

	SURFACE VEHICLE RECOMMENDED PRACTICE	SAE J1252 JUL2012
		Issued 1979-08 Revised 2012-07
		Superseding J1252 JUL1981
(R) SAE Wind Tunnel Test Procedure for Trucks and Buses		

RATIONALE

Wind tunnel testing of heavy vehicles has evolved in the past thirty years with new facility types, new ground simulation techniques, and more robust methods for estimating aerodynamic force and moment coefficients. References have been added for support of the narrative and emphasize the common elements between automotive and heavy vehicle testing, and thus avoid duplication of material. The origin of the US average annual wind speed was not disclosed in the original document and is now supported by references and calculations performed by the revision task force. The derivation of the wind averaged drag coefficient and a sample calculation have been added for completeness. Uncertainty bounds are a required element for any contemporary wind tunnel test report and a suggested uncertainty analysis method has been added for the first time with an included sample calculation.

1. SCOPE

The scope of this SAE Recommended Practice is sufficiently broad that it encompasses the full range of full-scale medium and heavy duty vehicles represented as either full-scale or reduced-scale wind tunnel models. The document provides guidance for wind tunnel testing to support current vehicle characterization, vehicle development, vehicle concept development, and vehicle component development.

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.

- i.) Aerodynamic Testing of Road Vehicles – Testing Methods and Procedures, SAE J2084, 1993.
- ii.) Aerodynamic Testing of Road Vehicles - Open Throat Wind Tunnel Adjustment Interference, SAE J2071, 1994.
- iii.) Closed Test Section Wind Tunnel Blockage Corrections for Road Vehicles, SP-1176, SAE International, 1996.
- iv.) Cooling Flow Measurement Techniques, SAE J2082, 1992.
- v.) Barlow, Rae, and Pope, Low-Speed Wind Tunnel Testing, 3rd ed., Wiley, 1999.
- vi.) Hucho, W.H., Aerodynamics of Road Vehicles, 4th ed., SAE 1998.
- vii.) Test Uncertainty, ASME PTC 19.1-2005.
- viii.) Recommended Best Practice for Climatic Wind Tunnel Correlation, SAE J2777, 2007.

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- ix) Vehicle Aerodynamics Terminology, SAE J1594, 2010.
- x) Wind Energy Resource Atlas of America, DOE/CH 10093-4, Oct. 1986, DE86004442
- xi) Barnard, R. H., Road Vehicle Aerodynamic Design, 3rd ed., Mech Aero, 2010.
- xii) Sumantran, V., Sovran, G., "Vehicle Aerodynamics", PT-49, SAE International, 1996
- xiii) Carr, G.W., "Wind Tunnel Blockage Corrections for Road Vehicle", MIRA, 1971/4.
- xiv) Carr G. W. and Stapleford W. R., "Blockage Effects in Automotive Wind-Tunnel Testing, SAE 8600093, 1986.
- xv) Broughton C. A., Rainbird W. J. and Kind R. K., "An experimental investigation of interference effects for high blockage bluff bodies in a slotted-wall wind tunnel test section," Wind Engineering , Vol 56, No 1, pp.23, Apr 1995.
- xvi) Lombardi G., and Carmassi S., "Wall Interference Effects: Analysis and Correction for Automotive Wind Tunnels", MIRA Vehicle Aerodynamics, pp 1, vol. 1, 2002
- xvii) Cooper K. R., Gerhardt H.J., Whitbread R., Garry K.P., Carr G.W., "A comparison of aerodynamic drag measurements on model trucks in closed-jet and open-jet wind tunnels". J. of Wind Engineering and Industrial Aerodynamics, Vol 22, Issue 2-3 June 1986, Page 299- 316.
- xviii) Storms B.L., Satran D. R., Heineck J. T. and Walker, S. M., "Detailed Experimental Results of Drag-Reduction Concepts on a Generic Tractor-Trailer". SAE 2005-01-3525, 2005.
- xix) "Blockage corrections for bluff bodies in confined flows" Engineering Sciences Data Unit (ESDU) article 80024 November 1980
- xx) Wind Tunnel Wall Corrections, AGARD-AG-336, Oct. 1998,
- xxi) Al Garni A.M., Bernal L. P. and Khalighi B., "Experimental Investigation of the Near Wake of a Pick-up Truck", SAE 2003-01-0651, 2003.
- xxii) Storms B, Satran D., Heineck J. and Walker S., "A Study of Reynolds Number Effects and Drag-Reduction Concepts on a Generic Tractor-Trailer". AIAA 2004-2251, 2004.

