SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
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SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J2263

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ROAD LOAD MEASUREMENT USING ONBOARD ANEMOMETRY AND COASTDOWN TECHNIQUES

1. *Scope*—This SAE Recommended Practice establishes a procedure for determination of vehicle road load force for speeds between 115 and 15 km/h (71.5 and 9.3 mph). It employs the coastdown method and applies to vehicles designed for on-road operation. The final result is a model of road load force (as a function of speed) during operation on a dry, level road under reference conditions of 20 °C (68 °F), 98.21 kPa (29.00 in-Hg), no wind, no precipitation, and the transmission in neutral.

1.1 Background—This document supplements SAE J1263 FEB96. SAE J1263 remains an alternative method for evaluating vehicle road load force during low wind conditions. This procedure incorporates recent advances in test equipment and data analysis; it more accurately defines vehicle road load force over an extended speed interval. Major changes are inclusion of real time anemometry to measure and compensate for wind conditions directly in front of the vehicle and use of a three term equation to model road force over a 115 to 15 km/h (71.5 to 9.3 mph) speed range. (The previous procedure relied on average wind conditions measured at distances up to several kilometers from the vehicle. Also, road load force was modeled by a two term equation and was, typically, simulated on a hydrokinetic dynamometer capable of being adjusted to reproduce this force at only one speed; performance at other speeds was a function of dynamometer characteristics.) In addition, this procedure specifically discusses and authorizes "split" coastdown runs which must be used when the test track is too short to allow a complete coastdown run due to the vehicle's performance, weight, or road load force characteristics.

2. References

2.1 **Applicable Publication**—The following publication forms 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 PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1263—Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques

2.2 **Related Publications—**The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 SAE Publications—Available from SAE 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE Paper 720099—The Determination of Vehicle Drag Contribution from Coast-Down Test, R. A. White and H. H. Korst
SAE Paper 760106—Test Procedures for the Evaluation of Aerodynamic Drag on Full-Scale Vehicles in Windy Environments, W. H. Walston, F. T. Buckley, Jr., and C. H. Marks
SAE Paper 760153—Tire Rolling Resistance Measurements from Coast-Down Tests, B. Dayman, Jr.
SAE Paper 760850—Analysis of Coast-Down Data to Access Aerodynamic Drag Reduction on Full-Scale Tractor-Trailer Trucks in Windy Environments, F. T. Buckley, Jr., C. H. Marks, W. H. Walston, Jr.
SAE Paper 770844—Prediction of Dynamometer Power Absorption to Simulate Light Duty Truck Road Load, G. D. Thompson
SAE Paper 780255—Tire Rolling Resistance—A Speed Dependent Contribution, J. R. Smith, J. C. Tracy, and D. S. Potter
SAE Paper 780334—The Analytical Basis of Automobile Coastdown Testing, T. P. Yasin
SAE Paper 780337—Realistic Effects of Winds on the Aerodynamics Resistance of Automobiles, B. Dayman, Jr.
SAE Paper 94020—A Detailed Drag Study Using the Coastdown Method, M. A. Passmore and G. M. Le Good
SAE Paper 950626—ABCD—An Improved Coast Down Test and Analysis Method, F. T. Buckley, Jr.
SAE Paper 970269—Determination of Coastdown Mechanical Loss Ambient Correction Factors for Use with SAE J2263 Road Tests, R. W. Andrews and D. J. Pruess

2.2.2 ISO Publication—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO/DIS 10521:1991-07-31—Motor vehicle road load—Determination under reference atmospheric conditions and reproduction on chassis dynamometer

2.2.3 Other Publication

Japan TRIAS 24-3 1985 (26 OCT 1985)

3. Definitions

3.1 Constrained Analysis—The vehicle's frontal area and aerodynamic drag coefficient have been independently determined and those values will be used in the equation of motion.

3.2 Driveline—The rotating components of a vehicle mechanically connected to the driving wheels when the transmission is in neutral gear. This includes the brake disks/drums, driveshafts, differential, propeller shaft, transmission output shaft, and some components within the transmission.

