



SURFACE VEHICLE INFORMATION REPORT

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(R) A Dictionary of Terms for the Dynamics and Handling of Single Track Vehicles
(Motorcycles, Scooters, Mopeds, and Bicycles)

RATIONALE

This document has been revised to comply with SAE Five-Year Review policy and to place it into the new SAE Technical Standards Board format. This is the first revision since the original issue (1985). The current (2019) revision updated terminology and definitions for newer technologies and motorcycle suspension designs and refinements. In revising this document, the committee reviewed existing SAE standards and relevant ISO standards in an effort to harmonize conflicting definitions, when possible. Additionally, terms that were more general in nature were removed from this document and may be found in the SAE Information Report SAE J3133.

This terminology is intended to provide a common nomenclature for use by those with a need to understand or describe the dynamics and handling of two-wheeled, single track vehicles. It is intended to span the gap between vehicle dynamics specialists and those with a more general interest. It is pertinent to such areas as education, vehicle design and development, the description of two-wheeler properties, rider training, and the preparation of standards and regulations.

This report was prepared by the SAE Motorcycle Technical Steering Committee, which solicits suggestions for improvements and additions to be considered in future revisions. Comments should be directed to SAE Headquarters.

SAE J1451 has been reaffirmed to comply with the SAE Five-Year Review policy.

FOREWORD

The term motorcycle, as used in the standard, refers to a motorized two-wheel, single track vehicle, in which the front caster assembly and the swing arm assembly are attached to the frame body with respective rigid joints that allows movement about only one axis, respectively. The front caster assembly rotates about an axis fixed in the vehicle frame and the swing arm assembly rotates about a lateral axis, also fixed in the vehicle frame. For simple dynamic evaluations, the vehicle frame and swing arm assembly can be considered to be a single rigid body, and the associated lateral and longitudinal coupling is ignored.

In simple dynamic terms a motorcycle is assumed to consist of nominally rigid bodies: a front caster mechanism (front fork assembly), the frame body also functioning as a caster mechanism, and the swing arm assembly. More detailed analyses can include additional rigid body elements such as the rotating wheels and drive line components, as well as flexibility within the component bodies. While computational modeling of a motorcycle can be more complex, these three simplified bodies, axes and motions can adequately describe basic single-track vehicle lateral-directional dynamics for many purposes. The term "vehicle" means motorcycle, scooter, moped, or bicycle accordingly in this definition.

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This Report references a vehicle-fixed axis system that is connected to and moves with the vehicle's frame body. It is a mutually perpendicular set of three axes fixed in the longitudinal plane of symmetry of the upright vehicle. The initial orientation of the longitudinal axis is horizontal and in the direction of straight line forward motion, the lateral axis is directed toward the right side of the vehicle, and the initially unperturbed vertical axis is down and parallel to the gravity vector.

NOTE: The vehicle axis system can be placed anywhere in the vehicle but is usually fixed at the frame body's center of gravity or at ground level below that.

A corresponding Earth-fixed axis system has axes parallel to the initial orientation of the vehicle axis system. This ground-based axis system is an inertial reference frame and is used to describe a vehicle trajectory or motion referenced to a fixed ground point.

Axis Systems - To simplify the explanations, the document avoids the scientifically common usage of x, y, z to define axis systems, and instead uses the descriptive terms; longitudinal, lateral, and vertical.

Motions are described by translations along the vehicle-fixed axes and the following angular rotations: roll about the longitudinal axis, yaw about the vertical axis, and pitch about the lateral axis.

NOTE: If the longitudinal axis is not defined as passing through the front and rear tire contact points, the apparent rolling motion or lean of the rider, relative to the ground, represents a combination of roll and translation.

Single track vehicles other than motorcycles may have different configurations. For example, most bicycles consist of only two nominally rigid bodies with no swing arm.

For dynamic analysis purposes, these terms assume a rigid rider, seated in the normal riding position, atop the frame body and centered in the longitudinal plane of symmetry unless otherwise defined.

For most purposes the terms weight or mass can be used interchangeably with the exception of characterizing motions where there is a clear distinction between weight and mass. Weight is simply mass times acceleration due to gravity 32.2 ft/s^2 (9.81 m/s^2).

1. SCOPE

Terminology within this document is limited to the dynamics and handling characteristics of single track, two-wheeled vehicles.

