SAE WIND TUNNEL TEST PROCEDURE FOR TRUCKS AND BUSES

Foreword—This Document has also changed to comply with the new SAE Technical Standards Board format.

1. Scope—The scope of this SAE Recommended Practice is sufficiently broad that it can encompass the full range of current heavy duty vehicles, vehicle modifications, and prototype configurations. The test procedure describes methods for examination of the vehicle's flow field using surface pressures and flow visualization.

1.1 Introduction—This SAE Recommended Practice describes a wind tunnel testing procedure for the measurement of the aerodynamic characteristics of heavy duty trucks and buses using established model testing techniques. The main emphasis is on the measurement of aerodynamic drag under flow conditions representative of the full range of vehicle operating conditions. This SAE Recommended Practice is intended as a guide toward an eventual standard, but may be subject to frequent changes in order to keep pace with experience and technological advances. Because the wind tunnel techniques are still evolving, there are areas where a generally acceptable approach cannot be recommended. These areas are discussed in the associated *information report* and it is suggested that this document be considered an essential reference when using the recommended practice.

2. References—There are no referenced publications specified herein.

3. Objective—The objective of this recommended practice is to provide a standard wind tunnel testing procedure for heavy duty trucks and buses. The use of this procedure should improve the comparability of aerodynamic data taken in different wind tunnels and should ensure that good data quality is obtained.

4. Nomenclature

A—Projected frontal area of the vehicle or model. Projected frontal area is defined as that area which could be measured by planimeter using a front-view photograph taken of the back lighted vehicle or model with a camera located such that parallax is negligible. This area includes tires, wheels, suspension, and driveline components which extend below the body or front bumper, but excludes, upper body tractor or trailer mounted protuberances such as mirrors and clearance lights. Alternately, 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 = $RM/\frac{1}{2}\rho V^2 Aw$.

C_{YM}—Yawing moment coefficient = $YM/\frac{1}{2}\rho V^2 Aw$.

C_{PM}—Pitching moment coefficient = $PM/\frac{1}{2}\rho V^2 Aw$.

$\overline{C}_D$—Wind averaged drag coefficient.

D—Aerodynamic drag force acting parallel to the longitudinal axis of the vehicle, or model, and positive aft.

$\overline{D}$—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.

R_e—Reynolds number = $\rho Vw/\mu$.

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—Equivalent free airstream velocity relative to the vehicle or model.

V_T—Vehicle velocity relative to the roadway.

V_W—Mean wind velocity. (See Figure 1.)

w—Maximum width (excluding mirror and safety protuberances) of vehicle or model.

wb—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 1.)

ψ—Angle of yaw of the vehicle or model relative to the equivalent free airstream. (See Figure 1.)

5. **Test Facility Requirement**—The aerodynamic tests should be performed in the wind tunnel facility having the capability, equipment, and the experienced personnel necessary for an accurate evaluation of the aerodynamic forces acting on a surface vehicle. A facility that can satisfy the requirements detailed in the following sections will be considered acceptable.

5.1 **Ground-Boundary Simulation**—An acceptable ground-boundary simulation should be one which minimizes the height of the boundary layer displacement thickness relative to the underbody ground clearance at the vehicle's leading edge. This practice recommends a separate, impermeable ground board which spans the wind tunnel and divides the tunnel providing a new test section above the board. The ground board should be installed nominally parallel to the tunnel axis and well above the tunnel floor's boundary layer. The ground board should extend at least two body widths (w) upstream of the model and four to six body widths downstream. The ground board leading edge should be shaped to minimize boundary layer thickness. Tufts should be used on the ground board upstream of the model, with the model in place, to establish that no upstream flow separation occurs with the model mounted.

