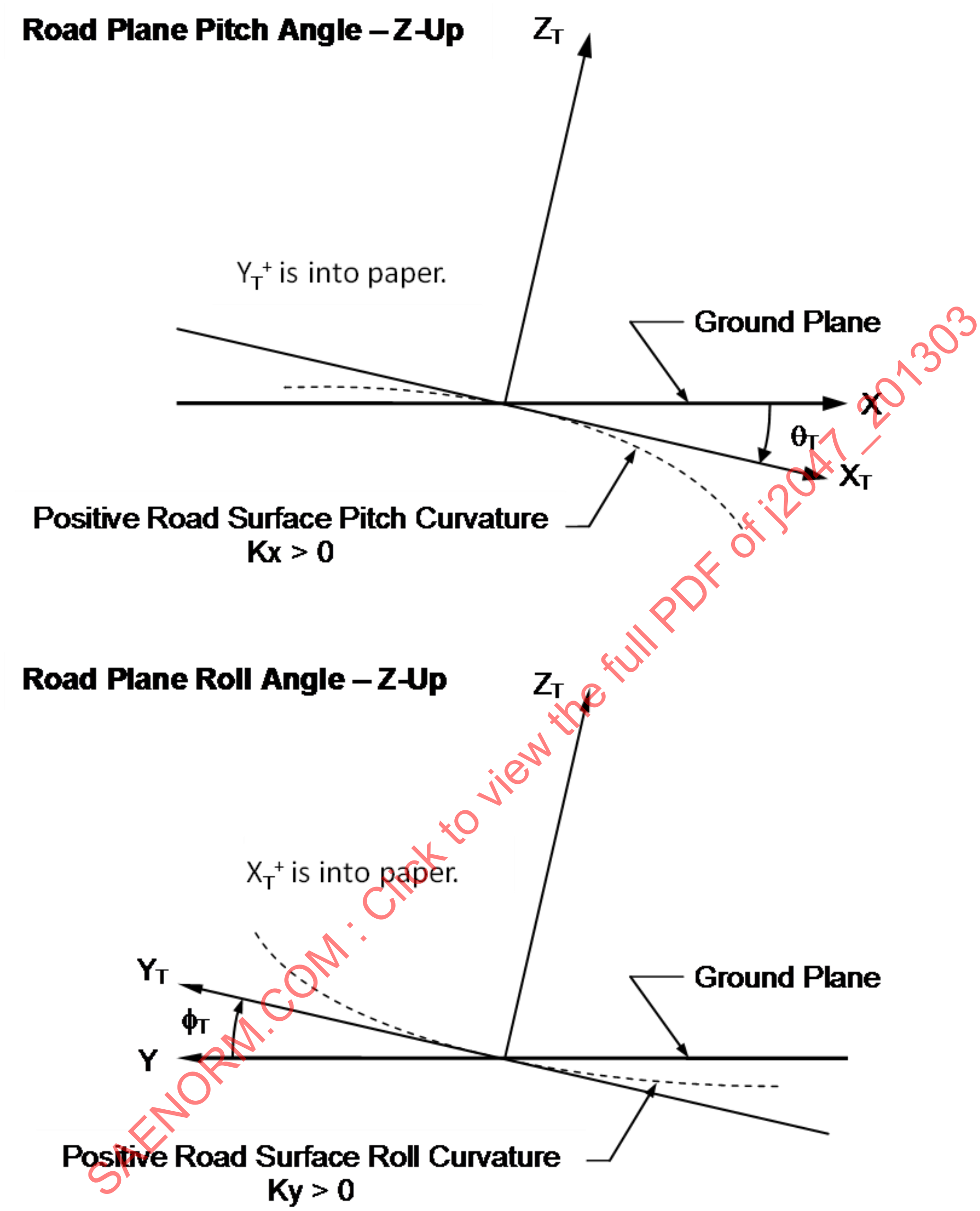


FIGURE 8A – ROAD PLANE ORIENTATION TO GROUND PLANE FOR Z-UP AXIS SYSTEM (POSITIVE ANGLES SHOWN) ROAD SURFACE CURVATURE

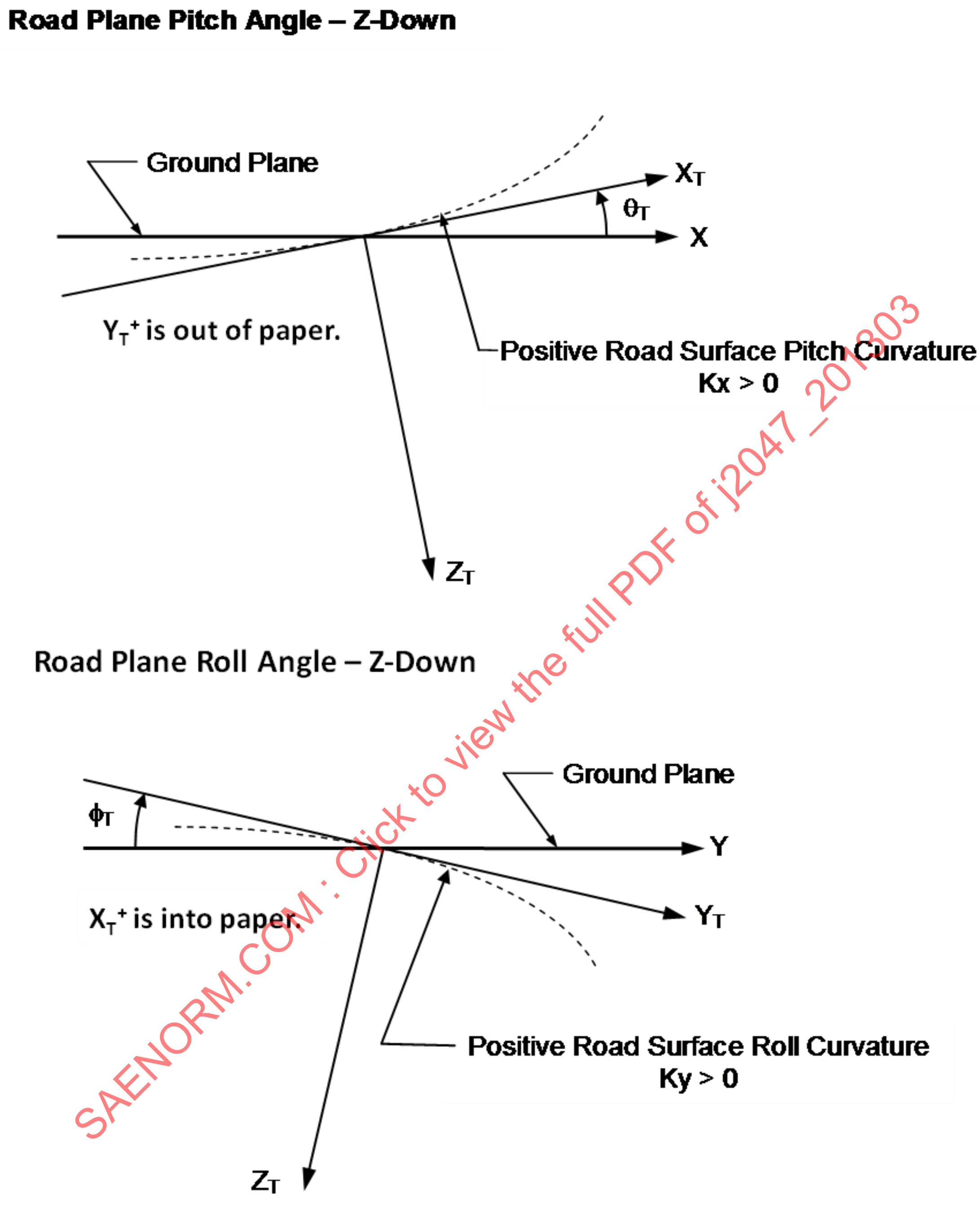


FIGURE 8B – ROAD PLANE ORIENTATION TO GROUND PLANE FOR Z-DOWN OR SAE AXIS SYSTEMS (POSITIVE ANGLES SHOWN)

5.3.3 Road Surface Curvature

The curvature of the road surface determined about the X and Y axes in the ground plane.

5.3.3.1 Road Surface Pitch Curvature, K_X

The first derivative of the road plane pitch angle with respect to distance traveled along the X-Axis. (See Equation 1.)

$$K_X = d\theta_T / dX \quad \text{(Eq. 1)}$$

5.3.3.2 Road Surface Roll Curvature, K_Y

The first derivative of the road plane roll angle with respect to distance traveled along the Y-Axis. (See Equation 2.)

$$K_Y = d\phi_T / dY \quad \text{(Eq. 2)}$$

6. COORDINATE SYSTEMS DESCRIBING TIRE BEHAVIOR

In the context of SAE J670 (2008) this terminology contains coordinate systems not axis systems.

6.1 Reference Frame

A geometric environment in which all points remain fixed with respect to each other at all times.

6.2 Axis Systems

A set of three orthogonal directions associated with the X, Y, and Z axes. Right-handed coordinate systems are assumed throughout this document except where differences are explicitly noted. For right-handed systems

$$\hat{Z} = \hat{X} \times \hat{Y} \quad \text{(Eq. 3)}$$

6.2.1 Base Vectors $\hat{X}$, $\hat{Y}$, $\hat{Z}$

The set of three orthogonal unit vectors selected as a base to represent all other vectors within an axis system.

NOTE: The base vector symbology chosen is the same as that used in SAE J670.

6.3 Coordinate System

Systems used to assign a unique ordered trio of values (X, Y, Z) to each point in a reference frame. A coordinate system consists of an axis system plus an origin point.

6.4 Earth-Fixed Coordinate System X_E, Y_E, Z_E

Right-handed orthogonal coordinate system fixed in the inertial reference. The X_E and Y_E axes are parallel to the ground plane. The Z_E axis is aligned with the gravitational axis. The positive Z_E axis points upward in the Z-Up orientation. The positive Z_E axis points downward in the Z-Down orientation. The compass orientation of the X_E axis is arbitrary and should be based on the needs of the analysis or test. The location of the origin is generally an arbitrary point defined by the user.

NOTE: This coordinate system is usually used for describing the trajectories of the vehicle and its component parts. This system can also be used to describe the direction of the wind velocity, which influences vehicle motion.

6.5 Tire Coordinate Systems

NOTE: This terminology recognizes the three existing tire coordinate systems: Z-Up (the ISO 8855 Wheel Axis System at the time of publication of this document), Z-Down introduced in 2008 version of SAE J670 as a replacement for the Historic SAE Tire Axis System, and the SAE Historic Tire Coordinate (Axis) System (SAE 670E) as coequal and provides conversions from one to the other in Table 2. When definitions are coordinate system dependent, all are given.

NOTE: TABLE 2 is found in APPENDIX A – TABLES.

6.5.1 Z-Up Tire Coordinate System (Wheel Axis System (ISO 8855))

A reference system intended for the orientation of forces and moments exerted on the tire by the road and also for angular orientation of the tire with respect to the road plane. It is an orthogonal, right-handed, three-axis coordinate system originating at the contact center. The X_T and Y_T axes are located in the road plane. The Z_T axis is perpendicular to the road plane and is positive out-of-the-road plane. The X_T axis coincides with the contact line. It is positive forward. The Y_T axis is positive to the left. (See Figure 9A.)

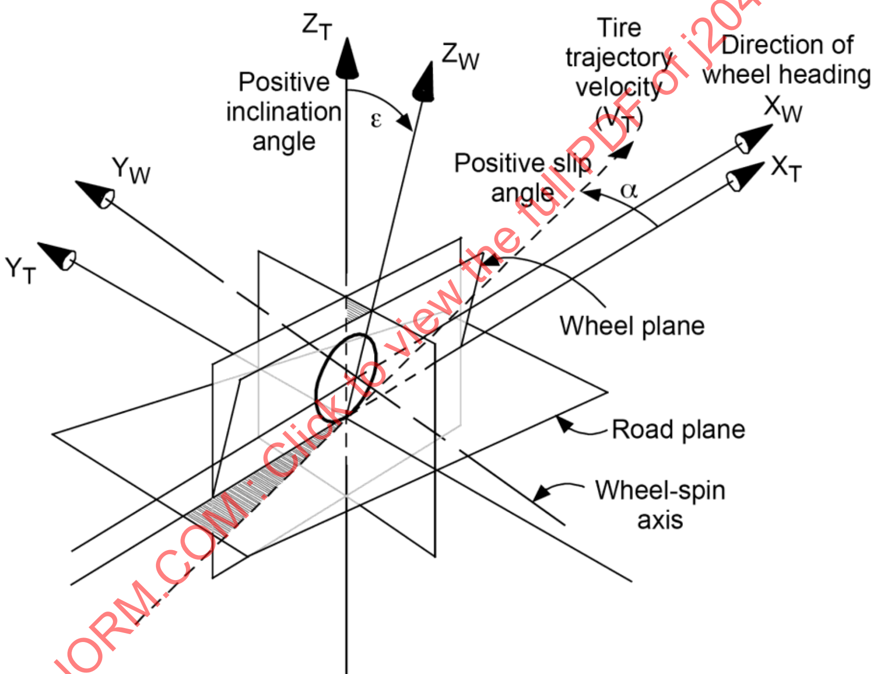


FIGURE 9A – TIRE AND WHEEL AXIS SYSTEMS – Z-UP

6.5.2 Z-Down Tire Coordinate System

A reference system intended for the orientation of forces and moments exerted on the tire by the road and also for angular orientation of tire with respect to the road plane. It is an orthogonal, right-handed, three-axis coordinate system originating at the contact center. The X_T and Y_T axes are located in the road plane. The Z_T axis is perpendicular to the road plane and is positive into-the-road plane. The X_T axis coincides with the contact line. It is positive forward. The Y_T axis is positive to the right. (See Figure 9B.)

NOTE: In J670(2008) this system was introduced to bring the spindle torque and wheel angular velocities into compliance with the requirements of a right handed coordinate system. Otherwise this system and the SAE Historic Tire Coordinate (Axis) System (J670E) are identical.

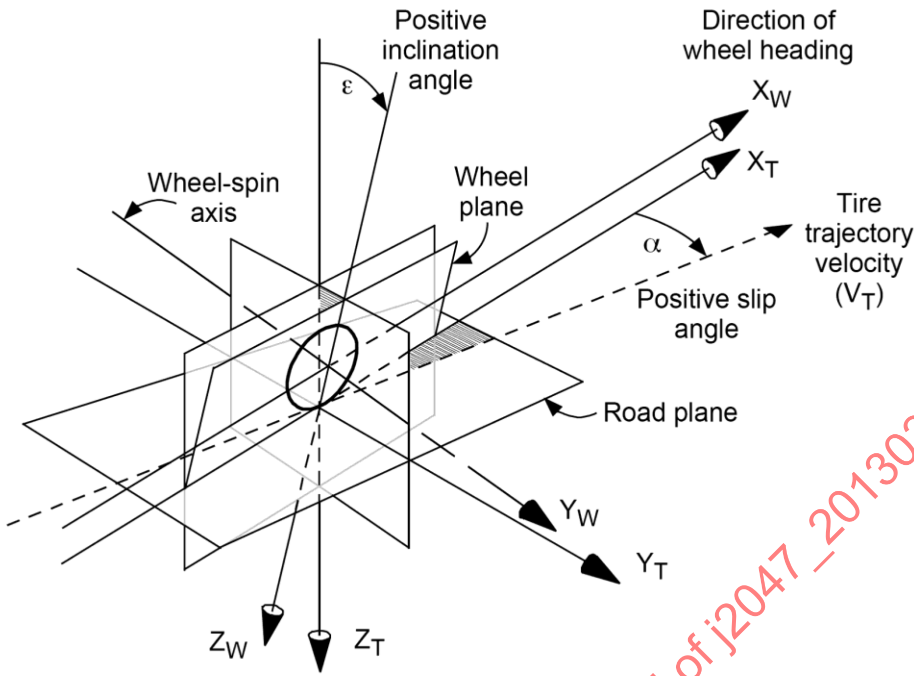


FIGURE 9B - TIRE AND WHEEL AXIS SYSTEM – Z-DOWN

6.5.3 Historic SAE Tire Coordinate System (X' Y' Z') (SAE J670 (2008 – APPENDIX C)

This system is identical to the Z-Down System except for reversal of the Wheel-Spin Axis, which reverses the senses of spindle torque and wheel angular velocity as outlined in the note under Section 6.5.2. (See Figure 9C)

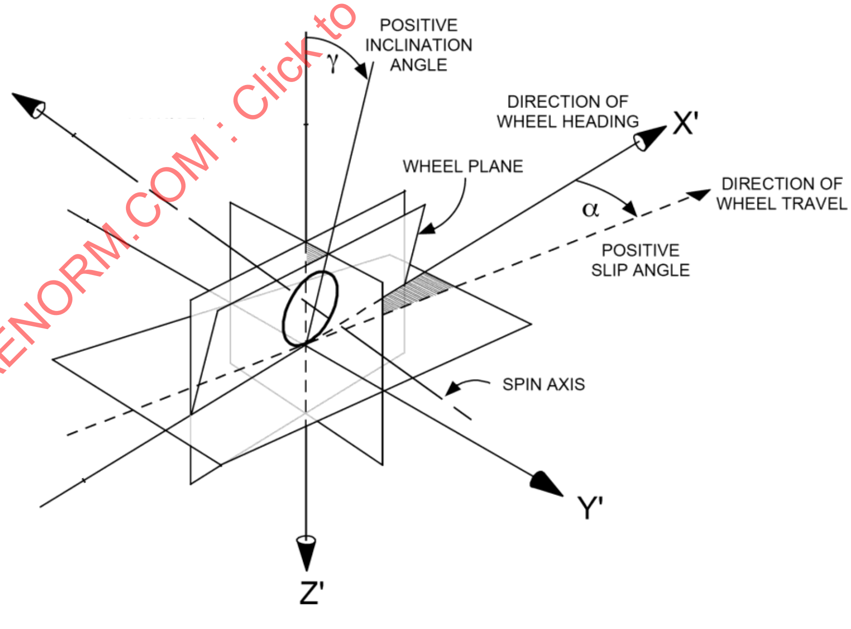


FIGURE 9C – HISTORIC SAE TIRE AXIS SYSTEM

6.5.4 Wheel Coordinate Systems (X_W, Y_W, Z_W)

The X_W and Z_W axes are in the wheel plane. X_W is parallel to the road plane applicable to the tire of concern. X_W is positive in the forward direction. Y_W is coincident with the spindle axis. Y_W is positive to the left in the Z-Up system and positive to the right in the Z-Down system. The positive Z_W axis points upward in the Z-Up system and downward in the Z-Down system. The origin of each system is at the intersection of the wheel plane and the spindle axis. The systems are shown in Figures 9A and 9B.