1.1 Purpose

This terminology is intended to provide a common nomenclature for use by those with a need to understand or describe the dynamics and handling of two-wheeled, single track vehicles. It is intended to span the gap between vehicle dynamics specialists and those with a more general interest.

2. REFERENCES

2.1 Applicable Documents

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

2.2 Related Publications

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

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J213 Motorcycle Classifications

SAE J670 Vehicle Dynamics Terminology

Dictionary of Automotive Engineering, SAE, 2nd Edition, 1995 (Dictionary of AE)

2.2.2 Other Publications

Vittore Cossalter - Motorcycle Dynamics (2nd Edition) (Cossalter)

Hurt, H.H., Ouellet, J.V., and Thom, D.R., Motorcycle Accident Cause Factors and Identification of Countermeasures Volume I: Technical Report; Traffic Safety Center, University of Southern California, U.S. Dot-HS-5-01160, January 1981(Final Report) (Hurt)

Phil Irving - Motorcycle Engineering Clymer Publications, 5th printing, 1973. (Irving)

Paul Thede and Lee Parks - Race Tech's Motorcycle Suspension Bible (2010) (Thede et al.)

3. DEFINITIONS

3.1 ACCELERATION

Time rate of change of velocity.

3.2 ACCELERATION CONTROL INPUT

Positioning, or application of force to, a control means of the propulsion system (e.g., throttle grip, cruise control) for the purpose of maintaining or changing vehicle longitudinal velocity (speed). See *throttle (control)*.

3.3 ACCELERATION INDEX

Ratio of steer torque to lateral acceleration in a steady state turn.

3.4 AERODYNAMIC DRAG FORCE

Longitudinal component of the aerodynamic forces acting on the motorcycle. Force opposite to the direction of travel due to aerodynamic resistance, measured in the longitudinal plane of symmetry of the vehicle. For some engineering purposes, it can be defined, alternatively, parallel to the relative wind vector.

3.5 AERODYNAMIC LIFT

Force in the direction of the vertical axis caused by aerodynamic forces acting on the motorcycle.



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3.6 AERODYNAMIC PITCH MOMENT

Moment about the lateral axis caused by the aerodynamic forces and moments acting on the motorcycle.

3.7 AERODYNAMIC ROLL MOMENT

Moment about the longitudinal axis caused by the aerodynamic forces and moments acting on the motorcycle.

3.8 AERODYNAMIC SIDESLIP ANGLE

Angle formed between the longitudinal axis and the relative wind velocity in the horizontal plane.

3.9 AERODYNAMIC YAW MOMENT

Moment about the vertical axis caused by the aerodynamic forces and moments acting on the motorcycle.

3.10 ALIGNING MOMENT (ON TIRE)

Moment at the tire contact point, due to tire/roadway interaction which tends to keep the wheel plane parallel to the motorcycle velocity vector. Refer to SAE J670.

3.11 ALIGNMENT VARIATION

Displacements and deformations of a rotating wheel and the suspension caused by forces and moments applied to the wheel.

3.12 AMBIENT WIND VELOCITY

Horizontal component of the wind velocity relative to the roadway (horizontal plane).

3.13 ANGULAR ORIENTATION OF THE MOTORCYCLE

Orientation of the vehicle-fixed axis system (relative to the earth-fixed system) which is given by the following three angular rotations: roll is rotation about the longitudinal axis, yaw is rotation about the vertical axis, and pitch is rotation about the lateral axis.

3.14 ANGULAR VELOCITY

Rotational velocity about an axis, which does not include any translational component.

3.15 ANTI-SQUAT

The tendency of rear suspension to extend under longitudinal acceleration.

3.16 APPROACH ANGLE

The smallest angle, in a planar side view of a motorcycle, formed by the surface on which the motorcycle is standing and a line tangent to the front tire circumference and touching any part of the motorcycle forward of the front tire (such as the front fender).

3.17 ASYMPTOTIC STABILITY

The state of stability at a prescribed trim condition where, for a small disturbance or control input, the motorcycle motion variables tend to return to the trim values.

3.18 AUTOSTABILIZING

The dynamic behavior of the front fork assembly whereby it tends to return to a centered position if proceeding in a straight line or to a trim condition if the motorcycle is in a turn.

3.19 AXIS SYSTEM

A coordinate system fixed in the vehicle, a component body, or the roadway (earth), for purposes of defining positions and motions.

3.20 AXLE

The shaft which comprises the spin axis of a wheel.