3. OBJECTIVE

The objective of this document is to provide recommended practices for wind tunnel testing of medium and heavy duty trucks and buses represented as either full-scale or reduced-scale wind tunnel models. This document will help guide the wind tunnel user towards making the best choices for achieving specific testing objectives and help to insure good data quality through best practices. The primary focus of this document is in establishing good practices for characterizing medium and heavy vehicle aerodynamic behavior when operating in the natural environment. Medium and heavy truck and bus testing requirements are similar to automotive testing requirements; however, there are some distinct differences between truck and bus testing as compared to automotive testing. Principal ones are due to differences in typical dimensions. In general, trucks and buses are taller relative to their width than automobiles. Trucks and buses are also generally longer relative to their width than automobiles. Trucks, but not buses, generally have higher average ground clearance than automobiles. Trucks and buses generally have blunter rear ends than automobiles and therefore have longer wakes relative to their widths. All of these characteristic differences lead to some effects on wind tunnel practices for these classes of vehicles. Vans included in the category of light trucks and often tested by the same groups who carry out automobile development have been recognized as having requirements somewhat different from automobiles generally. For brevity, this document highlights the requirements that differ from automotive practice and cites the references for detailed coverage of common requirements.

4. MODEL DEFINITIONS

The aerodynamic characteristics of a model/test article must accurately represent the full scale operational aerodynamics of the vehicle or class of vehicles under investigation. It is recognized that the model type and the associated geometric details will vary based upon the wind tunnel capability, costs and test program objectives.

4.1 Full Scale Models

Full scale models include actual vehicles and models of concept, development and production vehicles produced at a full scale when compared to the as-manufactured size of a representative operational vehicle.

4.2 Reduced Scale Models

All models of concept, development and production vehicles produced at a reduced scale when compared to the full scale of a representative operational vehicle.

4.3 Concept Vehicle

A concept vehicle model is any model at either full or reduced scale that contains all of the aerodynamically relevant features that are required to evaluate the overall characteristics of a vehicle and/or the detailed characteristics of a component. The concept vehicle may lack the complete geometric representation required of a production vehicle. As an example, consider a model lacking an inlet for the engine cooling system, with wheels, but no axles or drive train.

4.4 Production Vehicle

A production vehicle model is any model at either full or reduced scale that accurately represents a production vehicle with high fidelity as specified in section 9.1.5.

5. NOMENCLATURE

5.1 Aerodynamic Parameters

A Projected frontal area of the model. Projected frontal area is defined as that area described by the silhouette (shadow) of a vehicle on a plane behind and normal to the longitudinal axis if it were lit from the front using a collimated light source. This area includes tires, wheels, suspension, and driveline components which extend below the body or front bumper. Alternatively, maximum width times height of the vehicle or model may be used. The area and method used must be stated in the report. The width and height measurements should exclude mirrors and safety protuberances.

C_D Drag force coefficient = $D/(\frac{1}{2}\rho V^2 A)$.

C_L Lift force coefficient = $L/(\frac{1}{2}\rho V^2 A)$.

C_S Side force coefficient = $S/(\frac{1}{2}\rho V^2 A)$.

C_{RM} Rolling moment coefficient = $RM/(\frac{1}{2}\rho V^2 A w)$.

