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Tire Performance Technology

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. The Tire Performance Terminology draft was initially limited to tire forces and moments. Later, for reasons of convenience, terms and definitions from other related tire performance areas, such as kinematics, noise, and vibrations, non-uniformities, wear, and modes of degradation were added to make it more complete. In the past, terms and definitions related to different aspects of tire performance have been scattered in different standards developed by different committees working most independently from each other. Because of this practice, different terminologies frequently duplicate each other, use different terms for the same item, and provide different definitions for the same term. This results in inconsistencies and confusion. Different aspects of tire performance such as forces and moments, tread wear, etc., are interrelated and mutually influence each other. For example, tread wear is produced by tire forces. At the same time, tread wear influences tire force and moment characteristics. To account for these real performance interactions, the terms and definitions pertaining to different aspects of tire performance have been combined in this terminology.

The terms and definitions 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 carried more than one name, the one believed most descriptive was listed first, and the others were shown in parentheses. In some cases, existing definitions had to be altered or new ones introduced to achieve consistency and, we hope, international acceptance.

If more than one term had the same definition, the preferred term was listed first. Other terms were listed in parentheses. Preference was 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

If more than one definition was found to apply to the same term, preference was given to the definition in agreement with the three criteria just listed. In exceptional cases, when a term or a definition appeared to be inadequate or questionable, it was replaced by a new one and an explanation was given in the Notes.

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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. These terms and conditions were written using exactly the same wording as that used in the original documents. If any discrepancies should be found, the wording used in the latest edition of the document issued by the organization or committee under whose jurisdiction these terms and definitions have been originally developed, shall apply.

This work has been performed by a team of specialists from industry, standards organizations, technical universities, and many other organizations from major industrial countries. Hopefully, if the final form of this terminology is used by everybody working in the tire and vehicle fields, misunderstandings and ambiguities will be avoided in technical presentations, reports, papers, discussions, etc., thus saving time, effort, and cost.

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1. Scope—The 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 nonhighway tires.

2. References

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

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

SAE J670e—Vehicle Dynamic Terminology
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

2.1.2 ISO STANDARDS—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 3911-1977 (E)—Wheels/rims nomenclature, designation, marking, and units of measurement
ISO 8855-1991—Road vehicles—Vehicle dynamics and road holding ability—Vocabulary

2.1.3 U.S. FEDERAL STANDARDS—Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

49CFR575.104—Uniform Tire Quality Grading
FMVSS 109—New Pneumatic Tires—Passenger Cars
FMVSS 119 49CFR571.119—New Pneumatic Tires for Vehicles Other Than Passenger Cars

2.1.4 TIRE AND RIM ASSOCIATION PUBLICATION—Available from The Tire and Rim Association, 175 Montrose West Avenue, Copley, OH 44321.

Tire and Rim Association Year Book

2.1.5 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM F 1016-86—Standard Practice for Tire Treadwear Analysis
ASTM F 1046-87—Standard Guide for Preparing Artificially Worn Passenger and Light Truck Tires for Testing
ASTM F 1426-93—Standard Practice for Identifying Tire Tread Surface Irregular Wear Patterns Resulting From Tire Use

2.2 Related Publicationss—The following publications are provided for information purposes only and are not a required part of this document.

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

SAE J341a—Truck and Bus Tire Performance Requirements and Test Procedures
SAE J918c—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 Mile
SAE J1106-07—Laboratory Testing Machines and Procedures for Measuring the Steady-State Force and Moment Properties of Passenger Car Tires
SAE J1269-70—Rolling Resistance Measurement Procedure for Passenger Car, Light Truck, and Highway Truck and Bus Tires
SAE J1351—A Dictionary of Terms for the Dynamics and Handling of Single-Track Vehicles (Motorcycles, Mopeds, and Bicycles)
SAE J2013—Military Tire Glossary
SAE R-101—Dictionary of Automotive Engineering, D. Goodsell, 1989
SAE SP750—Glossary of Automotive Terms
SAE Paper 960999—The Role of Steer and Sideslip in the Mechanism of Slip Angle, W. Bergman, Dirk Pelargus, 1996

2.2.2 ASTM STANDARDS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM F 376-79—Standard Method of Testing Tires for Wet Traction in Cornering (Without Torque Application) Using Highway Vehicles
ASTM F 403-86—Standard Test Method for Tires for Wet Traction in Straight-Ahead Braking, Using Highway Vehicles
ASTM F 408-86—Standard Test Method for Tires for Wet Traction in Straight-Ahead Braking, Using a Towed Trailer
ASTM F 421-89—Standard Test Method for Groove and Void Depth in Passenger Car Tires
ASTM F 424-86—Standard Test Method for Tires for Wet Driving Traction in Straight-Ahead Motion Using Highway Vehicles
ASTM F 435-86—Standard Test Method for Peak Wet Traction of Tires With Driving Torque Application Using Highway Vehicles
ASTM F 538-91—Standard Terminology Relating to Characteristics and Performances of Tires
ASTM F 724-86—Standard Practice for Outdoor Evaluation of Tire Sidewall Component Cracking Resistance
ASTM F 762-88—Standard Practice for Determining Change in Groove (or Void) Depth With Distance Traveled for Passenger Car Tires
ASTM F 870-84—Standard Method for Obtaining Tread Footprints of Passenger Car Tires for Calculation of Groove Area Fraction

2.2.3 ISO PUBLICATIONS—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 3877/1-1978 (E/F/R)—Tyres, valves and tubes—List of equivalent terms—Part 1: Tyres
ISO 4222/1-1978 (e/F)—Definitions of some terms used in the tire industry—Part 1: Pneumatic Tyres

2.2.4 E.T.R.T.O PUBLICATION—Available from European Tyre and Rim Technical Organization, 32 Avenue, Brugmann 1060 Brussels, Belgium.

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

2.3 Other Publications

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

3. Wheel Nomenclature

3.1 Wheel—A rotating load-carrying member between the tire and the hub. It usually consists of two major parts: (a) the rim and (b) the wheel disc. The rim and wheel disc may be integral, permanently attached, or detachable.

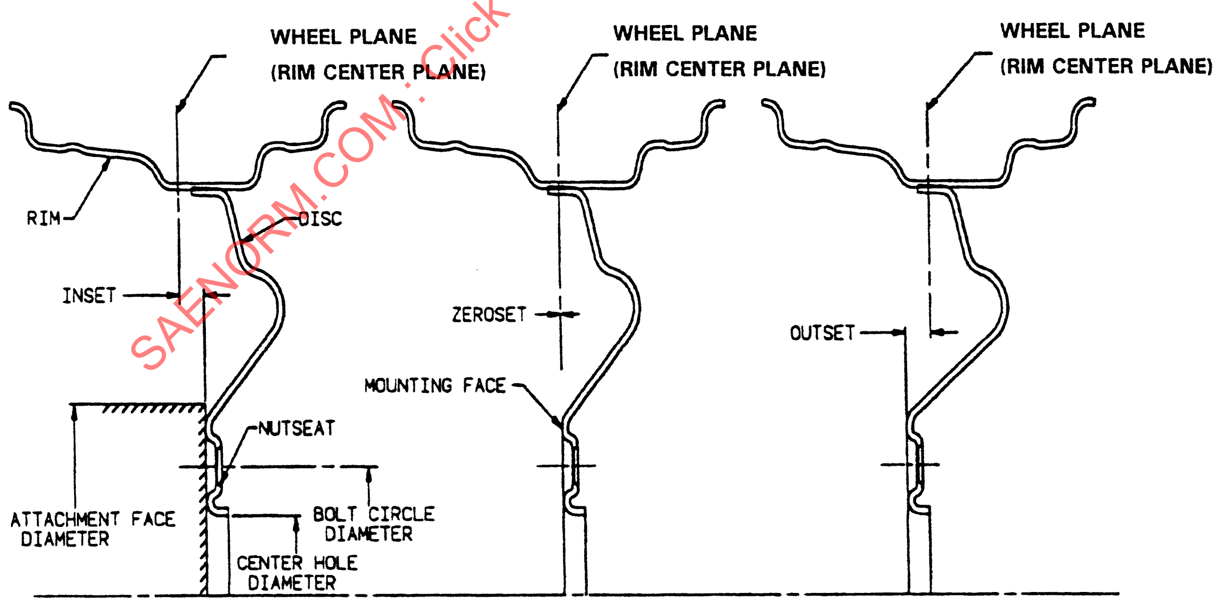
NOTE—Definition of the wheel has been changed from "A load-carrying member between the tire and the axle" (ISO 3911) to "A load-carrying member between the tire and the hub," because the wheel disc is connected to the hub or brake drum or rotor, which serves as a hub, and not to the axle. A similar change was made in the definition of the wheel disc (3.3).

3.1.1 INSET WHEEL—A wheel constructed so that the wheel plane (center plane of the rim) is located inboard of the attachment face of the disc. Inset is the distance from the attachment face of the disc to the center plane of the rim (see Figure 1A).

3.1.2 ZEROSET WHEEL—A wheel constructed so that the wheel plane (center plane of the rim) is coincident with the attachment face of the disc (see Figure 1B).

3.1.3 OUTSET WHEEL—A wheel constructed so that the wheel plane (center plane of the rim) is located outboard of the attachment face of the disc. Outset is the distance from the attachment face of the disc to the center plane of the rim (see Figure 1C).

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



1a–Inset Wheel 1b–Zeroset Wheel 1c–Outset Wheel

FIGURE 1—WHEEL OFFSET

RIM NOMENCLATURE

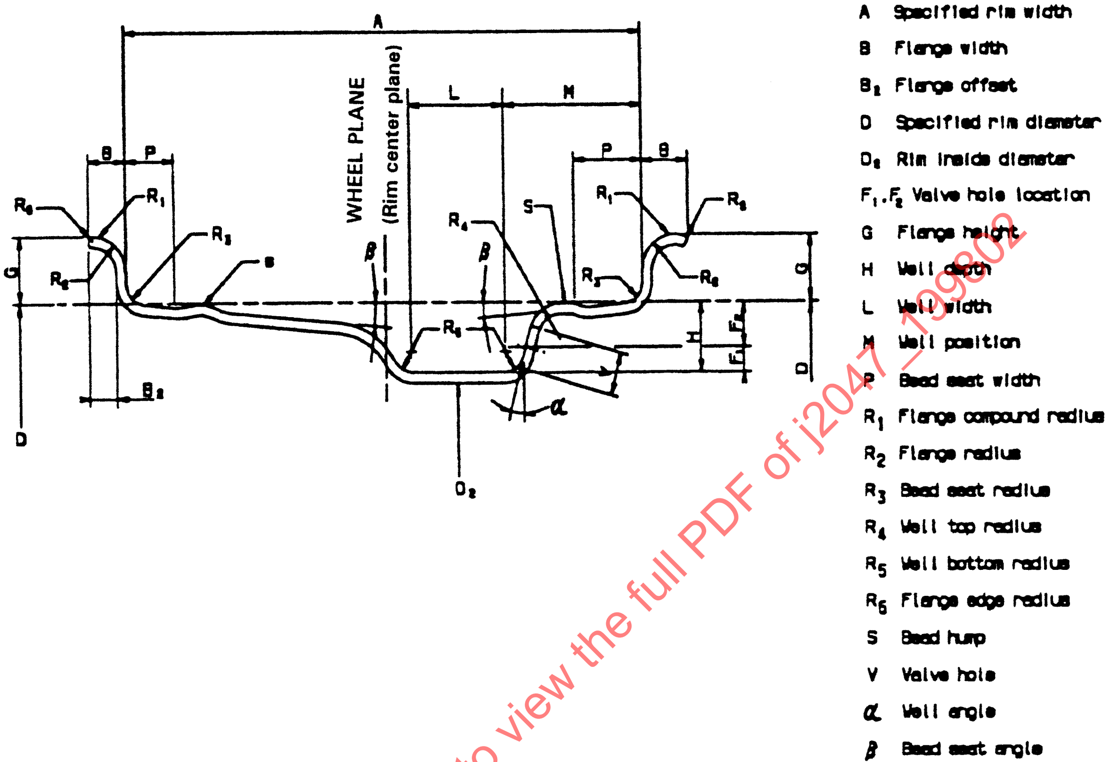


FIGURE 2—RIM

3.2.1 RIM FLANGE—The part of the rim which provides lateral support to the tire and a means of attaching balance weights and decorative trim components.

3.2.2 BEAD SEAT—That part of the rim which provides radial support to the tire.

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 or bead seat taper.

3.2.4 VALVE HOLE—The hold or slot in the rim which accommodates the valve for tire inflation.

3.3 Wheel Disc—That part of the wheel which is the supporting member between the hub and the rim. (See Figure 3.)

3.3.1 DISC FLANGE—The part of the disc that supports the rim.

3.3.2 HAT—The transition point in the disc between the disc flange and the attachment area.

3.3.3 ATTACHMENT FACE—The datum surface of the disc that interfaces with the hub face.

3.3.4 INNER MOUNTING PAD—The attachment face of the disc located inside the bolt circle.

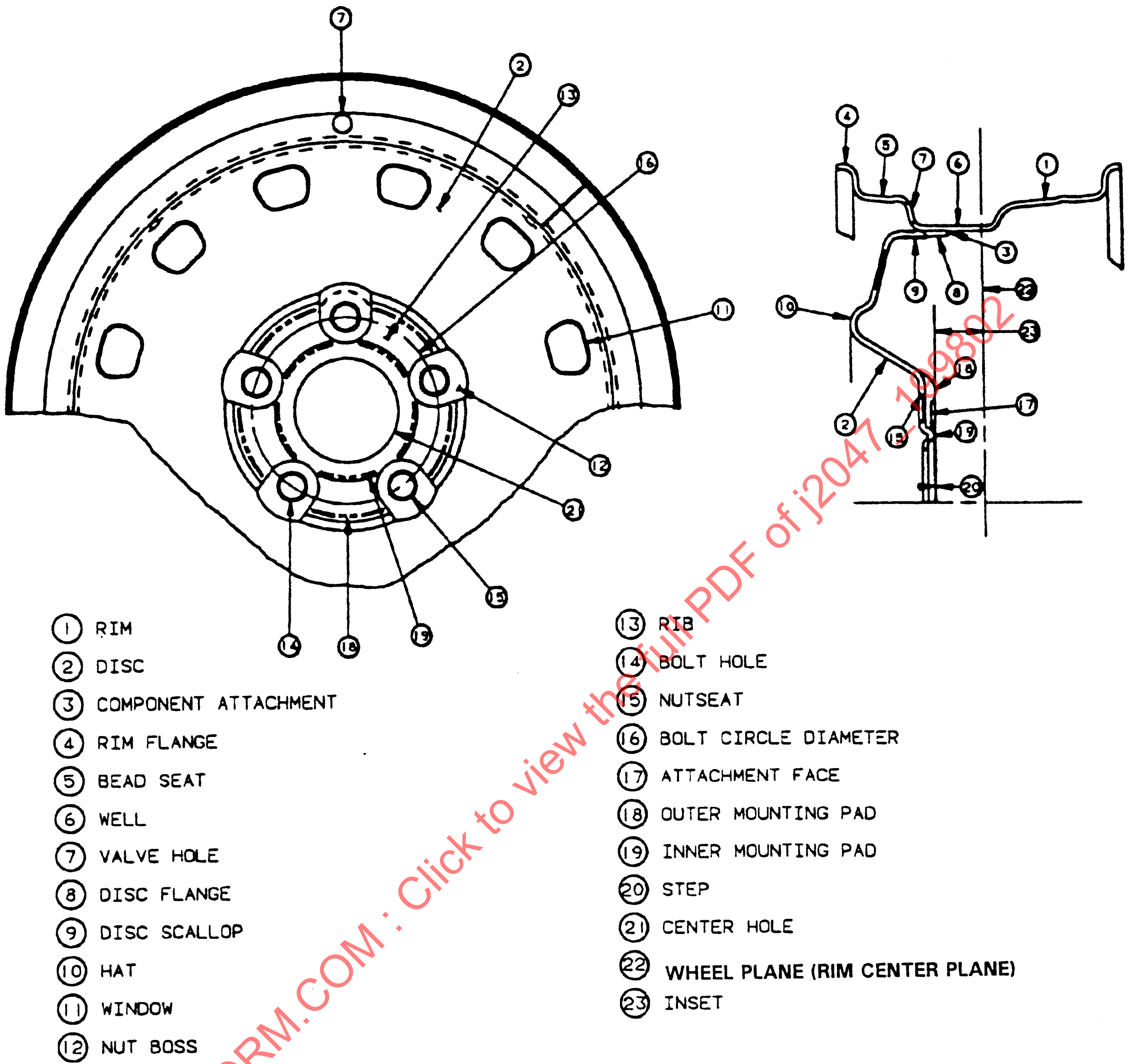


FIGURE 3—TWO-PIECE WHEEL-DISC

3.3.5 OUTER MOUNTING PAD—The attachment face of the disc located outside the bolt circle.

3.3.6 NUT BOSS—A raised portion in the attachment face containing the bolt hole.

3.3.7 STEP—The axial distance between the datum of the outer mounting pad and the inner mounting pad.

3.3.8 BOLT HOLE—Stud clearance hole.

3.3.9 NUT SEAT—The chamfered portion of the disc that is the bearing surface for the nut.

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

3.3.11 RIB—The raised area between the bolt holes.

3.3.12 CENTER HOLE—The clearance hole for the pilot of the hub.

3.3.13 SCALLOP—A relief in the disc flange, reducing the contact area between the disc and rim.

3.3.14 WINDOW—A hole created in the surface of the disc.

3.4 Component Attachment—The connection of the disc and rim components.

3.5 Wheel Designations and Dimensions

3.5.1 WHEEL PLANE (RIM CENTER PLANE)—The central plane of the wheel normal to the spin axis. It is located halfway between the rim flanges.

NOTE—The term "wheel plane" has been adopted from the ISO 8855 and SAE J670e terminologies. The term "rim center plane" has been adopted from the SAE J1982 nomenclature.

3.5.2 RIM WIDTH (TIRE AND RIM ASSOCIATION YEAR BOOK)—The distance between the inside surfaces of the rim flanges.

3.5.3 MEASURING RIM WIDTH (DESIGN RIM WIDTH)—The specific rim width assigned to each tire size designation to determine basic tire dimensions.

3.5.4 SPECIFIED RIM DIAMETER—The diameter at the intersection of the bead seat and the projection of the vertical portion of the rim flange.