6.5.5 SAE Parallel Tire Coordinate System (X", Y", Z")

This is a special version of the Z-Down Wheel Coordinate System introduced in SAE J2710 and SAE J2730. In this case the inclination and slip angles are always zero. It is shown in Figure 9D.

NOTE: This system is for the study of tire vibration properties with respect rough road surfaces. A Z-Up equivalent is a special version of the Z-Up Wheel Plane Coordinate System with inclination and slip angles of zero.

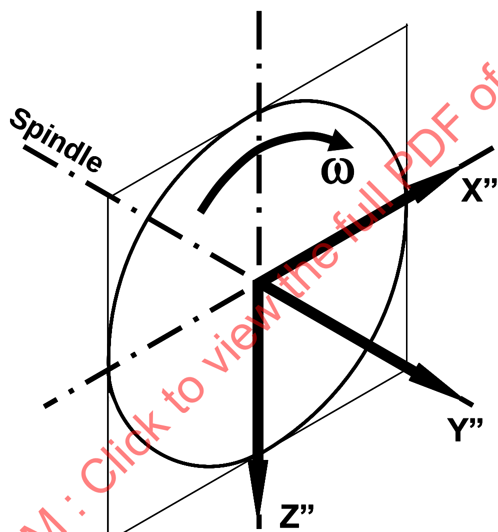


FIGURE 9D – SAE PARALLEL TIRE COORDINATE SYSTEM

6.5.6 Tire Uniformity (Tire Face) Coordinate System (F, L, R)

A reference system intended for orientation of tire forces and moments with respect to the tire face. It is an orthogonal, right-handed, three-axis coordinate system, originating in the wheel center. F, the fore-aft-axis, and the L, lateral-axis, are parallel to the road plane, neither slip nor inclination angles ever exist. The L-axis coincides with the spin-axis with its positive direction pointing outboard with respect to the tire face, which is to the right in this system. The R, radial-axis, is perpendicular to the road plane with its positive direction out-of-the-road plane. The F-axis forms an orthogonal, right-handed, set with the L_F and R_F axes; its positive direction points rearward. (See Figure 9E.)

NOTE: The tire face system is used in the tire industry primarily for tire uniformity measurements, which are conducted at zero slip angle and zero inclination angle. The tire face system is a specialized system with its original form introduced in the 1960s and early 1970s for use with uniformity machines, in tire factories.

Initially, this system had only two axes for orientation of radial and lateral forces. This system was devised with no consideration of the already existing Historic SAE tire coordinate (axis) system (Section 6.5.3).

The third axis, the longitudinal axis was added to satisfy the expanding need to consider longitudinal forces. Unfortunately, the choice of positive direction for this axis was limited by restrictions imposed by the existing factory machines. These machines were devised to accommodate the radial axis with positive direction out-of-the-road plane and lateral axis with positive direction pointing outboard with respect to the tire face when simulating operation on the right side of a vehicle. Because of these restrictions, it was not possible to convert the original de facto two-axis system into orthogonal right-handed, three-axis system with positive direction of the longitudinal axis forward. To make this conversion, it was necessary to reverse the positive direction of the longitudinal axis from forward to rearward. The tire face system is a 180° rotation of the Z-Up coordinate system.

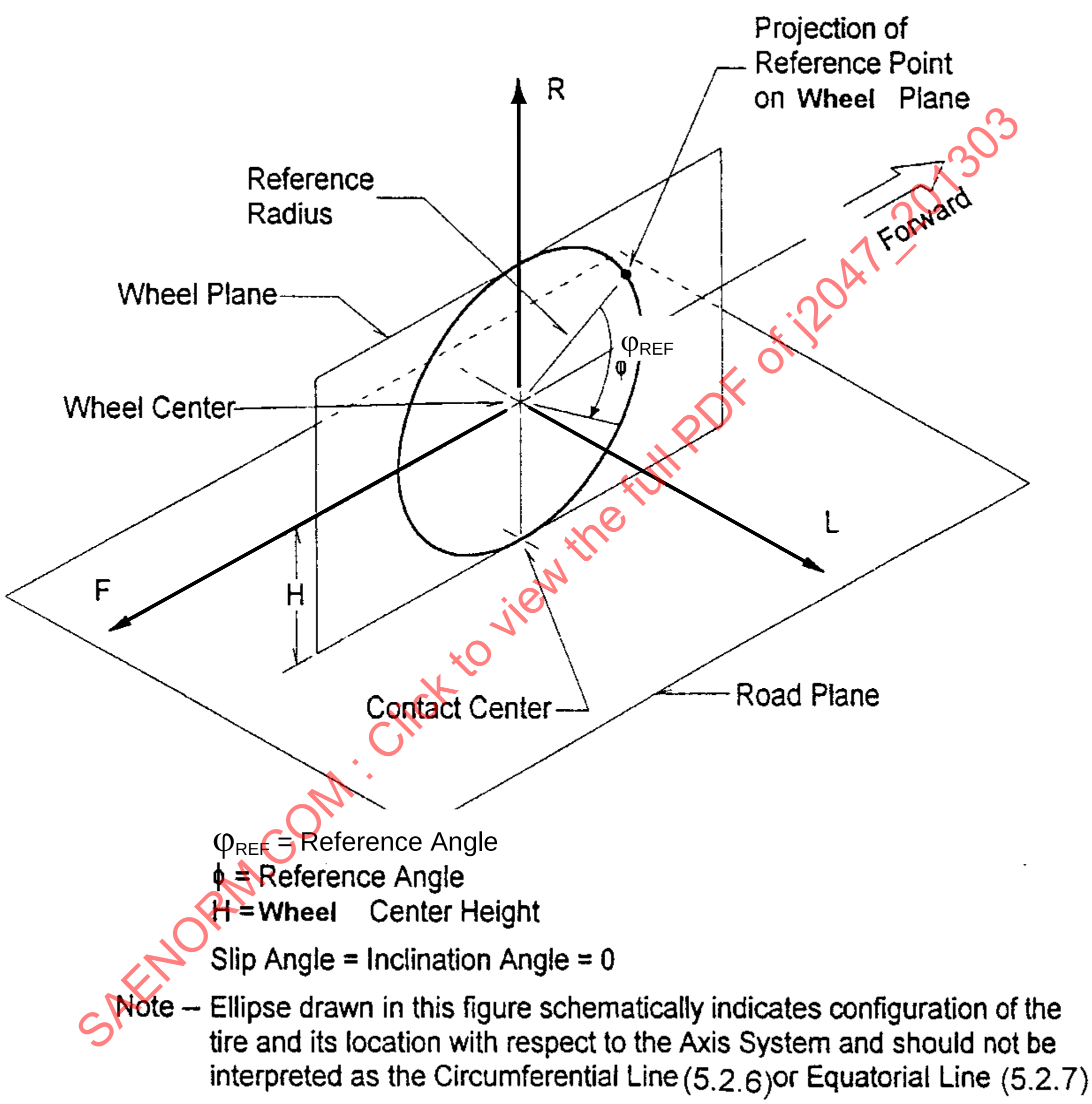


FIGURE 9E – TIRE FACE COORDINATE SYSTEM

6.5.6.1 Reference Point

Any mark on the tire face that is used to identify the angular location of tire components. (See Figure 9E)

NOTE: The reference point can be set anywhere on the tire face, but its location must be recorded. For example, a convenient location would be the beginning of the first character of the small tire-size designation near the bead.

6.5.6.2 Reference Radius

A line between the normal projection of the reference point onto the wheel plane and the wheel center. (See Figure 9E.)

6.5.6.3 Reference Angle, φ_{REF}

The angle from the reference radius to a particular tire component or feature. The reference angle is clockwise when the tire face is viewed. (See Figure 8E.)

6.6 Wheel Plane Orientation

The angular orientation of the wheel plane with respect to the road plane and direction of wheel travel over the road plane. It results from a sequence of two rotations: Rotation about the Z_T (Z') -axis and rotation about the X_T (X') -axis. This angular orientation is usually expressed in terms of slip angle and inclination angle. The sign convention for slip angle and inclination angle is determined by the choice of the coordinate system. (See Figures 9A, 9B, and 9C.) Transformation of slip angle and inclination angle between the three systems is shown in Table 2 in APPENDIX A - TABLES.

6.6.1 Slip Angle, α

The angle from the X_T (X')-axis to the Trajectory Velocity (Section 7.2.1). It is positive for a right turn in the Z-Up Tire Coordinate System and positive for a left turn in the Z-Down and Historic SAE Tire Coordinate Systems.

6.6.2 Inclination Angle ε (γ)

The angle from the Z_T (Z')-axis to the wheel plane. It is positive, to the right, in the Z-Up, Z-Down, and Historic SAE Tire Coordinate Systems.

7. TIRE ROLLING CHARACTERISTICS

In this section tire refers to the entire tire/wheel assembly not just to the tire.

7.1 Tire Rolling Modes

7.1.1 Straight Free-Rolling Tire

A loaded-rolling tire moving without applied torque along a linear path (zero path curvature) at zero slip and inclination angles.

NOTE: In defining the straight free-rolling tire, it is assumed that (a) the tire rotates at a constant spin velocity and (b) the tire is pulled or pushed by applying a longitudinal force at its center, sufficient to balance rolling loss and friction torque.

7.1.2 Straight Torqued-Rolling Tire

A loaded-rolling tire moving under braking or driving torque along a linear path (zero path curvature) at zero slip angle and zero inclination angle.

7.1.3 Free-Rolling Cornering Tire

A loaded-rolling tire moving without applied torque along a curvilinear path at given values of slip angle and/or inclination angle.

7.1.4 Cornering Torqued Tire

A loaded-rolling tire moving under braking or driving torque along a curvilinear path at given values of slip angle and/or inclination angle.

7.2 Tire Velocities

7.2.1 Trajectory Velocity, V_T

Vector quantity expressing the velocity of the tire contact center in the Earth-fixed coordinate system. The direction of the trajectory velocity is identical with the direction of the tangent to the trajectory of the contact center. V_T is illustrated in Figures 9A – 9C and in Figures 11A – 11C.

7.2.2 Wheel-Spin Velocity (Wheel Rotation Speed), ω_W

The angular velocity of the wheel about the spin axis. The wheel-spin velocity in the case of straight free-rolling is ω_{W0}.

7.2.3 Longitudinal Slip Velocity

The difference between the spin velocity of the straight driving or braking wheel and the spin velocity in straight free-rolling.

7.2.4 Longitudinal Slip Ratio, S_X

The ratio of longitudinal slip velocity to the spin velocity in straight free-rolling. (See Equation 4.)

$$S_X = [\omega_W - \omega_{W0}]/\omega_{W0} \qquad \text{(Eq. 4)}$$

Both ω_W and ω_{W0} are determined at the same longitudinal velocity.

NOTE: The classical definition of slip ratio is the one presented in Equation 4. It is defined such that positive slip ratio is associated with driving. Calculation of longitudinal slip is based on an assumption that the straight free-rolling tire has zero slip. Since the slip due to rolling resistance is very small as compared to slip due to braking or driving torque, the slip due to rolling resistance is classically neglected in straight free-rolling. A further complication arises when dealing with slip beginning from a stop as ω_{W0} is zero, which causes Equation 3 to yield infinity. For starting and other very slow rolling cases the slip ratio definitions presented in the work of Clover and Bernard published in Vehicle Systems Dynamics is more appropriate. Be sure to note that in their work Clover and Bernard defined the process such that negative slip ratio leads to driving the reverse of what is expressed herein.

7.3 Wheel Kinematics

7.3.1 Revolutions per Kilometer (Revolutions per Mile – See note below Eq. 5.) n

The number of revolutions per kilometer of the straight-rolling driven or torqued tire traveling at a constant longitudinal velocity. The number of revolutions per kilometer for the straight free-rolling tire is n_0. (See Equation 5.)

$$n = n_0\left(1 + S_X\right) \qquad \text{(Eq. 5)}$$

NOTE: Revolutions per mile = 1.609347 n

7.3.2 Distance per Revolution (Dynamic Rolling Circumference), C_R

The distance traveled by the wheel center per revolution at constant longitudinal velocity. (See Equation 6.)

$$C_R = 1000/n\,(\text{meter}) \qquad \text{(Eq. 6)}$$

7.3.3 Dynamic Rolling Radius (Effective Rolling Radius), R_{DYN} (R_E)

The distance traveled by the wheel center per radian of rotation at constant trajectory velocity. This distance is derived from distance per revolution and is equal to the ratio of trajectory velocity to spin velocity. (See Equation 7.)

$$R_{DYN}\left(R_E\right) = C_R / 2\pi = V_T / \omega\left(meter\right) \quad \text{(Eq. 7)}$$

8. STANDARD LOADS

8.1 Tire Load

The load or weight supported by the tire.

8.1.1 Tire Load Limits (Load Rating)

The maximum loads recommended by a tire and rim standards organization for a given tire at a given cold inflation pressure.

NOTE: Various load rating systems such as standard load and extra load, load range, ply rating, star marking, etc., are used for different applications. Standard load and extra load are for passenger car tires, load range is for truck and motorcycle tires, ply rating for agricultural, industrial, off-the-road, and aircraft tires; and star marking is for radial, agricultural, and off-the-road tires. For further details refer to current T&RA book.

8.1.2 Tire Vertical Load

The absolute value of tire normal force.

9. VEHICLE APPLIED TORQUE

In this section wheel refers to the entire tire/wheel assembly.

9.1 Applied Torque (Wheel Torque), T_W

The external torque applied from the vehicle to the wheel about the spin axis. (See, Figures 10A – 10C.)

9.1.1 Driving Torque

Applied torque that produces a tire driving force.

NOTE: Driving torque is used to: (a) accelerate the vehicle, (b) maintain desired vehicle speed and (c) to provide energy necessary to produce lateral forces.

9.1.2 Braking Torque

Applied torque that produces a tire braking force.

NOTE: Braking torque is used to: (a) decelerate the vehicle and (b) to maintain vehicle speed at a desired level when driving downhill.

9.1.3 Wheel Bearing Torque

Applied torque caused by bearing friction about the spin axis.

10. TIRE FORCES AND MOMENTS

The total force and moment exerted on the tire by the road can be represented by three force components and three moment components, as shown in Figures 10A – 10C. One force and one moment act in the direction of, and about, each of the three axes in the tire coordinate systems described in Section 6. See Figures 9. The three moments and two of the three forces are generally treated as dependent variables. In tire testing and tire modeling, tire normal force is generally treated as an independent variable as is wheel torque (Section 9.1). The magnitudes of the dependent forces and moments typically vary as a function of the tire normal force and wheel torque. Additionally, the magnitudes of the dependent forces and moments including nonuniformity forces and moments are somewhat affected by the direction of tire rotation, although this effect is usually neglected except in pull force and moment studies. (See Section 11.)

The forces and moments acting on the tire by the road at any instant may be summed into one resultant force vector and one resultant moment vector having a common coordinate system origin. The line of action of the resultant force vector may be moved to any coordinate system origin (point of interest), providing the resultant moment vector is altered accordingly.

Transformations between the various coordinate systems for the forces and moments defined in this section and discussed in amplified detail in Sections 11 – 15 are defined in Table 2 in APPENDIX A –TABLES.

NOTE: Forces and moments may vary with change in independent variables such as slip angle, inclination angle, wheel load, wheel torque, speed, coefficient of friction, curvature of the road surface, and dependent variables such as path curvature, tread wear, and tire temperature. Furthermore, forces and moments may vary periodically with each wheel revolution, due to tire nonuniformity. (See Section 17.) In steady-state testing, periodic variations of forces and moments are usually eliminated by computing their average values for each incremental input of slip angle, wheel load, etc., from their instantaneous values taken at a specified sampling rate during two or more wheel revolutions. In non-steady state tests, the measured instantaneous values of forces and moments are influenced by controlled change of input variables such as slip angle, wheel load, etc., and also by periodic variations resulting from tire nonuniformity. The relative effect of periodic force and moment variations due to tire nonuniformity is particularly significant when the change of slip angle occurs at or near its zero value. The instantaneous values of forces and moments are influenced not only by the instantaneous values of independent input variables such as slip angle, wheel load, etc., but also by their rate of change with respect to time, and by the reversals of this rate of change (for example, change from an increase of slip angle to a decrease of slip angle or vice versa).

10.1 Tire Force, $\vec{F}_T$

A vector quantity expressing the sum of the forces exerted on the tire by the road at any instant, with its line of action passing through the contact center.

NOTE: The forces shown in Figures 10A, 10B, or 10C are summed to produce tire force in the tire coordinate system being used.

