

	<b>SURFACE VEHICLE RECOMMENDED PRACTICE</b>	<b>SAE</b>	<b>J1594 JUL2010</b>
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		Superseding	J512 DEC94
(R) Vehicle Aerodynamics Terminology			

## RATIONALE

This document has been revised to correct numerous errors and omissions in the previous (1994) revision. That revision, whose sole purpose was to place it into the new SAE Technical Standards Board format, was the only revision to the original (1987) issue. The current (2010) revision has also been used as an opportunity to update applicable references, delete those that are no longer readily available, improve the organization of the document, and modify the directional sense of the axes system as indicated below.

The following is the rationale for selection of specific terminologies, conventions, and definitions.

**Axes System** – The SAE Road Vehicle Aerodynamics Committee agreed to modify the axes system in the original SAE J1594 issued in 1987, to have x positive rearward and z positive upward, to correspond with the positive directions of drag and lift, respectively. This change does not affect the positive sense of the aerodynamic forces and moments as defined in the previous version of SAE J1594, only their directional sense (specifically for drag, lift, yawing moment, and rolling moment) relative to the signs of the x and z axes in the new axes system.

**Resolving Center** – Center of gravity (c.g.) and body geometry-defined resolving centers used in vehicle dynamics (Reference 2.1.1.1) and aeronautics, respectively, are not satisfactory for road vehicle aerodynamics applications. A large portion of automotive aerodynamics development testing is performed before the vehicle c.g. is known. The c.g. location can also vary significantly with vehicle option content and loading. Relating the axis center to the body geometry is also problematic when major body geometry changes are explored during wind tunnel tests. These situations are avoided by placing the resolving center at ground level, positioned at mid-wheelbase and mid-track. An added advantage of this location is the direct translation of aerodynamic loading to tire contact patch ground reactions.

**Forces and Moments** – The primary terminology for aerodynamic force and moment components (drag, lift, side force, pitching moment, yawing moment, and rolling moment) were adopted from aeronautical usage. The symbols for drag and lift (D & L) were also taken from aeronautics. To maintain consistency with the symbols for drag and lift, and to provide a mnemonic aid, the other component symbols (S, PM, YM and RM) were based on terminology.

**Attitude Angles** – Vehicle attitude angle definitions and symbols also correspond to existing aerodynamics terminology as used for aircraft development.

**Force and Moment Coefficients** – Aerodynamic coefficient definitions were chosen consistent with aeronautical terminology, with one exception. Unlike typical aerodynamics convention, the wheelbase is used to compute moment coefficients. Although it makes more aerodynamic sense to use a body length dimension, this is more likely to change during wind tunnel development than wheelbase. Using wheelbase (WB) provides an additional advantage with the chosen axes system in simplifying the computation of axle loadings. For example, the lift coefficient for the front axle is then equal to  $CLF = CL/2 + CPM$ . However, if CPM were based on an overall length (OAL), a ratio of WB and OAL would have to be included in the computation.

**Vehicle Parameters** – The wheelbase designator (L) used in vehicle dynamics (Reference 2.1.1.1) was not adopted, since it is used for the aerodynamic lift force. Frontal area and scale factor symbols are consistent with aerodynamic usage.

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Flow Parameters – Symbols and definitions for air flow parameters were chosen consistent with aerodynamics terminology. The definition of equivalent full scale velocity ( $V_{EQ}$ ) is included to provide a simple means of relating reduced scale model flow conditions to full scale. Standard day conditions were chosen to correspond to those defined at sea level conditions for the U.S. Standard Atmosphere adopted by NASA, NOAA and USAF in 1976 (Reference 2.1.3.1). For high-speed (motorsports) and high-humidity (thermal) applications, references are cited to account for the effects of compressibility on dynamic pressure and relative humidity on air density, if deemed necessary.

Yaw-Weighted Drag Coefficient – Ambient wind magnitude, heading angle and vehicle path directions have an effect on the overall average aerodynamic drag of a vehicle during a particular duty cycle. The yaw-weighted drag coefficient is defined as the average drag coefficient during a particular driving schedule and ambient wind input. The wind and driving schedule factors affecting the wind-averaged drag coefficient have not been standardized. Some examples of yaw-weighted drag coefficient computations are given in References 2.1.1.2 - 2.1.1.4.