3.5.5 RIM DIAMETER DESIGNATION (NOMINAL RIM DIAMETER)—The nominal rim diameter assigned for tire/rim matching.

NOTE—Nominal—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.

3.5.6 RIM PROFILE (RIM CONTOUR)—The radial cross-sectional shape of a rim.

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

3.5.8 RIM SIZE DESIGNATION—Rim diameter designation x rim contour designation. Example: 15 x 6 J, which denotes a 15 in nominal rim diameter, 6 in nominal rim width, and J rim profile.

3.5.9 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 Nomenclature

4.1 Pneumatic Tire—A flexible, hollow semi-toroid mounted on the rim and filled with compressed gas (usually air) to attenuate road impact forces and produce vehicle control forces.

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.

EXAMPLE—P205/60R15 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 15 in, load index 90, and speed symbol H.

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. Example: P205/60R15.

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.

4.2.3 TIRE CONSTRUCTION—The generic type of tire construction 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)—Pneumatic tire in which the ply cords extend to the beads and are laid at alternate angles substantially less than 90 degrees to the centerline of the tread.

4.2.3.2 Bias Belted Tire (Belted Tire)—Pneumatic tire structure of diagonal (bias ply) type in which the carcass is restricted by a belt comprising two or more layers of substantially inextensible cord material laid at alternate angles close to those of the carcass.

4.2.3.3 Radial Ply Tire—Pneumatic tire in which the ply cords extend to the beads and are laid substantially at 90 degrees to the centerline of the tread, the carcass being stabilized by an essentially inextensible circumferential Belt.

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.

4.2.3.6 Retreaded Tire—A tire to which a new tread has been affixed in place of the initial tread.

4.2.4 TIRE CONDITION

4.2.4.1 New Tire—A tire which has been neither used nor subjected to retreading.

4.2.4.2 Grown Tire—A tire which has undergone expansion due to use in service and past inflation.

4.2.5 INTENDED TIRE APPLICATION—The intended usage of a tire, often identified by a letter code. For example: passenger car (P), light truck (LT).

4.2.5.1 Control Tire—Tire used as a reference in a controlled test involving a group of tires.

4.2.5.2 Dual Tires (Twinned Fitment)—Two similar tires mounted side-by-side at the same axle end.

4.2.6 DOT CODE—Letters and numbers molded or branded into or onto the sidewall of tire designated for use on highways containing codes for manufacturer, size, type (optional), date of manufacture of the tire, and the symbol identifying the country of origin (for example, DOT is the acronym for U.S. Department of Transportation). Example: UDXXXXX409 where UD denotes plant number, XXXXX company code, and 409 manufacturing date, the 40th week of 1989.

4.2.7 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 of inflation growth (see, for example, the T&RA Year Book). Protective ribs, bars, 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 of inflation growth (see, for example, the T&RA Year Book). Protective ribs, bars, and decorations are included.

4.3.2.1 Tire Maximum Overall (Grown) Tire Width—The overall width including allowances for manufacturing, growth, and growth in-service.

4.3.3 SECTION HEIGHT—The height of radial cross section of a tire including 24-hour inflation growth, usually 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 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 and aging.

4.3.6 SIZE FACTOR—The sum of section width and overall diameter of a tire.

4.4 Tire Components and Elements—See Figure 4.

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 Sidewall Rubber—The layer of rubber compound on the outside of the sidewall; it may include ornamental or protective ribs.

4.4.1.3 White Sidewall—A sidewall containing white or light-colored compounds used for decoration or lettering.

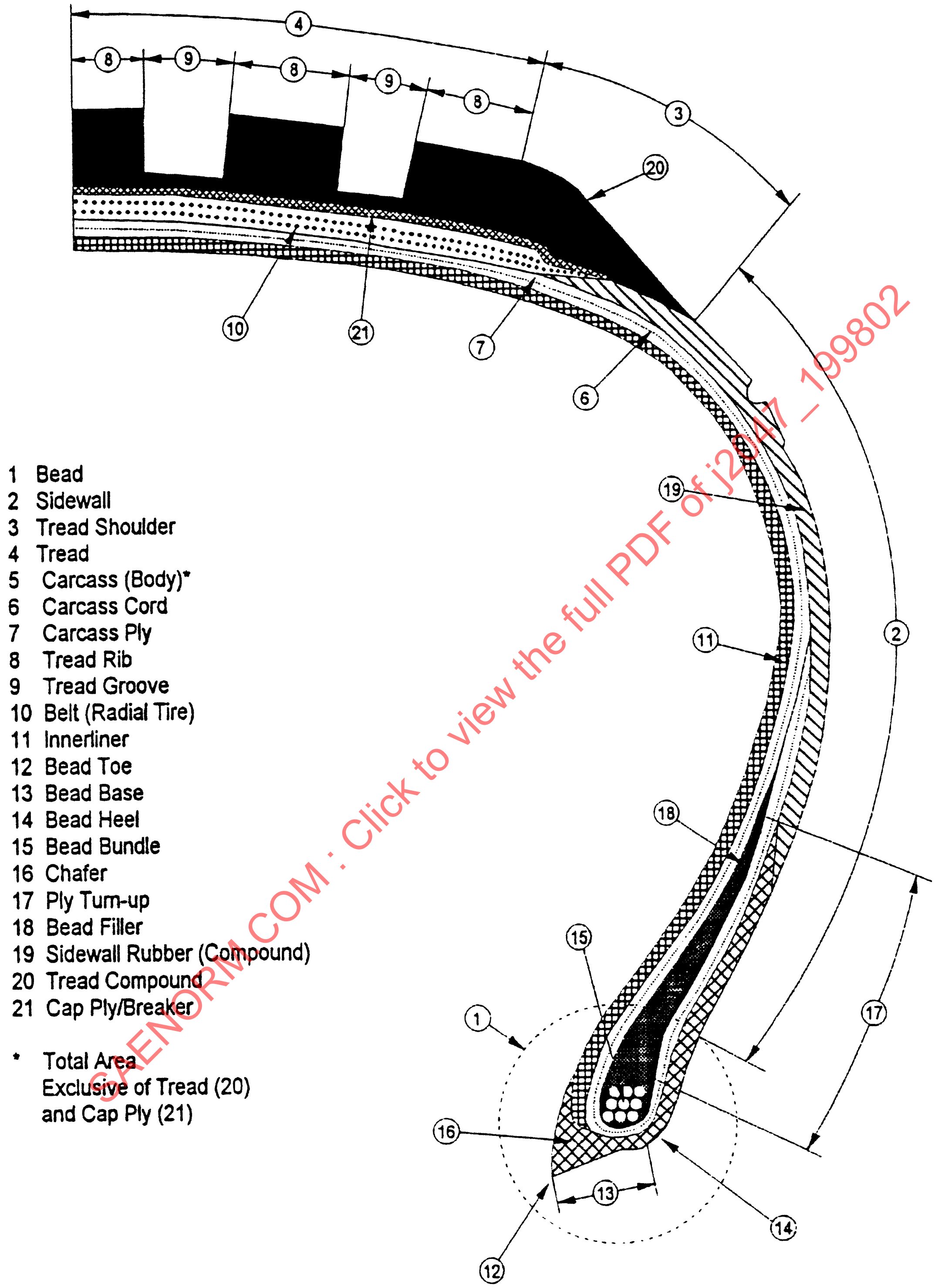


FIGURE 4—TIRE COMPONENTS AND TIRE ELEMENTS

4.4.1.4 *Black Sidewall*—A sidewall without light-colored compounds.

4.4.1.5 *Cover Strip (Cover Gum Strip)*—A thin layer of compound (usually black) covering part of the white sidewall surface of the finished tire.

4.4.1.6 *Veneer*—An extended cover strip.

4.4.2 BEAD—A circumferentially stiff ring of material wrapped or reinforced by tire cords and shaped to fit the rim. The bead anchors the body cords of the tire to the rim so that they can resist external and internal (pneumatic) forces (see Figure 4).

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 edge of bead base.

4.4.2.3 *Bead Heel*—Outer edge of bead base.

4.4.2.4 *Bead Bundle (Bead Coils, Bead Cord)*—A circumferentially stiff hoop usually 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 *Chafer (Rim Strip; Clinch Strip)*—A layer of rubber compound, with or without fabric reinforcement, applied to the bead for resisting external damage.

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

4.4.3 TREAD—The peripheral portion of the tire designed to contact the road surface.

4.4.3.1 *Tread Band*—An annular volume of rubber that encompasses 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 the outer edge or shoulder of the tread band.

4.4.3.4 *Shoulder Row*—A row located at or near the shoulder of the tread band.

4.4.3.5 *Tread Contour*—The surface contour across the tread of an inflated, unloaded tire without consideration of the depressions and variations of the tread pattern.

4.4.3.6 *Tread Radius*—The effective radius of the tread contour curvature measured in the plane of the spin axis.

4.4.3.7 *Tread Arc Width*—The peripheral distance between the two tread shoulders measured along the tread contour. For a tire with round shoulders, the peripheral distance between the imaginary extensions of the sidewall contours and their points of intersections with the extension of the tread contour, 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. For tires with rounded tread shoulders, see the definition of tread arc width.

4.4.3.9 *Tread Pattern*—The molded geometric configuration on the peripheral tread face, generally composed of tread projections and voids.

4.4.3.10 *Tread Projection*—Raised portions of the tread pattern, contacting the road surface when passing through the footprint.

4.4.3.11 *Rib*—An essentially continuous, circumferential tread projection.

4.4.3.12 *Element (Lug, Block)*—A discontinuous tread projection.

4.4.3.13 *Row*—A sequence of tread elements along a circumferential line.

4.4.3.14 *Groove*—An essentially continuous channel molded or cut into the tread rubber. Kerfs and cuts are not included.

4.4.3.15 *Void*—An open space between tread elements or ribs.

4.4.3.16 *Groove (Void) 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.

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 of a tire (anchored to the bead) that contains the inflation-pressure generated forces.

4.4.5 CORD—A filamentary assembly formed by twisting together spun strands of textile or nontextile filaments, for reinforcing various tire components.

4.4.5.1 *Cord Angle*—The angle between a cord in a ply and the equatorial line of the tread center.

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 4).

4.4.6.3 *Stabilizer Plies*—The plies extending from tread shoulder to tread shoulder which form a belt usually constraining the circumference of the tire. The cord angle of the stabilizer plies is usually significantly lower than that of the ply cords.

4.4.6.4 *Belt*—An assembly of one or more pairs of stabilizer plies with their cords usually running at alternate angles.

4.4.6.5 *Cap Ply*—A stabilizer ply applied on top of the belt to improve belt performance at high speeds. The cord angle of a stabilizer ply is usually very small.

4.4.6.6 *Breaker*—Ply (or plies) in a diagonal tire extending from tread shoulder to tread shoulder.

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

4.4.8 INSERT—Material inserted or interposed between adjacent components or elements.

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

4.4.10 SPLICE—The joint formed by overlapping the ends of a tire component during tire building.

4.4.11 FOOTPRINT—The contact area of a tire loaded against a flat or curved surface.

NOTE—Flat surface is usually assumed in mathematical analysis of wheel forces and moments.

4.4.11.1 Gross Contact Area—The area of the footprint as described by the size and shape of the footprint including grooves and voids in the tread pattern.

4.4.11.2 Net Contact Area—The area of the footprint as described by the size and shape of the footprint excluding grooves and voids in the tread pattern.

4.4.11.3 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 wheel.

4.4.11.4 Contact Length—The distance between the extreme points of the leading and trailing edge of the footprint measured parallel to the wheel plane of the straight free-rolling wheel.

4.4.11.5 Footprint Aspect Ratio—The tire footprint length divided by the tire footprint width times 100.

4.5 Special Tire Outer Surfaces

4.5.1 TIRE FACE—The outwardly directed side of a tire if mounted on a vehicle according to the vehicle manufacturer's specification or general practice. Currently, in the USA, the tire face is usually the side without a DOT Number (serial number). Other examples of tire faces are: the side with a white sidewall or other decorations (e.g., raised large letters), or the side with a curb rib. In Europe, it is not mandatory to have the DOT (serial) number on the tire face.

4.5.2 TIRE GENERAL SURFACE—The idealized outer surface of a tire without grooves, kerfs, molded letters, and other intended irregularities.

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 a load supported by the axle, (c) generating tangential forces between the tire tread surface and the road surface, necessary for control of vehicle motion, and (d) absorbing disturbance forces due to road 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 J670e. 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 spin axis intersects the wheel plane.

5.2.3 SPIN AXIS—The axis of wheel rotation.

NOTE—For the purposes of this terminology, the spin axis is the axis of rotation of the wheel about the spindle bearings. This is a common and industrially useful definition. It is recognized that in a pure mechanics sense the wheel rotates instantaneously about an axis which is skewed with respect to the wheel plane. The orientation of the instantaneous spin axis changes moment by moment.

5.2.4 CONTACT LINE—The intersection of the wheel plane and the road plane.

5.2.5 CONTACT CENTER (CENTER-OF-TIRE CONTACT)—The intersection of the contact line and the normal projection of the spin axis onto the road plane.

NOTE—The term contact center has been introduced in this terminology to replace a similar term "center-of-tire contact" used in SAE J670e and ISO 8855. The center-of-tire contact, may not be the geometrical center-of-tire contact area. Note, that the tire is an elastic body which deflects under application of forces and moments. Because of this deformation, the tire circumference does not remain fixed in relationship to the rim. Consequently, no point on the tire circumference, within the boundaries of the contact area, can properly serve as the origin of the axis system used to define forces and moments acting on the wheel. The term "center-of-tire contact" represents a projection of the wheel center on to the ground plane and therefore is related to the wheel rather than the tire. Therefore, it is proper to call it "center-of-wheel contact" abbreviated as "contact center."

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 WHEEL CENTER HEIGHT, H—The distance between wheel center and its normal projection onto the road plane. (See Figure 5 and 6.5.1.)

NOTE—Wheel Center Height—On a flat road surface, the wheel center height is equal to the moment arm of the tangential force or its longitudinal or lateral components with respect to the wheel center. However, on a curved road surface, the wheel center height is not equal to the moment arm of the tangential force or its longitudinal or lateral components.

5.2.9 STATIC LOADED RADIUS, r_{stat}—The wheel center height of a loaded nonrolling wheel at zero inclination angle.

NOTE—The term "radius" in 5.2.8 is general industrial usage. It is not compatible with the mathematical meaning of "radius" as the reciprocal of curvature at a given point. The pneumatic tire flattens under load. Therefore, the curvature at the contact point is always zero, and consequently in mathematical terms, the "radius" at this point is infinity.

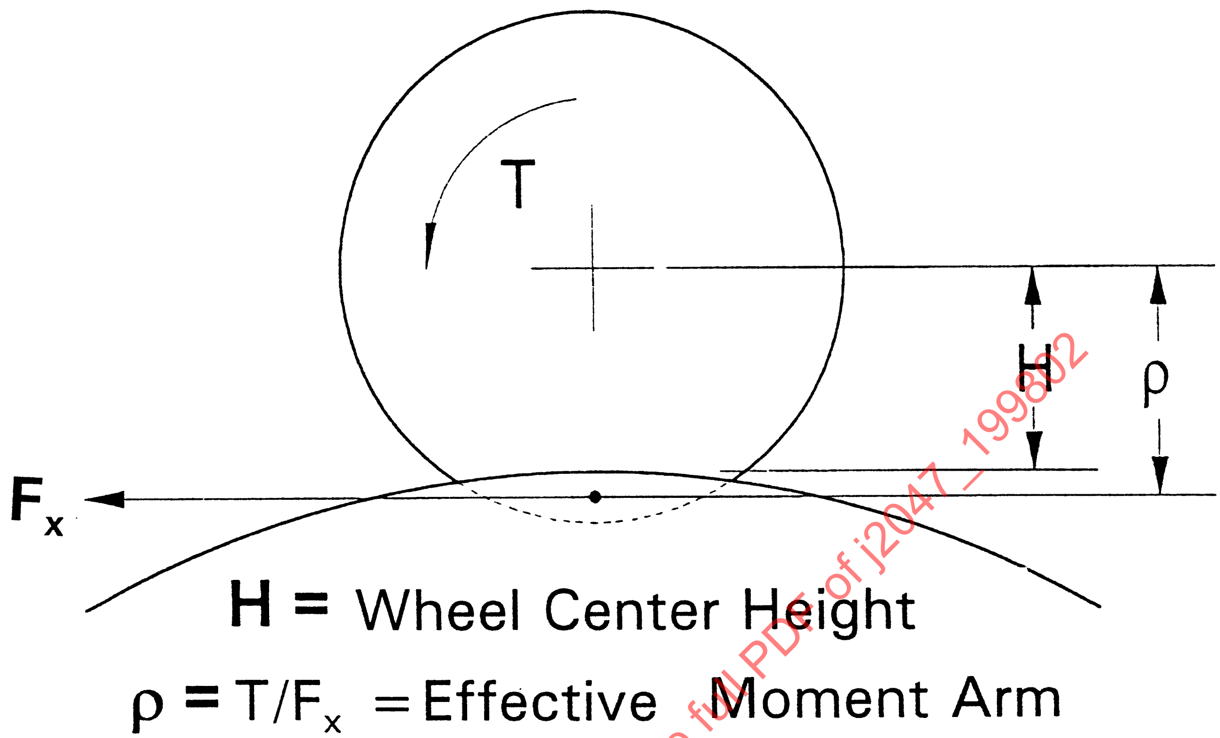


FIGURE 5—WHEEL CENTER HEIGHT AND EFFECTIVE MOMENT ARM FOR A CURVED ROAD SURFACE

5.3 Road Surface—Flat, curved, undulated, or some other shape surface supporting the wheel and providing friction necessary to generate tangential forces in the road plane.

NOTE—The road surface at any point may have general curvature in the direction of the X_r-axis and the direction of the Y_r-axis of the road axis system (see 6.2) and be inclined so that the road plane, the plane tangent to the road surface, is inclined in the direction of both the X_r-axis and Y_r-axis. The road plane generally is not horizontal as is implied in the SAE J670e terminology, 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.

An inclination of the road plane affects the wheel forces and moments encountered in vehicle road tests and computer simulations, however, it has no effect on wheel forces and moments measured in laboratory machines. On laboratory machines, the wheel load acting on the wheel results from an external force applied at the wheel spindle. Since this force always acts normal to the road plane, it does not produce any tangential forces in the road plane. The generally oriented (inclined) road plane introduced in this terminology instead of the horizontal plane used in the SAE J670e and ISO 8855, makes it necessary to change several terms, for example: normal instead of vertical, tangential instead of horizontal, out-of-the-road plane instead of upward, into-the-road plane instead of downward, etc.