C_{YM}	Yawing moment coefficient = $YM/(\frac{1}{2}\rho V^2 A_w)$.
C_{PM}	Pitching moment coefficient = $PM/(\frac{1}{2}\rho V^2 A_w)$.
$\bar{C}_D$	Wind averaged drag coefficient.
d	Component reference dimension.
D	Aerodynamic drag force acting parallel to the longitudinal axis of the vehicle, or model, and positive aft.
$\bar{D}$	Wind average drag force with same axis and sense as D.
L	Aerodynamic lift force acting normal to the ground and positive upward.
PM	Aerodynamically induced pitching moment. Moment about a horizontal axis which is normal to the vertical centerplane of the vehicle, or model, and positive when it tends to raise the vehicle's nose.
Re _w	Overall Vehicle Reynolds number = $\rho V_w/\mu$.
Re _d	Component Reynolds number = $\rho V_d/\mu$.
RM	Aerodynamically induced rolling moment. Moment about a horizontal axis located in the vertical centerplane of the vehicle, or model, and positive when it tends to lower the right side of the vehicle.
S	Aerodynamic side force acting normal to the vertical centerplane of the vehicle, or model, and positive to the right.
V	Velocity relative to the vehicle or model (See Figure 2).
V _T	Vehicle velocity relative to the roadway (See Figure 2).
V _w	Mean wind velocity (See Figure 2).
w	Maximum width (excluding mirror and safety protuberances) of vehicle or model.
w _b	Wheel base.
YM	Aerodynamically induced yawing moment. Moment about a vertical axis fixed into the vertical centerplane of the vehicle, or model, and positive when it tends to rotate the vehicle nose to the right.
μ	Absolute viscosity of air.
ρ	Mass density of air.
ϕ	Angle of the mean wind relative to the vertical centerplane of the vehicle (See Figure 2).
ψ	Angle of yaw of the vehicle or model relative to the equivalent free airstream. (See Figure 2).

5.2 Force and Moment Sign Convention

The recommended sign convention is illustrated in Figure 1. It is recommended that the moment reference center be placed along the intersection of the vehicle vertical plane of symmetry and the ground. The longitudinal location for straight trucks and buses should be at the wheel base mid-point, and for tractor trailers should be at the center line of the tractor rear axle(s) as shown in Figure 3.

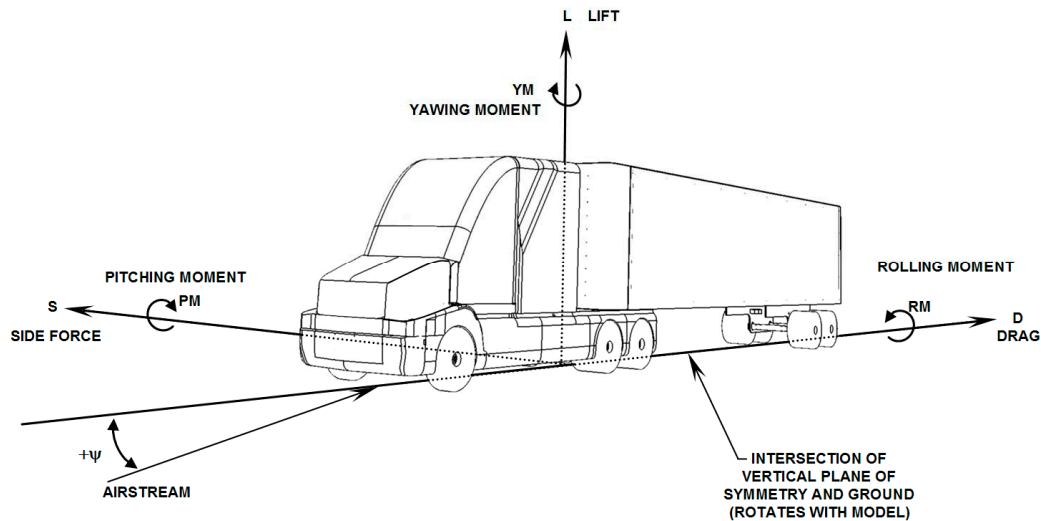


FIGURE 1 - DEFINITION OF FORCES, MOMENTS, AND THE STABILITY AXES COORDINATE SYSTEM

5.3 Relative Airspeed and Yaw Angle

A road vehicle traveling at velocity V_T subject to natural wind velocity V_w will experience relative airspeed V at yaw angle ψ .

