SAE INTERNATIONAL

SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Road Load Measurement Using Onboard Anemometry and Coastdown Techniques

RATIONALE

This document has been updated to align it with SAE J2264 and Environmental Protection Agency guidance CD-15-04, issued February 23, 2015. The document has also been edited for clarity.

1. SCOPE

This SAE Recommended Practice establishes a procedure for determination of vehicle road load force for speeds between 115 km/h and 15 km/h (or between 70 mph and 10 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.

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 +1 724-776-4970 (outside USA), www.sae.org.

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 SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

Andrews, R. and Pruess, D., "Determination of Coastdown Mechanical Loss Ambient Correction Factors for use with J2263 Road Tests," SAE Technical Paper 970269, 1997, https://doi.org/10.4271/970269.

Buckley, F., "ABCD - An Improved Coast Down Test and Analysis Method," SAE Technical Paper 950626, 1995, https://doi.org/10.4271/950626.

Buckley, F., Marks, C., and Walston, W., "Analysis of Coast-Down Data to Assess Aerodynamic Drag Reduction on Full-Scale Tractor-Trailer Trucks in Windy Environments," SAE Technical Paper 760850, 1976, https://doi.org/10.4271/760850.

Dayman, B., "Realistic Effects of Winds on the Aerodynamic Resistance of Automobiles," SAE Technical Paper 780337, 1978, https://doi.org/10.4271/780337.

Dayman, B., "Tire Rolling Resistance Measurements From Coast-Down Tests," SAE Technical Paper 760153, 1976, https://doi.org/10.4271/760153.

Passmore, M. and Le Good, G., "A Detailed Drag Study Using the Coastdown Method," SAE Technical Paper 940420, 1994, https://doi.org/10.4271/940420.

Smith, J., Tracy, J., and Potter, D., "Tire Rolling Resistance - A Speed Dependent Contribution," SAE Technical Paper 780255, 1978, https://doi.org/10.4271/780255.

Thompson, G., "Prediction of Dynamometer Power Absorption to Simulate Light Duty Truck Road Load," SAE Technical Paper 770844, 1977, https://doi.org/10.4271/770844.

Walston, W., Buckley, F., and Marks, C., "Test Procedures for the Evaluation of Aerodynamic Drag on Full-Scale Vehicles in Windy Environments," SAE Technical Paper 760106, 1976, https://doi.org/10.4271/760106.

White, R. and Korst, H., "The Determination of Vehicle Drag Contributions from Coast-Down Tests," SAE Technical Paper 720099, 1972, https://doi.org/10.4271/720099.

Yasin, T., "The Analytical Basis of Automobile Coastdown Testing," SAE Technical Paper 780334, 1978, https://doi.org/10.4271/780334.

2.2.2 ISO Publications

Copies of these documents are available online at http://webstore.ansi.org/.

ISO/DIS 10521:1991-07-31 Motor Vehicle Road Load - Determination Under Reference Atmospheric Conditions and Reproduction on Chassis Dynamometer

2.2.3 Sample Program

A working sample program is furnished as a proposed method of following this document. The full executable program, sample data, instructions, and the underlying visual basic code can be obtained at:

https://drive.google.com/open?id=1f9E-Fncm3b_U2MYSap1y619VlenlhRNP

3. DEFINITIONS

3.1 AMBIENT TEMPERATURE

The true air temperature shielded from the sun and track.

3.2 CONSTRAINED ANALYSIS

An analysis option in which the coefficients used to describe the road load force are determined using values for vehicle frontal area and coefficient of aerodynamic drag that were determined independently.