3.21 AXLE OFF-SET

Perpendicular distance between the front axle and the centerline of the front fork tubes.

3.22 BANK ANGLE

See *roll angle*.

3.23 BANK MOMENT

See *roll moment*.

3.24 BANK TO TURN

The process of rolling a motorcycle to accomplish a turn.

3.25 BANK VELOCITY

See *roll velocity*.

3.26 BANKING

Common motorcyclist term used to describe rolling actions or angles. See *roll angle*.

3.27 BODY

Refers to the rigid part of a vehicle or vehicle component, for dynamic analysis or descriptive purposes.

3.28 BOTTOMING

See *bottoming out*.

3.29 BOTTOMING OUT

Typically used to indicate the vehicle suspension system is at maximum compression. Can also refer to the frame or chassis contacting the ground plane or roadway.

3.30 BOUNCE MOTION

Translational motion of the vehicle in the direction of an earth-fixed vertical axis. Vertical translation if the vehicle is upright. Refer to SAE J670.

3.31 BRAKING

The process of decelerating the vehicle by applying the brakes.

3.32 BRAKING CONTROL INPUT

An application of force to a brake lever or brake pedal for the purpose of changing or maintaining vehicle longitudinal velocity (speed).

3.33 CAMBER

Inclination of the plane of a wheel relative to the inertial vertical.

3.34 CAMBER ANGLE

The roll or tilt angle of the plane of a wheel, measured relative to vertical, assuming the roadway is horizontal. Referred to as inclination angle in SAE J670.

3.35 CAMBER FORCE

Tire lateral force due to wheel camber angle.

3.36 CAMBER STIFFNESS

Change in tire lateral force due to a change in camber angle, usually evaluated around zero camber angle and at zero tire slip angle.

NOTE: Stiffness is a word of art referring to a gradient or sensitivity.

3.37 CAMBER THRUST

See *camber force*.

3.38 CAMBER TORQUE

Component about the vertical axis of moments applied from the road plane to the wheel due to camber angle when the tire slip angle is zero.

3.39 CAPSIZE

Describes a motorcycle falling over to the side.

3.40 CAPSIZE MODE

A usually low frequency dynamic characteristic of the vehicle. If stable, a disturbed vehicle will gradually return to an upright or trim roll angle; and if unstable, the vehicle will gradually roll and turn from its original direction of travel. If the capsize instability is slow, on the order of seconds, it is easy for the rider to control.

3.41 CASTER

Refers to the longitudinal distance, at the ground, between the vertical plane through the wheel spin axis and the projected point of intersection of the steering axis at the ground. For a motorcycle, see *mechanical trail*.

3.42 CASTER ANGLE

See *rake angle*.

3.43 CASTER MECHANISM

A physical device in which a rolling wheel trails behind a pivot axis and is free to swivel to provide a self-centering effect on the wheel. For example, a typical front fork assembly. For in-line, two-wheel vehicles, caster combined with an angled steering axis (rake), contributes to directional stability at speed.

3.44 CENTER OF GRAVITY (C.G.)

Point in a free rigid body where, if a force is applied, only translational acceleration results. Conversely, if a force is applied to a free body at any point other than the center of gravity, a rotational acceleration will occur, due to the resulting moment about the center of gravity.

3.45 C.G.

See *center of gravity*.

3.46 CENTRIFUGAL CASTER

Self-centering effect created by the rotation of a wheel and gyroscopic moments.

3.47 CENTRIFUGAL FORCE

An apparent force or acceleration at a point on a rotating body perpendicular to the axis of rotation.

3.48 CENTRIPETAL ACCELERATION

When turning or cornering at a given forward velocity, a lateral acceleration vector pointed toward the outside of the turn. A lateral acceleration due to turning or cornering at a given forward velocity.

3.49 CLOSED LOOP CONTROL

See *feedback control*.

3.50 COEFFICIENT OF FRICTION

The ratio of the translational force applied between two adjacent surfaces to the force pressing them together. Can be "static" or "sliding". Coefficient of static friction is the value just before relative motion occurs between the two surfaces. Coefficient of sliding friction is after relative motion occurs. See *friction*. For example, a measure of the amount of friction or grip between a vehicle's tires and the roadway surface.

3.51 COMPLIANCE (MECHANICAL)

Structural deflection, axial or torsional bending.