5.3.1 ROAD PLANE—A reference plane tangent to the road surface at the contact center. (See Note in 5.3.)

5.3.1.1 Road Plane Elevation Angle, λ—The angle from the normal projection of the X_r-axis onto the ground plane to the X_r-axis. The angle is positive for clockwise rotation about the positive branch of the Y_r-axis (See Figure 6.)

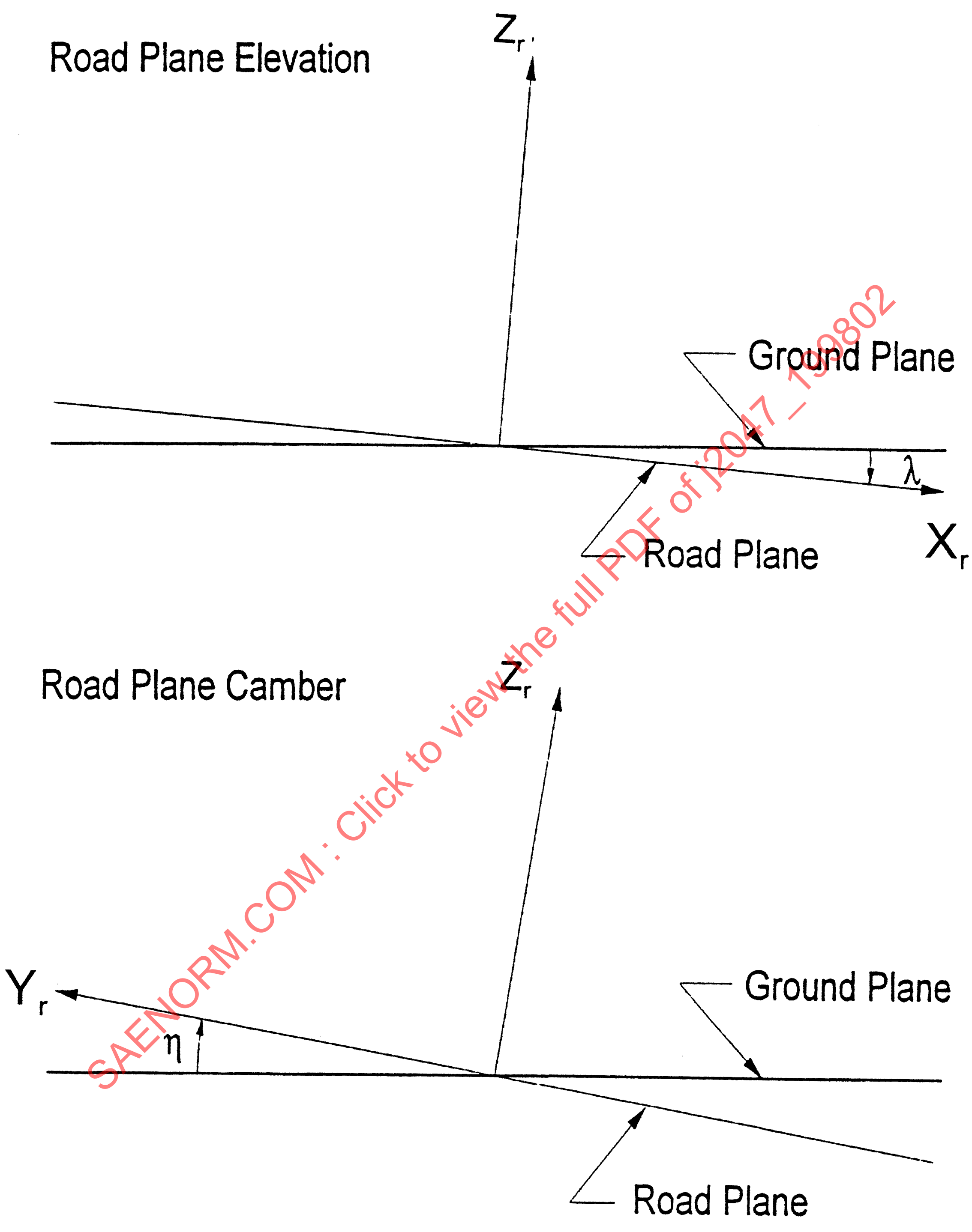


FIGURE 6—ROAD PLANE ORIENTATION WITH RESPECT TO GROUND PLANE ORIENTATION IN ROAD AXIS SYSTEM. POSITIVE ANGLES SHOWN.

5.3.1.2 *Road Plane Camber Angle,* η—The angle from the normal projection of the Y_r-axis onto the ground plane to the Y_r-axis. The angle is positive for clockwise rotation about the positive branch of the X_r-axis. (See Figure 6.)

5.3.2 GROUND PLANE—The horizontal plane in the Earth normal to the gravitational vector at the origin of the $X_E Y_E Z_E$ Earth-fixed axis system (see 6.1).

NOTE—The term "ground plane" has been used interchangeably with the term "road plane" in the SAE J670e terminology. Although neither of these two terms was defined, it was implied that each of them represents a horizontal reference plane. The "ground plane" first was defined in the ISO 8855 terminology as a horizontal reference plane. However, the concept of a generally oriented (inclined) road plane was not envisioned at that time. Generally, the ground plane not necessarily passes through the origin of the road axis system as it is shown in Figure 6. Depending on choice of the origin of the Earth-fixed axis system, the origin of the road axis system can be below or above the ground plane.

5.3.3 ROAD SURFACE CURVATURE—The curvature of the road surface determined in the X_rZ_r and Y_rZ_r planes.

5.3.3.1 *Road Surface Curvature in the X_rZ_r Plane, K_x*—The first derivative of the road plane elevation angle with respect to distance traveled along the X_r-axis. (See Equation 1.)

$$K_x = d\lambda / dX_r \qquad \text{(Eq. 1)}$$

5.3.3.2 *Road Surface Curvature in the Y_rZ_r Plane, K_Y*—The first derivative of the road plane camber angle with respect to distance travelled along the Y_r-axis. (See Equation 2.)

$$K_Y = d\eta / dY_r \qquad \text{(Eq. 2)}$$

6. Axis Systems

6.1 Earth-Fixed Axis System $X_EY_EZ_E$—Right-handed orthogonal coordinate system fixed on the Earth. The X_E- and Y_E-axis are in the ground plane and the Z_E-axis points upward. 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. To account for the effect of wind, the $X_EY_EZ_E$ Earth-fixed axis system should be oriented according to generally used geographical conventions. The X_E-axis should be parallel to the equator with positive direction toward the east; the Y_E-axis should be parallel to the meridian with the positive direction toward the north.

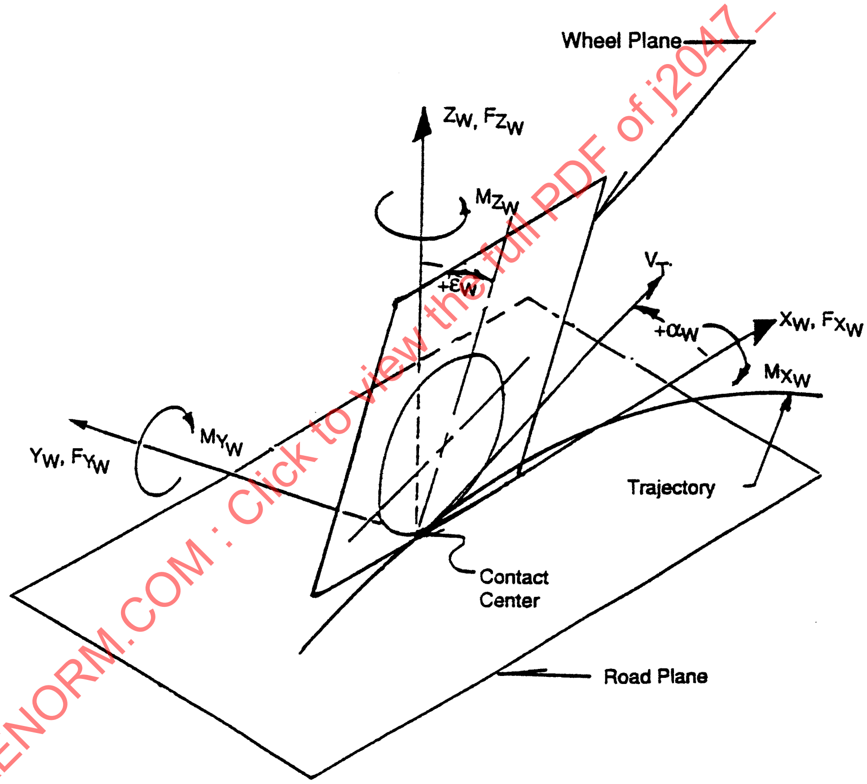
6.2 Road Axis System X_r Y_r Z_r—An axis system intended for describing the angular orientation of the road plane with respect to the ground plane. It is an orthogonal right-handed coordinate system originating at the contact center. The X_r- and Y_r-axes are located in the road plane. The Z_r-axis is perpendicular to the road plane with its positive direction out-of-the-road plane. The direction of the positive X_r-axis coincides with the direction of the trajectory velocity (7.2.1). The positive direction of the Y_r-axis is to the left.

6.3 Wheel (Tire) Axis Systems

NOTE—This terminology recognizes the two existing axis systems: the ISO 8855 Wheel Axis System and the SAE J760e Tire Axis System as coequal systems and provides conversions from one to the other. When definitions are axis system dependent, both ISO and SAE definitions are given. The ISO definition is given first and then the SAE definition. Conversion of data to a format compatible with the axis orientation used in a vehicle dynamics program may be necessary (SAE Paper 960999).

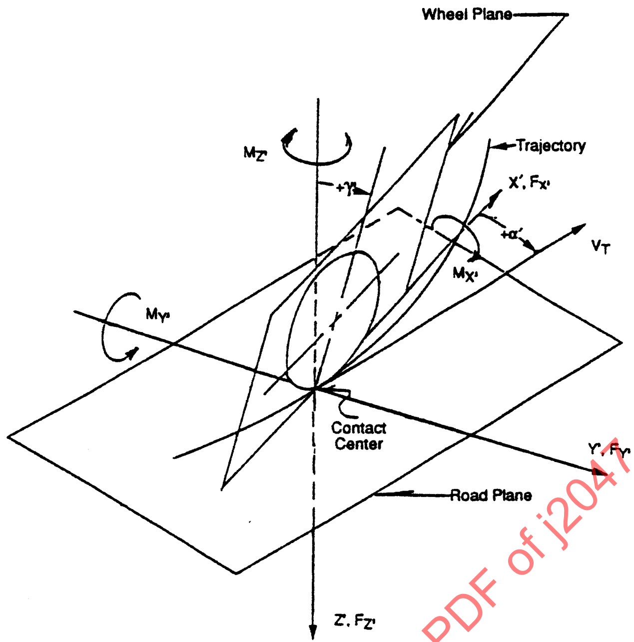
6.3.1 WHEEL AXIS SYSTEM (X_W, Y_W, Z_W) (ISO 8855)—A reference system intended for the orientation of forces and moments exerted on the wheel by the road and also for angular orientation of wheel with respect to the road plane. It is an orthogonal, right-handed, three-axis coordinate system originating at the contact center. The X_W- and Y_W-axes are located in the road plane. The Z_W-axis is perpendicular to the road plane and is positive out-of-the-road plane. The X_W-axis coincides with the contact line; its positive direction is forward. The Y_W-axis is positive to the left. (See Figure 7A.)

6.3.2 TIRE AXIS SYSTEM (X' Y' Z') (SAE J670e)—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'- and Y'-axes are located in the road plane. The Z'-axis is perpendicular to the road plane and it is positive into the road plane. The X'-axis coincides with the contact line; its positive direction is forward. The Y'-axis is positive to the right. (See Figure 7B.) Transformation from the tire axis system to the wheel axis system for the axes, forces, and moments is shown in Figure 8.



Note: Ellipse drawn in this figure schematically indicates configuration of the tire and its location with respect to the axis system and should not be interpreted as the Circumferential Line (5.2.6) or Equatorial Line (5.2.7)

FIGURE 7A—WHEEL AXIS SYSTEM (ISO 8855)



Note: Ellipse drawn in this figure schematically indicates configuration of the tire and its location with respect to the axis system and should not be interpreted as the Circumferential Line (5.2.6) or Equatorial Line (5.2.7)

FIGURE 7B—TIRE AXIS SYSTEM (SAE J670e)

$$\underset{\text{ISO 8855}}{\begin{vmatrix} X_W \\ Y_W \\ Z_W \end{vmatrix}} = \begin{vmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{vmatrix} \bullet \underset{\text{J670e}}{\begin{vmatrix} X' \\ Y' \\ Z' \end{vmatrix}}$$

$$\underset{\text{ISO 8855}}{\begin{vmatrix} F_{X_W} \\ F_{Y_W} \\ F_{Z_W} \\ M_{X_W} \\ M_{Y_W} \\ M_{Z_W} \\ T \end{vmatrix}} = \begin{vmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{vmatrix} \bullet \underset{\text{J670e}}{\begin{vmatrix} F_{X'} \\ F_{Y'} \\ F_{Z'} \\ M_{X'} \\ M_{Y'} \\ M_{Z'} \\ T \end{vmatrix}}$$

FIGURE 8—TRANSFORMATION FROM THE TIRE AXIS SYSTEM TO THE WHEEL AXIS SYSTEM FOR THE AXES, FORCES, AND MOMENTS

6.4 Wheel Plane Orientation—The angular orientation of the wheel plane with respect to the road plane and direction of wheel travel, resulting from a sequence of two rotations: Rotation about the Z_W (Z')-axis and rotation about the X_W (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 7A and 7B.) Transformation of slip angle and inclination angle between the wheel and tire systems is shown in Figure 9.

6.4.1 SLIP ANGLE α_W (α')—An angle between the X_W (X')-axis to the tangent to the trajectory of the contact center. It is positive to the left in the wheel axis system and to the right in the tire axis system.

6.4.2 INCLINATION ANGLE ε_W (γ)—An angle from the Z_W (Z')-axis to the wheel plane. It is positive to the right in both axis systems.

ISO 8855 J670e

$$\begin{vmatrix} \alpha_W \\ \varepsilon_W \end{vmatrix} = \begin{vmatrix} -1 & 0 \\ 0 & 1 \end{vmatrix} \bullet \begin{vmatrix} \alpha' \\ \gamma' \end{vmatrix}$$

FIGURE 9—TRANSFORMATION OF SLIP ANGLE AND INCLINATION ANGLE FROM THE TIRE AXIS SYSTEM TO THE WHEEL AXIS SYSTEM

6.5 Tire Uniformity Axis Systems

6.5.1 TIRE FACE SYSTEM, FLR—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_F, the fore-aft-axis, and the L_F, lateral-axis, are parallel to the road plane, no inclination angle ever exists. The L_F-axis coincides with the spin-axis with its positive direction pointing outboard with respect to the tire face. The R_F, radial-axis, is perpendicular to the road plane with its positive direction out-of-the-road plane. The F_F-axis forms an orthogonal set with the L_F and R_F axes; its positive direction points rearward. (See Figure 10.)

NOTE—The tire face system is used in the tire industry primarily for tire uniformity measurements, which are usually conducted at zero slip angle and zero inclination angle. The tire face system is a specialized axis system introduced in the 1960s and early 1970s for use primarily with uniformity machines, in the 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 SAE J670e tire axis system.

Recently the third axis, the longitudinal axis has been added to satisfy the expanding needs of the industry. Unfortunately, the choice of positive direction of this axis was limited by restrictions imposed by existing 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. 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.

6.5.2 REFERENCE POINT—Any mark on the tire face that is used to identify the angular location of tire components. (See Figure 10.)

NOTE—Reference Point—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.

6.5.3 REFERENCE RADIUS—A line between the normal projection of the reference point onto the wheel plane and the wheel center. (See Figure 10.)

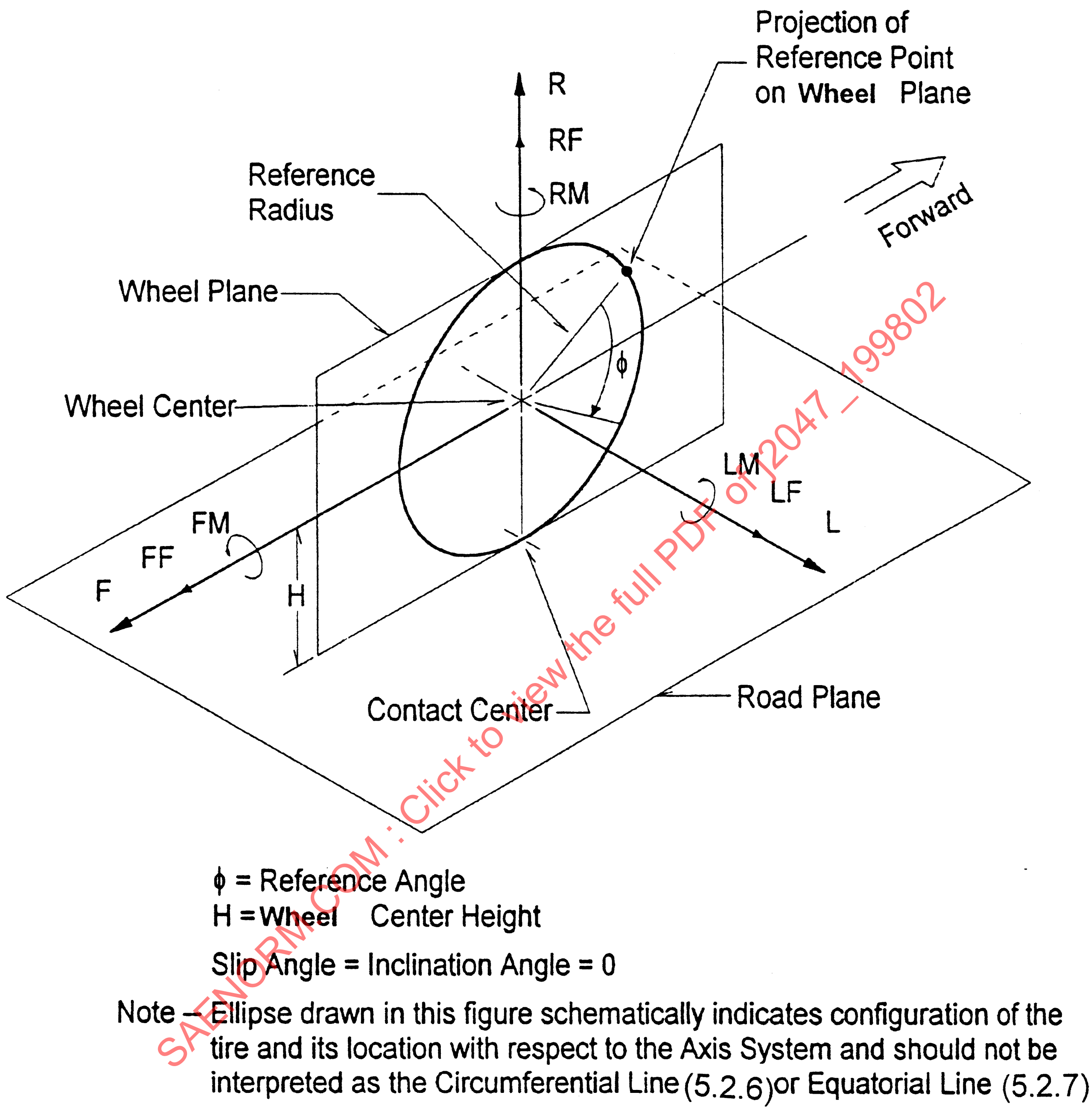


FIGURE 10—TIRE FACE SYSTEM

6.5.4 REFERENCE ANGLE, ϕ—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 10.).

7. Wheel Rolling Characteristics

7.1 Wheel Rolling Modes

7.1.1 STRAIGHT FREE-ROLLING WHEEL—A loaded-rolling wheel moving at zero braking or driving torque along a linear path (zero path curvature) at zero slip angle and zero inclination angle.