5.2 **Wind Tunnel Selection and Reynolds Number Capability**—The wind tunnel test section size and speed range are primarily determined by the minimum acceptable test Reynolds number:

$$Re_{min} = \frac{\rho Vw}{\mu} = 0.7 \times 10^6 \tag{Eq. 1}$$

VEHICLE
LONGITUDINAL
AXIS
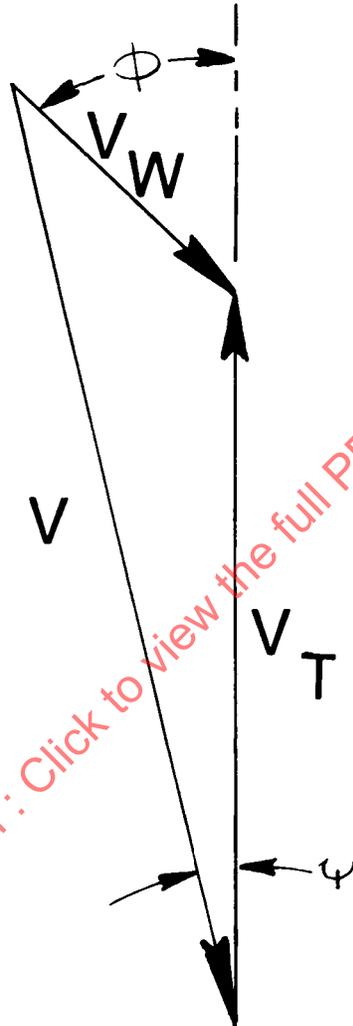
FIGURE 1—RELATIVE AIRSPEED VECTOR DIAGRAM

It is recommended that a higher value of Reynolds number be used whenever possible. The wind tunnel should be large enough that this Reynolds number requirement can be met, or exceeded, for the model size chosen and test speeds available without incurring significant blockage and wall interference effects. It is recommended that the model frontal area at zero yaw angle should not exceed 5% of the active test section area (the area above the ground board). The model height should not exceed 0.3 of the test section height, and the projected frontal width when yawed to the maximum angle required should not exceed 0.3 of the tunnel width.

6.   *Wind Tunnel Model Requirements*—Models must be accurately and rigidly constructed, geometrically scaled, and possess sufficient detail to reproduce all important full scale local flow disturbances. The model size should be selected to simultaneously satisfy the Reynolds number, blockage, ground plane, and wall interference conditions outlined in paragraphs 5.1 and 5.2.

6.1   **Model Details**—Particular attention should be paid to model details such as horns, lights, mirrors, intake and exhaust stacks, roof air conditioners, hood and door discontinuities, etc., which are located near regions of possible flow separation. Underbody structural details and the major driveline components should be reproduced. The engine cooling air flow path including engine block, engine compartment, and radiator porosity should be simulated. Static tire deflection should be modeled using flats of the appropriate size on all wheels. Portions of the model that are removable, or variable, such as corner blocks, front or rear-end shapes, add-on members as well as variable clearances and gaps should be designed for accurate positioning using pins or reference marks. The wind tunnel model's construction should be sufficiently rigid that static or dynamic deflections of the vehicle or its components will not affect the model's flow field or the balance output.

6.2   **Model Mounting**—The model mounting system must be sufficiently rigid that deflections cannot cause erroneous measurements as noted in paragraph 5.1. The model should be installed at the exact scale height above the ground board and with an attitude which correctly represents the prototype. Care should be taken to ensure that model-to-ground or model-support-to-ground interference does not occur. A fouling alarm is recommended. The model attachment to the balance should not create significant flow interference or unaccountable tare effects. The tire-to-ground interface should be simulated by a small gap between the tire and ground board or by resting the tire contact path on a support pad of equivalent area that is flush-mounted with the ground board.

7.   *Test Procedure*—The following sections define the wind tunnel measurements which provide the required aerodynamic data and recommended methods for obtaining these data.

7.1   **Test Section Flow Calibration**—A series of measurements should be made above the ground plane with the model absent to define the characteristics of the flow in which the model is placed.

The turbulence level, flow angularity, uniformity of the velocity field over the test cross-section, and longitudinal static pressure gradient should be measured above the ground board. In addition, the ground board boundary layer thickness should be measured at the location of the model leading edge. The wind tunnel dynamic pressure measuring system should be calibrated against an accurate Pitot-static tube mounted at the location of the model mid-length and mid-height point.