3.3 DRIVELINE

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

3.4 EFFECTIVE TEST TRACK MASS (M_{TE})

The effective mass of an individual test vehicle, including the vehicle's mass (as determined by weighing) plus the equivalent mass of rotating components:

$$M_{TE} = M_{VEH} + M_R \quad \text{(Eq. 1)}$$

Using 3.5 to estimate the equivalent mass of rotating components, M_{TE} can be calculated as follows:

$$M_{TE} = 1.03 \cdot M_{VEH} \quad \text{(Eq. 2)}$$

3.5 EQUIVALENT MASS OF ROTATING COMPONENTS (M_R)

This is the contribution of rotational inertia to the resistance of the vehicle to longitudinal motion. For light-duty vehicles, the rotational inertia is typically estimated to be equal to 3% of the vehicle's mass:

$$M_R = 0.03 \cdot M_{VEH} \quad \text{(Eq. 3)}$$

This estimate is not applicable for vehicles with other than single, normal-sized wheels, such as dual-wheel trucks, or other driveline components, which are likely to result in an equivalent mass greater than 3% of the vehicle's mass. These vehicles require a more appropriate estimation or determination of the actual effective mass of the rotating drive components.

3.6 EQUIVALENT TEST WEIGHT

Test weight as dictated by U.S. Code of Federal Regulations (40 CFR §86) that is assigned to represent a class of test vehicles.

3.7 MECHANICAL DRAG (D_{mech})

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

3.8 RELATIVE WIND SPEED (V_r)

Apparent wind speed relative to the vehicle. This is the magnitude of the relative wind vector, which is the ambient wind velocity relative to vehicle velocity. Wind velocity is assumed to lie in the horizontal plane.

3.9 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.

3.10 TEST VEHICLE MASS (M_{VEH})

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

3.11 YAW ANGLE (Y)

Wind direction relative to the direction of vehicle travel. This is the angle between the vehicle body longitudinal axis and the relative wind vector. Yaw angle has a value of zero when the wind vector and vehicle velocity vector are in opposite directions, and is positive when the wind approaches the vehicle from the left.

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	magnitude of generic drag force acting opposite of the direction of motion
D_{aero}	N	aerodynamic drag
D_{grav}	N	gravitational drag
D_{mech}	N	mechanical drag
(dV/dt)	ms^{-2}	acceleration
F_0	N	coefficient of road load force
F_1	N/(km/h)	coefficient of road load force
F_2	$N/(km/h)^2$	coefficient of road load force
g	ms^{-2}	gravitational constant 9.80665
(dh/ds)		grade
M_{VEH}	kg	test vehicle mass
M_{TE}	kg	effective test track mass
M_R	kg	equivalent mass of rotating components
ρ	kg/m^3	air density
t	seconds	time
T	°C	average ambient temperature
V	km/h	vehicle speed
V_r	km/h	relative wind speed
Y	degrees	yaw angle

5. INSTRUMENTATION

5.1 Calibration

All instrumentation shall be calibrated. Calibration intervals should be according to good engineering judgment and in accordance with the equipment manufacturer's specifications.

5.2 Time

(Elapsed) time shall be measured to an accuracy of ±0.001 second and shall be recorded to a resolution of 0.01 second.

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 should be measured at the approximate mid-point of the vehicle's frontal cross section and approximately 2 m (6.6 feet) 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." (This is not the only possible measurement location. Caution must be used to determine the wind velocity correction factor at the exact measurement location.)

5.5 Yaw Angle

Yaw angle should be measured at the approximate mid-point of the vehicle's cross section and approximately 2 m (6.6 feet) in front of it. Yaw angle 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." (This is not the only position that can be used. Caution must be used to determine the measured versus actual yaw angle transfer function for the exact measurement location.)

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 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

Ambient temperature shall be measured to a resolution and accuracy of 1 °C (1.8 °F) in a location that is not influenced by the vehicle. Check for temperature measurement duration/average.

5.7 Barometric Pressure

Barometric pressure shall be measured to a resolution and accuracy of 0.3 kPa (0.1 in-Hg). Data from a central facility weather station is acceptable. Track-side pressure readings are preferred.

5.8 Vehicle Mass

Test vehicle mass shall be measured to an accuracy of ±10 kg (22 pounds). For vehicles with a test mass over 4000 kg (8818 pounds), the accuracy requirement is ±20 kg (44 pounds).