NOTE—In defining the straight free-rolling wheel, it is assumed that (a) the wheel rotates at a constant spin velocity and (b) the wheel 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 WHEEL—A loaded-rolling wheel 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 WHEEL—A loaded-rolling wheel moving at zero braking or driving torque along a curvilinear path at given values of slip angle and/or inclination angle.

7.1.4 CORNERING TORQUED WHEEL—A loaded-rolling wheel moving under braking or driving torque along a curvilinear path at given values of slip angle and/or inclination angle.

7.2 Wheel Velocities

7.2.1 TRAJECTORY VELOCITY, V_T—Vector quantity expressing the velocity of the tire contact center in the Earth-fixed axis system. The direction of the trajectory velocity is identical with the direction of the tangent to the trajectory of the contact center.

7.2.2 SPIN VELOCITY (WHEEL ROTATION SPEED), ω—The angular velocity of the wheel about the spin axis. The spin velocity of the straight free-rolling wheel is ω_0.

7.2.3 LONGITUDINAL SLIP VELOCITY—The difference between the spin velocity of the straight driving or braking wheel and the spin velocity of the straight free-rolling wheel.

7.2.4 LONGITUDINAL SLIP, S_X—The ratio of longitudinal slip velocity to the spin velocity of the straight free-rolling wheel. (See Equation 3.)

$$S_x = [\omega - \omega_0] / \omega_0 \qquad \text{(Eq. 3)}$$

Both ω and ω_0 are determined at the same longitudinal velocity.

NOTE—Calculation of longitudinal slip is based on an assumption that the straight free-rolling wheel 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 can be neglected in the straight free-rolling wheel.

7.3 Wheel Kinematics

7.3.1 REVOLUTIONS PER KILOMETER (REVOLUTIONS PER MILE) n—The number of revolutions per kilometer of the straight-rolling driven or braked wheel traveling at a constant longitudinal velocity. The revolutions per kilometer of the straight free-rolling wheel is n_0. (See Equation 4.)

$$n = n_0(1 + S_x) \quad \text{(Eq. 4)}$$

where:

S_x = Longitudinal Slip

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 5.)

$$C_R = 1000/n(\text{meter}) \quad \text{(Eq. 5)}$$

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 6.)

$$r_{dyn}(R_e) = C_R/2\pi = V_T/\omega \ (\text{meter}) \quad \text{(Eq. 6)}$$

7.4 Wheel (Tire) Direction of Rotation

7.4.1 CLOCKWISE ROTATION (CW)—Clockwise rotation of the tire face. Example: Right tires of a forward-moving vehicle when viewed from a position to the right of the vehicle looking along the $+Y_W$-axis or the -Y'-axis.

7.4.2 COUNTERCLOCKWISE ROTATION (ANTI-CLOCKWISE ROTATION) (CCW)—Counterclockwise rotation of the tire face. Example: Left tires of a forward-moving vehicle when viewed from a position to the left of the vehicle looking along the $–Y_W$-axis or the +Y'-axis.

8. Standard Loads and Inflation Pressures

8.1 Cold Inflation Pressure—The inflation pressure of a tire at prevailing ambient temperature with no pressure build-up caused by tire service.

8.1.1 MAXIMUM COLD INFLATION PRESSURE—The highest permissible cold inflation pressure for a given tire.

8.2 Tire Load—The load or weight supported by the tire.

8.2.1 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.

9. Wheel Torque and Wheel Load

9.1 Wheel Torque, T—The external torque exerted upon the wheel about the spin axis.

9.1.1 DRIVING TORQUE—Positive wheel torque.

NOTE—Driving torque is used for the following purposes: (a) to accelerate the vehicle, (b) to maintain vehicle speed at a desired level and (c) to provide energy necessary to produce lateral forces when the tire operates at a slip angle. Therefore, the definition of driving torque cannot be limited to acceleration only.

9.1.2 BRAKING TORQUE—Negative wheel torque.

NOTE—Braking torque is used for the following purposes: (a) to decelerate the vehicle (b) to maintain vehicle speed at a desired level when driving downhill. Therefore, definition of braking torque cannot be limited to deceleration only.

9.1.3 WHEEL BEARING TORQUE, T_B—The wheel torque caused by bearing friction about the spin axis.

9.2 Wheel Load (Load, Normal Wheel Load, Normal Load)—Defined in 10.2.

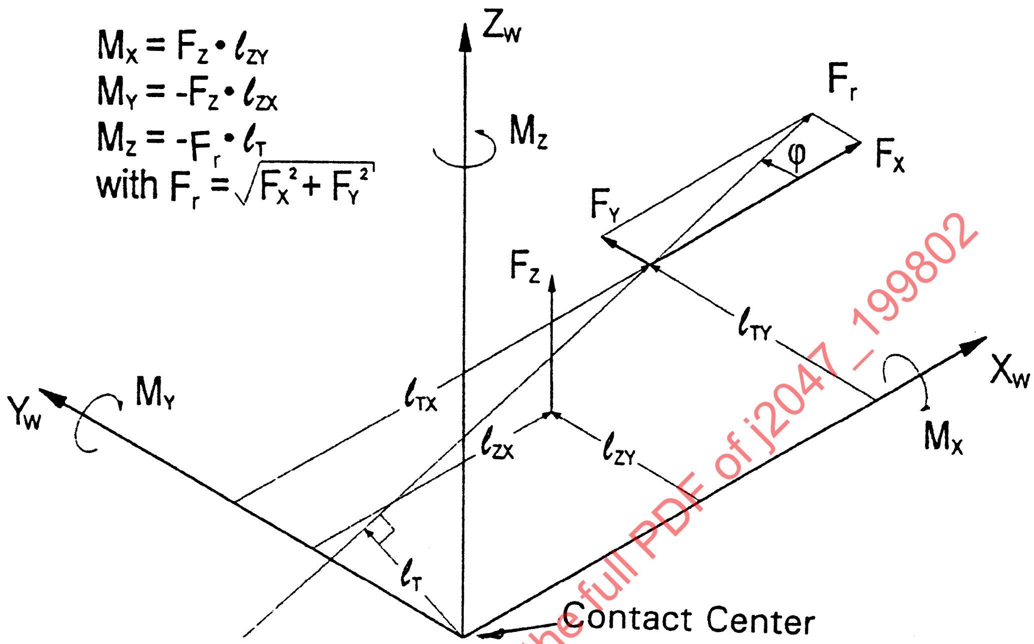
9.3 Vertical Load—The normal reaction of the tire on the road which is equal to the negative of normal force.

NOTE—The positive vertical load has been used in SAE J670e, instead of negative normal force, to normalize the lateral force and longitudinal force components. This terminology, employing an absolute value of normal force, eliminates the need for vertical load. Therefore, this term is obsolete.

10. Wheel Forces and Moments—Forces and moments exerted at any instant upon the wheel by the road can be represented by three forces and three moments. One force and one moment acts in the direction of each of the three axes in any of the axis systems described in Section 6.

NOTE—Forces and moments may vary with change of independent variables such as slip angle, inclination angle, wheel load, wheel torque, speed, coefficient of friction, and 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 (change from an increase of slip angle to a decrease of slip angle or vice versa).

10.1 Tangential Force (Resultant Traction Force), F_r—The resultant force vector exerted on the wheel by the road in the X_WY_W (X'Y') plane (road plane). (See Figures 11 and 12.)



F_X = Longitudinal Force
F_Y = Lateral Force
F_Z = Normal Force
F_r = Tangential Force
φ = Tangential Force Angle

M_X = Overturning Moment
M_Y = Rolling Moment
M_Z = Aligning Moment
ℓ_{ZX} = Rolling Moment Arm
ℓ_{ZY} = Overturning Moment Arm
ℓ_{TX} = Pneumatic Trail (Lateral Force Moment Arm)
ℓ_{TY} = Longitudinal Force Moment Arm
ℓ_T = Aligning Moment Arm

FIGURE 11—RELATIONS BETWEEN FORCES AND MOMENTS IN THE ROAD PLANE

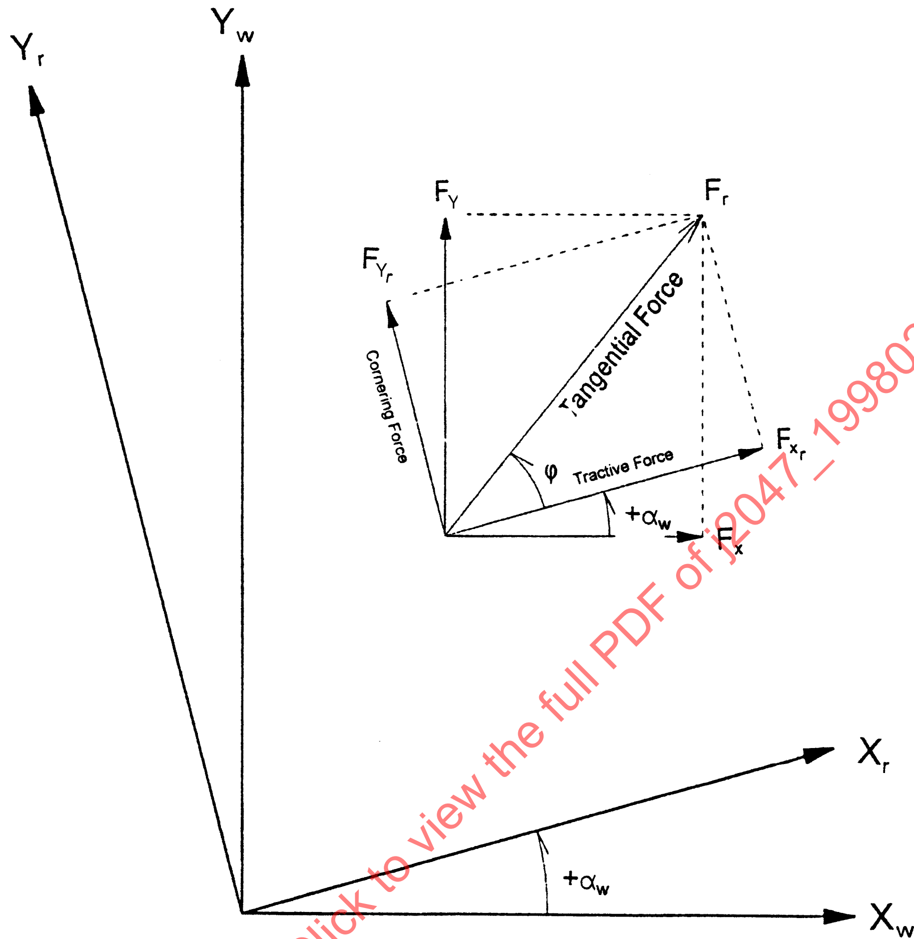


FIGURE 12—WHEEL FORCES WITHIN THE ROAD PLANE

10.1.1 HORIZONTAL FORCE, F_H—The normal projection of the tangential force vector onto the ground plane.

10.1.2 TANGENTIAL FORCE ANGLE (TRACTION VECTOR ANGLE), φ—The angle between the tangential force and the X_W (X')-axis. (See Figure 11.) (See Equation 7.)

$$\varphi = \arctan(F_Y / F_X) \quad \text{(Eq. 7)}$$

10.1.3 LONGITUDINAL FORCE (FORE-AFT FORCE), F_{X_W} ($F_{X'}$)—The component of the tangential force in the X_W-(X') direction. (See Figure 11.)

10.1.3.1 Longitudinal Force Offset (Rolling Resistance Force) F_{XO}—The longitudinal force of the straight free-rolling wheel resulting from bearing friction and tire energy loss.

10.1.3.2 Driving Force—The longitudinal force resulting from driving torque application.

10.1.3.3 Braking Force—The longitudinal force resulting from braking torque application.

10.1.4 LATERAL FORCE (SIDE FORCE), F_{Y_W} ($F_{Y'}$)—The component of the tangential force in the Y_W (Y')-direction. (See Figure 11.)

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

NOTE—The term "slip angle force" has been introduced in SAE J670e as a supplement to a camber force, which has been widely used in technical publications for quite a long time. These lateral force components have been defined separately from each other. However, in most practical applications they occur simultaneously. This results in an interaction between the parameters producing these forces. For example, inclination angle, which is the major independent variable producing camber force, also affects the slip angle force. Therefore, the slip angle force can be considered as a function of slip angle and inclination angle and not slip angle alone. The same reasoning is also applicable to camber force.

10.1.4.2 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. (See Note in 10.1.4.1.)

10.1.5 TRACTIVE FORCE, F_{x_r}—The component of the Tangential Force in direction of the X_r-axis of the road system. (See Figure 12.) (See Equation 8.)

$$F_{X_r} = F_X \cos\alpha + F_Y \sin\alpha \quad \text{(Eq. 8)}$$

10.1.5.1 Drag Force—A negative tractive force.

10.1.6 CORNERING FORCE (CENTRAL FORCE) F_{Y_r}—The component of the tangential force in direction of the Y_r-axis of the road axis system. (See Figure 12.) (See Equation 9.)

$$F_{Y_r} = -F_X \sin\alpha + F_Y \cos\alpha \quad \text{(Eq. 9)}$$

10.2 Normal Force (Radial Force, Normal Wheel Load, Normal Load, Load, Wheel Load) F_{z_w} **($F_{Z'}$)—**The component of the resultant force vector exerted by the road on the wheel in the Z_W (–Z') direction (perpendicular to the road plane).

10.2.1 VERTICAL FORCE, F_V—The component of the resultant force vector, exerted on the wheel by the road in the direction coincident with the gravitation vector. Vertical force is identical with the normal force on a horizontal road plane.

10.3 Overturning Moment, M_{x_w} **($M_{X'}$)—**The moment exerted on the wheel by the road about the X_W (X')-axis. Positive clockwise when viewed in the positive direction of X_W (X')-axis. (See Figure 11.)

10.3.1 OVERTURNING MOMENT ARM, l_{ZY}—The perpendicular distance in the X_WY_W (X'Y') plane (road plane) between the line of application of normal force and the X_W (X')-axis. The overturning moment arm is not a measurable quantity, but it can be computed as shown in Equation 10 and Figure 11.

$$l_{ZY} = M_X / F_Z \quad \text{(Eq. 10)}$$

10.4 Rolling Moment (Rolling Resistance Moment), M_{Y_w} **($M_{Y'}$)—**The moment exerted on the wheel by the road about the Y_W (Y')-axis. Positive clockwise when viewing in positive direction of Y_W (Y')-axis. (See Figure 11.)

10.4.1 ROLLING MOMENT ARM, $l_{Z,X}$—The perpendicular distance in the X_wY_w (X'Y') plane (road plane) between the line of application of normal force and the Y_W (Y')-axis. The Rolling Moment Arm is not a measurable quantity, but can be computed as shown in Figure 11 and Equation 11:

$$l_{ZX} = M_Y / F_Z \quad \text{(Eq. 11)}$$

10.5 Aligning Moment (Aligning Torque, Self-Aligning Torque), M_{z_w} **($M_{z'}$)—**The moment exerted by the road on the wheel about the Z_W (Z')-axis. Positive clockwise when viewed in positive direction of Z_W (Z')-axis. (See Figure 11.)

10.5.1 ALIGNING MOMENT ARM (PNEUMATIC ARM), l_T—The perpendicular distance between the contact center and the line of action of the tangential force. (See Figure 11.) The aligning moment arm is not a measurable quantity, but it can be computed as shown in Equation 12:

$$l_T = -M_Z / [F_x^2 + F_Y^2]^{1/2} \qquad \text{(Eq. 12)}$$

l_T is positive for positive aligning moment.

10.5.1.1 Pneumatic Trail, l_{TX}—The distance between Y_W (Y')-axis and lateral force by which the lateral force, F_Y, should be multiplied to obtain the component of aligning moment due to lateral force. (See Figure 11.) (See Equation 13.)

$$l_{TX} = M_Z / F_Y \qquad \text{at } F_x = 0 \qquad \text{(Eq. 13)}$$

10.5.1.2 Longitudinal Force Moment Arm, l_{TY}—The distance between X_W (X')-axis and longitudinal force, by which the longitudinal force should be multiplied to obtain the component of aligning moment due to longitudinal force. (See Figure 11.) (See Equation 14.)

$$l_{TY} = M_Z / F_X \qquad \text{at } F_Y = 0 \qquad \text{(Eq. 14)}$$

11. Pull Forces and Moments—Pull forces and moments are caused by tire intrinsic properties such as unintentional asymmetries in tire material and construction or deliberate structural asymmetries or both. They are computed as the average values of instantaneous lateral force and instantaneous aligning moment.

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. It is not proper to assume that the properties of the individual tires will necessarily cancel tendencies toward vehicle self steer (pull).