7.2   **Force and Moment Requirements**—The main requirement of the wind tunnel test is the determination of a model vehicle's mean (time-average) aerodynamic drag along its longitudinal axis as a function of yaw angle. It is recommended that the remaining five data components, as defined in the Nomenclature, be determined. The forces and moments should be reduced to coefficient form using the stability axes coordinate system. This coordinate system consists of a set of orthogonal axes fixed in the vehicle and yawing with it as shown in Figure 2.
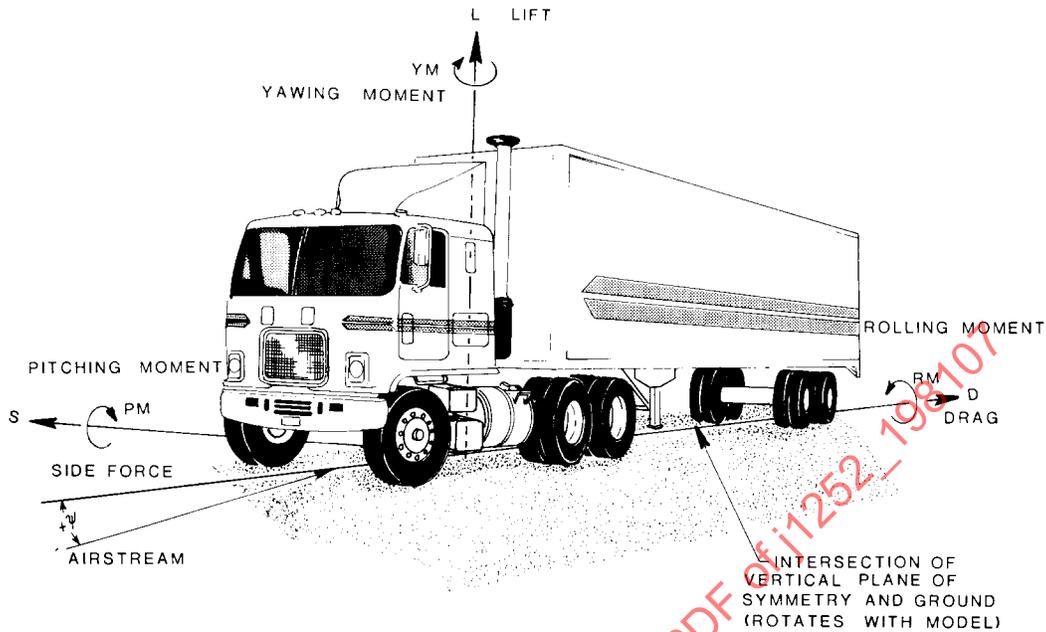
FIGURE 2—DEFINITION OF FORCES, MOMENTS,
AND THE STABILITY AXES COORDINATE SYSTEM

It is recommended that the moment reference center be placed along the intersection of the vehicle vertical plane of symmetry and at 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. A sufficiently long measurement averaging time should be used to provide a steady measurement which is repeatable to within 1%.

7.3 Yaw Angle Simulation—An approximation of the effects of ambient winds is obtained by yawing the model about a vertical axis relative to the approaching airstream. The range of yaw angles should be at least -5 deg to +20 deg. A sufficient number of runs should be made from -20 deg to +20 deg to check for possible asymmetrical data due to designed-in or accidental model asymmetries. The yaw angle increment should be no greater than 3 deg up to 15 deg yaw angle and no greater than 5 deg beyond that value. A 0 deg yaw point should be taken at the beginning and end of each run to establish repeatability. An estimate of the average aerodynamic drag of a vehicle in highway operation can be provided by a computation of the wind-averaged drag coefficient. See Appendix I.