10.2 Tire Moment, $\vec{M}_T$

A vector quantity expressing the sum of the moments exerted on the tire by the road at any instant, consistent with the line of action of the tire force.

NOTE: The moments in Figures 10A, 10B, or 10C are summed to produce the tire moment in the tire coordinate system being used.

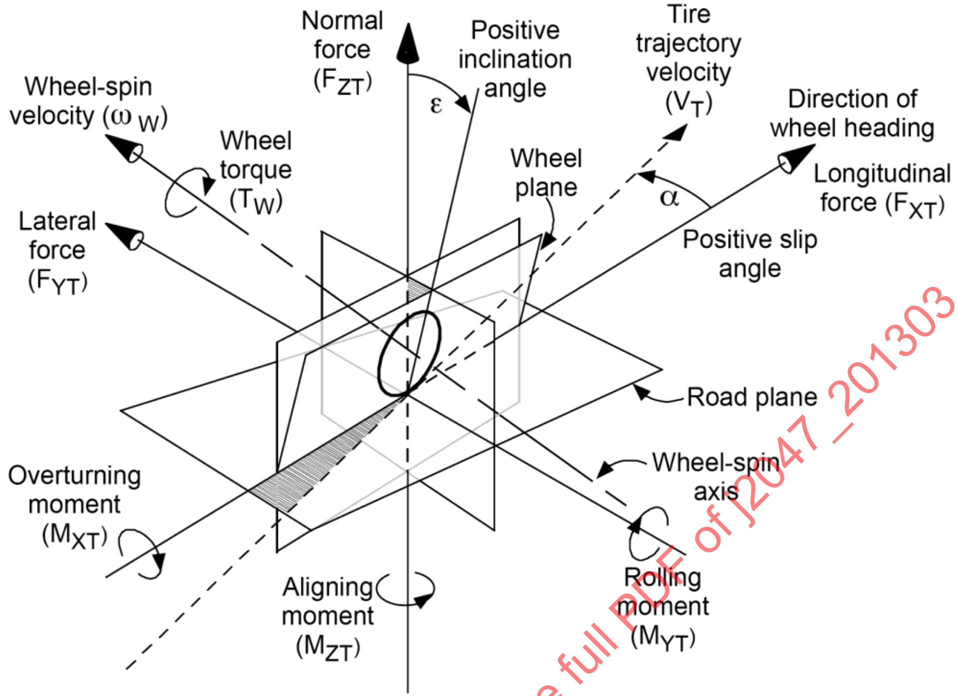


FIGURE 10A – TIRE FORCE AND MOMENT NOMENCLATURE – Z- UP (ISO 8855)

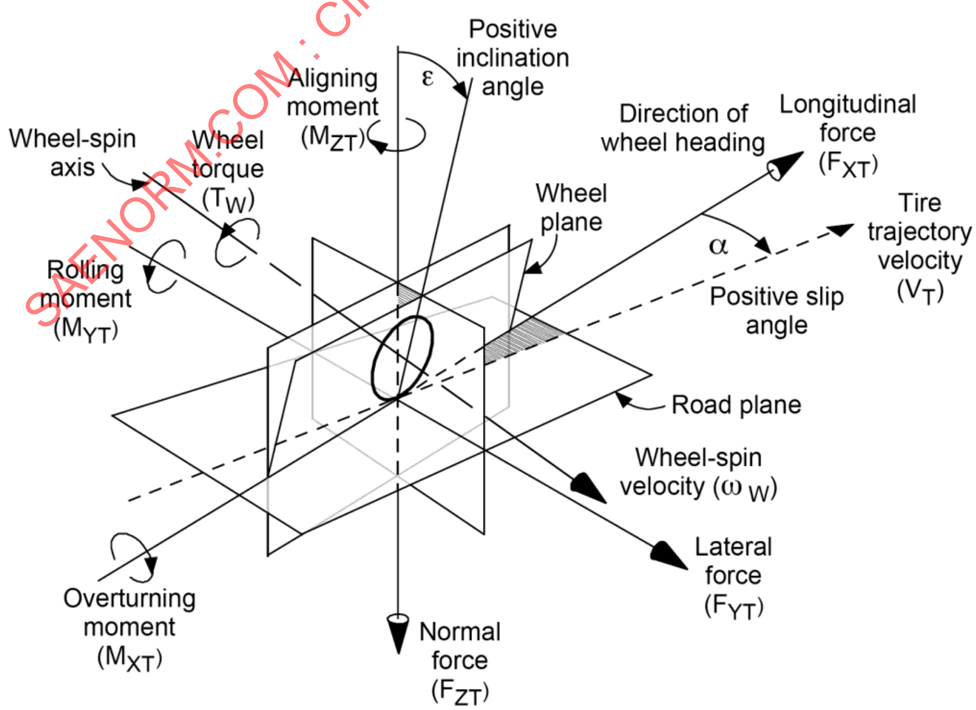


FIGURE 10B – FORCE AND MOMENT NOMEMCLATURE – Z-DOWN

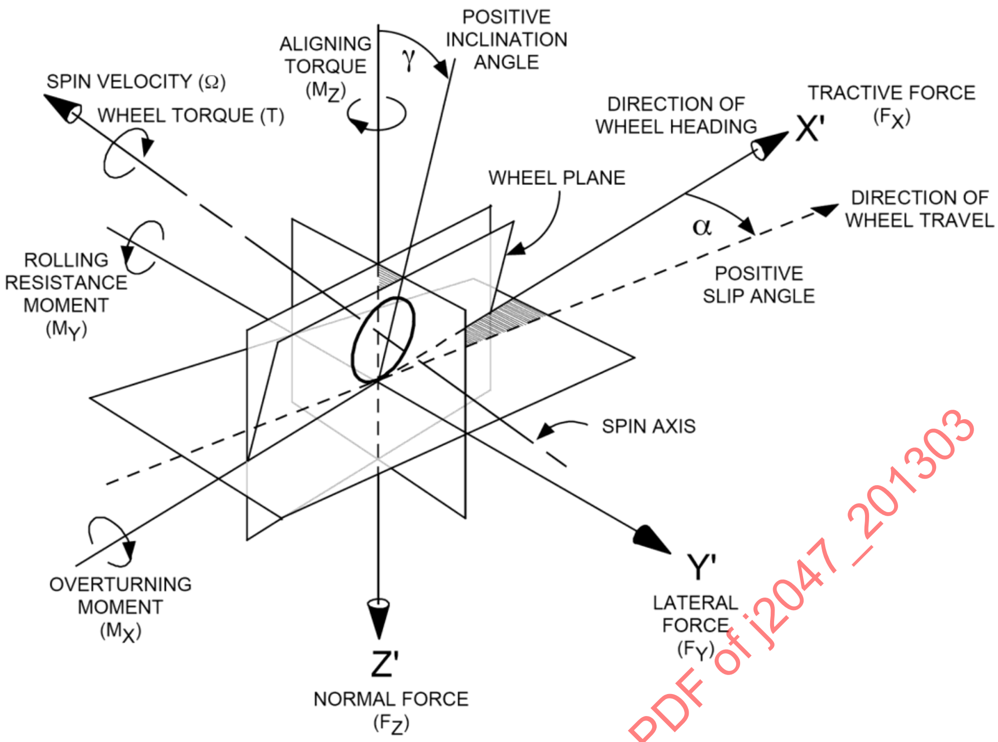


FIGURE 10C – FORCE AND MOMENT NOMENCLATURE – HISTORIC SAE

10.3 Tangential Force (Shear Force, Resultant Traction Force), $\vec{F}_R$

A vector, which expresses the sum of the forces exerted on the tire by the road in the X_TY_T (X'Y') plane (road plane). (See Figures 11A, 11B, or 11C for the appropriate sketch.)

NOTE: The individual tire forces do not really act through the center of contact (tire coordinate system origin), but rather at offsets in the X_T-Y_T (X'-Y') plane. As noted at the outset of Section 10, the moments are introduced to allow for this with the forces treated as if they actually act at the center of contact. Force offset vectors can be introduced for each force in order to compute the required moments. The only individual offset commonly used is that for lateral force in the case of pure slip angle loading. This offset, pneumatic trail, is discussed in Section 10.7.1. The offsets do not define a common point of action for the resultant tire forces. This arises from the fact that each force is the resultant from integration of a different footprint stress. Each stress has a different spatial distribution within the footprint.

NOTE: The tangential force magnitude is defined in Equation 8. The angle between the line of action of the tangential force and the X_T (X') axis is defined by Equation 9.

$$|F_R| = \sqrt{F_{XT}^2 + F_{YT}^2} \quad \text{(Eq. 8)}$$

10.3.1 Tangential Force Offset, $\vec{l}_T$

$\vec{l}_T$ is the moment arm by which the line of action of the tangential force is offset from the origin to generate $\vec{M}_{ZT}$, Section 10.7. The tangential force offset is illustrated in Figures 11A - 11C.

10.3.2 Tangential Force Angle (Traction Vector Angle), φ

The angle between the tangential force, $\vec{F}_R$, and the positive branch of the X_T (X')-axis, Equation 9.

$$\varphi = arc\tan\left(F_{YT} / F_{XT}\right) \quad \text{(Eq. 9)}$$

10.3.3 Horizontal Force, $\vec{F}_H$

The normal projection of the tangential force vector onto the ground plane.

10.3.4 Longitudinal Force (Fore-Aft Force), F_{XT} (F_X)

The component of the tire force in the X_T (X') direction. (See Figures 10A – 10C.)

NOTE: This is equivalent to the definition given in J670 (2008) where the individual forces are defined as scalar components of the tire force in the direction of a particular axis.

10.3.4.1 Longitudinal Force Offset (Rolling Resistance Force) F_{XT0}

The longitudinal force of the straight free-rolling wheel resulting from tire energy loss.

10.3.4.2 Driving Force

The positive longitudinal force resulting from driving torque application.

10.3.4.3 Braking Force

The negative longitudinal force resulting from braking torque application.

10.3.5 Lateral Force (Side Force), F_{YT} (F_Y)

The component of the tire force in the Y_T (Y') direction. (See Figures 10A – 10C.)

10.3.5.1 Camber Force (Camber Thrust)

The lateral force component attributable solely to inclination angle, usually expressed as the lateral force at zero slip angle, with the lateral force offset subtracted.

10.3.6 Tractive Force, F_{XR}

The component of the tangential force in the direction of the trajectory velocity. (See Equation 10.)

$$F_{XR} = F_{XT} \cos\alpha + F_{YT} \sin\alpha \quad \text{(Eq. 10)}$$

10.3.6.1 Drag Force

A negative tractive force.

10.3.7 Cornering Force (Central Force) F_{YC}

The component of the tangential force perpendicular to the trajectory velocity. (See Equation 11.)

$$F_{YC} = -F_{XT}\sin\alpha + F_{YT}\cos\alpha \quad \text{(Eq. 11)}$$

10.4 Normal Force (Radial Force, Normal Wheel Load, Normal Load, Load, Wheel Load) F_{ZT} (F_Z)

The component of the tire force exerted by the road on the tire in the Z_T (Z') direction (perpendicular to the road plane).

10.4.1 Tire Vertical Force, F_V

The component of the tire force vector, exerted on the tire by the road in the direction coincident with the gravitation vector. Vertical force is identical with the normal force, if the road plane is horizontal.

10.4.2 Tire Load

The absolute value of the normal force with the tire standing on a horizontal road plane.

10.5 Overturning Moment, M_{XT} (M_X)

The moment exerted on the tire by the road about the X_T (X')-axis. Positive clockwise when viewed in the positive direction of the X_T (X')-axis. (See Figures 10A – 10C.)

10.6 Rolling Moment (Rolling Resistance Moment), M_{YT} (M_Y)

The moment exerted on the wheel by the road about the Y_T (Y')-axis. Positive clockwise when viewing in positive direction of the Y_T (Y')-axis. (See Figure 10A – 10C.)

10.7 Aligning Moment (Aligning Torque, Self-Aligning Torque), M_{ZT} (M_Z)

The moment exerted by the road on the tire about the Z_T (Z')-axis. Positive clockwise when viewed in positive direction of Z_T (Z')-axis. (See Figures 10A – 10C.) $\vec{M}_{ZT}$, the aligning moment vector, is the resultant of the cross product of $\vec{l}_T$ and $\vec{F}_R$ shown in Equation 12.

$$\vec{M}_{ZT} = \vec{l}_T \times \vec{F}_R \quad \text{(Eq.12)}$$

10.7.1 Pneumatic Trail, l_{TX}

The distance between Y_T (Y')-axis and lateral force by which the lateral force, F_{YT}, should be multiplied to obtain the component of aligning moment due to lateral force alone. (See Equation 13.)

$$l_{TX} = M_{ZT} / F_{YT} \quad \text{(Eq. 13)}$$

NOTE: Pneumatic trail ignores any F_{XT} effect. It only considers the apparent fore-aft offset of the line of lateral force action from the origin of the tire coordinate system.

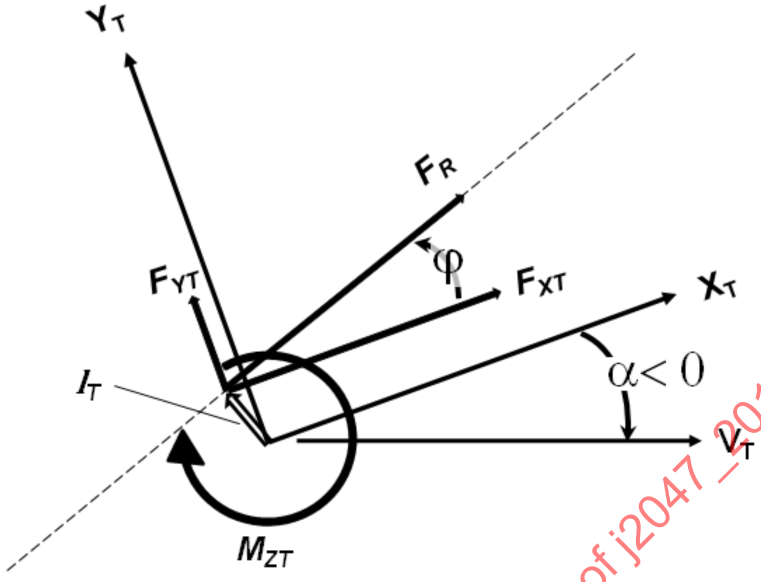


FIGURE 11A – TIRE FORCES AND MOMENTS IN THE ROAD PLANE – Z – UP

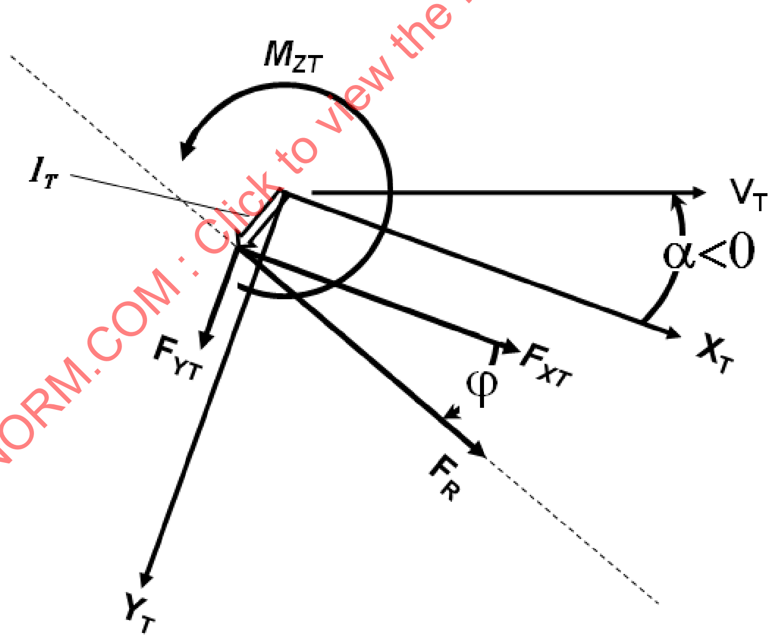


FIGURE 11B - TIRE FORCES AND MOMENTS IN THE ROAD PLANE – Z – DOWN

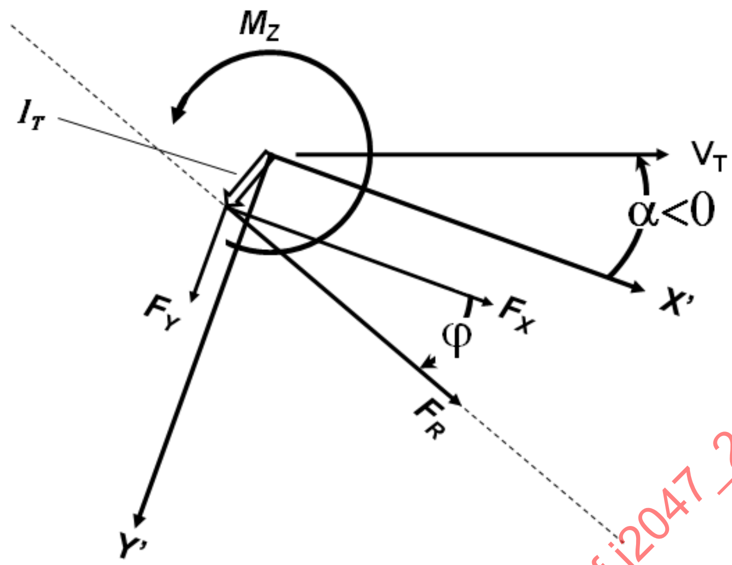


FIGURE 11C - TIRE FORCES AND MOMENTS IN THE ROAD PLANE – SAE HISTORIC

NOTE: Figures 11A – 11C are drawn so as to produce positive lateral force in the respective tire coordinate systems. Consequently the slip angles shown are negative as noted. Also, the longitudinal forces shown are driving forces. The diagrams for the in-plane forces and moment for Z-Down (Figure 11B) and the SAE Historic (Figure 11C) coordinate systems are identical except for labeling.