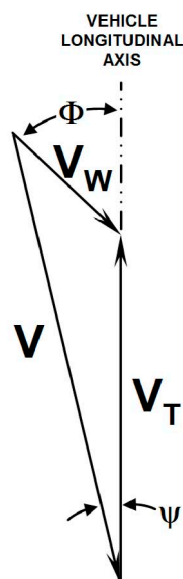


FIGURE 2 - RELATIVE AIRSPEED VECTOR DIAGRAM



5.4 Truck and Bus Dimensions

It should be noted that dimensions may vary from the left to the right side of the vehicle. It is recommended, that in the case of dimensions that could be measured on either side, both sides be recorded.

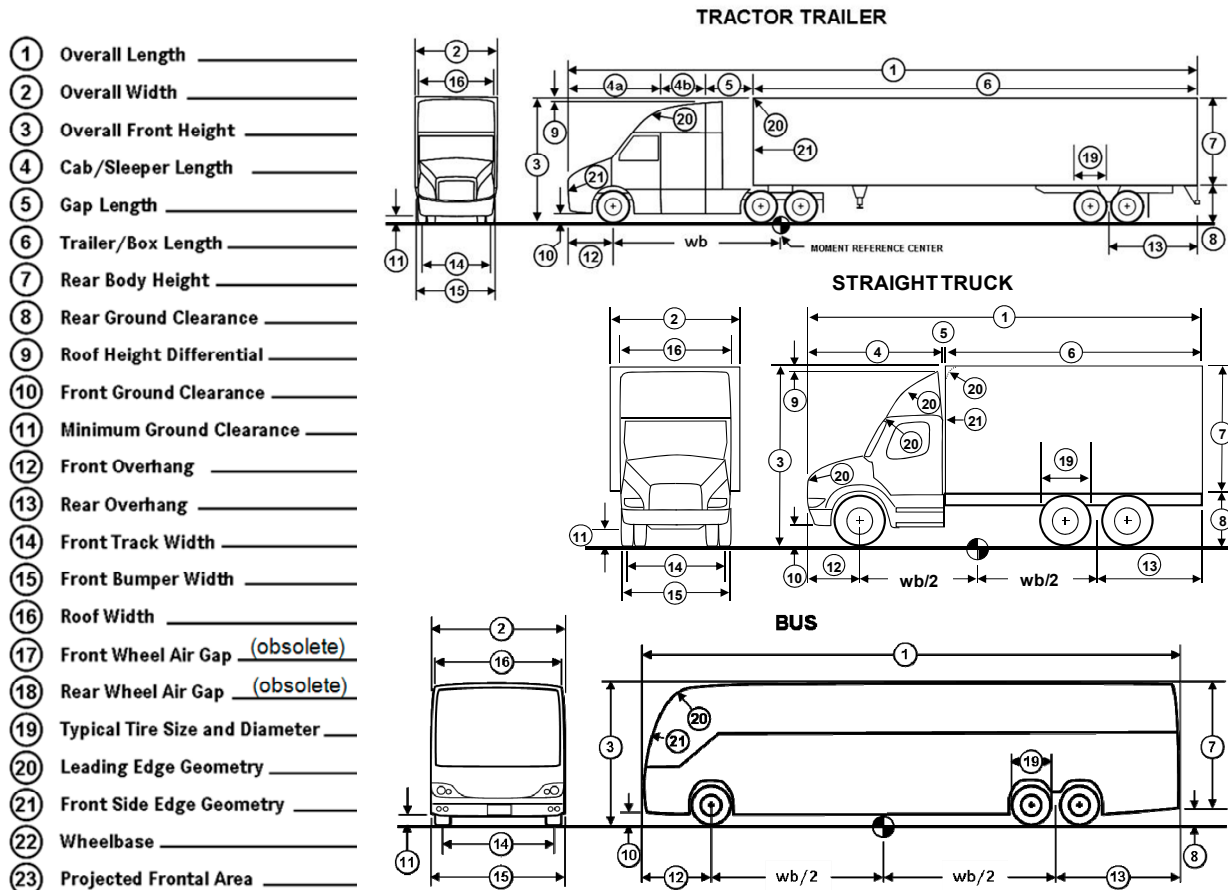


FIGURE 3 - TRUCK AND BUS DIMENSIONS

6. OBJECTIVES OF WIND TUNNEL TESTING

There are two primary objectives for wind tunnel testing of trucks and buses, aerodynamic development of a new vehicle and improvement of existing vehicles through modifications to the basic vehicle or through add-on devices. The achievement of vehicle performance as measured by end users through fuel economy dictates the requirement for aerodynamic drag measurement as the primary objective of testing. It should be noted that a production vehicle drag coefficient obtained through wind tunnel measurements will inherently vary with choice of facility.