TRACTOR-TRAILER

STRAIGHT TRUCK

BUS
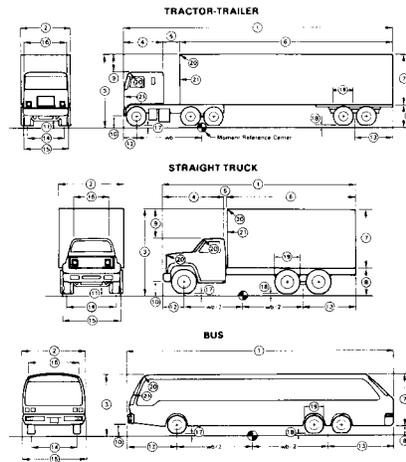
①	Overall Length _____
②	Overall Width _____
③	Overall Front Height _____
④	Cab Length _____
⑤	Gap Length _____
⑥	Trailer/Box Length _____
⑦	Rear Body Height _____
⑧	Rear Ground Clearance _____
⑨	Roof Height Differential _____
⑩	Front Ground Clearance _____
⑪	Minimum Ground Clearance _____
⑫	Front Overhang _____
⑬	Rear Overhang _____
⑭	Front Track Width _____
⑮	Front Bumper Width _____
⑯	Roof Width _____
⑰	Front Wheel Air Gap _____
⑱	Rear Wheel Air Gap _____
⑲	Typical Tire Size and Diameter _____
⑳	Leading Edge Geometry _____
㉑	Front Side Edge Geometry _____
㉒	Wheel Base _____
㉓	Projected Frontal Area _____

FIGURE 3—MINIMUM MODEL DIMENSIONS REQUIRED

7.4   Reynolds Number Effects—Tests should be performed to determine the effect of Reynolds number on the measured forces and moments. These tests should be performed at 0 deg yaw angle and at least one other value over the airstream velocity range of the tunnel. Once 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 constant for the yaw angles investigated. A maximum test velocity of 300 ft/s (92 m/s) should not be exceeded in order to avoid compressibility effects.

7.5   Engine-Cooling Airflow Effects—The effect of engine-cooling airflow rate on drag should be investigated by conducting tests at the two extreme airflow rates of zero and maximum airflow in addition to that used for the base line test. Zero airflow is defined as that achieved by blocking the entrance to the model's engine compartment, and maximum airflow is defined as that established by removing all restrictions to the airflow at the radiator location. The model's engine should remain in place for all tests. Tests should be made over the entire range of yaw angles. If extensive model modifications are made, it is recommended that the effect of engine-cooling airflow rate be reinvestigated. Where passive means cannot be used to simulate the cooling airflow (as with some buses) consideration should be given to the use of active means.

7.6 **Wind Tunnel Data Corrections—**A correction to the drag coefficient for a longitudinal pressure gradient (horizontal buoyancy) should be made if the correction exceeds 1% of the measured drag coefficient. The application of a correction to account for the effects of the model solid and wake blockage is optional. The form of any correction used must be specified as required in paragraph 7.9.

7.7 **Flow Visualization—**It is useful, but not necessary, to monitor the model flow field with an indicator such as smoke, tufts, or an oil film. This permits a rough correlation with known full scale flow details.

7.8 **Surface Pressures—**Surface pressure measurements may assist in determining the local effects of vehicle modifications and in assessing the contribution of certain parts of a vehicle to total drag. Care should be taken that pressures are averaged over a sufficient period of time to assure data repeatability.

7.9 **Data Presentation—**Sufficient background data should be presented to completely define the wind tunnel and ground simulation, test flow field, and the model's geometry. The following minimum data are required:

   Test facility dimensions.
   Ground board location and dimensions.
   Model location on ground board.
   Model dimensions as shown (include true projected frontal area if available) in Figure 3.
   Photographs of model configurations.
   Photographs of model installed in wind tunnel.
   Description of model modifications.
   Description of engine cooling flow simulation.
   Results of Reynolds number test.
   Results of engine cooling flow test.
   All dimensional data used for data reduction.
   Flow calibration items required in paragraph 7.1.
   Data correction items used, paragraph 7.6.

All model test data should be presented in tabular form, and as much as is practical, or necessary, in graphical form. Should a blockage correction be used, the correction must be defined and the increments or factors applied must be presented.

8. *Notes*

8.1 **Marginal Indicia—**The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE TRUCK AND BUS COMMITTEE