11. PULL FORCES AND MOMENTS

Pull forces and moments are offsets caused by tire intrinsic properties such as asymmetries in tire material placement or anisotropic structural stiffness or both. The asymmetries or anisotropies may be either by design or unintentional. The resulting forces and moments are the averages of the instantaneous lateral force and aligning moment over a tire revolution. The precise values depend on the sense of tire rotation. The values are coordinate independent with respect to the tire structure, but the equations used in their determination are coordinate system dependent because of the particular viewpoints taken in either tire or test machine coordinate systems. This is illustrated in Sections 11.2 – 11.5, which are based on material from a 2010 ITEC paper by Pottinger.

NOTE: The effect of the lateral force and aligning moment offsets combined with vehicle suspension characteristics can cause a vehicle to move laterally as if it were steering itself in the absence of driver input. Colloquially, the offsets are called pull forces because the vehicle can act as if it were being pulled to the side. The actual vehicle behavior is a response to the properties of all the tires on the vehicle and the details of how the vehicle uses the tires.

11.1 Tire Rotation Sense

The tire rotation sense is defined by the tire face (Section 4.5.1) orientation and the side of the forward moving vehicle on which the tire is mounted. The rotation sense clockwise or counterclockwise is that perceived by an observer looking toward the mounting side of the vehicle, as the vehicle passes by.

11.1.1 Right (Clockwise) Rotation

Right rotation occurs when a tire is mounted on the right side of a vehicle with the tire face outward.

11.1.2 Left (Counterclockwise) Rotation

Left rotation occurs when a tire is mounted on the left side of a vehicle with the tire face outward.

11.2 Pull Components

The pull components are of two types: one that behaves as if the tire had an inbuilt inclination angle and the other as if the tire had an inbuilt slip angle. Both components typically exist simultaneously.

NOTE: The equivalent angles are small.

11.2.1 Conicity

Conicity is a lateral force, F_{YCON}, and associated aligning moment, M_{ZCON}, that cause the tire to behave as if it had an inbuilt inclination angle. The individual tire acts as if it were always inclined in one particular direction with respect to the tire face.

NOTE: A tire with conicity rolls as if it were a cone. The cause of this behavior is differential belt constraint typically due to the belt being slightly off-center with respect to the tire center plane. The tire rolls toward the side to which the belt is off-center. This is primarily a manufacturing imprecision effect. Figures 12 and 13 illustrate tire conicity behavior described in terms of an example test machine coordinate system for the generic machine mounting senses used to study pull effects. The example machine coordinate system is identical to the Z-Down tire coordinate system when the tire is tested as if it were rolling in the direction of the positive X_M - Axis. Descriptions in either machine or tire coordinate systems are valid, but it is necessary to understand how they are associated to avoid confusion.

11.2.2 Plysteer

Plysteer is a lateral force, F_{YPLY}, and aligning moment, M_{ZPLY}, which cause the tire to behave as if it had an inbuilt steer angle. The individual tire acts as if it were always steered slightly in a particular direction.

NOTE: The cause of this behavior is structural anisotropy due the set of cord angles, ply layups, and tread sculpture elements, which exists within a given tire design. Plysteer is primarily a design effect. Figures 12 and 13 illustrate tire plysteer behavior described in terms of an example test machine coordinate system (X_M, Y_M, Z_M) for the generic machine mounting senses used to study pull effects. The example machine coordinate system is identical to the Z-Down tire coordinate system when the tire is tested as if it were rolling in the direction of the positive X_M - Axis. Descriptions in either machine or tire coordinate systems are valid, but it is necessary to understand how they are associated to avoid confusion.

11.3 Lateral Force Offset, F_{YO}

The lateral force of the straight free-rolling tire resulting from the individual tire's construction. It is different in right and left rotation.

11.3.1 Lateral Force Offset for Right Rotation, F_{YOR}

Its algebraic value depends on the coordinate system chosen.

NOTE: In both Figures 12 and 13 F_{Y0R} has an identical value and is termed F_{YM1} in Equations (14 - 17) for purposes of clarity.

11.3.2 Lateral Force Offset for Left Rotation, F_{YOL}

Its algebraic value depends on the coordinate system chosen.

NOTE: In Figure 13 F_{YOL}, termed F_{YM3} for the purposes of clarity in Equations (14) and (16), is reversed in sense with respect to F_{YOL}, in Figure 12, termed F_{ym2} in Equations (15) and (17). F_{ym3} is the negative of F_{ym2}.

11.4 Aligning Moment Offset, M_{ZO}

The aligning moment of the straight free-rolling tire resulting from the individual tire's construction. It is different in left and right rotation.

11.4.1 Aligning Moment Offset for Right Rotation, M_{ZOR}

Its algebraic value depends on the coordinate system chosen.

NOTE: In both Figures 12 and 13 M_{ZOR} is identical algebraically and is termed M_{ZM1} in Equations (18-21).

11.4.2 Aligning Moment Offset for Left Rotation, M_{ZOL}.

Its algebraic value depends on the coordinate system chosen.

NOTE: In both Figures 12 and 13 M_{ZOL} is identical algebraically and is termed M_{ZM2} in Equations (18) and (20) for measurements taken in the flipped mode, Figure 12. M_{ZOL} is termed M_{ZM3} in Equations (19) and (21) for measurements taken in the backward / forward test mode, Figure 13. M_{ZM2} and M_{ZM3} are identical.

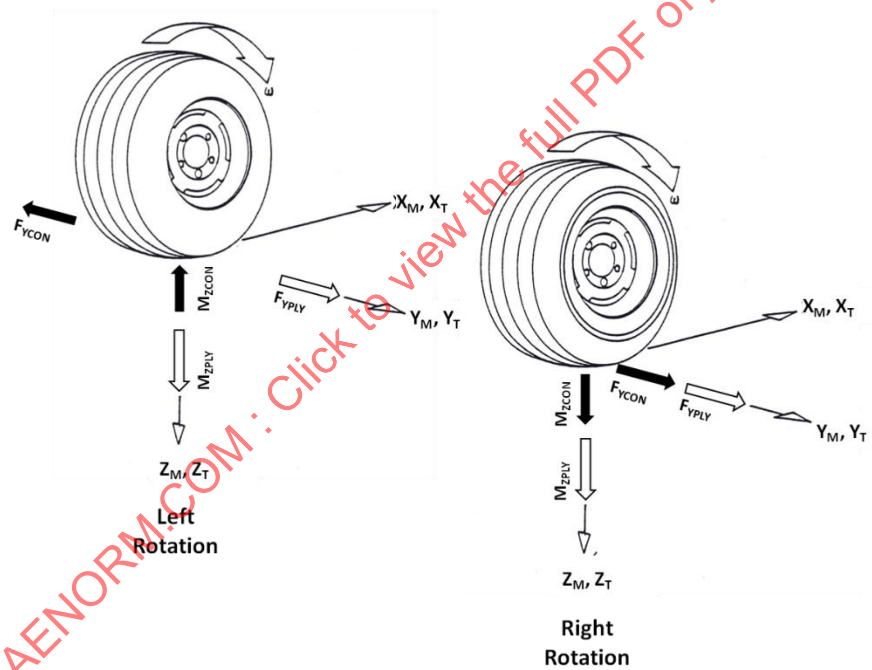


FIGURE 12 – SCHEMATIC OF A FLIPPED PULL TEST

NOTE: In the flipped test, Figure 12, the tire is first tested in right rotation then dismounted from the test machine and flipped over so that it can be tested in left rotation with the test machine roadway continuing to move in the same direction. The tire face is signified by the presence of a ring representing a white sidewall.

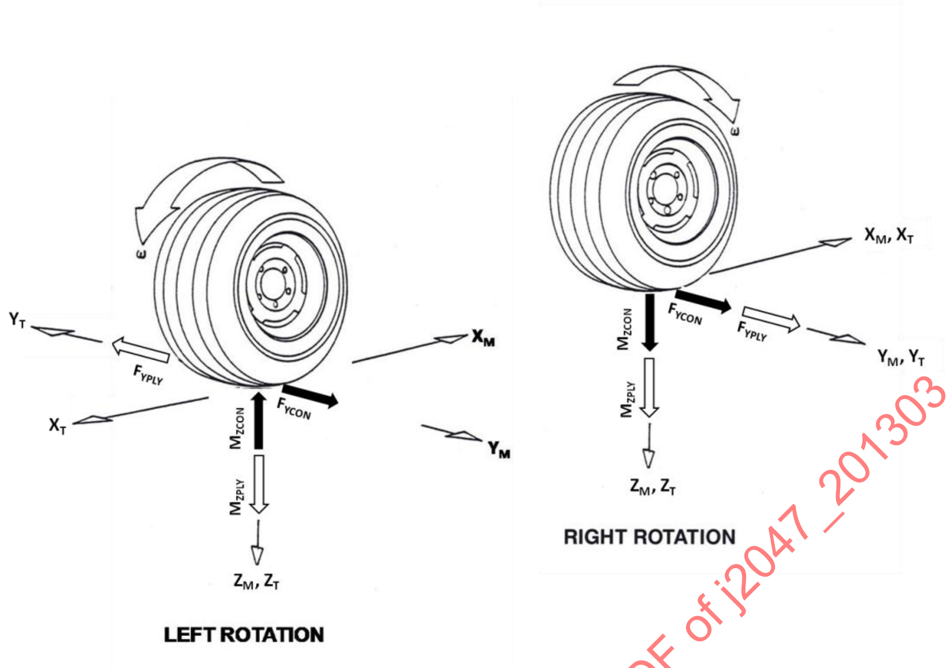


FIGURE 13 – SCHEMATIC OF A BACKWARD / FORWARD PULL TEST

NOTE: In the backward / forward test, Figure 13, the tire mounting does not change between right and left rotation, but the direction of roadway motion is reversed. Again the ring representing a white sidewall denotes the tire face.

11.5 Determination of Pull Force and Moment Offsets from Test Data

NOTE: For a complete derivation of the equations in Section 11.5 see the ITEC paper by Pottinger.

11.5.1 Conicity Lateral Force, F_{YCON}

Lateral force offset component which does not change direction with respect to the tire face due to a change of tire direction of rotation. It changes sign with respect to tire coordinate systems, when the tire direction of rotation is reversed. See Figures 12 and 13. F_{YCON} is computed from lateral force offset determinations in right and left rotation. (See Equations 14 and 15.)

$$F_{YCON} = 0.5[F_{YOR} + F_{YOL}] = 0.5[F_{YM1}+F_{YM3}] \text{ from a Backward and Forward Test} \quad \text{(Eq. 14)}$$

$$F_{YCON} = 0.5[F_{YOR}-F_{YOL}] = 0.5[F_{YM1}-F_{YM2}] \text{ from a Flipped Test} \quad \text{(Eq.15)}$$

11.5.2 Plysteer Lateral Force, F_{YPLY}

Lateral force offset component which changes its direction with respect to the tire face with a change in tire direction of rotation. It does not change sign with respect to the tire coordinate system if the tire direction of rotation is reversed, Figures 12 and 13.) F_{YPLY} is computed from lateral force offset determinations in right and left rotation, Equations 16 and 17.)

$$F_{YPLY} = 0.5[F_{YOR} - F_{YOL}] = 0.5[F_{YM1} - F_{YM3}] \text{ from the Backward and Forward Test} \quad \text{(Eq. 16)}$$

$$F_{YPLY} = 0.5[F_{YOR} + F_{YOL}] = 0.5[F_{YM1} + F_{YM2}] \text{ from Flipped Test} \quad \text{(Eq.17)}$$

NOTE: The note under Section 11.3.2 points out that F_{YM3} is the negative of F_{YM2}, which is obvious from examining Figures 12 and 13. Substitution of minus F_{YM2} for F_{YM3} in Equations (14) and (16) produces Equations (15) and (17) respectively. Therefore, both ways of testing yield the same result if the test machine is without fault.

11.5.3 Conicity Aligning Moment, M_{ZCON}

Aligning moment offset component associated with conicity lateral force. It changes sign with respect to the tire or test machine coordinate systems when the tire changes from right to left rotation as shown in Figures 12 and 13.

$$M_{ZCON} = 0.5[M_{ZOR} - M_{ZOL}] = 0.5\{M_{ZM1} - M_{ZM2}] \text{ from Flipped Test} \quad \text{(Eq. 18)}$$

$$M_{ZCON} = 0.5\,[M_{ZOR} - M_{ZOL}] = 0.5[M_{ZM1} - M_{ZM3}] \text{ from Backward / Forward Test} \quad \text{(Eq. 19)}$$

NOTE: Equations (18) and (19) are identical, as M_{ZM2} and M_{ZM3} are identical. Therefore, both ways of testing yield the same result if the test machine is without fault.

11.5.4 Plysteer Aligning Moment, M_{ZPLY}

Aligning moment offset component associated with plysteer lateral force. It does not change sign with respect to the tire or test machine coordinate systems when the tire changes from right to left rotation as shown in Figures 12 and 13.

$$M_{ZPLY} = 0.5[M_{ZOR} + M_{ZOL}] = 0.5[M_{ZM1} + M_{ZM2}] \text{ from Flipped Test} \quad \text{(Eq. 20)}$$

$$M_{ZPLY} = 0.5[M_{ZOR} + M_{ZOL}] = 0.5[M_{ZM1} + M_{ZM3}] \text{ from Backward / Forward Test} \quad \text{(Eq. 21)}$$

NOTE: Equations (20) and (21) are identical, as M_{ZM2} and M_{ZM3} are identical. Therefore, both ways of testing yield the same result, if the test machine is without fault.

11.6 Residual Lateral Force and Aligning Torque

With the presence of lateral force and aligning moment offsets, Sections 11.3 and 11.4, the lateral force and aligning torque of a rolling tire do not typically become zero at the same slip angle, Figure 14. Where this condition exists on the front axle of the vehicle, self steer will occur.

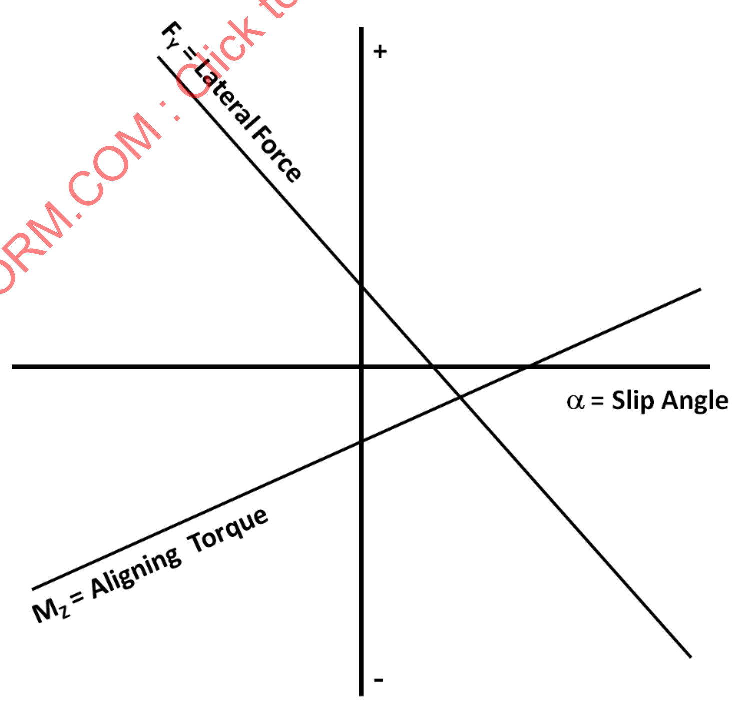


FIGURE 14 – LATERAL FORCE AND ALIGNING TORQUE FOR A TYPICAL TIRE NEAR ZERO SLIP ANGLE

11.6.1 Residual Lateral Force, F_{YR}

The lateral force at the slip angle for which the aligning moment of the free-rolling tire at zero inclination angle is zero, Figure 15.

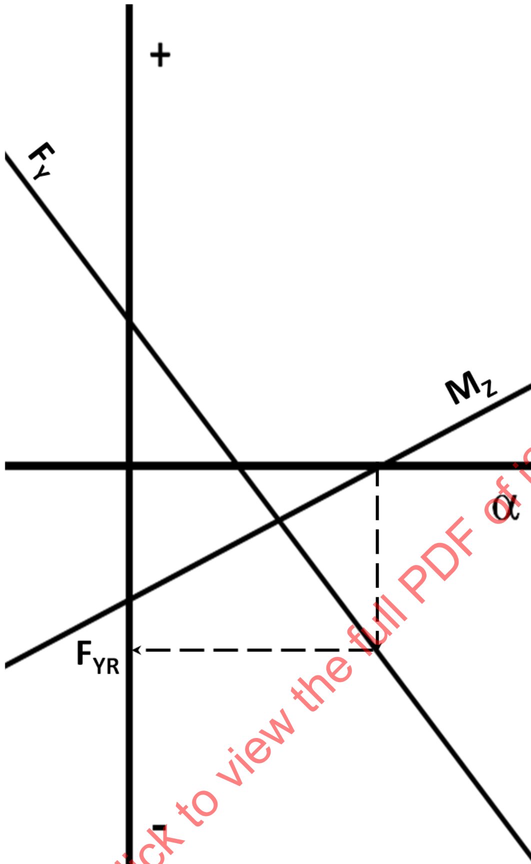


FIGURE 15 – RESIDUAL LATERAL FORCE

11.6.1.1 Conicity Residual Lateral Force, F_{YRC}

The lateral force of a tire without plysteer existing when the aligning moment of a tire without plysteer is zero. It is computed from residual lateral force determination in right (cw) and left (ccw) rotation by Equation 22.

$$F_{YRC} = 0.5[F_{YRR} - F_{YRL}] \text{ with respect to the tire coordinate system} \quad \text{(Eq. 22)}$$

11.6.1.2 Plysteer Residual Lateral Force, F_{YRP}

The lateral force of a tire without conicity existing when the aligning moment of a tire without conicity is zero. It is computed from residual lateral force determination in right (cw) and left (ccw) rotation by Equation 23.

$$F_{YRP} = 0.5[F_{YRR} + F_{YRL}] \text{ with respect to the tire coordinate system} \quad \text{(Eq. 23)}$$

11.6.2 Residual Aligning Moment, M_{ZR}

The aligning moment of a tire at the slip angle for which the lateral force of the free-rolling cornering wheel at zero inclination angle is zero, Figure 16.