3.3 Effective Vehicle Mass—The sum of the vehicle test mass and the effective mass of rotating components.

3.4 Effective Mass of Rotating Components—The rotational inertia of driveline and non-drive axle components that rotate with the wheels expressed as additional "linear" mass. For passenger cars without dual drive tires, if the actual effective mass of rotating components is unknown, the effective mass of all rotating components may be estimated as 3.0% of the vehicle test mass.

3.5 Mechanical Drag—The force opposing vehicle movement due to tire-rolling resistance and friction in the driveline and non-drive axle components.

3.6 **Road Load Force**—The total force encountered by a vehicle by reason of motion on a level, smooth surface; it includes aerodynamic and mechanical drag components and is expressed as a function of vehicle speed.

3.7 **Test Mass**—The mass of the vehicle at the conclusion of the test; including driver, instrument operator (if any), and all instrumentation.

4. Symbols—See Table 1.

TABLE 1—SYMBOLS

Symbol	Units	Description
A	m^2	frontal area
a_0 .. a_n	deg^{-n}	coefficients for aerodynamic drag, as a function of yaw angle
A_m	N	coefficient of mechanical drag
B_m	N/(km/h)	coefficient of mechanical drag
C_m	$N/(km/h)^2$	coefficient of mechanical drag
Baro	kPa	barometric pressure
$C_d(Y)$		coefficient of aerodynamic drag at yaw angle Y
D	N	drag
D_{aero}	N	aerodynamic drag
D_f	N	front axle drag (including driveline)
D_{grav}	N	gravitational drag
D_{mech}	N	mechanical drag
D_r	N	rear axle drag (including driveline)
D_{tire}	N	tire rolling resistance
(dV/dt)	ms^{-2}	acceleration
g	ms^{-2}	gravitational constant
(dh/ds)		sine of slope
M	kg	mass of vehicle
M_e	kg	effective vehicle mass (including rotating components)
r(rho)	kg/m^3	air density
t	s	time
T	C	temperature
V	km/h	vehicle speed
V_r	km/h	apparent wind speed relative to vehicle
Y	deg	yaw angle of apparent wind relative to direction of vehicle travel
w	N	weight

5. Instrumentation

5.1 **Calibration**—All instrumentation shall be calibrated.

5.2 **Time**—(Elapsed) time shall be measured to an accuracy of ±0.001 s and shall be recorded to a resolution of 0.01 s.

5.3 **Vehicle Speed**—Vehicle speed shall be measured to an accuracy of 0.2 km/h (0.1 mph) and shall be recorded to a resolution of 0.2 km/h (0.1 mph).

5.4 Relative Wind Speed—Relative wind speed shall be measured at the approximate mid-point of the vehicle's frontal cross section and approximately 2 m in front of it. Relative wind speed shall be measured to an accuracy of 1 km/h (0.6 mph) and shall be recorded to a resolution of 1 km/h (0.6 mph). Calibration of the anemometer shall include corrections for vehicle "blockage."

5.5 Relative Wind Direction (Yaw)—Wind direction relative to the direction of vehicle travel shall be measured at the approximate mid-point of the vehicle's cross section and approximately 2 m in front of it. Relative wind direction shall be measured to an accuracy of 3 degrees and shall be recorded to a resolution of 1 degree, the "dead band" of the instrument shall not exceed 10 degrees and shall be directed toward the rear of the vehicle. Calibration of the instrument shall include corrections for vehicle "blockage."

5.5.1 EXCEPTION—When the relative wind direction instrument is calibrated by means of operation on the vehicle undergoing the road load determination, and where such calibration occurs as part of the test sequence (including pre- and post-test operation) and without removing or installing the instrument, the accuracy requirements set forth in 5.5 do not apply. (Under these limitations, the calibration of the instrument to account for vehicle blockage makes an "accuracy" specification unnecessary; as long as the instrument responds the same way during calibration and testing, the needs of the procedure are satisfied.)

5.6 Ambient Temperature—Resolution and accuracy of 1 °C (1.8 °F), true air temperature (shielded from the sun and track); temperature shall be measured in front of the vehicle.

5.7 Atmospheric Pressure—Resolution and accuracy to 0.3 kPa (0.1 in-hg), data from a central facility weather station is acceptable.