6.1 Production and Concept Vehicle Aerodynamic Characterization

The main objective of production and concept vehicle aerodynamic characterization tests is the determination of the vehicle's mean (time-averaged) aerodynamic drag along its longitudinal axis as a function of yaw angle for the purpose of performance prediction. Comparative studies of add-on devices are conducted by referencing measurements from a baseline (reference) geometry over a range of yaw angles.

6.1.1 Yaw Polar Requirements and Relevance to On-Road Operations

A vehicle operating in the natural environment will experience a relative airspeed acting at a yaw angle as depicted in Figure 2. When characterizing a vehicle for use in a specific geographic region, it is recommended that an average wind speed be estimated for the intended area of operation. The average value for the continental US is the recommended default choice for vehicles intended to operate everywhere in this region. Medium and heavy trucks and buses differ from automobiles in that the rate of change of drag with yaw angle is greatly increased (approximately 10 times). Figure 4 shows comparative drag coefficient versus yaw response for various vehicle types. A wind averaged drag coefficient is the recommended metric to incorporate the integrated effect of the relative wind contribution to drag. Computation of the wind averaged drag coefficient at the vehicle highway operating speed (V_T) for the average wind speed (V_w) is recommended for use in vehicle comparative testing, and vehicle performance prediction and simulation. For instance, it is possible that an aerodynamic device may reduce drag at low yaw angles and increase drag at higher yaw angles. A complete evaluation of an aerodynamic device for use on a medium or heavy truck or bus will include wind averaged drag coefficients.