11.1 Lateral Force Offset, F_{YO}**—**The lateral force of the straight free-rolling wheel resulting from the individual tire's construction. It is determined for clockwise and counterclockwise rotation.

11.1.1 LATERAL FORCE OFFSET FOR CLOCKWISE ROTATION, $F_{YO(CW)}$—Is equal to the sum of conicity lateral force and plysteer lateral force.

11.1.2 LATERAL FORCE OFFSET FOR COUNTERCLOCKWISE ROTATION, $F_{YO(CCW)}$—Is equal to the difference between conicity lateral force and plysteer lateral force.

11.1.3 CONICITY LATERAL FORCE, $F_{Y(CON)}$—Lateral force offset component which does not change direction with respect to the tire face due to a change of tire direction of rotation, but changes sign with respect to the wheel axis system, when the tire direction of rotation is reversed. It is computed from lateral force offset determinations in clockwise and counterclockwise rotation (See Figures 13A and 13B). (See Equations 15 and 16.)

$$F_{Y(CON)} = 0.5[F_{YO(CW)} + F_{YO(CCW)}] \text{ with respect to the tire face system} \qquad \text{(Eq. 15)}$$

$$F_{Y(CON)} = 0.5[F_{YO(CW)} - F_{YO(CCW)}] \text{ with respect to the wheel axis system} \qquad \text{(Eq. 16)}$$

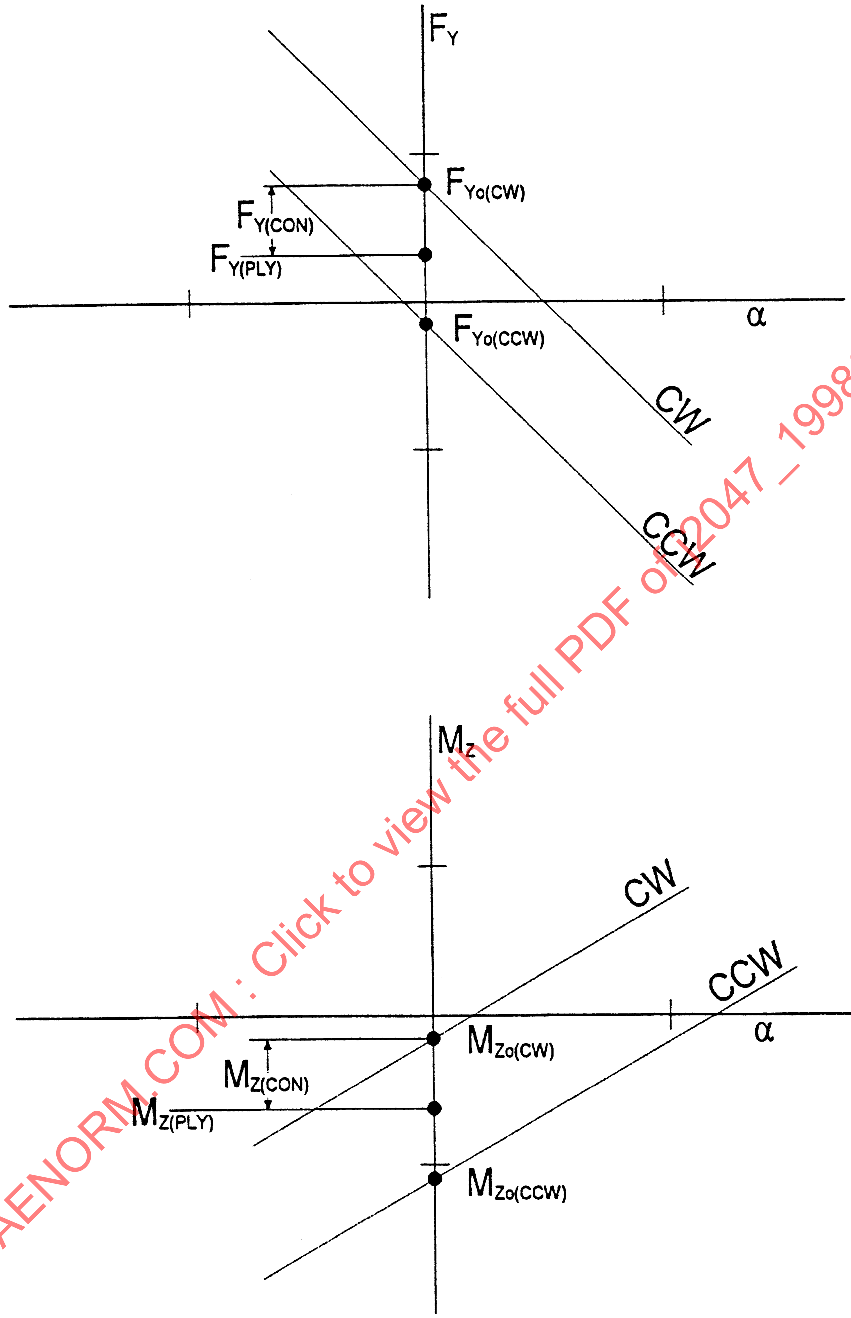


FIGURE 13A—CONICITY AND PLYSTEER COMPONENTS OF LATERAL FORCE AND ALIGNING MOMENT

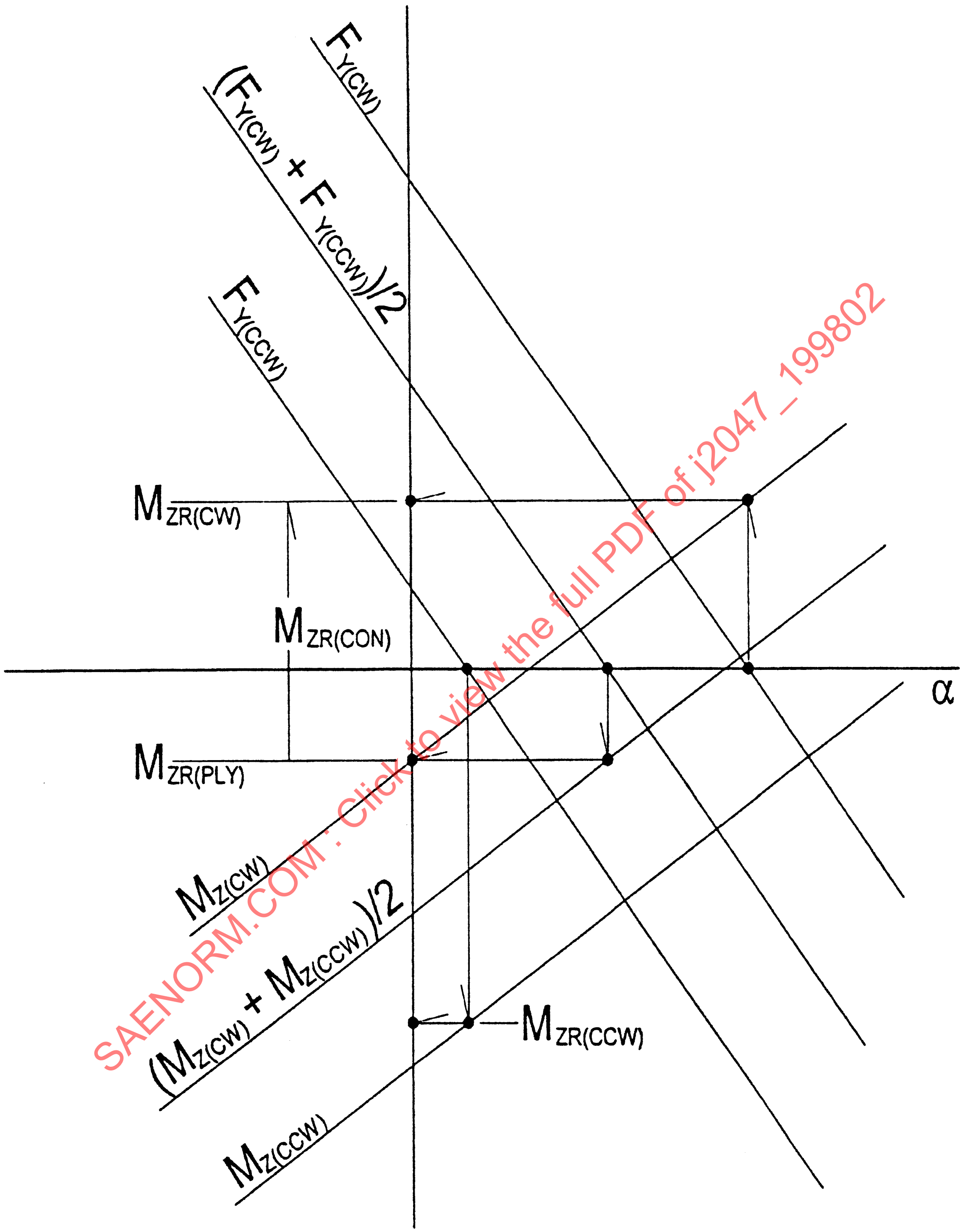


FIGURE 13B—CONICITY AND PLYSTEER COMPONENTS OF RESIDUAL ALIGNING MOMENT

NOTE—To explain the effect of change in direction of tire rotation on direction and sign of conicity and plysteer forces, let us observe these forces at the front right wheel of a moving vehicle. (See Figures 14 and 15.) It is assumed that conicity force and plysteer force are acting inboard during clockwise rotation of the tire, which corresponds to forward motion of the vehicle and therefore have positive signs with respect to the wheel axis system. (See Figure 14.) Reversal of rotation from clockwise to counterclockwise will result in a change in direction of plysteer force with respect to the vehicle from inboard to outboard, but would not effect the direction of conicity force, which will continue to act inboard. (See Figure 15.) The reversal of rotation from clockwise to counterclockwise will also result in change of direction of x- and y-axes of the wheel axis system with respect to the vehicle. This is because the x-axis is always in the direction toward which the wheel is rolling. The positive direction of y-axis changes from inboard to outboard. (See Figure 15.) Therefore, the inboard acting conicity force will become negative and outboard acting plysteer force will become positive. This explains why the conicity force changes sign with respect to the wheel axis system, and the plysteer force does not change sign, with a change in direction of tire rotation.

In contrast with the wheel axis system, orientation of the F-axis (x-axis) and L-axis (y-axis) does not change with the change of direction of rotation in the tire face system, because these axes are fixed with respect to the tire face. Therefore, in the tire face system, the conicity lateral force does not change its sign and the plysteer lateral force does change its sign when the tire direction of rotation is reversed.

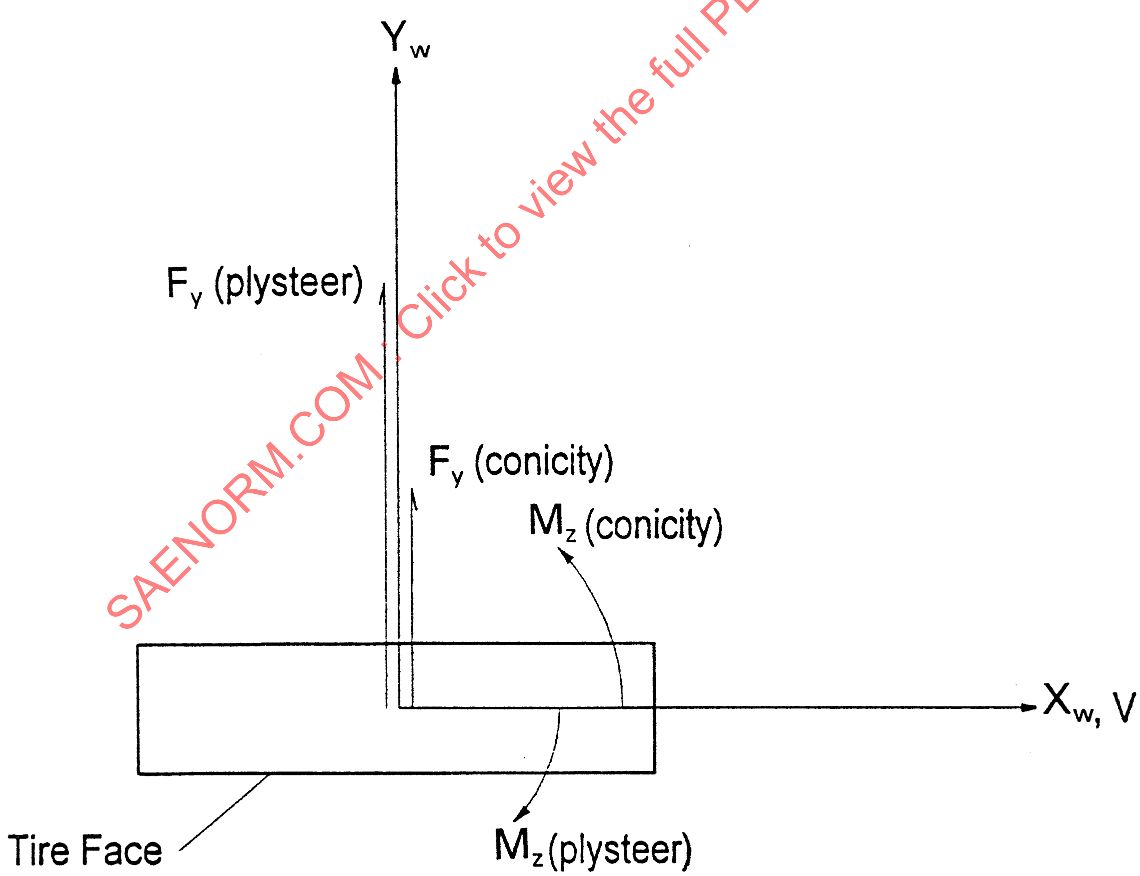


FIGURE 14—PLYSTEER AND CONICITY FORCES DURING CLOCKWISE WHEEL ROTATION

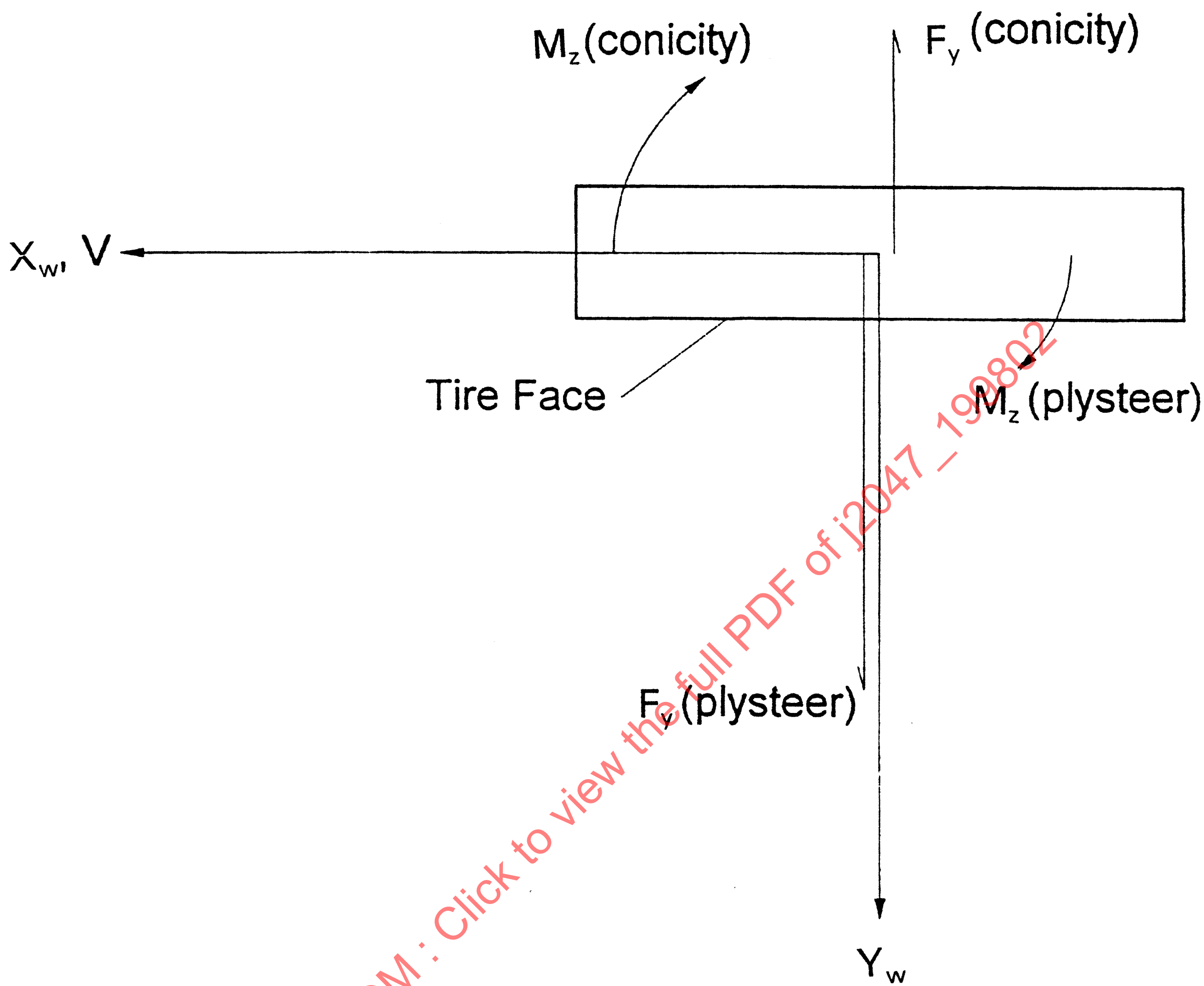


FIGURE 15—PLYSTEER AND CONICITY FORCES DURING COUNTERCLOCKWISE ROTATION OF THE WHEEL

11.1.4 PLYSTEER LATERAL FORCE, $F_{Y(PLY)}$—Lateral force offset component which changes its direction with respect to the tire face with a change in tire direction of rotation, but does not change sign with respect to the wheel axis system if the tire direction of rotation is reversed. (See Note in 11.1.3.) It is computed from lateral force offset determinations in clockwise and counterclockwise rotation. (See Figures 13A and 13B.) (See Equations 17 and 18.)

$$F_{Y(PLY)} = 0.5[F_{YO(CW)} - F_{YO(CCW)}] \text{ with respect to the tire face system} \quad \text{(Eq. 17)}$$

$$F_{Y(PLY)} = 0.5[F_{YO(CW)} + F_{YO(CCW)}] \text{ with respect to the wheel axis system} \quad \text{(Eq. 18)}$$

11.1.5 RESIDUAL LATERAL FORCE, F_{YR}—The lateral force at the slip angle for which the aligning moment of the free-rolling wheel at zero inclination angle is zero.