5.8 Tire Pressure—Tire pressure shall be measured to an accuracy of ±5 kPa (1 psi).

5.9 Vehicle Mass—Vehicle (and axle) mass shall be measured to an accuracy of ±10 kg (22 lb). For vehicles over 4000 kg (8818 lb), the accuracy requirement is ±20 kg (44 lb).

6. Vehicle Preparation

6.1 Break-In—The vehicle and tires shall have accumulated a minimum of 3500 km (2175 miles) and preferably 6500 km (4039 miles) of road service prior to testing. Tires may be broken-in using a different vehicle but under similar load conditions as the test vehicle. Tires shall have at least 50% of their original tread depth remaining.

6.2 Vehicle Check-In—The test vehicle shall be identified. Any differences from the normal configuration or any mechanical malfunctions shall be described. The following information shall be recorded prior to the test:

a. Vehicle description including make, model, model year, body style, VIN (or prototype number), engine, and transmission type.
b. Tire size, manufacturer, construction code, model, tire performance code (TPC) or equivalent (if available), DOT identification number for each tire (if available), and the amount of tread on each tire.
c. Aerodynamic drag coefficient, measurement method, and where measured; only if "constrained analysis" is to be used.
d. Frontal area and how determined; only if "constrained analysis" is to be used.
e. Vehicle ride or time heights measured using the procedure specified by the manufacturer or, if no such procedure is specified, to top of the wheel well, or equivalent, for each wheel.
f. Manufacturer's minimum recommended tire inflation pressure.
g. Wheel bearing and brake drag for abnormal conditions.

6.3 Vehicle Maintenance—If necessary, fluid levels shall be corrected to manufacturer's specifications.

6.4 Instrumentation—Any instrumentation shall be installed on the vehicle in such a manner as to minimize effects on the operating characteristics of the vehicle.

6.5 Fuel—The vehicle fuel tank shall be filled. For multiple fuel tanks, only the main (largest) tank shall be filled. Prototype vehicles may have the amount of fuel adjusted as necessary to meet the required test weight.

6.6 Prototype Vehicle Mass—Prototype vehicles shall be ballasted (or have mass removed) to simulate the mass and distribution of a production vehicle undergoing the test.

6.7 Light Truck Mass—When tested for compliance purposes, light trucks shall be ballasted to the appropriate mass as required by regulation.

6.8 Tire Pressure—The vehicle tires shall be inflated to the vehicle manufacturer's minimum recommended inflation pressure, adjusted for changes in temperature between the tire temperature at the time of inflation and the test track ambient temperature. (For normal passenger vehicle tires this correction is approximately a 1 kPa increase for each degree Celsius that the tire temperature exceeds the track ambient temperature.)

6.8.1 OPTION—Where tire temperatures are not stable or when the test is not to be run immediately after vehicle preparation, the tires shall be inflated to the manufacturers minimum recommended tire pressure plus 10%. The vehicle shall be parked near the test track area with the tires shielded from the sun for a minimum of 4 h.

7. Test Conditions

7.1 Temperature—Ambient temperature shall be between 5 and 35 °C (41 to 95 °F).

7.2 Wind—Average wind speed shall not exceed 35 km/h (21.7 mph) nor shall wind gusts exceed 50 km/h (31.1 mph).

7.3 Fog and Precipitation—Tests may not be run during fog or precipitation conditions.

7.4 Road Conditions—The test road must be dry, clean, straight, smooth, be hard surfaced, not have excessive crown, and have a constant grade of no more than 0.5%. (There is no grade restriction if the grade is known as a function of position and vehicle position will be recorded, or calculated, on a real-time basis. The force due to the grade must then be factored into the data analysis.)

8. Pretest Operations

8.1 Tire Pressure—If not already adjusted for the track ambient temperature, the vehicle tire pressures shall be bled down to the manufacturer,s minimum recommended tire pressure.

8.2 Vehicle Mass—The vehicle shall be weighed to verify that it has been adjusted (if required) to the correct total mass and individual axle loads.

8.3 Vehicle Preconditioning—A minimum of 30 min operation at 80 km/h (49.7 mph) is required to precondition the vehicle and tires. This preconditioning period may be used to calibrate instrumentation.