## FOREWORD

The original SAE Road Vehicle Aerodynamics Terminology included in SAE J670 (ca. 1974) was found inadequate for use by vehicle aerodynamics engineers. The originating Vehicle Dynamics Committee therefore appointed F.N. Beuavais as chairman and organizer of a new Vehicle Aerodynamics Subcommittee. This subcommittee first met in October 1975 to begin work on a new Aerodynamics Terminology. A comprehensive survey of terminology used in North America, Europe, and Japan showed that there was no standard set of nomenclature in use. The subcommittee in association with a number of non-member contributors used this survey, along with traditional (aircraft) aerodynamics and vehicle dynamics nomenclature, as inputs to a first draft document completed in 1977.

The ever-increasing activity in ground vehicle aerodynamics led to the formation of a full committee, the Road Vehicle Aerodynamics Committee (RVAC), in 1983. The RVAC completed the final revisions of the terminology and voted its initial adoption in March 1986.

### 1. SCOPE

This terminology is intended to provide a common nomenclature for use in publishing road vehicle aerodynamics data and reports.

### 2. REFERENCES

#### 2.1 Applicable Documents

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

##### 2.1.1 SAE Publications

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

##### 2.1.1.1 SAE J670 –Vehicle Dynamics Terminology

##### 2.1.1.2 SAE J1252 – SAE Wind Tunnel Test Procedure for Trucks and Buses

- 2.1.1.3 SAE Paper No. 750704 – Comparison of Effectiveness of Commercially Available Devices for the Reduction of Aerodynamic Drag on Tractor Trailers, 1975.
- 2.1.1.4 SAE Paper No. 840298 – The Effect of Ambient Wind on a Road Vehicle's Aerodynamic Work Requirement and Fuel Consumption, 1984.
- 2.1.1.5 Aerodynamics of Road Vehicles, W.-H. Hucho, 4th Edition, 1998.
- 2.1.1.6 SAE Paper No. 2005-01-0870 – Uncertainty Analysis of Aerodynamic Coefficients in an Automotive Wind Tunnel, 2005.
- 2.1.1.7 SAE TSB003 – Rules for SAE use of SI (Metric) Units

## 2.1.2 NACA Publication

Available online from NASA.

- 2.1.2.1 Report 1135 – Equations, Tables, and Charts for Compressible Flow, 1953.

## 2.1.3 NOAA Publication

Available online from the National Technical Information Service.

- 2.1.3.1 NOAA-S/T 76/1562—U.S. Standard Atmosphere, 1976. Product Code ADA035728.

## 2.1.4 Wiley-interscience Publication

Available from John S. Wiley and Sons, New York.

- 2.1.4.1 Low-Speed Wind Tunnel Testing, J.B. Barlow, W.H. Rae, and A. Pope, 3rd Edition, 1999.

## 2.2 Related Publications

Not applicable.

## 3. AXES SYSTEM AND VEHICLE ANGLES

### 3.1 Orientation

The stability axes system yaws with the vehicle or model (Figure 1). Axes form an orthogonal system, which is, as seen by the driver:

- a. x direction: positive rearward
- b. y direction: positive right
- c. z direction: positive up

### 3.2 Resolving Center

The origin of the axes system is located in the plane of the ground surface at mid-wheelbase and mid-track.

### 3.3 Vehicle Angles

- a. Pitch Angle ( $\alpha$ ): Angle between the vehicle body longitudinal axis (x-direction) and the ground surface, positive nose-up.
- b. Yaw Angle ( $\psi$ ): Angle between the x-axis and the free-stream velocity vector ( $\vec{V}_\infty$ ), positive nose-right (Figure 2).
- c. Roll Angle ( $\phi$ ): Angle between the vehicle body lateral axis (y-direction) and the ground surface, positive right side down.

## 4. TERMINOLOGY

### 4.1 Vehicle Parameters

- a. Wheelbase (WB): Distance (in the x-direction) between the front and rear axles.
- b. Frontal Area (A): Vehicle area projection in the x-direction.
- c. Scale Factor ( $\sigma$ ): Model dimensional fraction of full scale vehicle.
- d. Vehicle Velocity ( $\vec{V}$ ): Vehicle velocity vector with magnitude V in the -x direction (Figure 2).