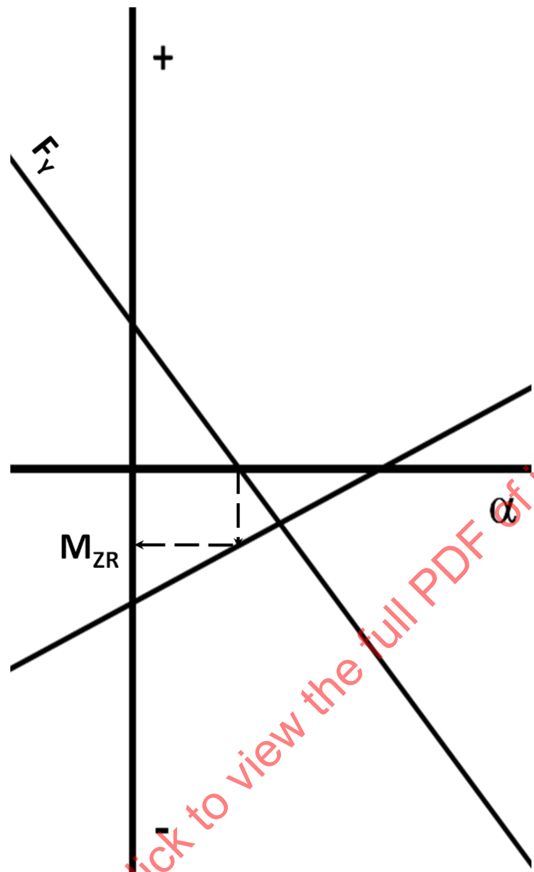


FIGURE 16 – RESIDUAL ALIGNING MOMENT

11.6.2.1 Conicity Residual Aligning Moment, M_{ZRC}

A residual aligning moment component which changes sign with respect to either the tire or tire face coordinate systems if the tire direction of rotation is reversed. It is computed from residual aligning moment data in right (cw) rotation and left (ccw) rotation by Equation 24:

$$M_{ZRC} = 0.5[M_{ZRR} - M_{ZRL}] \text{ with respect to the tire coordinate system} \qquad \text{(Eq. 24)}$$

11.6.2.2 Plysteer Residual Aligning Moment, M_{ZRP}

A residual aligning moment component that does not change sign with respect to either the tire or tire face coordinate systems when the wheel direction of rotation is reversed. It is computed from residual aligning moment data in right (cw) rotation and left (ccw) rotation by Equation 25:

$$M_{ZRP} = 0.5[M_{ZRR} + M_{ZRL}] \text{ with respect to the tire coordinate system} \qquad \text{(Eq. 25)}$$

12. DYNAMIC FORCES

12.1 Dynamic Force

Force characterized by random or periodic oscillatory variations due to vehicle maneuvers, road roughness, or tire-wheel assembly nonuniformity.

12.2 Dynamic Wheel Load

Component of the dynamic force in the Z_T (Z') direction.

12.2.1 Peak-to-Peak Dynamic Wheel Load

The measure of dynamic wheel load the value of which is determined as the difference between the maximum and the minimum values of normal force during one cycle of periodic dynamic wheel load variation.

12.3 Dynamic Longitudinal Force

Component of the dynamic force in the X_T (X') direction.

12.3.1 Peak-to-Peak Dynamic Longitudinal Force

The measure of dynamic longitudinal force the value of which is determined as the difference between the maximum and the minimum values of longitudinal force during one cycle of periodic dynamic wheel load variation or periodic drive torque variation.

12.4 Dynamic Lateral Force

Component of the dynamic force in the Y_T (Y') direction.

12.4.1 Peak-to-Peak Dynamic Lateral Force

The measure of dynamic lateral force the value of which is determined as the difference between the maximum and the minimum values of lateral force during one cycle of periodic dynamic wheel load variation or periodic slip angle variation.

13. TANGENTIAL FORCE PROPERTIES

13.1 Tangential Force Coefficient (Resultant Traction Coefficient.)

The absolute value of the ratio of tangential force to normal force.

13.2 Skid

The sliding of the entire tread contact area over the road surface. Skid may occur in braking, braking/cornering, driving, driving/cornering, and cornering.

NOTE: Skid is initiated at the time when the value of the tangential force coefficient (13.1) reaches the value of the peak coefficient of friction (22.1.1). At this instant, the coefficient of friction (22.1) starts to decline from its maximum value (peak coefficient of friction (22.1.1), maximum longitudinal force coefficient (13.3.1.1), maximum driving force coefficient (13.3.2.1), and maximum braking force coefficient (13.3.3.1)), reached at the critical longitudinal slip (13.3.1.3), to its reduced value (sliding coefficient of friction (22.1.2), spinning driving force coefficient (13.3.2.2), or sliding braking force coefficient (13.3.3.2), reached at the maximum slip value.

13.2.1 Hydroplaning (Aquaplaning)

The loss of direct tread rubber/road contact and hence of tire traction, caused by a water layer separating the tire and road on wet roads.

13.3 Longitudinal Force Properties

13.3.1 Longitudinal Force Coefficient

The absolute value of the ratio of longitudinal force to normal force. (See Figure 17.)

13.3.1.1 Maximum Longitudinal Force Coefficient

The maximum value of the longitudinal force coefficient attainable on a given road surface under given test conditions.

NOTE: The maximum in straight ahead braking may be expressed as the maximum braking force coefficient (13.3.3.1), longitudinal force coefficient, which is also known as peak friction coefficient, and is usually measured as a peak value of braking coefficient for a given tire and a given road surface and environmental conditions such as wheel load, speed, road surface temperatures, etc. Since the values of normal force and speed vary during vehicle operating conditions, this coefficient is usually expressed as a function of speed and normal force, by using regression coefficients obtained from analysis of test data. The same test and analysis technique are used for sliding braking force coefficient (13.3.3.2). The values of maximum driving force coefficient (13.3.2.1) and spinning driving force coefficient (13.3.2.2) can be significantly different from the corresponding values of braking coefficients. Therefore, the driving coefficients should be determined from separate measurements and cannot be assumed to be equal to braking coefficients.

13.3.1.2 Longitudinal Adhesion Utilization Coefficient

The ratio of the longitudinal force coefficient to the maximum longitudinal force coefficient under given test conditions.

13.3.1.3 Critical Longitudinal Slip

The longitudinal slip at the maximum longitudinal force coefficient. (See Figure 17.)

13.3.2 Driving Force Coefficient (Driving Coefficient)

The absolute value of the ratio of driving force to normal force. (See Note in 13.1.)

13.3.2.1 Maximum Driving Force Coefficient (Driving Traction Coefficient, Peak Driving Coefficient)

The maximum value of the driving force coefficient of the driven tire attainable on a given road surface under given test conditions.

13.3.2.2 Spinning Driving Force Coefficient

The value of the driving force coefficient of the spinning tire attainable on a given road surface under a given test condition.

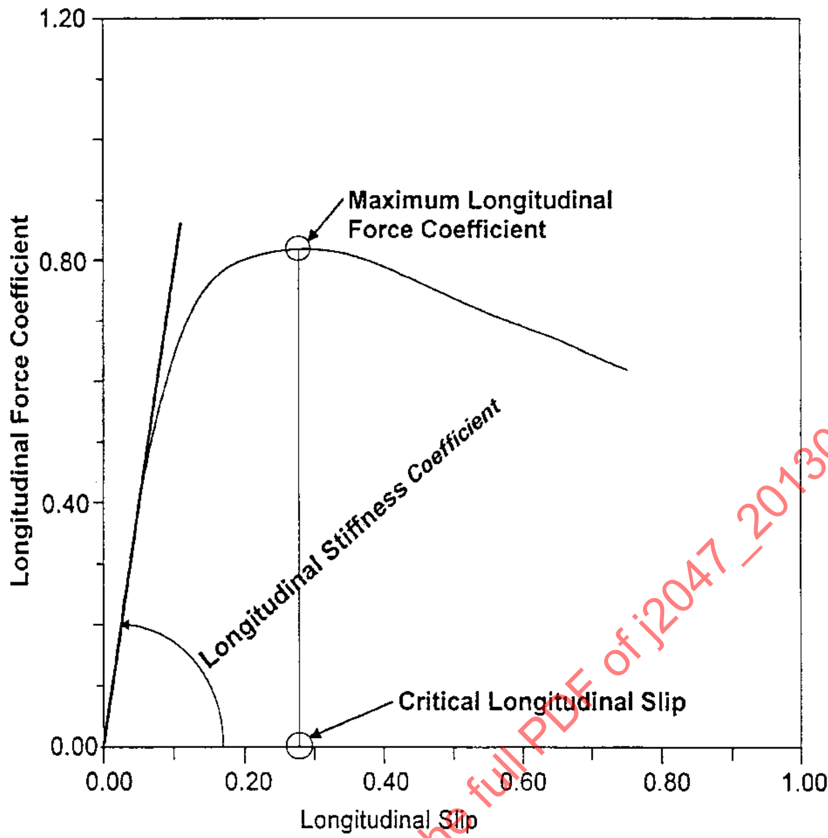


FIGURE 17 - EXAMPLE OF LONGITUDINAL FORCE COEFFICIENT VERSUS LONGITUDINAL SLIP

13.3.3 Braking Force Coefficient (Braking Coefficient)

The absolute value of the ratio of braking force to normal force.

13.3.3.1 Maximum Braking Force Coefficient (Braking Traction Coefficient, Peak Braking Force Coefficient)

The maximum value of the braking force coefficient attainable on a given road surface under given test conditions.

13.3.3.2 Sliding Braking Force Coefficient (Sliding Braking Traction Coefficient)

The value of the braking force coefficient of the tire on a locked wheel attainable on a given road surface.

13.3.3.3 Locked Wheel

The wheel traversing a road surface without rotation about the spin axis (spin velocity is zero).

13.3.4 Longitudinal Stiffness (Braking/Driving Stiffness; Longitudinal Force/Longitudinal Slip Gradient), C_S

The absolute value of the first derivative of longitudinal force with respect to longitudinal slip, usually determined at zero longitudinal slip, zero slip angle, and zero inclination angle (zero path curvature).

13.3.4.1 Longitudinal Stiffness Coefficient (Braking/Driving Stiffness Coefficient), C_{SC}

The absolute value of the ratio of longitudinal stiffness to the normal force.

13.3.5 Dynamic Longitudinal Force Properties

Longitudinal force properties associated with dynamic forces.

13.3.5.1 Longitudinal Force Dynamic Loss

The loss of longitudinal force due to dynamic tire loading. It is the difference between the average values of longitudinal force determined at zero dynamic tire load and that of the tire on a rough surface at the same nominal load with both tests conducted at the same constant torque.

13.3.5.2 Longitudinal Force Dynamic Loss Coefficient

The absolute value of the ratio of longitudinal force dynamic loss to the value of longitudinal force determined on a smooth road surface (zero dynamic tire load) at the same test conditions.

13.4 Steady-State Lateral Force Properties

Lateral force properties resulting from constant values of slip angle or some other independent variable such as inclination angle, tire load, or applied torque.

13.4.1 Lateral Force Coefficient

The absolute value of the ratio of lateral force to normal force. (See Figure 18.)

13.4.2 Maximum Lateral Force Coefficient (Lateral Traction Coefficient; Peak Lateral Force Coefficient)

The maximum value of the lateral force coefficient attainable for a tire on a free-rolling cornering wheel on a given road surface at given test conditions.

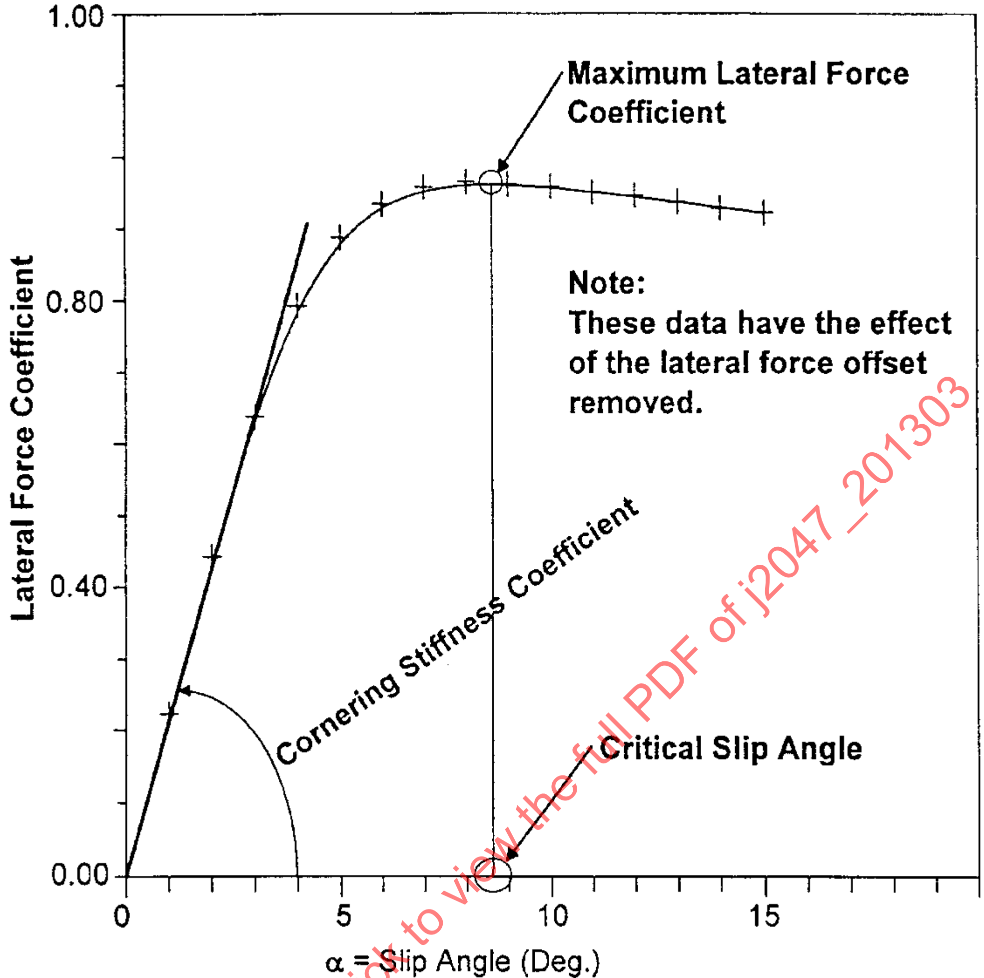


FIGURE 18 - EXAMPLE OF LATERAL FORCE COEFFICIENT VERSUS SLIP ANGLE

13.4.3 Sliding Lateral Force Coefficient

The value of the lateral force coefficient of the laterally-sliding tire with zero angular velocity.

13.4.4 Critical Slip Angle

Value of slip angle at which the maximum lateral force occurs under given conditions.

13.4.5 Cornering Stiffness (Cornering Power) $C\alpha$

The absolute value of the first derivative of lateral force with respect to slip angle, usually determined at zero slip angle, zero inclination angle, zero longitudinal slip, and zero path curvature.

NOTE: For practical purposes, the first derivative of lateral force with respect to slip angle may be approximated as the absolute value of the quantity yielded by subtracting the –1 degree slip angle value of the lateral force from +1 degree slip angle value of lateral force and dividing by 2. For more accurate approximation of the first derivative of lateral force with respect to slip angle, a linear regression analysis of test data may be used within a narrow range of slip angle values. If radians are used, the units should be adjusted accordingly.

13.4.6 Cornering Stiffness Coefficient (Cornering Coefficient) $C_{\alpha C}$

The absolute value of the ratio of cornering stiffness to normal force.

13.4.6.1 Cornering Stiffness Load Sensitivity

The absolute value of the first derivative of the cornering stiffness coefficient with respect to normal force.

13.4.7 Camber Stiffness, C_{ε} (C_{γ})

The absolute value of the first derivative of the lateral force with respect to inclination angle, usually determined at zero inclination angle, zero slip angle, zero longitudinal slip and zero path curvature.

13.4.8 Camber Stiffness Coefficient, $c_{\varepsilon c}$ ($c_{\gamma c}$)

The absolute value of the ratio of camber stiffness to normal force.

13.4.9 Lateral Force Gradient

The first derivative of lateral force with respect to slip angle at any given value of Slip Angle.

NOTE: Lateral Force Gradient is has been introduced in order to differentiate it from a similar term, cornering stiffness (13.4.5), which expresses the rate of change of lateral force with respect to slip angle at zero slip angle only.

13.4.10 Lateral Force Load Sensitivity

The absolute value of the first derivative of lateral force with respect to normal force at any given value of slip angle.

13.4.11 Lateral Force Torque Sensitivity

The absolute value of the first derivative of lateral force with respect to applied torque (Section 9.1) at any given value of slip angle.