9. Coastdown Test

9.1 Vehicle Condition—Vehicle windows and vents must be closed. Headlights shall be turned on. Accessories may be used. Use of accessories which affect engine speed shall be noted; such use shall be duplicated during any subsequent dynamometer adjustments.

9.2 Test Runs—A minimum of 10 runs are made in alternating directions; 5 runs in each direction.

9.3 Procedure—The test shall begin immediately following preconditioning. At the start of each run, accelerate the vehicle to 125 km/h (77.7 mph), or (higher if necessary to gather stabilized data) which is 10 km/h (6.2 mph) above the highest speed in the coastdown range. Stabilize at the required speed, let the accelerator pedal return to the idle position, shift the transmission into neutral, re-engage the manual transmission clutch (if so equipped), and start the recording equipment. At a speed below 15 km/h (9.3 mph) which is the lowest speed in the coastdown range, stop the recording equipment, engage the transmission and prepare for the next run which shall be in the opposite direction. The test shall be conducted so that the time between runs is minimized to reduce the effect of changes in tire and lubricant temperatures.

9.3.1 SPLIT RUN OPTION—If data cannot be collected in a continuous fashion for the entire speed range (due to insufficient track length) "split" runs are permitted. In a split run, data is first collected for the high-speed portion, 125 to "X" km/h, in each direction; then low-speed data is collected, "X" + 15 km/h to the lower limit. The process is then repeated until 5 complete 125 to 15 km/h run pairs have been completed.

9.4 Lane Changes—While collecting data, lane changes should be avoided, if possible. Gradual lane changes over a distance of 500 m are permissible.

10. Data

10.1 Test Run Information—Actual time at the start of the test shall be recorded, elapsed time shall be measured (or calculated) from that time. The following information shall be recorded at the start of each run, including aborted runs. Items may be recorded manually or by the data logging system:

a. Run number (method of identifying each run)
b. Elapsed time
c. Ambient temperature
d. Ambient pressure
e. Ambient humidity
f. Run direction
g. Track temperature

10.2 Test Run Data—The following data shall be measured and recorded at 0.2 or 1.0 s intervals during the procedure. Data for the various parameters shall be synchronized, i.e., measured over and associated with a given time interval.

a. Elapsed time
b. Vehicle speed
c. Air velocity (speed, direction) relative to the vehicle
d. Ambient temperature

10.3 End of Test Data—Upon conclusion of the test, weigh the vehicle to determine the total mass including the driver, fifth wheel (up), if used, and all other instrumentation. Record. Determine average wind, peak wind speeds, and average barometer pressure during the test portion. Record.

10.4 Data Recording Option—Data may be recorded continuously, e.g., from the beginning of preconditioning through the completion of the test as long as the beginning and end of each test run can be identified.

11. Equation of Motion

11.1 Assumptions—The assumptions behind the following equations can be found in Appendix A.

11.2 General Form—The general form of the equation of motion can be written as shown in Equation 1:

$$M_e(dV/dt) = D_{mech} + D_{aero} + D_{grav} \quad \text{(Eq. 1)}$$

where:

$D_{mech} = D_{tire} + D_f + D_r$
$D_{aero} = (1/2)\ rC_D(Y)AV_r^2$
$D_{grav} = W(dh/ds)$
M_e = Effective vehicle mass

11.3 Mechanical Drag—Although mechanical drag consists of separate components representing tire (D_{tire}), front and rear axle frictional losses (D_F and D_R, including transmission losses), it can be modeled as a three-term polynomial with respect to speed (V). See Equation 2:

$$D_{mech} = A_m + B_m V + C_m V^2 \tag{Eq. 2}$$

where:

A_m, B_m, and C_m are determined in the data analysis. These constants reflect the combined driveline and tire drag.