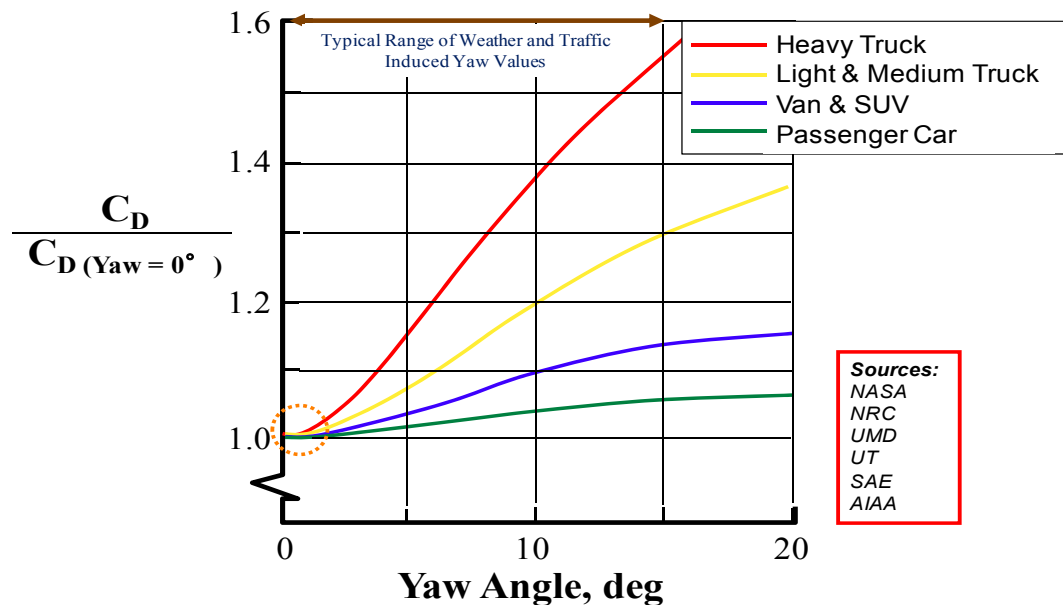


FIGURE 4 - YAW EFFECT ON DRAG COEFFICIENT FOR FAMILIES OF VEHICLES

6.1.2 Relation to Fuel Consumption Testing

The use of the wind averaged drag coefficient is recommended to correctly characterize the aerodynamic drag force acting on a medium and heavy truck or bus. When investigating the relative merit of devices that alter the vehicle drag and hence the fuel economy, it is important to include the integrated effect of the relative wind direction as described in 6.1.1. On-road and on-track fuel consumption testing in accordance with SAE and TMC fuel consumption recommended test procedures is subject to random wind conditions and is by nature an ineffective method for a production or concept vehicle characterization. Fuel consumption performance prediction is best based on a combination of a no-wind fuel consumption test coupled with a wind tunnel measured yaw dependent drag model.

6.2 Specialized Testing Objectives

6.2.1 Underbody Aerodynamics

Trucks have higher average ground clearance than automobiles. As the ground clearance of a model is reduced, the effect of the ground boundary simulation including wheel rotation becomes increasingly more important. For vehicles with very low ground clearance, a moving ground plane and rotating model wheels will provide the best simulation of the underbody aerodynamics around zero yaw. Whether fixed floor or moving ground plane simulations are used it should be noted that increased yaw typically degrades the simulation.

6.2.2 Internal Flow

The effect of the internal airflow rate on drag (such as engine cooling flow) can be investigated by conducting tests where inlets are blocked versus unblocked. Tests should be made over the entire range of yaw angles necessary for calculation of the wind averaged drag coefficient if the objective is production or concept vehicle aerodynamic characterization.

6.2.3 Detailed Tractor/ Component testing

Specialized full-scale tractor wind tunnel facilities that feature the use of a commercial tractor with a fixed facility simulation of a trailer or partial trailer may be used for aerodynamic evaluation of the tractor and tractor components. Comparative incremental force measurements and internal flow evaluations may be obtained on components at full fidelity. It should be noted that in facilities where yaw is not simulated, the wind averaged drag coefficient may not be computed.

6.2.4 Aero-Thermal Characterization

It is recommended that the aero-thermal characterization of a heavy truck or bus be conducted in a specialized test facility known as a Climatic Wind Tunnel. Typical testing includes evaluation of engine cooling systems and heating and air conditioning system performance while under load and subject to a range of ambient conditions. For more information the reader is directed to references i, iv, viii.

6.2.5 Research

Research objectives lead to testing of a basic or fundamental nature. These tests typically use small scale concept models where detail geometric fidelity requirements are often relaxed in order to control costs. The focus may be on preliminary evaluation of specific aerodynamic devices (or combinations thereof) or evaluations of vehicle designs with significant departures from current production vehicles. Note, although the model geometric fidelity requirement is not rigorous, the accurate modeling of full scale on-road global and local aerodynamic and flow field features is required. Research testing may be performed over a limited yaw range and may focus on flow visualization studies and surface pressure measurements. Most testing is done using reduced scale models in relatively small test facilities.

7. AERODYNAMIC REQUIREMENTS

The following section describes the fundamental aerodynamic criteria that should be addressed to achieve the best aerodynamic simulation.

7.1 Reynolds Number

7.1.1 Overall Vehicle

Tests should be performed to determine the effect of vehicle Reynolds number (Re_w) on the measured forces and moments over the range of yaw angles dictated by the test requirements. When the Reynolds number effects have been determined, the remainder of the test program should be performed at a Reynolds number above which the force and moment coefficients are essentially invariant for the yaw angles investigated. Reynolds effects can be determined using a velocity sweep. In tests where results require the best estimate of the overall absolute force and moment coefficients, particular attention should be paid to the Reynolds number scaling effects. A sampling of Reynolds number effects on truck and bus geometries is provided in section 4.4 of reference i. Compressibility is an additional consideration in developing a working Reynolds number and will need to be considered anytime the freestream Mach number exceeds 0.25. When operating near Mach 0.25, careful scrutiny of local conditions in the vicinity of model contour changes such as corners and rounds is required.