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Vehicle Aerodynamics Terminology

SAE Recommended Practice
Issued June 1987

Submitted for Recognition as
an American National Standard

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Land Sea Air and Space

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HIGHWAY VEHICLE PRACTICE

Submitted for recognition as an American National Standard

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VEHICLE AERODYNAMICS TERMINOLOGY.

1. **AXES SYSTEM:** Stability axes system which yaws with the car or model. Axes form an orthogonal system which is, as seen by the driver:

   x direction: positive forward
   y direction: positive right
   z direction: positive down

1.1 **Resolving Center:** Located in the plane of the ground surface at mid-wheelbase and mid-track.

1.2 **Forces and Moments:** The preferred designators for aerodynamic data are:

Drag (D): aerodynamic force acting along the x-axis, but positive rearward ($F_x = -D$).

Lift (L): aerodynamic force acting along the z-axis, but positive upward ($F_z = -L$).

Side Force (S): aerodynamic force acting along the y-axis, positive to the right ($F_y = S$).

Pitching Moment (PM): aerodynamic moment about the y-axis, positive nose-up ($M_y = PM$).

Yawing Moment (YM): aerodynamic moment about the z-axis, positive nose-right ($M_z = YM$).

Rolling Moment (RM): aerodynamic moment about the x-axis, positive right side down ($M_x = RM$).

Front Lift (LF): component of aerodynamic lift acting at the front axle.

1.2 (Continued):

           Rear Lift (LR):   component of aerodynamic lift acting at the rear axle.

    Front Side Force (SF):   component of aerodynamic side force acting at the front axle.

     Rear Side Force (SR):   component of aerodynamic side force acting at the rear axle.

Non-dimensional aerodynamic coefficients are designated by an upper case letter C with upper case subscripts identifying a force or moment component. For example,

$$\text{Lift Coefficient: } C_L$$

$$\text{Pitching Moment Coefficient: } C_{PM}$$

$$\text{Front Lift Coefficient: } C_{LF}$$

1.3   Attitude Angles:

    Pitch Angle (α):   angle between the vehicle body longitudinal axis (x-direction) and the ground surface, positive nose-up.

    Yaw Angle (ψ):   angle between the vehicle body longitudinal axis (x-direction) and the component of the relative air velocity vector in the x-y plane, positive nose-right.

    Roll Angle (ϕ):   angle between the vehicle body lateral axis (y-direction) and the ground surface, positive right side down.

2.   TERMINOLOGY:

2.1   Forces and Moments:

$$\text{Drag Coefficient: } C_D = D/(q_\infty \cdot A)$$

$$\text{Lift Coefficient: } C_L = L/(q_\infty \cdot A)$$

$$\text{Side Force Coefficient: } C_S = S/(q_\infty \cdot A)$$

$$\text{Pitching Moment Coefficient: } C_{PM} = PM/(q_\infty \cdot A \cdot WB)$$

$$\text{Yawing Moment Coefficient: } C_{YM} = YM/(q_\infty \cdot A \cdot WB)$$

$$\text{Rolling Moment Coefficient: } C_{RM} = RM/(q_\infty \cdot A \cdot WB)$$

Note: Moment coefficients for vehicles with more than two axles may be based on a length parameter other than wheelbase. In this case, the parameter should be specified.

2.2 Model Parameters:

Wheelbase (WB): distance (in the x-direction) between the front and rear axles.

Frontal Area (A): vehicle area projection in the x-direction.

Scale Factor (σ): model dimensional fraction of full scale vehicle.

2.3 Flow Parameters:

Resultant Air Velocity (V_∞): magnitude of the total relative air flow vector.

Dynamic Pressure (q_∞): $q_\infty = 1/2 \cdot \rho \cdot V_\infty^2$

Air Density (ρ): ρ = 1.2250 kg/m^3 at standard day conditions.

Air Viscosity (μ): μ = 1.7894X10^{-5} Ns/m^2 at standard day conditions.

Standard Day Conditions: dry air at 15°C and 101.325 kPa

Note: Air density and viscosity at other than standard day conditions can be computed from the following equations,

ρ = 1.2250 ·(288.16/(273.16+T))(p/101.325) Kg/m^3

μ = (1.7203+.00460·T)X10^{-5} (for T=0° to 60°C) Ns/m^2

T = air temperature in degrees Celsius
p = atmospheric pressure in kilo-Pascals

(Density and viscosity data from Ref. 3.6)

Boundary Layer Thickness (δ): height above ground surface where the local velocity (V) is 99% of the free stream velocity (V_∞).