11.4 Aerodynamic Drag Modeling—The aerodynamic drag coefficient, $C_d(Y)$, is modeled as a four-term polynomial with respect to Yaw angle (Y, Deg) (see Equation 3):

$$C_d(Y) = a_0 + a_1 Y + a_2 Y^2 + a_3 Y^3 + a_4 Y^4 \tag{Eq. 3}$$

where:

a_0 to a_4 are constant coefficients whose values are determined in the data analysis. The aerodynamic drag coefficient is combined with the vehicle frontal area (A) and relative wind velocity (V_r) to determine the aerodynamic drag (D_{aero}). See Equations 4 and 5.

$$D_{aero} = (1/2)rAV_r^2 C_d(Y) \tag{Eq. 4}$$

$$D_{aero} = (1/2)rAV_r^2(a_0 + a_1 Y + a_2 Y^2 + a_3 Y^3 + a_4 Y^4) \tag{Eq. 5}$$

11.5 Grade Correction—For test tracks which are not level, the force contribution due to gravity (D_{grav}) is the component of the vehicle weight acting in the "horizontal" direction of vehicle travel. The force is determined from the grade, i.e., the change in elevation per distance along the track (dh/ds), and the vehicle mass. The sign is a function of the direction, "up" or "down" hill (+ is up). See Equation 6.

$$D_{grav} = \pm Mg(dh/ds) \tag{Eq. 6}$$

11.6 Final Form of the Equation of Motion—See Equation 7.

$$M_e(dV/dt) = A_m + B_m V + C_m V^2 + (1/2)rAV_r^2(a_0 + a_1 Y + a_2 Y^2 + a_3 Y^3 + a_4 Y^4) \pm Mg(dh/ds) \tag{Eq. 7}$$

12. Data Reduction—This section describes a technique for analyzing a set of coastdown data employed in the determination of the coefficients used to describe the road load force. The end result is a three term equation describing the road load force as a function of velocity $F = A + BV + CV^2$ corrected to 20 °C (68 °F), 98.21 kPa (29.00 in-hg) and still air.

12.1 Determine Calibration Coefficients—If not previously determined, calibration factors (to correct for vehicle "blockage") must be determined for relative wind speed and yaw angle. One technique which may be used involves taking vehicle speed (V), relative wind velocity (V_r) and yaw (Y) measurements during the warm-up phase of the test procedure. Paired runs in alternate directions at a constant 80 km/h are made on the test track; average values for V, V_r and Y are determined for each run. By assuming that the wind during each pair of runs is constant, calibration factors can be selected which minimize the total errors in head and cross winds over all the run pairs; i.e., the sum of $(head_i - head_{i+1})^2$, etc. The user must select calibration techniques appropriate for the wind conditions encountered as well as the instruments used.

12.2 Derive Second by Second Observations—From the periodic data collected during the coastdown runs, determine values for V, (dV/dt), V_r^2, Y and (dh/ds) by applying calibration factors and data filtering as appropriate.

12.3 Preliminary Analysis—Using a linear regression technique, analyze all data points at once. Determine A_m, B_m, C_m, a_0, a_1, a_2, a_3, and a_4 given M_e, dV/dt, V, V_r, dh/ds, and air density.

12.4 Identify "Outliers"—For each data point, calculate a predicted force, M_e(dV/dt), and compare to that observed. "Flag" data points with excessive deviations, e.g., over three standard deviations.

12.5 Data Filtering—If desired, appropriate data "filtering" techniques may be employed. Smooth remaining data points.

12.6 Eliminate Extreme Data Points—"Flag" data points with yaw angles greater than ±20 degrees from the direction of vehicle travel; also "flag" data points with relative winds less than +5 km/h (to avoid backwind conditions), restrict data analysis to vehicle speeds form 115 to 15 km/h.

12.7 Final Data Analysis—Using a linear regression technique, analyze all data which has not been "flagged." Determine A_m, B_m, C_m, a_0, a_1, a_2, a_3, and a_4 given M_e, dV/dt, V, V_r, dh/ds, and air density.

12.8 Constrained Analysis Option—In a constrained analysis, the vehicle frontal area (A) and coefficient of drag (C_d) are fixed at values which have been previously determined; for example in a wind tunnel. This optional technique may allow for a more accurate separation of vehicle aerodynamic and mechanical drag; thus permitting a more accurate application of ambient correction factors.

12.9 Corrections—Correct the final results for instrument drag (if known), correct to standard ambient temperature and pressure conditions; 20 °C, 98.21 kPa. Mechanical drag terms ($A_m + B_mV + C_mV^2$) are multiplied by [1 + 0.0081 (T – 20)]; aerodynamic drag (D_{aero}) is corrected to a standard air density by multiplying by [(273 + T)/293] * [98.21/Baro].

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