11.1.6 PLYSTEER RESIDUAL LATERAL FORCE, $F_{YR(PLY)}$—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 clockwise and counterclockwise rotation by Equation 19.

$$F_{YR(PLY)} = 0.5(F_{YR(CW)} + F_{YR(CCW)}) \text{ with respect to the wheel axis system} \qquad \text{(Eq. 19)}$$

11.2 Aligning Moment Offset, M_{ZO}—The aligning moment of the straight free-rolling tire, resulting from tire construction nonuniformity or tire structure itself. It is determined for clockwise and counterclockwise rotation.

11.2.1 ALIGNING MOMENT OFFSET FOR CLOCKWISE ROTATION, $M_{ZO(CW)}$—Is equal to the sum of conicity aligning moment and plysteer aligning moment.

11.2.2 ALIGNING MOMENT OFFSET FOR COUNTERCLOCKWISE ROTATION, $M_{ZO(CCW)}$—Is equal to the difference between conicity aligning moment and plysteer aligning moment.

11.2.3 CONICITY ALIGNING MOMENT, $M_{Z(CON)}$—An aligning moment offset component that changes sign with respect to either the wheel or tire face axis system when the tire direction of rotation is reversed. (See Figure 13A.) It is computed from aligning moment offset determinations in clockwise rotation and counterclockwise rotation by Equation 20.

$$M_{Z(CON)} = 0.5(M_{ZO(CW)} - M_{ZO(CCW)}) \text{ with respect to the wheel axis system} \qquad \text{(Eq. 20)}$$

11.2.4 PLYSTEER ALIGNING MOMENT, $M_{Z(PLY)}$—An aligning moment offset component that does not change sign with respect to the either the wheel or tire face axis system when the wheel direction of rotation is reversed. (See Figure 13A.) It is computed from aligning moment offset determinations in clockwise rotation and counterclockwise rotation by Equation 21:

$$M_{Z(PLY)} = 0.5[M_{ZO(CW)} + M_{ZO(CCW)}] \text{ with respect to the wheel axis system} \qquad \text{(Eq. 21)}$$

11.3 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.

NOTE—Vehicle self steer in response to pull forces is always associated with the net lateral force on the vehicle not being zero at the same trim condition that produces a zero moment on the steering system. For a tire alone, the tire may induce vehicle self steer if the lateral force and aligning moment are not zero at the same slip angle. To some engineers, it seemed that aligning moment left over when lateral force was zero was a residual so they coined the term residual aligning moment.

11.3.1 CONICITY RESIDUAL ALIGNING MOMENT, $M_{ZR(CON)}$—A residual aligning moment component which changes sign with respect to either the wheel or tire face axis system if the wheel direction of rotation is reversed. (See Figure 13B.) It is computed from residual aligning moment determinations in clockwise rotation and counterclockwise rotation by Equation 22:

$$M_{ZR(CON)} = 0.5[M_{ZR(CW)} - M_{ZR(CCW)}] \text{ with respect to the wheel axis system} \qquad \text{(Eq. 22)}$$

11.3.2 PLYSTEER RESIDUAL ALIGNING MOMENT, $M_{ZR(PLY)}$—A residual aligning moment component that does not change sign with respect to either the wheel or tire face axis system when the wheel direction of rotation is reversed. (See Figure 13B.) It is computed from aligning moment offset determination in clockwise rotation and counterclockwise rotation by Equation 23:

$$M_{ZR(PLY)} = 0.5[M_{ZR(CW)} + M_{ZR(CCW)}] \text{ with respect to the wheel axis system} \qquad \text{(Eq. 23)}$$

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_W (–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_W (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_W (Y') direction.

12.4.1 PEAK-TO-PEAK 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 Coeff.)—The ratio of tangential force to the absolute value of normal force.

NOTE—The absolute value of normal force is used because the normal force is positive in the wheel axis system, but it is negative in the tire axis system.

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) start 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), 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), sliding braking force coefficient (13.3.3.2)), reached at the maximum slip value. The transition from the maximum to the minimum value of coefficient of friction results from propagation of sliding between the tread rubber and the road surface over the entire contact area.

13.2.1 HYDROPLANING (AQUAPLANING)—The reduction or loss of direct tread rubber/road contact and hence of tire traction, caused by a water layer separating tire and road on wet roads.

13.3 Longitudinal Force Properties

13.3.1 LONGITUDINAL FORCE COEFFICIENT—The ratio of longitudinal force to the absolute value of normal force. (See Figure 16 and Note in 13.1.)

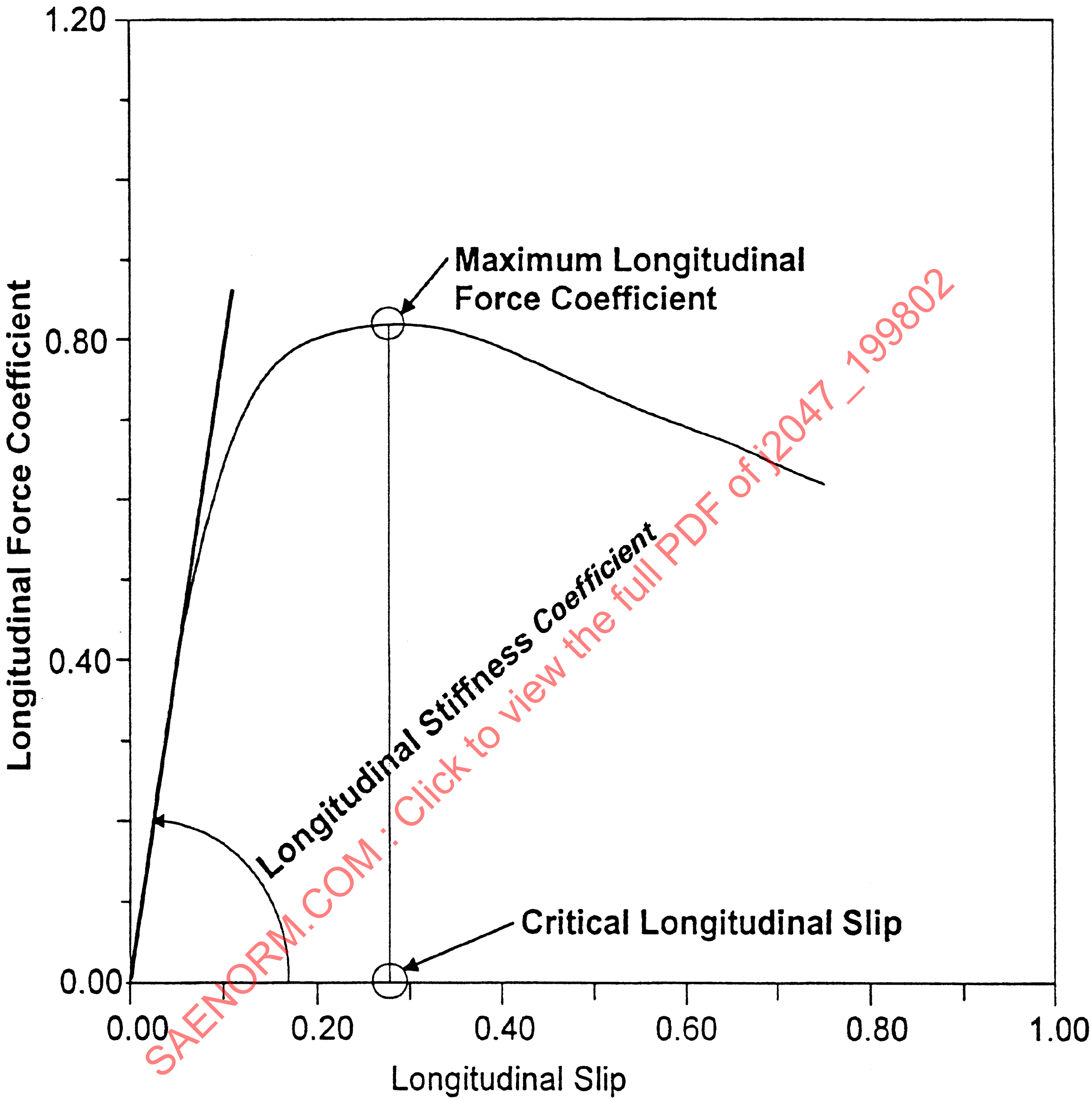


FIGURE 16—EXAMPLE OF LONGITUDINAL FORCE COEFFICIENT VERSUS LONGITUDINAL SLIP

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 and may be expressed as the maximum braking force coefficient (13.3.3.1), longitudinal force coefficient, which is also known as peak friction coefficient, 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.

13.3.2 DRIVING FORCE COEFFICIENT (DRIVING COEFF.)—The ratio of driving force to the absolute value of normal force. (See Note in 13.1.)

13.3.2.1 Maximum Driving Force Coefficient (Driving Traction Coeff.; Peak Driving Coeff.)—The maximum value of the driving force coefficient of the spinning wheel 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 wheel attainable on a given road surface under given test conditions.

13.3.3 BRAKING FORCE COEFFICIENT (BRAKING COEFF.)—The ratio of braking force to the absolute value of normal force. (See Note in 13.1.)

13.3.3.1 Maximum Braking Force Coefficient (Braking Traction Coeff.; Peak Braking Force Coeff.)—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 Coeff.)—The value of the braking force coefficient of the 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 Coeff.)—The ratio of longitudinal stiffness to the absolute value of normal force. (See Note in 13.1)

13.3.5 DYNAMIC LONGITUDINAL FORCE PROPERTIES—Longitudinal force properties associates with dynamic forces.

13.3.5.1 Longitudinal Force Dynamic Loss—The loss of longitudinal force due to dynamic wheel load. It is the difference between the average values of longitudinal force determined at zero dynamic wheel load and that at a given wheel load with both tests conducted at the same constant driving torque.

13.3.5.2 Longitudinal Force Dynamic Loss Coefficient—The ratio of longitudinal force dynamic loss to the value of longitudinal force determined on smooth road surface (zero dynamic wheel load) at the same test conditions.

13.4 Steady-State Lateral Force Properties—Lateral force properties resulting from an incremental change of slip angle or some other independent variable such as inclination angle, wheel load, or wheel torque.

13.4.1 LATERAL FORCE COEFFICIENT—The ratio of lateral force to the absolute value of normal force. (See Figure 17 and Note in 13.1.)

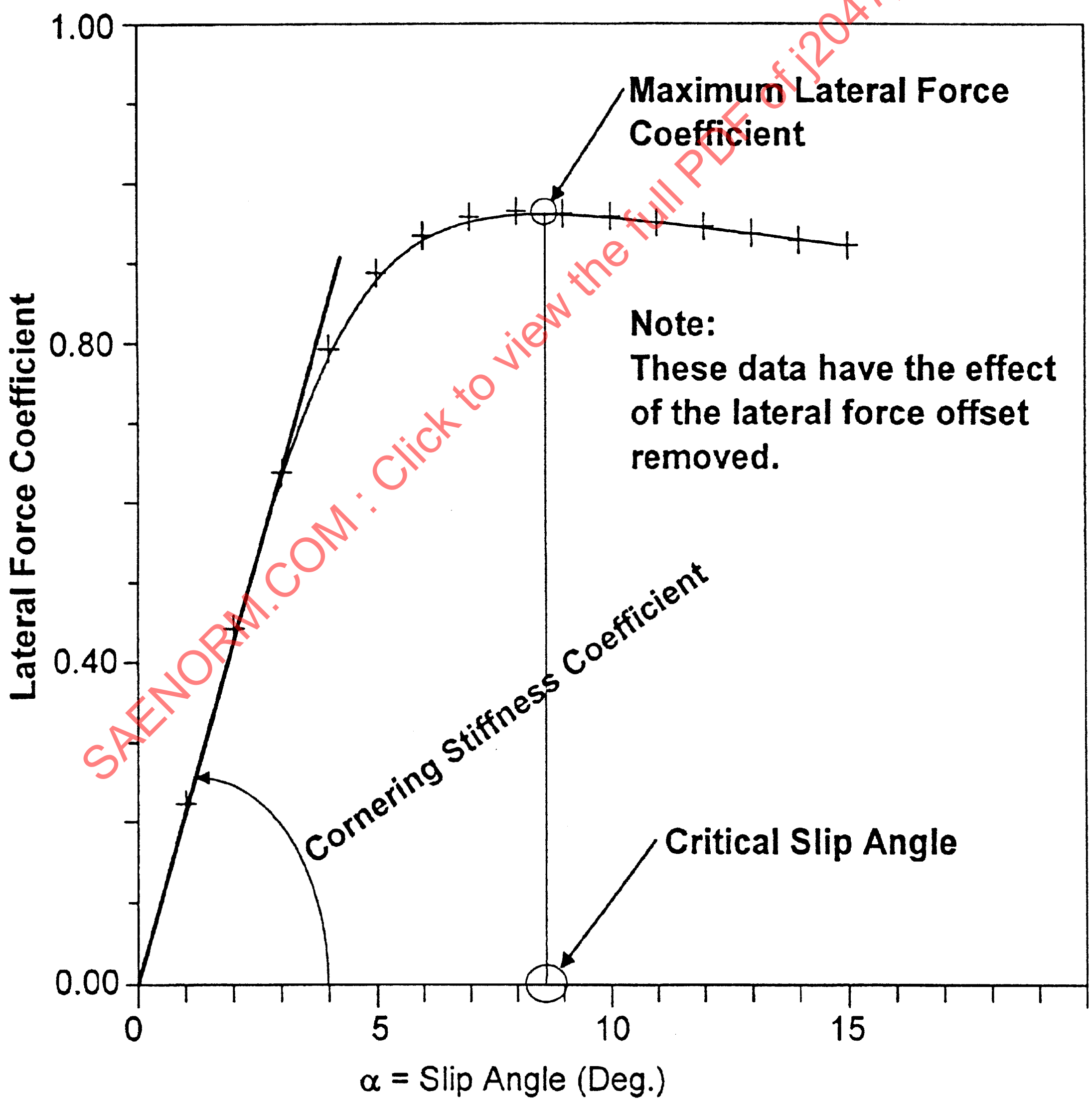


FIGURE 17—EXAMPLE OF LATERAL FORCE COEFFICIENT VERSUS SLIP ANGLE

13.4.2 MAXIMUM LATERAL FORCE COEFFICIENT (LATERAL TRACTION COEFF.; PEAK LATERAL FORCE COEFF.)—The maximum value of the lateral force coefficient attainable for a tire on a free-rolling cornering wheel on a given road surface and given test conditions.

13.4.3 SLIDING LATERAL FORCE COEFFICIENT—The value of the lateral force coefficient of the laterally-sliding wheel where spin velocity is zero.

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) Cα—The negative 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. The value of cornering stiffness is computed as the average cornering stiffness in clockwise and counterclockwise rotations. (See Equation 24.)

$$C\alpha = 0.5(C_{\alpha(CW)} + C_{\alpha(CCW)}) \quad \text{(Eq. 24)}$$

NOTE—For practical purposes, the first derivative of lateral force with respect to slip angle may be approximated as 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 ratio of cornering stiffness to the absolute value of normal force. (See Note in 13.1.)

13.4.6.1 Cornering Stiffness Load Sensitivity—The first derivative of the cornering stiffness coefficient with respect to the absolute value of normal force. (See Note in 13.1.)

13.4.6.2 Cornering Stiffness Torque Sensitivity—The first derivative of the cornering stiffness coefficient with respect to wheel torque.

13.4.7 CAMBER STIFFNESS, C_ε (C_γ)—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. The sign convention for camber stiffness is determined by the choice of coordinate system.

NOTE—Camber Stiffness is the negative of the first derivative of lateral force with respect to inclination angle in the wheel axis system and is the first derivative of lateral force with respect to inclination angle in the tire axis system.

13.4.8 CAMBER STIFFNESS COEFFICIENT, $C_{\varepsilon C}(C_{\gamma C})$—The ratio of camber stiffness to the absolute value of 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—The term lateral force gradient has been introduced in order to differentiate it from a similar term, cornering stiffness (13.4.5). Both terms express the rate of change of lateral force with respect to slip angle. However, the cornering stiffness is determined at zero slip angle only and the lateral force gradient at any value of slip angle.

13.4.10 LATERAL FORCE LOAD SENSITIVITY—The first derivative of lateral force with respect to the absolute value of normal force at any given value of slip angle.

13.4.11 LATERAL FORCE TORQUE SENSITIVITY—The first derivative of lateral force with respect to wheel torque 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, wheel 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 18. Based on concept shown in Figure 18, 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 18.)

13.5.2 LATERAL FORCE RESPONSE PHASE ANGLE—The phase shift between a sinusoidal input of slip angle, inclination angle, wheel 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, wheel load, etc., and the lateral force response. It is determined as the distance traveled by the wheel 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 19.)

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 19 and 20.)

13.5.5 DYNAMIC CORNERING STIFFNESS—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 20.)

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

13.7 Static Lateral Force Properties—Lateral force properties measured on static (nonrolling) tire.

13.7.1 LATERAL STIFFNESS—The first derivative of lateral force with respect to lateral displacement of the wheel center of the nonrolling wheel in the Y_W (Y')-axis direction relative to the supporting surface.