Displacement Thickness ($\delta*$): $\delta* = \int_0^\infty (1-V/V_\infty) \cdot dy$

Momentum Thickness (θ): $\theta = \int_0^\infty V/V_\infty(1-V/V_\infty) \cdot dy$

Pressure Coefficient (C_p): $C_p = (p-p_\infty)/q_\infty$

Local Static Pressure (p)

Free Stream Static Pressure (p_∞)

2.3 (Continued):

Reynolds Number per Unit Length (Re/1): $Re/1 = \rho \cdot V_\infty / \mu$

Equivalent Velocity (V_{EQ}): $V_{EQ} = V_\infty \cdot \sigma$

2.4 <u>Yaw-Weighted Drag Coefficient</u>: The yaw-weighted drag coefficient ($\bar{C}_D$) is defined as the average aerodynamic drag coefficient, based on vehicle speed (V), during a specified ambient wind input schedule (References 3.2, 3.3, & 3.7), where,

$$\bar{C}_D = \bar{D}(\psi, V_\infty)/(1/2 \cdot \rho \cdot V \cdot A)$$

2.5 <u>SI Metric Units</u>: All dimensional quantities are to be in metric units as specified in Reference 3.5.

3. <u>REFERENCES</u>:

3.1 SAE J670, Vehicle Dynamics Terminology

3.2 SAE J1252, SAE Wind Tunnel Test Procedures for Trucks and Buses

3.3 SAE P-59A, DOT/SAE Truck and Bus Fuel Economy Measurement Study Report, October 1976

3.4 ASME ASA-Y10.7-1954, Letter Symbols for Aeronautical Sciences

3.5 ASTM E380-76, Standard for Metric Practice

3.6 NOAA-S/T 76-1562, U.S. Standard Atmosphere, 1976, U.S. Government Printing Office, 1976

3.7 G. W. Carr, Aerodynamics as a Means to Vehicle Fuel Economy, ISME C210, 1978
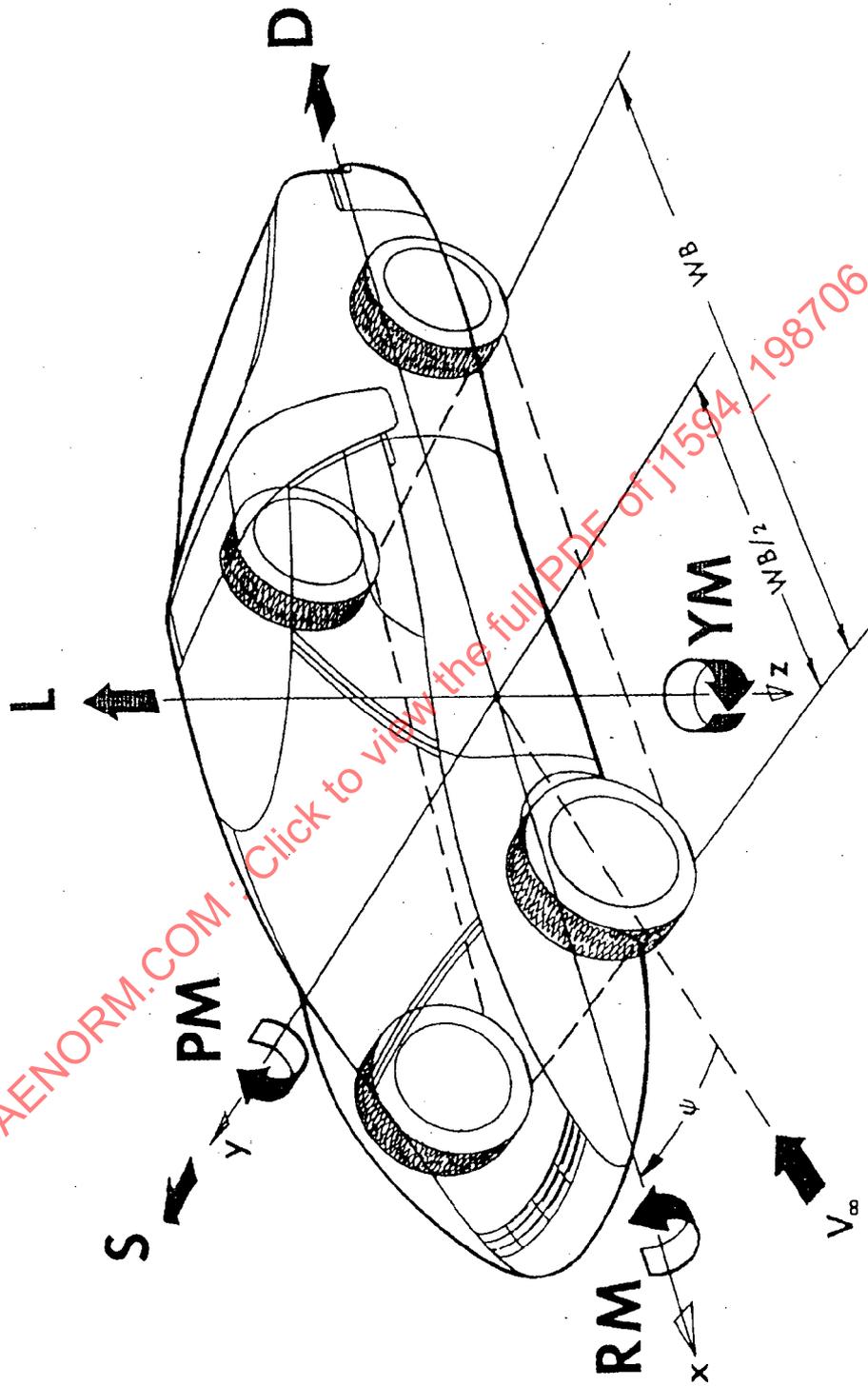
BACKGROUND:

The original SAE Road Vehicle Aerodynamics Terminology included in SAE J670c (c. 1974) was found inadequate for use by vehicle aerodynamics engineers. The originating Vehicle Dynamics Committee therefore appointed F. N. Beauvais 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, 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 final revisions of the terminology and voted its adoption in March 1986. A large number of individuals from industry, universities, and government agencies have contributed to this terminology document during its lengthy period of development. A combined list of member and non-member contributors, with their affiliations at the time of participation, is given under the heading of "Developed by..." at the end of this report.

RATIONALE:

This terminology is intended to provide a common nomenclature for use in publishing road vehicle aerodynamics data and reports. The following is a summary of the rationale for selection of specific terminology, conventions and definitions.

Axes System - The directional sense of the x-y-z axes were chosen consistent with both aeronautical and vehicle dynamics usage, e.g. see References 3.1 and 3.4.

Resolving Center - Center of gravity (c.g.) and body geometry-defined resolving centers used in vehicle dynamics and aeronautics, respectively, are not satisfactory for road vehicle aerodynamics application. A large portion of automotive aerodynamic 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 problematical 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.

<u>RATIONALE</u> (Continued):

Forces and Moments - The terminology for primary aerodynamic force and moment components (drag, lift, side force, pitching moment, yawing moment, and rolling moment) were adopted from aeronautical usage. The symbols and directional sense 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, & RM) were based on terminology.

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

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 an automotive wind tunnel development test 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 $C_{LF} = C_L/2 + C_{PM}$. However, if C_{PM} were based on an overall length (OAL), a ratio of OAL and WB would have to be included in the computation.

Model Parameters - The wheelbase designator (1) from vehicle dynamics was not adopted, since it is used for a number of other characteristics in aerodynamics (e.g. body length, section lift, and roll moment). Frontal area and scale factor symbols are consistent with common aerodynamic usage.

Flow Parameters - Symbols and definitions for air flow parameters were chosen consistent with aerodynamics terminology. A new definition of equivalent velocity (V_{EQ}) was included to provide a simple means of relating scale model flow conditions to full scale. Standard day conditions were chosen to correspond to those defined as sea level conditions for the U.S. Standard Atmosphere (Ref. 3.6) adopted by NASA, NOAA and USAF in 1976.

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 wind-averaged drag coefficient is defined as the average drag coefficient during a particular driving schedule and ambient wind input. These cannot be standardized, and several examples are given in the cited references.

<u>RELATIONSHIP OF SAE STANDARD TO ISO STANDARD</u>:

Not applicable.