3.52 COMPRESSION (SUSPENSION)

In spring or strut suspension systems, the reaction caused by upward movement of the wheel. Also refers to the relative displacement of sprung and unsprung masses in which the distance between the masses decreases from that at static condition, for any type of suspension system.

3.53 COMPRESSION DAMPING

Resistance to suspension compression velocity.

3.54 CONICITY

The deviation from true symmetry about the wheel plane of a tire, such that, instead of the tread profile forming an ideal cylinder, it forms a cone. In consequence, the tire's path would be curving and not straight.

3.55 CONICITY FORCE

Tire lateral force due to conicity when the tire slip angle and the camber angle are zero. It can be positive or negative.

3.56 CONTACT PATCH

Portion of a tire surface that is in contact with the roadway.

3.57 CONTROL INPUT

Positioning, or application of force, to a control means of the vehicle (typically, steering, braking, rider lean or throttle control) for the purpose of maintaining or inducing a change in the motion of the vehicle.

3.58 CONVERGENT STABILITY

State of stability, at a prescribed trim condition, where, a small disturbance or control input causes an oscillatory vehicle response of decreasing amplitude and the vehicle motion variables tend to return to the trim values. See also *asymptotic stability*.

3.59 CORNERING FORCE

Tire lateral force due mainly to slip and camber angle on cornering.

3.60 CORNERING LIMIT

Maximum vehicle lateral acceleration at a given speed; usually determined by road clearance of the vehicle's rigid structures (frame, engine cylinder heads, muffler, etc.) or by tire/roadway adhesion.

3.61 CORNERING STIFFNESS

Change in the lateral force due to a change in slip angle.

NOTE: Stiffness is a word of art referring to a gradient or sensitivity. Refer to SAE J670.

3.62 CORNERING WEAVE

A combined pitching and yawing motion which may occur in a steady-state turn, under certain adverse conditions. See *pitch-yaw coupling*.

3.63 COULOMB DAMPING

Damping in which a constant force due to sliding (Coulomb) friction opposes the vibratory motion.

3.64 COULOMB FRICTION

Friction force between two surfaces sliding against one another. Kinetic friction.

3.65 COUNTERBALANCE (RIDER ACTION)

Adjusting body position and weight to balance a motorcycle at very low speeds. Requires rider weight shift that is counter to, or opposes, the lean of the motorcycle.

3.66 COUNTER STEER (INITIATING A TURN)

Rider steer torque in the direction opposite to that which the vehicle is turning or is intended to turn. The counter steering torque necessary to initiate the roll angle required for a given turn should be distinguished from the sustained steer torque and steering angle necessary to maintain a constant radius and roll angle in a steady state turn. At all but the lowest speeds, the initial counter steer torque and angle are both opposite the desired turn direction. The sustained trim steer angle is typically in the same direction as the turn.

3.67 COUNTER STEER (CORRECTING A SLIDE)

If the rear wheel slides in a curve (i.e., the rear sideslip is much greater than the front) in this condition the handlebar must be steered away from the curve and reduced or opposite steering input must be adopted to compensate.

3.68 COUPLED MOTIONS

Coupling may occur when different vehicle motions and/or vehicle component motions (e.g., about different axes) are lightly damped and have similar frequencies. For example, it can result in the combined roll and yaw motions associated with the weave mode.

3.69 COURSE ANGLE

See *path angle*.

3.70 CURB MASS

Curb weight divided by gravitational constant.

3.71 CURB WEIGHT

The total weight of the motorcycle including all operating fluids, at recommended levels and fuel level of more than 90% of rated capacity, but without operator, passengers, or cargo.

3.72 DAMPER

A device which produces a reactive force or torque as a function of translational or rotational velocity, respectively. For example, a shock absorber.

3.73 DAMPER RATE

The amount of translational force or rotational torque produced by a damper as a function of velocity.

3.74 DAMPER STROKE

Displacement between the damper actuator positions when fully extended and when fully compressed.

3.75 DAMPING

For an oscillatory system, progressive reduction in the amplitude of oscillation. Dampers provide a reactive force or torque which opposes translational or rotational velocity. Damping can result from damping devices or from other damping properties of the vehicle.

3.76 DAMPING RATIO

A measure of the amount of damping for oscillatory systems. Refer to SAE J670.

3.77 DAMPING TORQUE OF THE FRONT CASTER ASSEMBLY

Damping torque about the steer axis at a given steer angle velocity which does not include damping due to tire and road surface interaction.