13.5 Transient (Nonsteady-State) Lateral Force Properties

Lateral force properties resulting when relaxation effects are significant from a continuous change of slip angle or some other independent variable such as inclination angle, load, etc.

13.5.1 Relaxation Length

The distance rolled by the tire while the lateral force builds to a particular percentage (typically 63.2%) of the steady-state lateral force following a step input in slip angle or load.

NOTE: This definition of relaxation length reflects current laboratory usage, which is different from generally used theoretical concept shown graphically in Figure 19. Based on concept shown in Figure 19, the relaxation length can be defined as follows:

Relaxation Length, σ—The length of normal projection of laterally deformed equatorial line in front of the leading edge of the contact area onto the contact line. It is determined as a distance between the point of intersection of the leading edge of the contact area with the contact line and the point of intersection of extension of a linear portion of deformed equatorial line with the contact line. (See Figure 19.)

13.5.2 Lateral Force Response Phase Angle

The phase shift between a sinusoidal input of slip angle, inclination angle, load, etc., and the sinusoidal lateral force response.

13.5.3 Lateral Force Response Distance Lag

The distance lag between a sinusoidal, step, or ramp input of slip angle, inclination angle, load, etc., and the lateral force response. It is determined as the distance traveled by the tire from the time instant at which the slip angle, inclination angle, etc., was zero to the time instant at which the lateral force was zero. (See Figure 20.)

13.5.4 Dynamic Lateral Force Offset

The lateral force of the wheel, subjected to sinusoidal, step, or ramp input of slip angle, inclination angle, wheel load, etc., resulting from lateral force response distant lag. (See Figures 20 and 21.)

13.5.5 Dynamic Cornering Stiffness

The absolute value of the first derivative of lateral force with respect to slip angle determined during continuous change of slip angle. It is computed as an average of cornering stiffness determined at zero slip angle during a decrease and during an increase of slip angle respectively. (See Figure 21.)

13.6 Dynamic Lateral Force Properties

Lateral force properties associated with dynamic forces.

13.6.1 Lateral Force Dynamic Loss

The Loss of lateral force due to dynamic wheel loads. It is determined as the difference between the average values of lateral force determined on a smooth road surface at a constant slip angle and inclination angle at zero dynamic wheel load and that determined at the same initial values, of slip angle and inclination angle at a given dynamic wheel load.

13.6.2 Lateral Force Dynamic Loss Coefficient

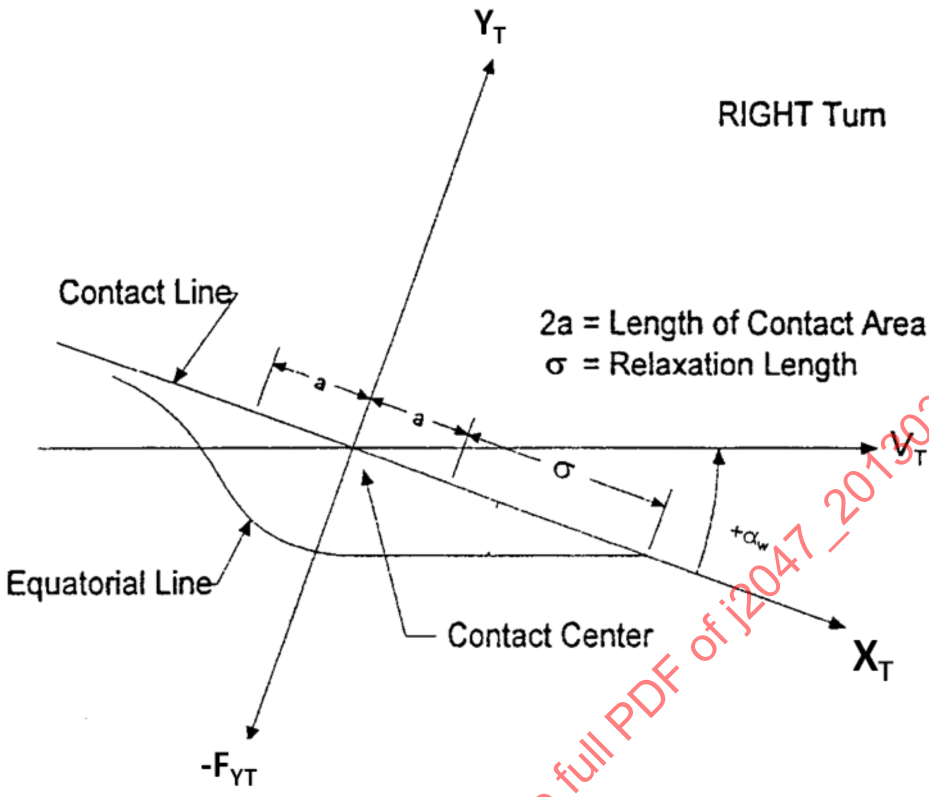
The absolute value of the ratio of lateral force dynamic loss to the value of lateral force determined on a smooth road surface (zero dynamic wheel load) at the same trim.

13.7 Static Lateral Force Properties

Lateral force properties measured on static (non-rolling) tire.

13.7.1 Lateral Stiffness

The first derivative of lateral force with respect to lateral displacement of the wheel center of the non-rolling wheel in the Y_T (Y')-axis direction relative to the supporting surface.



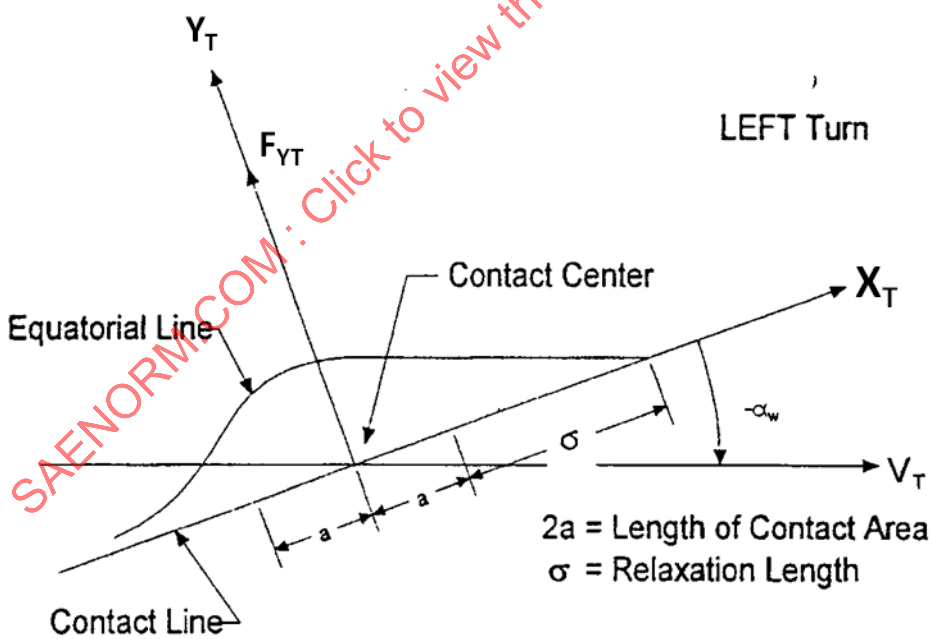


FIGURE 19 - DEFORMED EQUATORIAL LINE OF A TIRE TURNING LEFT AND RIGHT
Z-UP AXIS SYSTEM USED.

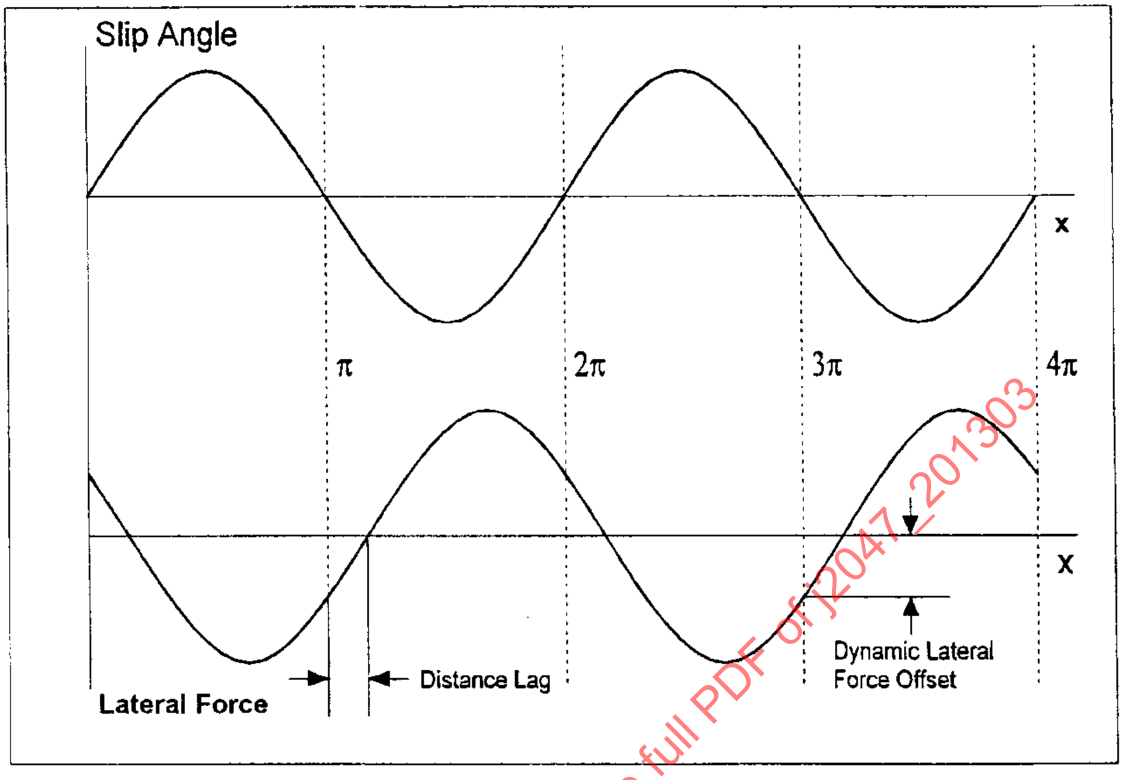


FIGURE 20 - LATERAL FORCE RESPONSE TO A SINUSOIDAL SLIP ANGLE INPUT

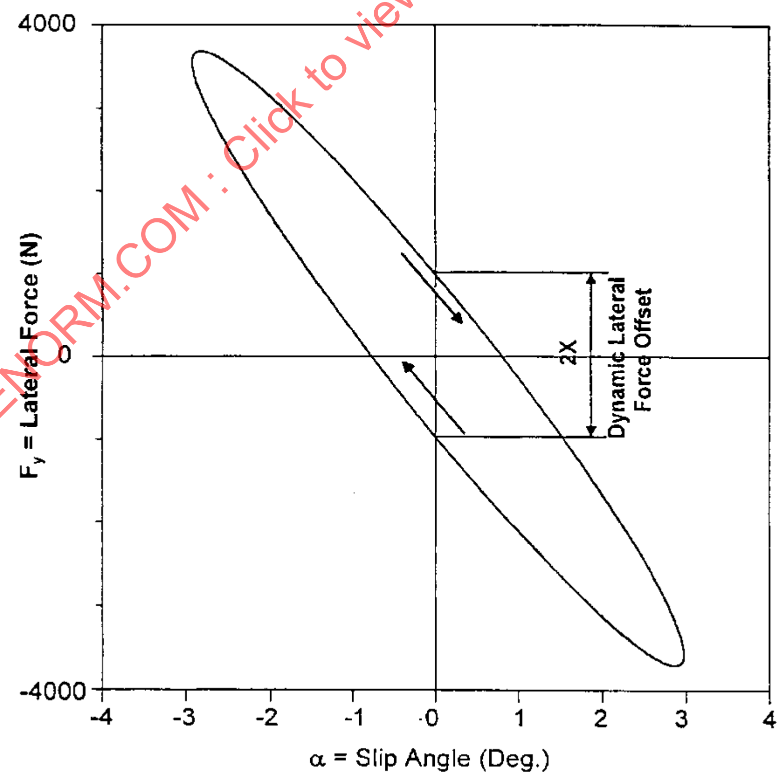


FIGURE 21 - DYNAMIC LATERAL FORCE OFFSET

14. NORMAL FORCE PROPERTIES

Outside of static deflection, determined for a non-rotating tire, and percent deflection, the properties noted in this section are speed dependent. If determined by testing, it is only necessary to account for the effect of tire uniformity, Section 17, on the data to make a proper determination.

14.1 Static Tire Deflection (Deflection [static])

The amount by which the section height is reduced under action of tire load. Its value is equal to the difference between one-half of the overall diameter and the static loaded radius.

14.1.1 Percent Deflection

The ratio of static tire deflection to the section height of the unloaded tire, usually expressed as a percentage.

14.2 Normal (Radial) Stiffness (Tire Rate), C_F

The absolute value of the first derivative of normal force with respect to tire deflection. (See Figure 22, a static example.)

NOTE: Although the normal stiffness is a variable, it can be considered as a constant within a wide range for radial tires, except for a relatively small range near zero normal force. (See Figure 22) Due to variability of normal stiffness in the region near zero normal force, the constant slope line expressing the relationship between the normal force and normal deflection does not pass through the coordinate origin, but intersects the x-axis (normal deflection) at a certain distance from the origin. This offset of normal deflection should be considered when a linear relationship is assumed between the normal force and normal deflection. Normal Stiffness of a rolling tire is a function influenced by speed, buildup of inflation pressure resulting from heat buildup in the tire, lateral force, etc.

14.3 Normal (Radial) Damping, δ

The mechanical energy loss during vertical oscillation of the tire caused by material hysteresis and road friction and characterized in accordance with the principles used in the study of mechanical vibrations.

14.4 Tire Enveloping

The ability of a tire to engulf road irregularities.

NOTE: For more information see the K. D. Marshall reference in Section 2.3.

15. ALIGNING MOMENT PROPERTIES

15.1 Aligning Stiffness, C_M

The absolute value of the first derivative of aligning moment with respect to slip angle, usually determined at zero slip angle, zero inclination angle, zero longitudinal slip, and zero path curvature. (See Figure 23 and Note in 13.4.5., which applies to aligning moment as well as to lateral force.)

15.1.1 Aligning Stiffness Coefficient

The absolute value of the ratio of aligning stiffness to normal force.

15.1.2 Aligning Stiffness Load Sensitivity

The absolute value of the first derivative of the aligning stiffness with respect to normal force.

15.1.3 Aligning Stiffness Torque Sensitivity

The first derivative of the aligning stiffness with respect to applied torque (Section 9.1).

15.2 Aligning Moment Torque Sensitivity

The first derivative of aligning moment with respect to applied torque (Section 9.1) at any slip angle.