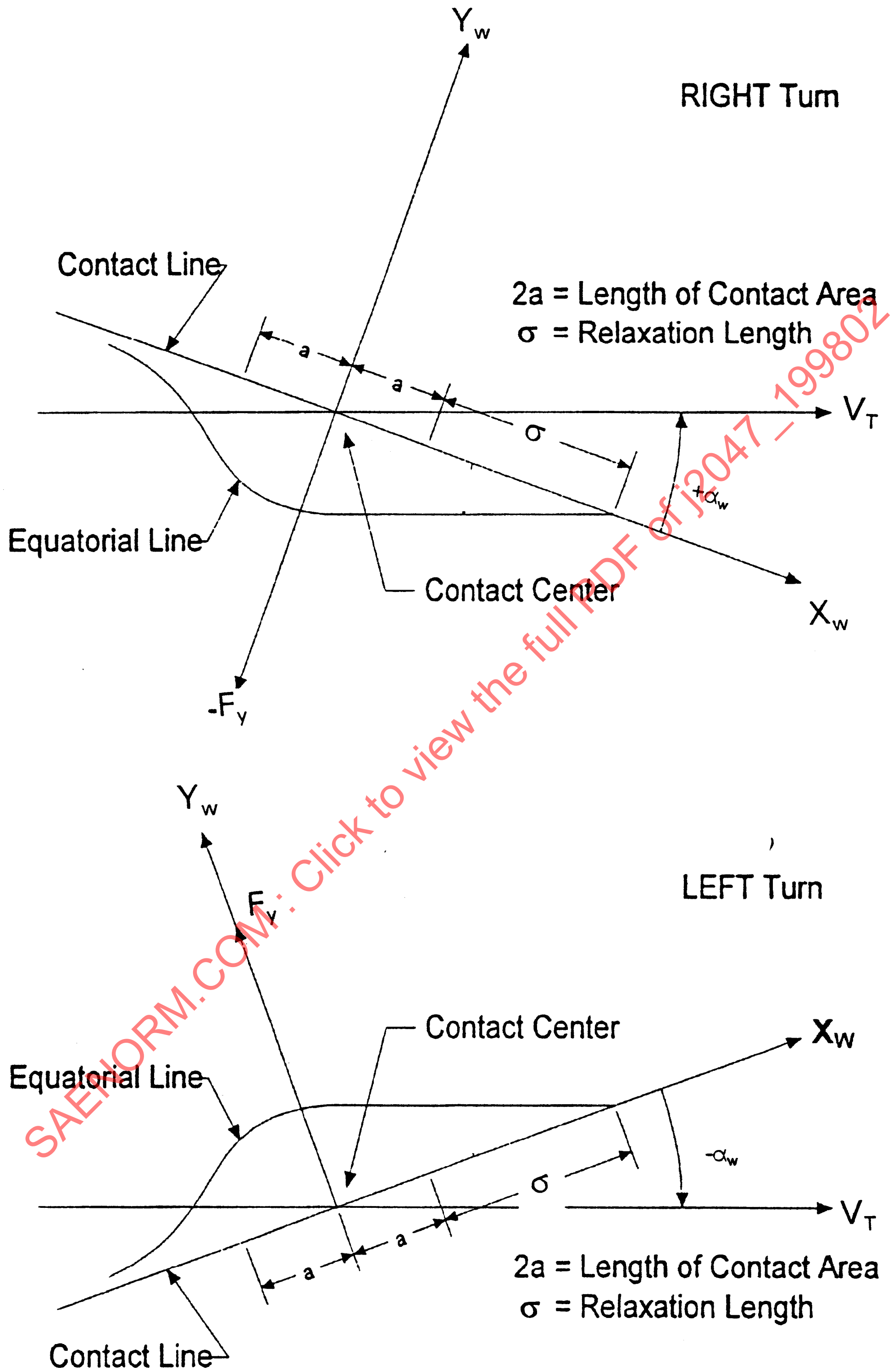


FIGURE 18—DEFORMED EQUATORIAL LINE OF A TIRE TURNING LEFT AND RIGHT.
ISO 8855 WHEEL AXIS SYSTEM USED.

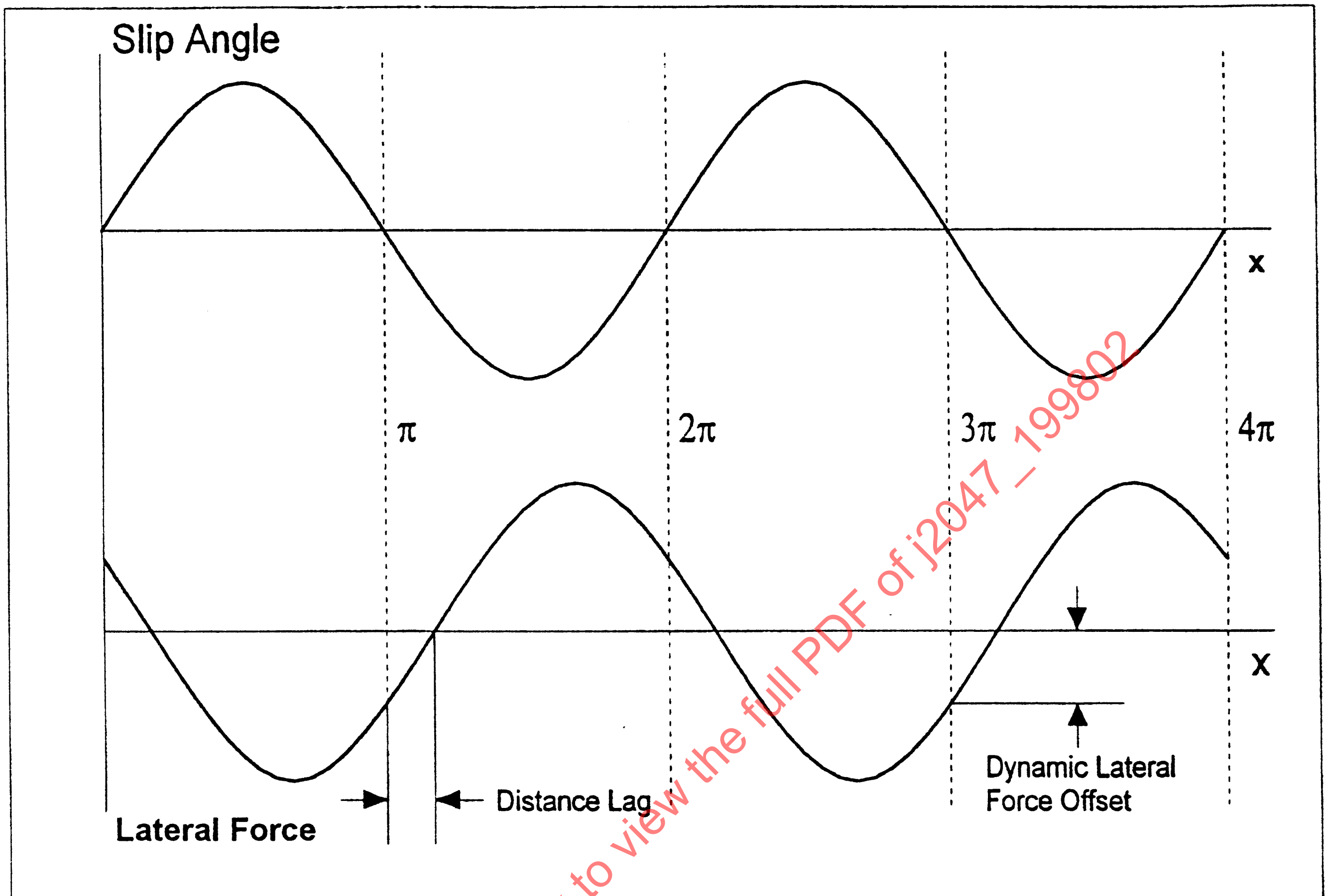


FIGURE 19—LATERAL FORCE RESPONSE TO A SINUSOIDAL SLIP ANGLE INPUT

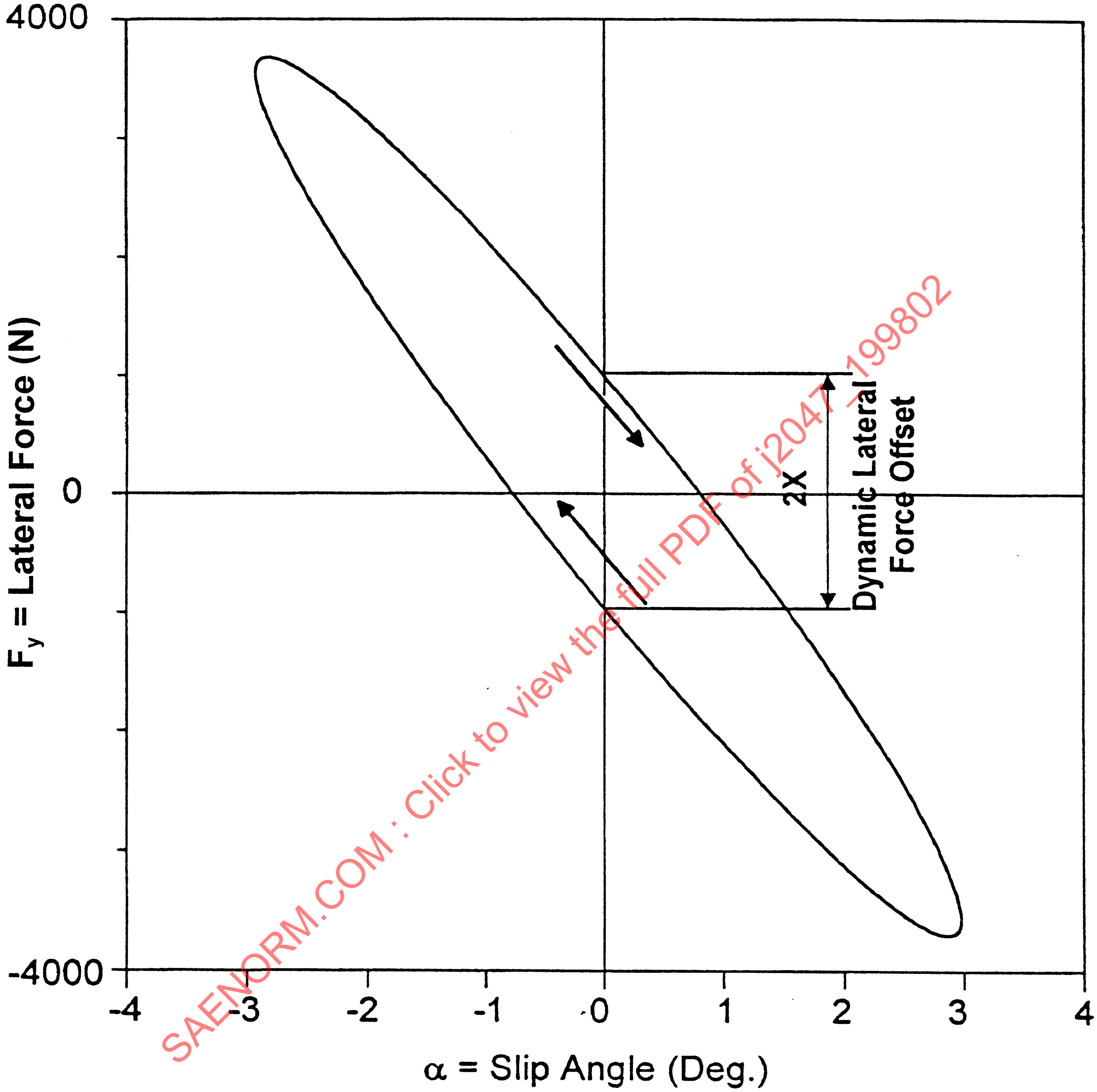


FIGURE 20—DYNAMIC LATERAL FORCE OFFSET

14. Normal Force Properties

14.1 Static Tire Deflection (Deflection [static])—The amount by which the section height is reduced under action of wheel 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 [static]), C_F—The first derivative of absolute value of normal force with respect to static tire deflection. (See Figure 21.)

NOTE—Although the normal stiffness is a variable, it can be considered as a constant within a wide range, except for a relatively small range near zero normal force. (See Figure 21.) 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. It should be noted that the term "normal stiffness," defined in 14.2, can be used for static condition (nonrolling tire) only and is not applicable for a rolling tire. Normal Stiffness of a rolling tire is a complex variable, which is influenced by speed, buildup of inflation pressure resulting from heat buildup in the tire, lateral force, and wheel torque.

14.3 Normal (Radial) Damping—The mechanical energy loss during a load/deflection cycle caused by material hysteresis and road friction.

14.4 Tire Enveloping—The ability of a tire to engulf road irregularities.

15. Aligning Moment Properties

15.1 Aligning Stiffness, C_M—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 22 and Note in 13.4.5.)

It is computed as the average of aligning stiffness of the tire in clockwise and counterclockwise rotations. (See Equation 25.)

$$C_M = 0.5(C_{M(CW)} + C_{M(CCW)}) \qquad \text{(Eq. 25)}$$

15.1.1 ALIGNING STIFFNESS COEFFICIENT—The ratio of aligning stiffness to the absolute value of normal force.

15.1.2 ALIGNING STIFFNESS LOAD SENSITIVITY—The first derivative of the aligning stiffness with respect to the absolute value of normal force.

15.1.3 ALIGNING STIFFNESS TORQUE SENSITIVITY—The first derivative of the aligning stiffness with respect to wheel torque.

15.2 Aligning Moment Torque Sensitivity—The first derivative of aligning moment with respect to wheel torque at any slip angle.

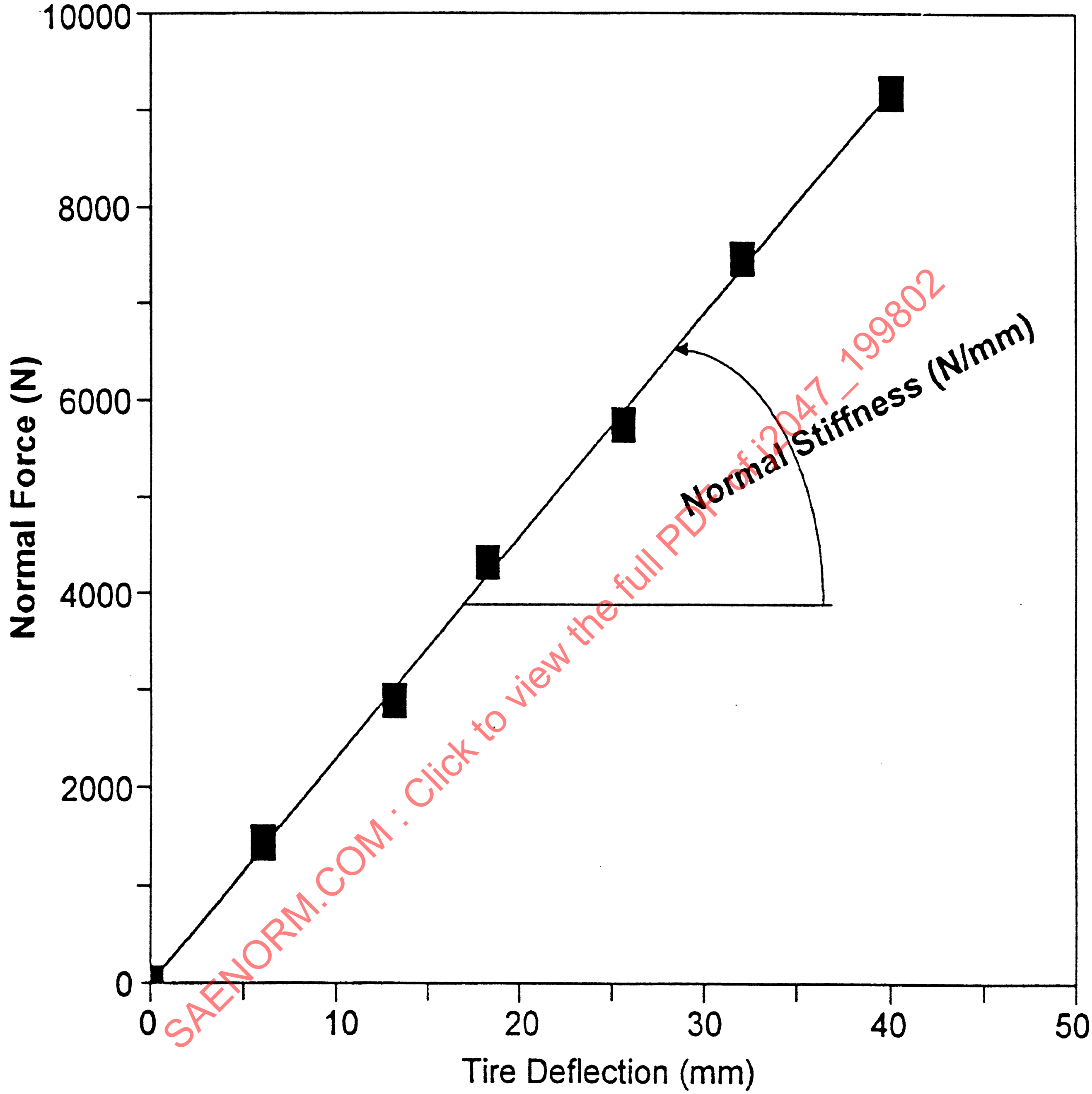


FIGURE 21—AN EXAMPLE OF NORMAL FORCE VERSUS TIRE DEFLECTION

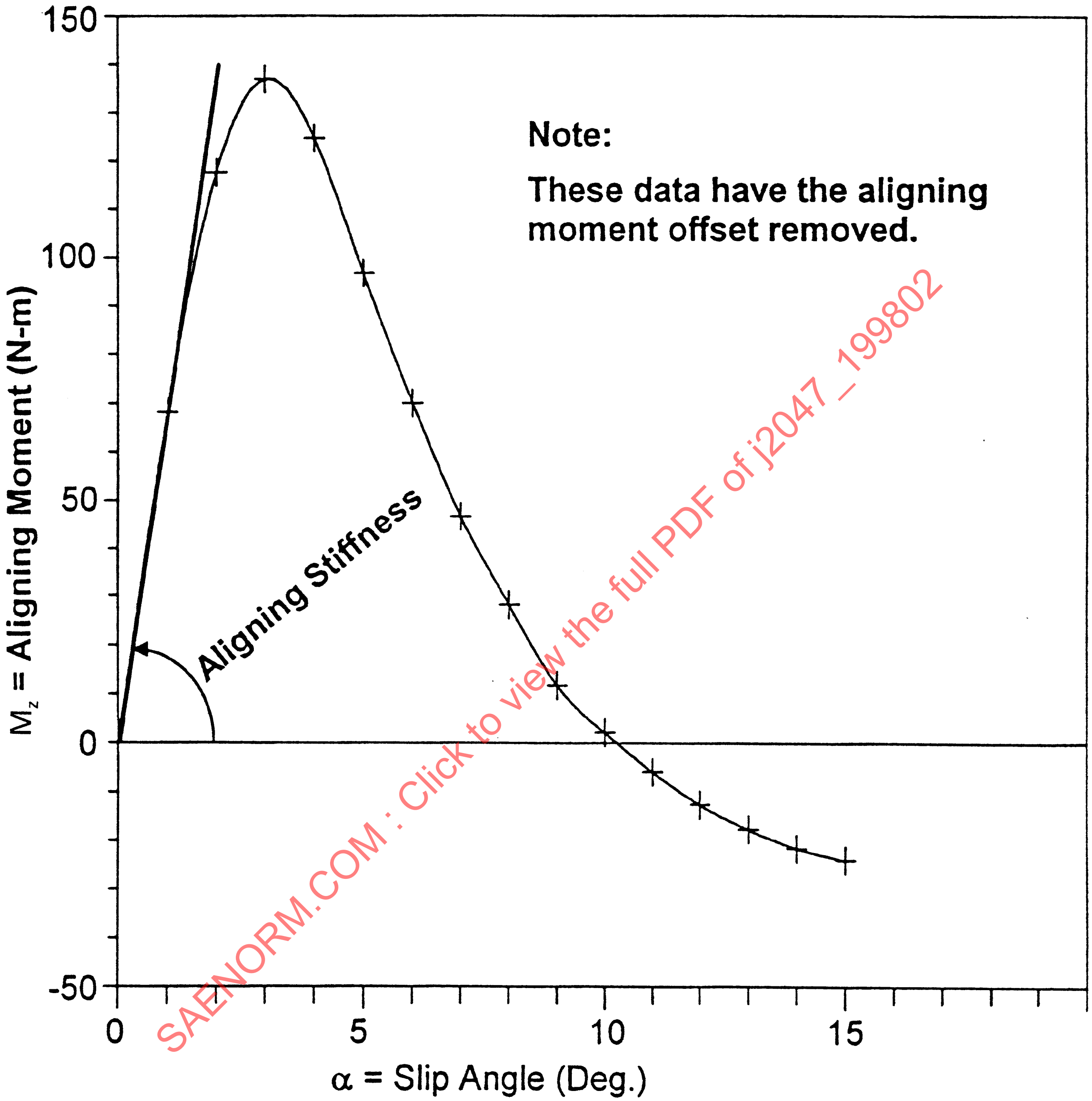


FIGURE 22—EXAMPLE OF ALIGNING MOMENT VERSUS SLIP ANGLE

16. Tire Power Loss

16.1 Tire Power Loss—The mechanical power input converted into heat by the tire. Equations 26 and 27 are given for a flat, horizontal roadway. For curved roadways (road wheel), more complex equations apply.