3.78 DEGREE-OF-FREEDOM

Characteristic motion of the vehicle, or a relative motion between component bodies. Measured about or along an axis. One or more degrees-of-freedom are associated with each mode of motion. Refer to SAE J670.

3.79 DEPARTURE ANGLE

The smallest angle, in a planar side view of a motorcycle, formed by the surface on which the motorcycle is standing and a line tangent to the rear tire circumference and touching any part of the motorcycle aft of the rear tire.

3.80 DESTABILIZE

To reduce the stability or damping, e.g., of a characteristic motion or dynamic mode.

3.81 DIRECTIONAL CONTROL

Control made by the rider in order to maintain or to change, the path and path angle of the motorcycle or a characteristic value. Also called lateral-directional control.

3.82 DIRECTIONAL STABILITY

Tendency of a vehicle to maintain a desired path under normal steering control, when subjected to directional disturbances such as cross-winds, roadway camber changes, or braking on irregular surfaces.

3.83 DISTURBANCE RESPONSE

Motion of the motorcycle resulting from external force or moment inputs applied to the motorcycle.

3.84 DIVE

Nose-down pitching due to front suspension compression and rear suspension extension during moderate to heavy braking.

3.85 DIVERGENCE

A motion with progressively increasing amplitude; an instability.

3.86 DIVERGENT INSTABILITY

State of instability at a prescribed trim where a small disturbance or control input causes an ever-increasing value of the motion variables.

3.87 DRAG (AERODYNAMIC)

See *aerodynamic drag force*.

3.88 DRIFT

Controlled lateral slide in a turn.

3.89 DRIFT OUT

Increase in the turning radius.

3.90 DRIVE TRAIN

The mechanism that transmits motive power from the motor/transmission to a driven wheel.

3.91 DRY WEIGHT

The total weight of the motorcycle without an operator, passenger, cargo and excluding all operational fluids.

3.92 DYNAMICS

Branch of classical mechanics concerned with the motions of a body or an assembly of bodies due to applied forces and moments.

3.93 EFFECTIVE CENTER OF TIRE CONTACT

Center of pressure in the contact area of the tire and the roadway.

3.94 EIGENVALUE

A value, derived from mathematical modeling and equations of motion, which describes the frequency, amplitude, and damping properties of a mode of motion.

3.95 EQUATIONS OF MOTION

A set of mathematical relationships which describes and quantifies the dynamics of the vehicle.



3.96 EQUILIBRIUM

A state of balance among the forces and moments acting on the vehicle, wherein the resulting motions have achieved steady-state values.

3.97 FAIRING, FRONT

A device mounted on the front of a motorcycle, whose purpose may include providing the rider some measure of protection from rain, wind and airborne hazards, reducing drag, modifying appearance, and/or managing airflow to cooling components. Fairings may be attached to either the front caster assembly or frame body assembly, and may incorporate head lamp(s), turn signals, a transparent windshield, accessories, and storage for small items.

3.98 FEEDBACK CONTROL

Process of comparing vehicle output motions with desired (input) motions in order to regulate against disturbances and follow a prescribed path. The rider accomplishes this by making control actions in response to perceived cues, thereby establishing feedback loops. Also called closed-loop control. See also *rider control*.

3.99 FIXED CONTROL

A mode of vehicle control wherein the position of some point of a control system is held fixed. Rider fixing the steering system typically results in an unstable condition.

3.100 FORCE CONTROL

The typical mode of motorcycle control wherein inputs or restraints are placed upon the steering system in the form of forces, independent from the displacement required.

3.101 FORK(S)

Mechanism connecting the steering head to the front wheel axle, usually consisting of two parallel legs.

3.102 FORK ASSEMBLY

A connected set of components which rotates as a single casting body about the steer axis. It includes the forks, front axle, wheel and tire, front brake, handlebars, front fender, etc., and in some cases the fairing, lights and/or windscreen.

3.103 FORK BRACE

A device that rigidly connects both fork legs between the top of the fender and the bottom of the triple clamp assembly. The additional bracing is intended to reduce fork flexing and twisting.

3.104 FORK BRIDGE

See *triple clamp*.

3.105 FORK CLAMP

See *triple clamp*.

3.106 FORK HINGE LINE

See *steer axis*.

3.107 FORK OFFSET

See *steer axis offset*.