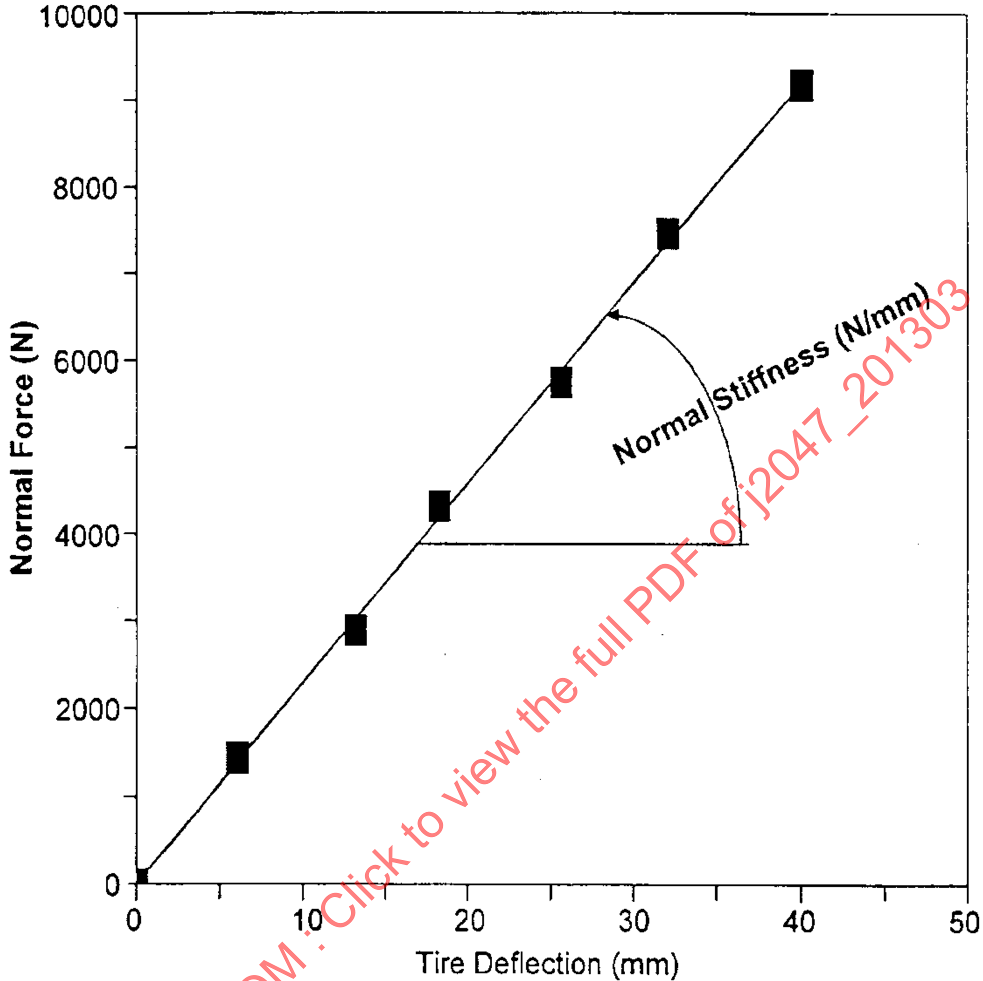


FIGURE 22 - AN EXAMPLE OF NORMAL FORCE VERSUS TIRE DEFLECTION

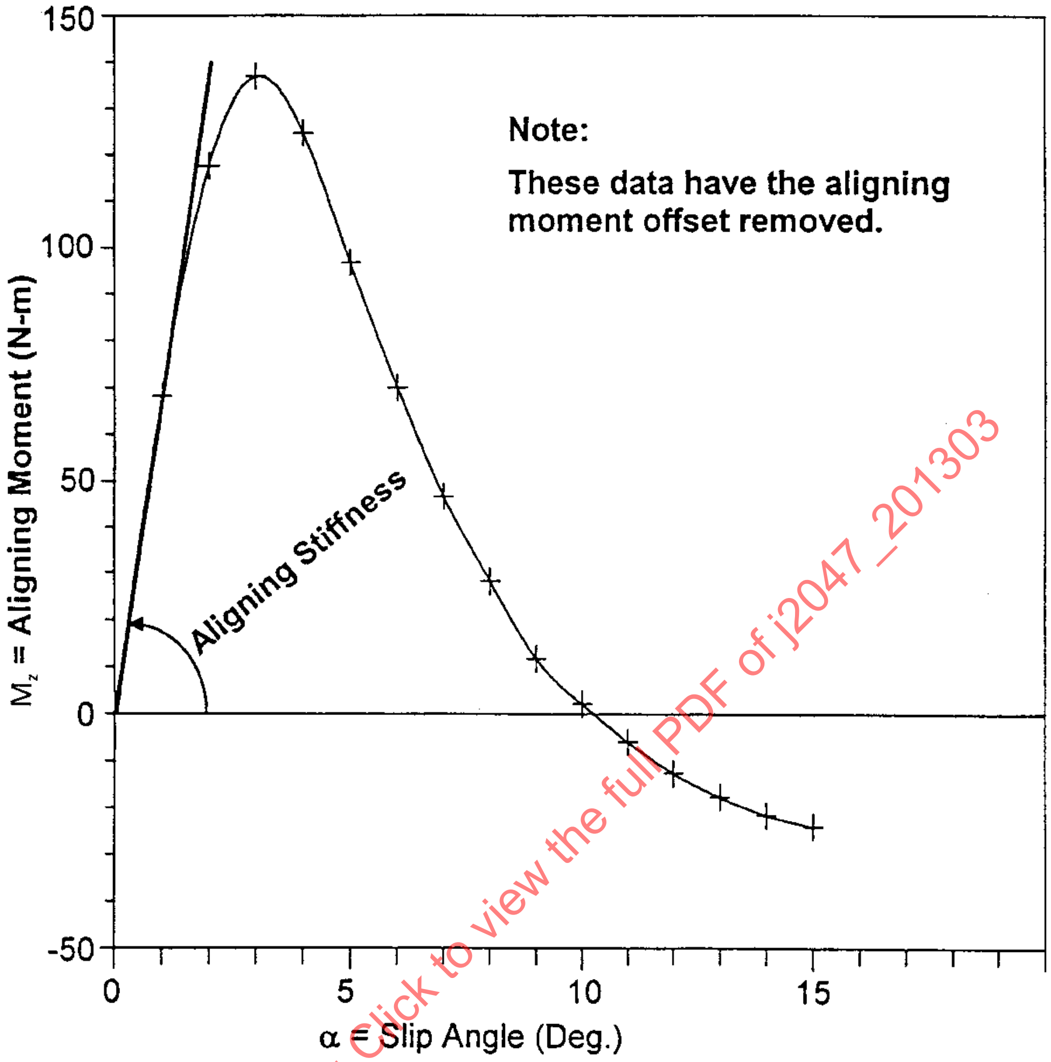


FIGURE 23 - EXAMPLE OF ALIGNING MOMENT VERSUS SLIP ANGLE

16. TIRE ROLLING RESISTANCE

A tire and its associated wheel form a thermodynamic system. As the assembly rolls, the energy required to support rolling and change the assembly's velocity (angular and translational) crosses the system boundary, as work, through action of forces at the spindle and footprint and through application of spindle torque. In this process of rolling and changing velocities energy loss occurs in the form of heat. This energy loss as heat is the source of tire rolling resistance.

On a hard surface, such as a road, the energy loss, exclusive of that due to slippage at the road surface and tire aerodynamic drag, occurs because of hysteresis in the tire material, which is subjected to deformation in rolling. Since the majority of tire operation occurs at low slip angles and torque levels, it is typical to characterize tire rolling resistance in straight free-rolling tests, such as, SAE J1269, SAE J2452, ISO 18164, and ISO 28580 in which work that maintains rolling is applied through the medium of the longitudinal force, rolling resistance force, acting from the spindle onto the tire / wheel assembly.

In the general operating situation on a vehicle many variables affect tire rolling resistance including torque application, road surface texture, tire temperature, and operating time. For a general discussion of complicating factors see Schuring in *Rubber Chemistry and Technology,* Vol. 53, No. 3 or Schuring and Futamura in *Rubber Chemistry and Technology,* Vol. 62, No. 3, 1990.

There are other energy losses that affect vehicles that are associated with the presence of tires, but are not part of rolling resistance, as it is defined herein. Aerodynamic drag of the tire is an example. Also, the components of tire footprint forces in the direction of a tire's trajectory vector may contribute to vehicle retarding force, but are not part of tire rolling resistance. Likewise spindle bearing torque is present when tires operate, but it isn't part of tire energy consumption. (See SAE J1270.)

16.1 Rolling Resistance Force, F_{RR}

The force which when multiplied by the distance traveled equals the energy consumed by the rolling tire, see Equation 26.

$$F_{RR} = E_R/d \quad \text{(Eq. 26)}$$

NOTE: If speed is constant, rolling resistance force can be stated in terms of power and velocity, as in Equation 27.

$$F_{RR} = P_R/V_T \quad \text{(Eq. 27)}$$

16.2 Rolling Resistance Coefficient, RRC

This is the ratio of the rolling resistance force to the load on the tire, see Equation 28.

$$RRC = F_{RR}/|F_{ZT}| \quad \text{(Eq. 28)}$$

NOTE: There are several common ways to express the rolling resistance coefficient, for example, newtons per kilonewton, kilograms-force per 1000 kilograms, and pounds per thousand pounds. This coefficient is a function of tire inflation pressure and may be a function of tire load.

16.3 Standard Reference Condition

A single value of tire load, inflation pressure, and speed specified so tires can be compared at a single condition.

16.4 Flat Surface Correction

Commonly rolling resistance force is measured on a test drum (round surface). This produces a result in excess of that for a flat surface. The SAE Recommended Practices and ISO Standards mentioned earlier in Section 16 provide a curvature correction equation (see SAE paper #82164 in SAE Special Publication #546, SAE Warrendale, PA, November 1983). The general application of this equation is in question at this time due to research in this paper: T., Unrau, H. J., and El-Haji, M., "Experimental Determination of the Effect of the Surface Curvature on Rolling Resistance Measurements," Tire Science and Technology, TSTCA, Vol. 37, No. 4, October – December 2009, pp. 254-278.

17. TIRE UNIFORMITY CHARACTERISTICS

Tire self excited vibration is characterized by periodic variations of tire forces, tire moments, and tire dimensions while the tire rotates, caused by tire intrinsic properties such as irregularities in tire materials and construction, or by nonuniform mass distribution around the spin axis, or both. Typically, two terms are used to group the self excited vibrations: uniformity and balance. The uniformity force and moment components are defined in the Tire Face Coordinate System (See Section 6.5.6 and Figure 9E). The tire face system is an extension of the system commonly used on factory uniformity machines. The relevant notation used in discussing uniformity characteristics is summarized in Figure 26.

NOTE: Pull forces and moments, which are often viewed as uniformity associated, have already been covered in Section 11.

17.1 Uniformity Forces and Moments

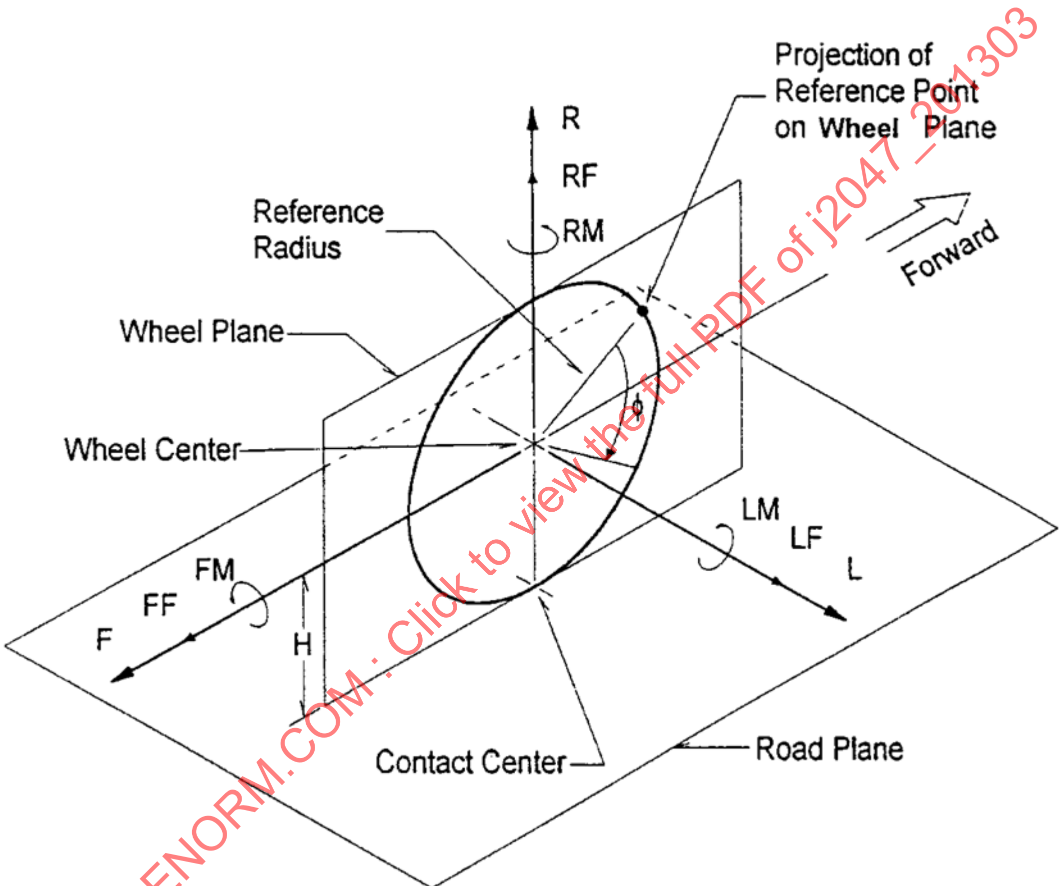
The forces and moments defined in the tire face system applied to the spindle for a special case, $\alpha=\gamma=0°$. The six components in the tire face system are shown in Figure 24. They exhibit a repeating waveform, which varies once per tire revolution.

17.1.1 Instantaneous Uniformity Force or Moment

The value of a force or moment determined as a function of reference angle, φ_{REF} (Section 6.5.6.3), for the straight-rolling tire equipped with a machined precision rim and operating at constant rolling wheel center height. (See Figure 25 for an example phrased in radial force terms.)

17.1.2 Average Uniformity Force or Moment

The average value of an instantaneous force or moment determined over one or more complete tire revolutions. An (AV) subscript appended to a force or moment signifies an average force or moment. For example, the average radial force is denoted as RF_{AV}.



Note – The ellipse in this figure represents the intersection of the tire and the wheel plane.

FIGURE 24 – UNIFORMITY FORCES AND MOMENTS

17.1.3 Uniformity Force or Moment Variation

The difference between instantaneous force or moment (as a function of reference angle, φ_{REF}) and average force or moment. It is signified by a (V) subscript appended to a force or moment. (See Figure 25 and Equation 29 for an example stated in radial force terms.)

$$RF_V = RF - RF_{AV} \quad \text{(Eq. 29)}$$

17.1.4 Peak-to-Peak Amplitude of a Uniformity Force or Moment

The difference between the maximum and minimum values of an instantaneous force and moment. The subscript (PP) signifies the peak-to-peak amplitude. For example, RF_{PP} is the peak-to-peak amplitude of radial force.

17.1.5 Peak-to-Peak Amplitude of the n^{th} Harmonic in a Fourier Series Representation of a Uniformity Force or Moment

The difference between the maximum and minimum values of a Fourier component of a force and moment. The subscript (Hn) signifies the peak-to-peak amplitude of the n^{th} harmonic. For example, RF_{Hn} is the peak-to-peak amplitude of the n^{th} harmonic of radial force.

17.1.6 High Point Angle of the nth Harmonic in a Fourier Series Representation of a Uniformity Force or Moment

The subscript (An) signifies the highpoint angle for the n^{th} harmonic of the particular force or moment to which it is appended. For example, RF_{An} is the highpoint angle for the n^{th} harmonic of radial force.

17.1.7 Fourier Series Representation of a Uniformity Force or Moment

Force and moment variation is usually expressed in a Fourier Series as a function of the reference angle. This is illustrated for radial force in the Fourier Series of Equation 30.

$$RF_V(\varphi_{REF}) = 0.5\Sigma\left\{RF_{Hn} \cdot \cos\left[n\left(\varphi_{REF} - RF_{An}\right)\right]\right\} \quad \text{(Eq. 30)}$$

For clarity see the following note and the example sketched in Figure 25 both of which are illustrations for radial force.

NOTE: The definitions given in this and the previous sections have direct physical meaning to the tire manufacturer and are therefore preferred over other, classic versions. All versions are interchangeable, of course. Equation 31 is the uniformity version of radial force used here as an example.

$$RF(\varphi_{REF}) = RF_{AV} + 0.5\Sigma\left\{RF_{Hn} \bullet \cos\left[n\left(\varphi_{REF} - RF_{An}\right)\right]\right\} \quad \text{(Eq. 31)}$$

It can be transformed into the classical Fourier Series, Equation 32, by substituting Equations 33, 34 and 35 into Equation 30.

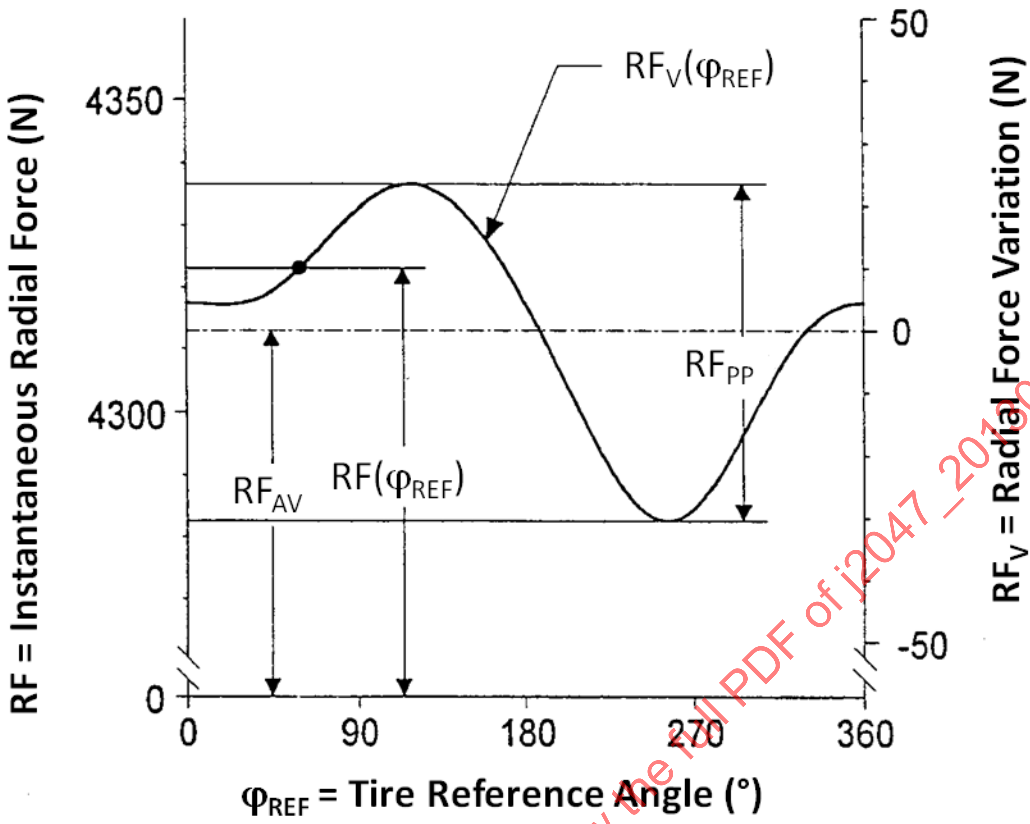
$$RF(\varphi_{REF}) = 0.5a_o + \Sigma\left[a_n \cos n\varphi_{REF} + b_n \sin n\varphi_{REF}\right] \quad \text{(Eq. 32)}$$

$$RF_{AV} = 0.5\ a_o \quad \text{(Eq. 33)}$$

$$0.5 \bullet RF_{Hn} \bullet \cos\left(nRF_{An}\right) = a_n \quad \text{(Eq. 34)}$$

$$0.5 \bullet RF_{Hn} \bullet \sin\left(nRF_{An}\right) = b_n \quad \text{(Eq. 35)}$$

Notations used for all the force, moment, and runout Fourier series relevant to the tire face system are shown in Figure 26.