NOTE—Tire heat is predominately generated by hysteretic absorption of a small part of the deformation energy imparted to the tire materials by the external load and, to a lesser extent, by road roughnesses. Also contributing to tire heat are slippage between tire and road as well as large tire vibrations, if they occur. Much less important contributors to tire heat are tire nonuniformities, aerodynamic drag, air pumping in the tire cavity, and airborne tire noise.

The power loss of the tire operated under torque (T) is:

$$P_{RF} = [(T - T_B)\omega] - [F_x \cos\alpha + F_y \sin\alpha]V_T \qquad \text{(Eq. 26)}$$

The power loss of the free-rolling tire is:

$$P_{RF} = -[T_B\omega] - [F_X V_T] \qquad \text{(Eq. 27)}$$

For the free-rolling wheel, both F_X and F_Y are measured at T = 0 in presence of bearing friction torque, T_B. The effect of bearing torque can be corrected by techniques not discussed here.

16.2 Rolling Loss (Rolling Resistance Force)—The tire power loss divided by the trajectory velocity.

NOTE—Rolling loss is defined as power loss divided by speed. Hence, the unit of rolling loss is (W)/(m/s). Although this unit can be abbreviated as Newton (N), which is the unit of force, rolling loss is not a force (as is often deduced from its unit); rather, it is an energy expended by the tire per unit distance traveled. This is recognized in two newer standards, SAE J1270 and ISO 8855.

The loss of the tire rolling under wheel torque is shown in Equation 28:

$$F_R = P_R / V_T \qquad \text{(Eq. 28)}$$

The rolling loss of the tire on the free-rolling wheel is shown in Equation 29:

$$F_{RF} = P_{RF} / V_T \qquad \text{(Eq. 29)}$$

The rolling loss of the tire on the straight, free-rolling wheel is shown in Equation 30:

$$F_{RO} = P_{RO} / V_T \qquad \text{(Eq. 30)}$$

17. Tire Uniformity Characteristics—Tire uniformity 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.

17.1 Force and Moment Variations

NOTE—At this time, instantaneous forces and moments are defined in the tire face system for a special case, $\alpha = \gamma = 0°$.

17.1.1 INSTANTANEOUS FORCE OR MOMENT, F OR M—The value of a force or moment determined as a function of reference angle, ϕ, for the straight-rolling tire equipped with a machined precision rim and operating at constant rolling wheel center height. (See Figure 23.)

17.1.2 AVERAGE FORCE OR MOMENT, FAV OR MAV—The average value of instantaneous forces or moments determined over one or more complete tire revolutions.

17.1.2.1 Average Radial Force, RFAV—The average value of instantaneous radial force determined over one or more complete tire revolutions.

17.1.2.2 Average Lateral Force, LFAV—The average value of instantaneous lateral force determined over one or more complete tire revolutions.

17.1.3 FORCE OR MOMENT VARIATION, FV OR MV—The difference between instantaneous force or moment (as a function of reference angle, ϕ) and average force or moment. (See Figure 23.) (See Equations 31 and 32.)

$$FV = F - FAV \qquad \text{(Eq. 31)}$$

$$MV = M - MAV \qquad \text{(Eq. 32)}$$

Force and moment variation is expressed as a function of the reference angle by Equations 33 and 34:

$$FV(\phi) = 0.5\Sigma\{FHn \cdot \cos[n\ (\phi - FAn)]\} \qquad \text{(Eq. 33)}$$

$$MV(\phi) = 0.5\Sigma\{FHn \cdot \cos[n\ (\phi - MAn)]\} \qquad \text{(Eq. 34)}$$

See the following note and the example given in Figure 23.

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. For instance, the uniformity version:

$$F(\phi) = FAV + 0.5\Sigma\{FHn \cdot \cos[n(\phi - FAn)]\} \qquad \text{(Eq. 35)}$$

can be transformed into the classical version Equation 36:

$$f(\phi) = 0.5a_o + \Sigma[a_n \cos n\phi + b_n \sin\ n\phi] \qquad \text{(Eq. 36)}$$

by substituting Equations 37, 38, and 39 into Equation 35:

$$FAV = 0.5\ a_o \qquad \text{(Eq. 37)}$$

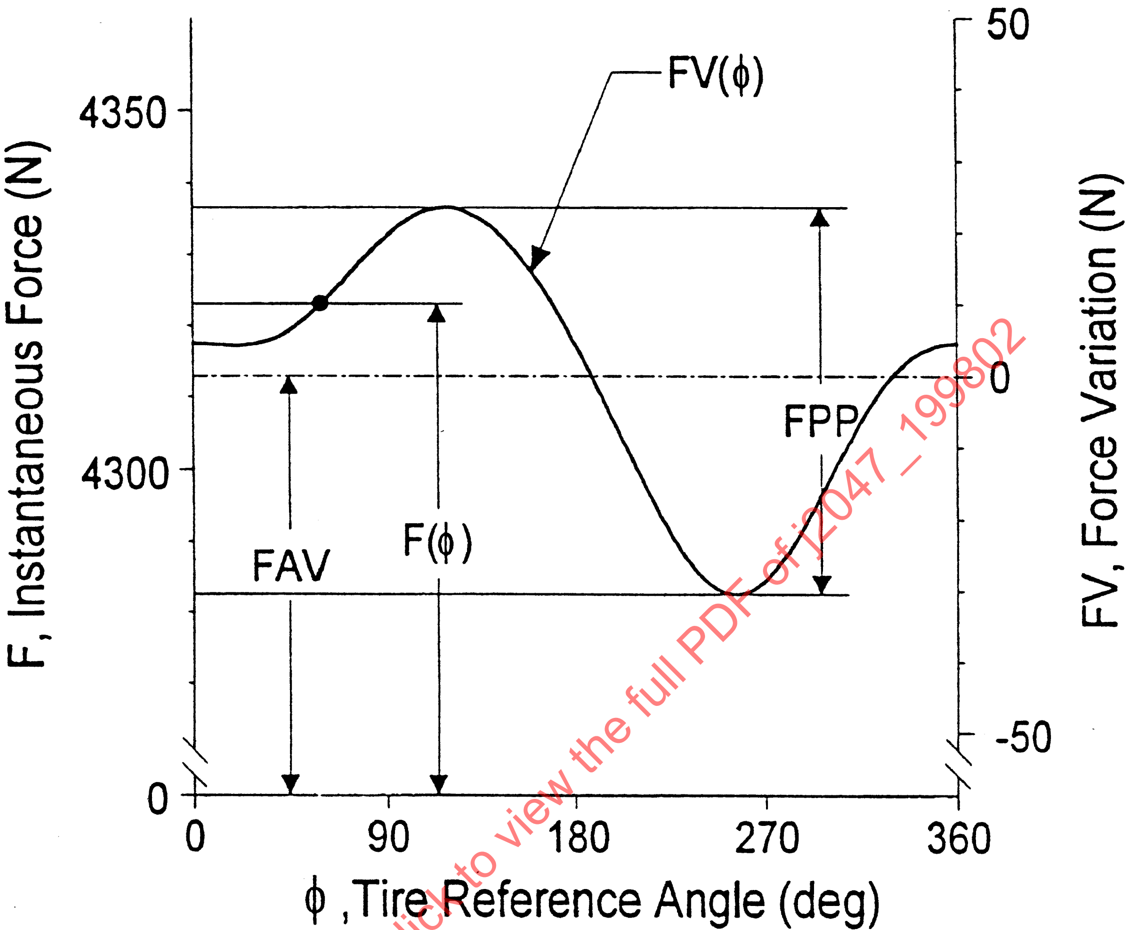
$$0.5 \cdot FHn \cdot \cos(nFAn) = a_n \qquad \text{(Eq. 38)}$$

$$0.5 \cdot FHn \cdot \sin(nFAn) = b_n \qquad \text{(Eq. 39)}$$

Individual parameters included in this series and some of their specific applications are defined in 17.1.4 through 17.1.11. Notations used for specific applications in the tire face system are summarized in Figure 24.

17.1.4 INSTANTANEOUS LONGITUDINAL FORCE, FF—The instantaneous force in F-direction as a function of reference angle, ϕ.

17.1.4.1 Longitudinal Force Variation (Fore-Aft Force Variation), FFV—The variation of the Instantaneous longitudinal force.



Fourier Series for curve shown is:

$F(\Phi) = FAV + FV$

$= FAV + 0.5[\,FH1 \bullet \cos(\Phi - FA1) + FH2 \bullet \cos(2(\Phi - FA2)) + FH3 \bullet \cos(3(\Phi - FA3))]$

$= 4313 + 0.5[44 \bullet \cos(\Phi - 90) + 18 \bullet \cos(2(\Phi - 150)) + 4 \bullet \cos(3(\Phi - 60))]$

FPP = 53N	FH1 = 44 N	FH2 = 18 N	FH3 = 4 N
FAV = 4313 N	FA1 = 90°	FA2 = 150°	FA3 = 60°

FIGURE 23—ILLUSTRATION OF FORCE VARIATION

<u>Terms and Symbols Employed When Using the Tire Face System</u>

TERM	VARIABLE				HARMONICS OF VARIABLE	
	INSTANTANEOUS	AVERAGE	VARIATION	PEAK-TO-PEAK	PEAK-TO-PEAK	HIGH POINT ANGLE
Fore-Aft Force	FF	FFAV	FFV	FFPP	FFHn	FFAn
Lateral Force	LF	LFAV	LFV	LFPP	LFHn	LFAn
Radial Force	RF	RFAV	RFV	RFPP	RFHn	RFAn
Fore-Aft Moment	FM	FMAV	FMV	FMPP	FMHn	FMAn
Lateral Moment	LM	LMAV	LMV	LMPP	LMHn	LMAn
Radial Moment	RM	RMAV	RMV	RMPP	RMHn	RMAn
Conicity Force	CF	CFAV	CFV	CFPP	CFHn	CFAn
Plysteer Force	PF	PFAV	PFV	PFPP	PFHn	PFAn
Radial Runout	RRO	RROAV	RROV	RROPP	RROHn	RROAn
Lateral Runout	LRO	LROAV	LROV	LROPP	LROHn	LROAn

FIGURE 24—SUMMARY OF TERMS AND SYMBOLS USED IN ANALYSIS OF TIRE UNIFORMITY

17.1.5 INSTANTANEOUS LATERAL FORCE, LF—The instantaneous force in L-direction as a function of reference angle, ϕ.

17.1.5.1 Conicity Instantaneous Lateral Force, CF—The component of an instantaneous lateral force which does not change its direction with respect to the tire face with a change in tire direction of rotation. It is computed from instantaneous lateral force determinations in clockwise rotation and counterclockwise direction of rotation by Equation 40:

$$CF(\phi) = 0.5[LF_{CW}(\phi) + LF_{CCW}(\phi)] \quad \text{(Eq. 40)}$$

The conicity instantaneous lateral force is a function of reference angle, ϕ.

17.1.5.2 Plysteer Instantaneous Lateral Force, PF—The component of an instantaneous lateral force which changes its direction with respect to the tire face with a change in tire direction of rotation. It is computed from instantaneous lateral force determinations in clockwise rotation and counterclockwise direction of rotation by Equation 41:

$$PF(\phi) = 0.5[LF_{CW}(\phi) - LF_{CCW}(\phi)] \quad \text{(Eq. 41)}$$

The plysteer instantaneous lateral force is a function of reference angle, ϕ.

17.1.5.3 Lateral Force Variation, LFV—Variation of the instantaneous lateral force.

17.1.6 INSTANTANEOUS RADIAL FORCE, RF—The instantaneous force in R-direction as a function of reference angle, ϕ.

17.1.6.1 Radial Force Variation, RFV—Variation of the instantaneous radial force.

17.1.7 INSTANTANEOUS ALIGNING MOMENT, RM—The instantaneous moment in R-direction as a function of reference angle, ϕ.

17.1.7.1 Instantaneous Aligning Moment Variation, RMV—Variation of the instantaneous aligning moment.

17.1.8 PEAK-TO-PEAK FORCE OR MOMENT VARIATION, FPP OR MPP—The difference between the maximum and minimum values of instantaneous force or moment during one revolution of the tire. (SeeFigure 23.)

17.1.9 REFERENCE ANGLE OF FORCE OR MOMENT VARIATION, ϕ—The reference angle at which a given force or moment is determined.

17.1.10 PEAK-TO-PEAK n-th HARMONIC OF FORCE OR MOMENT VARIATION, FHn OR MHn—The difference between the maximum and minimum values of the n-th harmonic component of force or moment during one revolution of the tire.

17.1.11 n-th HIGH POINT ANGLE OF FORCE OR MOMENT VARIATION, FAn OR MAn—The reference angle at which the first maximum value (high point) of the n-th harmonic component of force or moment variation is reached. (Example given in Figure 23.) This is the classical phase angle divided by the harmonic number.

17.2 Tire Runout

17.2.1 RUNOUT LINE—A straight line penetrating the tire general surface and lying within a plane that contains the spin axis (L-axis).

17.2.2 INSTANTANEOUS RUNOUT DISTANCE, RO—The distance from a fixed point outside the tire on the runout line to the point of intersection of the runout line with the tire general surface. The instantaneous runout distance is a function of reference angle, ϕ.

17.2.3 AVERAGE RUNOUT DISTANCE, ROAV—The difference between the instantaneous runout distance and runout variation. The positive direction of runout is pointing away from the spin axis. (See Equation 42.)

$$ROV = RO - ROAV \quad \text{(Eq. 42)}$$

The runout variation is expressed as a function of the reference angle by Equations 43 and 44:

$$RROV\ (\phi) = 0.5\Sigma\{RROHn \cdot \cos[n(\phi - RROAn)]\} \quad \text{(Eq. 43)}$$

$$LROV\ (\phi) = 0.5\Sigma\{LROHn \cdot \cos[n(\phi - LROAn)]\} \quad \text{(Eq. 44)}$$

Individual parameters included in this series and some specific applications are defined in 17.2.3.1 through 17.2.7. Notations used for specific applications in the tire face system are summarized in Figure 24.

17.2.3.1 Instantaneous Radial Runout, RRO—The instantaneous runout perpendicular to the spin axis.

17.2.3.2 Instantaneous Lateral Runout, LRO—The instantaneous runout parallel to the spin axis.

17.2.4 PEAK-TO-PEAK RUNOUT, ROPP—The difference between maximum and minimum runout during one tire revolution.

17.2.5 REFERENCE ANGLE OF RUNOUT, ϕ—The reference angle at which a given instantaneous value of runout is determined.

17.2.6 PEAK-TO-PEAK n-th HARMONIC OF RUNOUT, ROHn—The difference between the maximum and minimum values of n-th harmonic component of runout during one revolution of the tire.

17.2.7 n-th HIGH POINT ANGLE OF RUNOUT, ROAn—The reference angle at which the first maximum value (high point) of the n-th harmonic component of runout is reached. This is the classical phase angle divided by the harmonic number.

18. Tire Noise and Vibrations

18.1 Total Tire Noise—The total noise measured during the tire noise test. It is determined as the sum of individual noise elements.

18.2 Tread Noise—Airborne sound except squeal and slap, produced by interaction between the tire tread elements and a smooth road surface.

18.2.1 TONALITY—Tire noise (up to 2500 Hz) associated with the fundamental frequency and harmonics defined by the rate at which individual tread elements come into contact with the road surface.

18.2.2 SIZZLE—Tread noise characterized by a soft "frying" sound; particularly noticeable on a very smooth road surface.

18.3 Tread Vibrations—Vibrations (15 to 100 Hz) perceived tactually or audibly or both.

18.3.1 ROUGHNESS—Vibrations (15 to 100 Hz) perceived tactually or audibly (or both), generated by a tire rolling on a smooth road surface and producing the sensation of driving on a coarse or irregular road surface.

18.3.2 HARSHNESS—A quickly decaying response to single sharp edge tire impact evaluated primarily tactilely accompanied by noise in the 30 to 100 Hz range.

18.4 Squeal—Narrow-band airborne tire noise (600 to 1200 Hz) excited by either longitudinal slip or slip angle or both.

18.4.1 CORNERING SQUEAL—The squeal produced by a free-rolling wheel 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 the tire 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 Moan—A sustained, low-frequency (60 to 150 Hz) sound generated by higher harmonics of either force and moment variations, runout, or tread element vibrations.

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

18.9 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 is reduced to a depth equal to the height of tread wear indicator.

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.

19.1.5 AVERAGE TREAD DEPTH—The average depth of all tread grooves and voids.

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 Tread Wear 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.