### 4.2 Flow Parameters

- a. Wind Velocity ( $\vec{V}_W$ ): Ambient wind velocity vector, assumed to lie in the x-y plane, with magnitude  $V_W$  with direction  $\theta$  relative to the x-axis (Figure 2).
- b. Wind Angle ( $\theta$ ): Angle of the wind velocity vector relative to the x-axis (Figure 2), positive when the wind approaches from the left.
- c. Free-stream Speed ( $V_\infty$ ): Magnitude of the wind velocity vector relative to the vehicle velocity vector:  $V_\infty = |\vec{V}_W - \vec{V}|$ .
- d. Dynamic Pressure ( $q_\infty$ ):  $q_\infty = 1/2 \cdot \rho \cdot V_\infty^2$

NOTE: In wind tunnel applications, the dynamic pressure should be based on an empty-tunnel calibration. See References 2.1.1.5 and 2.1.4.1. At higher speeds (e.g., motorsports), compressibility corrections to dynamic pressure and velocity should be considered. See References 2.1.1.6 and 2.1.2.1.

- e. Air Density ( $\rho$ ):  $\rho = 1.2250 \text{ kg/m}^3$  at standard day conditions.
- f. Air Viscosity ( $\mu$ ):  $\mu = 1.7894 \times 10^{-5} \text{ N}\cdot\text{s/m}^2$  at standard day conditions.
- g. Standard Day Conditions: dry air at 15 °C and 101.325 kPa

NOTE: Dry air density and viscosity at other than standard day conditions can be computed from Equations 1 and 2:

$$\rho = 1.2250 \cdot (288.15 / (273.15 + T)) (\rho / 101.325) \text{ kg/m}^3 \quad (\text{Eq. 1})$$

$$\mu = (1.7203 + 0.00460 \cdot T) \times 10^{-5} (\text{for } T = 0^\circ \text{ to } 60^\circ \text{C}) \text{ N}\cdot\text{s/m}^2 \quad (\text{Eq. 2})$$

where:

T = Air temperature in degrees Celsius  
p = Atmospheric pressure in kiloPascals

(Density and viscosity data from Reference 2.1.3.1.)

In environments where relative humidity is high, the calculation of moist-air density as a function of temperature, pressure, and relative humidity should be considered. See Reference 2.1.4.1.

- h. Boundary Layer Thickness ( $\delta$ ): Height above a surface where the local velocity  $u(z)$  is 99% of the free-stream speed ( $V_\infty$ ).
- i. Displacement Thickness ( $\delta^*$ ):  $\delta^* = \int_0^\infty (1-u(z)/V_\infty) \cdot dz$
- j. Momentum Thickness ( $\Theta$ ):  $\Theta = \int_0^\infty u(z)/V_\infty(1-u(z)/V_\infty) \cdot dz$
- k. Local Static Pressure ( $p$ )
- l. Free-Stream Static Pressure ( $p_\infty$ )
- m. Pressure Coefficient ( $C_p$ ):  $C_p = (p-p_\infty)/q_\infty$
- n. Reynolds Number per Unit Length ( $Re/l$ ):  $Re/l = \rho \cdot V_\infty / \mu$
- o. Reynolds Number ( $Re$ ):  $Re = \rho \cdot V_\infty \cdot WB / \mu$
- p. Equivalent Velocity ( $V_{EQ}$ ):  $V_{EQ} = V_\infty \cdot \sigma$

#### 4.3 Forces and Moments

The preferred designators for aerodynamic forces and moments are (see Figure 1):

- a. Drag (D): Aerodynamic force acting along the x-axis, positive rearward ( $F_x = D$ ).
- b. Lift (L): Aerodynamic force acting along the z-axis, positive upward ( $F_z = L$ ).
- c. Side Force (S): Aerodynamic force acting along the y-axis, positive to the right ( $F_y = S$ ).
- d. Pitching Moment (PM): Aerodynamic moment about the y-axis, positive nose-up ( $M_y = PM$ ).
- e. Yawing Moment (YM): Aerodynamic moment about the z-axis, positive nose-right ( $M_z = -YM$ ).
- f. Rolling Moment (RM): Aerodynamic moment about the x-axis, positive right side down ( $M_x = -RM$ ).
- g. Front Lift (LF): Component of aerodynamic lift acting at the front axle ( $LF = L/2 + PM/WB$ ).
- h. Rear Lift (LR): Component of aerodynamic lift acting at the rear axle ( $LR = L/2 - PM/WB$ ).
- i. Front Side Force (SF): Component of aerodynamic side force acting at the front axle ( $SF = S/2 + YM/WB$ ).
- j. Rear Side Force (SF): Component of aerodynamic side force acting at the rear axle ( $SF = S/2 - YM/WB$ ).