Fourier Series for curve shown is:

$$RF(\varphi_{REF}) = RF_{AV} + RF_V$$
$$= RF_{AV} + 0.5\ \{RF_{H1} \bullet \cos[\varphi_{REF} - RF_{A1}] + RF_{H2} \bullet \cos([2(\varphi_{REF} - RF_{A2})] + RF_{H3} \bullet \cos([3(\varphi_{REF} - RF_{A3})]\ \}$$
$$= 4313 + 0.5\ \{44 \bullet \cos\ [\varphi_{REF} - 90] + 18 \bullet \cos\ [2(\varphi_{REF}\ - 150)] + 4 \bullet \cos\ [3(\varphi_{REF}\ \ -60)]\}$$

$RF_{PP} = 53$ N	$RF_{H1} = 44$ N	$RF_{H2} = 18$ N	$RF_{H3} = 4$ N
$RF_{AV} = 4313$N	$RF_{A1} = 90^0$	$RF_{A2} = 150^0$	$RF_{A3} = 60^0$

FIGURE 25 – RADIAL FORCE ILLUSTRATION OF FORCE VARIATION

Terms and Symbols Employed When Using the Tire Face System

TERM	VARIABLES				HARMONICS OF VARIABLES	
	INSTANTANEOUS	AVERAGE	VARIATION	P-TO-P	P-TO-P	HIGH POINT ANGLE
Fore-Aft Force	FF	FF_{AV}	FF_V	FF_{PP}	FF_{Hn}	FF_{An}
Lateral Force	LF	LF_{AV}	LF_V	LF_{PP}	LF_{Hn}	LF_{An}
Radial Force	RF	RF_{AV}	RF_V	RF_{PP}	RF_{Hn}	RF_{An}
Fore-Aft Moment	FM	FM_{AV}	FM_V	FM_{PP}	FM_{Hn}	FM_{An}
Lateral Moment	LM	LM_{AV}	LM_V	LM_{PP}	LM_{Hn}	LM_{An}
Radial Moment	RM	RM_{AV}	RM_V	RM_{PP}	RM_{Hn}	RM_{An}
Radial Runout	RRO	RRO_{AV}	RRO_V	RRO_{PP}	RRO_{Hn}	RRO_{An}
Lateral Runout	LRO	LRO_{AV}	LRO_V	LRO_{PP}	LRO_{Hn}	LRO_{An}

FIGURE 26 - SUMMARY OF TERMS AND SYMBOLS USED IN ANALYSIS OF TIRE UNIFORMITY

17.2 Tire Runout

The tire surface exhibits radial and lateral dimensional variations, the waveforms of which, repeat once per tire circumference at each point on the tire general surface. Certain components of these dimensional variations are associated with the uniformity forces and moments. They are measured at a location of the engineers choosing in a plane that penetrates the tire general surface and lying contains the spin axis (L-axis). They are described in a manner analogous to that used for the uniformity forces and moments.

17.2.1 Instantaneous Runout Distances

These are either a radial or lateral distance from a fixed point outside the tire to the tire general surface at the measurement location chosen. These are functions $\varphi_{REF.}$

17.2.1.1 Instantaneous Radial Runout, RRO

The instantaneous runout perpendicular to the spin axis.

17.2.1.2 Instantaneous Lateral Runout, LRO

The instantaneous runout parallel to the spin axis.

NOTE: For both RRO and LRO average values, variation, peak-to-peak values, peak-to-peak harmonic values, and harmonic high point angles are defined exactly as for uniformity forces and moments. Thus, there is no need to replicate the basic definitions phrased in terms of runouts instead of forces and moments. The relevant terms and symbols are summarized in Figure 26.

17.3 Balance

When a tire-wheel assembly, (ASSEMBLY), rotates about a spindle without road contact, the ASSEMBLY exerts a spinning force and a spinning couple on the spindle. This occurs, if the mass distribution in the ASSEMBLY is not: 1) rotationally symmetric with regard to the spindle and 2) symmetric with respect to the wheel plane, which is the center plane of the ASSEMBLY. These vectors can be eliminated by assuming that the ASSEMBLY is a rigid body and appropriately adding two counterbalancing masses commonly referred to as balance weights. The process is called tire balancing.

NOTE: The tire is slightly non-rigid so it is suggested that balancing be carried out at an angular velocity simulating median interstate highway driving speed.

17.3.1 Static Balance

The balance component canceling the effect exerted by the rotationally nonsymmetrical distribution of mass about the spindle is referred to as the Static Balance because it can be detected with the ASSEMBLY not rotating. The imbalance associated with Static Balance acts as if it were a concentrated mass located at a radius of the engineer's choosing.

17.3.2 Dynamic Balance

The balance component canceling the effect of a couple exerted about the wheel plane by the ASSEMBLY mass being asymmetrically distributed with respect to the wheel plane can only be detected with the ASSEMBLY spinning. It acts effectively as if it were a pair of concentrated masses located at a radius of the engineer's choosing in two planes symmetrically offset from the wheel plane along the spindle.

18. TIRE NOISE AND VIBRATIONS

The noise aspect of this is really tire pavement interaction noise, but is often referred as tire noise. A basic reference for tire noise and vibration is the chapter by K. D. Marshall referenced in Section 2.3. It contains reference citations for most of the subjects defined in this section.

18.1 Total Tire Noise

The total noise measured during a tire noise test. It is the sum of individual noise elements. This comprises both structure borne and airborne noise

18.2 Tread Noise

Airborne sound except squeal and slap, produced by interaction between the tire tread and a smooth road surface, typically a sand asphalt on test pads.

18.2.1 Tonality

Sharp, easily perceived, single frequency peaks in the spectrum of airborne tire noise (up to 2500 Hz) associated with the fundamental tire rotational frequency and its harmonics. This is usually associated with tread elements or non-uniformities coming into contact with the road surface.

18.2.2 Sizzle

Tread noise characterized by a soft "frying" or "tape ripping" sound generated by tread adhesion to the road surface. This can also be caused by trapping and expulsion of air within sipes. It is most easily noticed on a very smooth asphalt road surface or epoxy surface in hot weather.

18.2.3 Tire Roughness

Vibrations (25 to 50 Hz) perceived tactually, generated by higher harmonics of uniformity for a tire rolling on a smooth road surface. The sensation is one of driving on a coarse or irregular road surface.

NOTE: The perceptibly equivalent effect present when driving on a coarse surface is referred to as road roughness.

18.2.4 Tire Harshness

A 25 to 50 Hz quickly decaying response to single sharp edge tire impact such as a tar strip evaluated primarily tactilely. It may accompanied by noise in the 30 to 100 Hz range.

18.3 Boom

Boom is a 30 to 100 Hz acoustical disturbance associated with standing waves within the passenger compartment, which may be excited by tire roughness, road roughness, or tire harshness effects.

18.4 Squeal

Narrow-band high frequency airborne tire noise (600 to 1200 Hz) involving stick-slip oscillations of the tread elements excited by either longitudinal slip or cornering or both.

18.4.1 Cornering Squeal

The squeal produced by a free-rolling tire operating at a slip angle.

18.4.2 Braking / Acceleration Squeal

The squeal resulting from longitudinal slip.

18.5 Thump

A periodic vibration or audible sound (or both), generated by a tire tread band irregularity such as a heavy splice and producing a pounding sensation synchronous with wheel rotation.

18.6 Slap

A "smacking" noise produced by a tire traversing road seams such as tar strips and expansion joints at medium and high speeds.

18.7 Beat

A rhythmic sound generated by two dominant tones separated by 1 or 2 Hz.

18.8 Growl

A low-frequency (300 Hz and lower) tread noise related to tire spin velocity (like tire noise generated by the metal grate surface of a bridge). Growl is most noticeable during deceleration, especially during braking.

19. TIRE TREAD WEAR

19.1 Wear Performance Criteria

19.1.1 Tread-Life

The distance travelled that is required to produce wear-out.

19.1.2 Wear-Out

A tire condition where any point on the tread adjacent to a wear indicator is worn down to a height equal to the height of tread wear indicator or any other point on the tread is worn down to the base of the grooves.

19.1.3 Bald Tire

A tire without tread pattern (e.g., a tire completely worn down to the base of the grooves and beyond).

19.1.4 Average Groove Depth

The average depth of a given groove in the circumferential direction.

19.1.5 Average Tread Depth

The average depth of all circumferential grooves.

19.1.6 Incremental Wear

The average tread depth loss between two successive measurements of a tire subjected to wear.

19.1.7 Wear Rate

The groove (void) depth reduction per unit distance traveled after break-in.

19.1.8 Percentage Tread Loss

The average tread depth reduction as percent of the initial average tread depth minus the height of tread wear indicators.

19.1.9 Wear Performance Index

Ratio relating the wear performance of a test tire to that of a control tire tested under the same conditions at the same time.

19.1.9.1 Treadlife Index

Wear performance index based on percentage tread loss.

19.1.9.2 Wear Rate Index

Wear performance index based on wear rate.

19.1.10 Regular Wear (Uniform Wear)

Wear at a nearly uniform wear rate across and around the tread.

19.1.11 Irregular Wear

Any wear pattern resulting from significantly different wear rates on different parts of the tread.

19.2 Irregular Wear Types

19.2.1 Intra-Projection Wear

A type of irregular wear characterized by a different wear rate at two or more locations within a given projection.

19.2.1.1 Heel-Toe Wear

A type of irregular wear characterized by different wear rates at the leading and trailing edges of a projection (element).

19.2.1.2 Feather Wear (Feathering)

A type of element irregular wear characterized by thin strips of rubber extending from the edge of the element.

19.2.2 Inter-Projection Wear

A type of irregular wear characterized by different wear rates on one or more adjacent projections (either transverse or circumferential orientation); this results in step-off in tread depth between two adjacent projections.

19.2.2.1 Shoulder Wear

A type of irregular wear characterized by an increased wear rate in the outer edge of the shoulder rib or row compared to the inner shoulder edge.

19.2.2.2 Row/Rib Wear (Step Wear)

A type of irregular wear characterized by a greater wear rate in one or more rows/ribs.

19.2.2.3 Center Wear

A type of irregular wear characterized by a wear rate continuously increasing from shoulder to center of the tread band.

19.2.3 Independent Wear

A type of irregular wear, which is essentially independent of individual projections if the pattern contains these projections.

19.2.3.1 Diagonal Wear

A type of irregular wear characterized by an increased wear rate region or band oriented transversely (from shoulder to shoulder) at some non-90 degree angle with respect to the circumferential centerline of the tread band.

19.2.3.2 Cup Wear (Cupping)

A type of irregular wear characterized by a variation in wear rate that may be periodic (essentially cycloidally shaped) around the tread band circumference in one or more rows.

19.2.3.3 Clip and Tear Wear

A special type of irregular wear characterized by a rough tread surface which may contain cracks, abrasion pits, or surface ruptures.

20. TIRE STRUCTURAL DEGRADATION

These are types of tire structural fatigue effects that may appear in service. The examples shown are illustrations taken from the NHTSA Tire Aging Project: Roadwheel Removal Codes v2.2 dated 4/13/2006. A given defect may be visually somewhat different from the illustrations. Serious defect study is commonly called Tire Forensics. A good place to start is with “Tire Forensic Investigation: Analyzing Tire Failure” by Thomas R. Giapponi published by SAE.

20.1 Separation

Tire structural degradation in which delamination occurs between components within the tire structure. Numerous examples follow.

20.1.1 Bead Separation

Separation between components in the bead area.

20.1.2 Ply Separation

De-lamination of adjacent tire plies, Figure 27.

FIGURE 27 - PLY SEPARATION BETWEEN BELT PLIES AND BELT AND CARCASS PLIES

20.1.3 Cord Separation

Separation of cords from adjacent rubber, Figure 28.

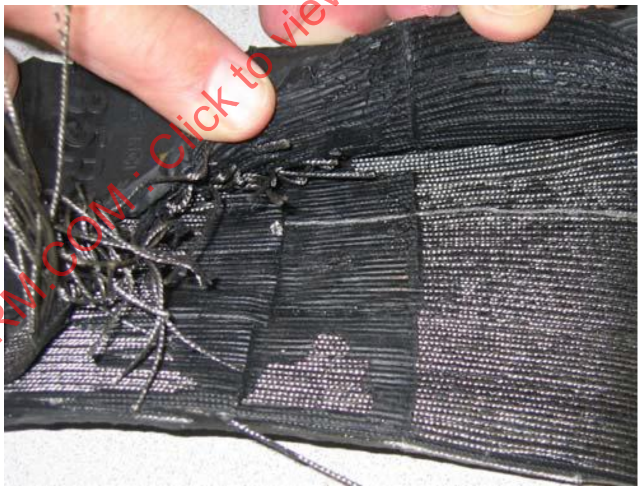


FIGURE 28 - CORD SEPARATION

20.1.4 Tread Separation

Separation of tread from body or tread from belt.

20.1.5 Belt Edge Separation

Separation of the belt from the carcass, or between belt plies.

NOTE: This may take many forms dependent on how far the process has progressed. Figure 27 shows an example that has not yet progressed to the surface. Figure 29 provides two examples of possible appearances.

FIGURE 29 – BELT EDGE SEPARATION EXAMPLES

20.1.6 Inner Liner Separation

Separation of inner liner from carcass.

20.1.7 Sidewall Separation

Separation of the outer rubber compound from the cord material in the sidewall, Figure 30.

FIGURE 30 – SIDEWALL SEPARATION EXAMPLE

20.1.8 Splice Opening

Separation of overlapping or butting ends of a component.

20.1.9 Tread Chunking

Tearing out of sizable pieces from the tread elements, Figure 31.

FIGURE 31 – AN EXAMPLE OF TREAD CHUNKING

20.1.10 Blister

A bubble-like void in the tire structure, Figure 32.

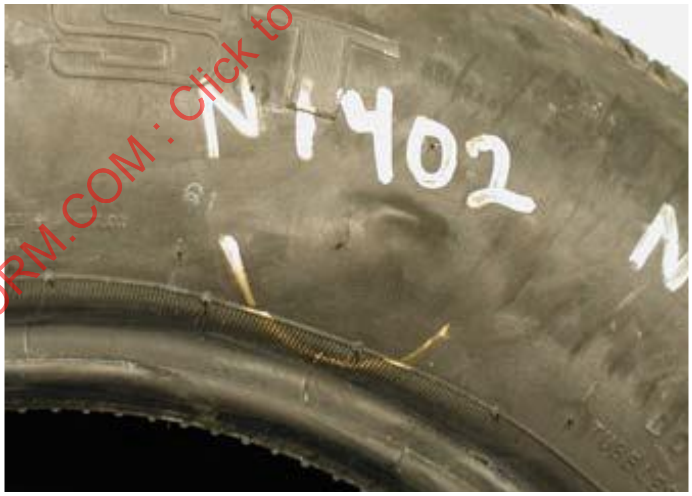


FIGURE 32 – BLISTER ON SIDEWALL

20.1.11 Tearing

Massive removal of lugs or parts of the tread, Figure 33.

FIGURE 33 - TEARING

20.2 Cracking

Tire degradation caused by cracks in tread, sidewall, innerliner, etc., often extending to the cords, Figure 34.

FIGURE 34 – CRACK IN SIDEWALL

20.2.1 Flex Cracking

Deep cracks primarily caused by flex fatigue.

20.2.2 Groove Cracking

Cracks in the tread grooves.

20.2.3 Splice Cracking

A crack or crack pattern originating at a splice.

20.2.4 Juncture Cracking

A crack originating at a juncture of two components and propagating randomly.

20.2.5 Weather Cracking

Surface cracks induced usually by the action of ozone on sidewall areas under tension.

20.2.6 Checking (Crazing)

Minute, closely grouped network cracks of little depth, caused by the action of ozone.

20.3 Bead Degradation

Degradation of the bead area produced by severe chafing, mismounting, and other external causes, Figure 35.

FIGURE 35 – BEAD DEGRADATION

20.4 Rupture

Tire damage caused by cutting and tearing of tire components (including cords) due to excessive flexing, impact, road hazard intrusion, etc.

20.4.1 Impact Break

Rupture of tire carcass caused by sudden shock.

20.4.2 Blow-Out

Sudden bursting of a tire.

20.4.3 Puncture

A hole in the tire caused by a sharp object (nail, glass, etc.).

21. TIRE INTEGRITY

21.1 Tire Dimensional Stability

The ability of a tire to maintain its dimensions within limits set by a standards organization or an original equipment (OE) customer.

21.2 Impact Resistance

The ability of a tire to withstand impact forces produced by pot holes, bumps, etc., without structural damage.

21.3 Puncture Resistance

The ability of a tire to resist penetration of a sharp object through the tread or carcass and into the air chamber.

21.4 Air Retention

The ability of a tire to retain air pressure within the tire cavity.

21.5 Minimum Performance Requirements

Specified by a standards organization, an original equipment (OE) customer, or government regulations. Example: Federal Motor Vehicle Safety Standards (FMVSS) Nos. 109, 119, and 139.

21.5.1 Tire Plunger Strength

The strength of an inflated tire as indicated by its absorption of the energy in deforming and penetrating the tire structure under specified conditions.

21.5.2 Tire Endurance

A measure of the ability of an inflated and loaded tire to withstand prolonged running without structural failure and loss of air when tested under specified conditions.

21.5.3 High-Speed Performance

The ability of an inflated and loaded tire to withstand high speeds without structural failure and loss of air when tested under specified conditions.

21.5.4 Tire Heat Build-Up Resistance

The ability of a tire to resist failure resulting from generation of heat caused by an increase of speed, tire deformation, slip, or other conditions.

21.5.5 Bead Unseating Resistance

The ability of an inflated tire to resist unseating of the bead by a gradually increased force applied to the sidewall under specified conditions.