6. VEHICLE PREPARATION

6.1 Break-In

The test vehicle should be in the condition and adjustment recommended by the manufacturer for normal operation. For regulatory testing, the test vehicle and tires should be aged with sufficient mileage to represent the road load force at the 4000-mile (6440-km) test point. Mileage accumulation should be conducted at speeds and loads that are representative of both subsequent coastdown and dynamometer testing.

NOTE: For example, heavy-duty vehicles may be ballasted to the adjusted loaded vehicle weight, as specified in 40 CFR §86.1803-01, 40 CFR §1066.805.

Tires may be broken in separately from the test vehicle, either using a different vehicle or test method, provided that they are broken in to an equivalent mileage as the test vehicle and similar load conditions. Mileage accumulation for vehicles with multiple driveline modes should be conducted using the same mode that will be used for road load determination.

6.2 Vehicle Check-In

The test vehicle shall be identified. The test vehicle should be in the condition and adjustment recommended by the manufacturer for normal operation. 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, vehicle identification number (VIN), engine, and transmission type.

b. Tire size, manufacturer, Tire Identification Number (TIN) for each tire (if available), Tire Performance Criteria (TPC) or equivalent (if available), and the depth of tread on each tire.

c. Aerodynamic drag coefficient only if “constrained analysis” is to be used.

d. Frontal area.

e. Vehicle ride 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 at test conditions.

f. Manufacturer’s minimum recommended tire inflation pressure.

g. Abnormal wheel bearing and brake drag (if present).

h. Wheel alignment parameters (should be representative of manufacturer’s mean specification).

NOTE: For regulatory testing purposes, the test vehicle should be representative of the sub-configuration for which the road loads are being determined.

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 should have sufficient fuel to complete the testing. However, the fuel volume may be adjusted if necessary to meet any ballasting and attitude requirements.

6.6 Tire Pressure

The vehicle tires shall be inflated to the vehicle manufacturer's recommended cold inflation pressure after a soak period of at least 4 hours. (If more than one inflation pressure is recommended, the minimum pressure recommended by the manufacturer shall be used.) Prior to the soak period, the tires shall be inflated to a pressure no more than 10% greater than the manufacturers' recommended cold inflation pressure. The tire pressure must be adjusted for changes in temperature between the tire soak area temperature at the time of inflation and the ambient temperature. (For normal passenger vehicle tires, this correction is approximately a 1 kPa increase for each 1 °C (1 psi increase for each 13 °F) that the tire temperature exceeds the ambient temperature.) Alternatively, the vehicle may be parked outside near the test track area with the tires shielded from the sun for a minimum of 4 hours prior to setting the tire pressure. The tire pressure should be set immediately prior to beginning the test procedure. The tire pressure must be set and recorded prior to moving the vehicle to avoid false readings. The tire pressure shall be measured to an accuracy of ±3 kPa (±0.5 psi).

7. TEST CONDITIONS

7.1 Temperature

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

7.2 Wind

Average wind speed shall not exceed 25.1 km/h (15.6 mph).

Wind gusts shall not exceed 36.0 km/h (22.4 mph).

Average crosswinds shall not exceed 10 km/h (6.2 mph). The maximum crosswind gust shall not exceed 15 km/h (9.3 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%. The grade must be constant ±0.1% when measured over a 50 m (164 feet) interval throughout the test section. 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 as described in 11.5. See Appendix B for additional considerations regarding track surfaces.

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. For U.S. regulatory testing, the coastdown test vehicle weight must be adjusted to the equivalent test weight (ETW) specification for the sub-configuration it is representing including the driver and test equipment. An allowance for the fuel consumed during the test can be added to the pre-test weight. The post-test vehicle weight including the driver and all test equipment, M_{VEH}, must be within 25 pounds (11.3 kg) of the ETW specification for the sub-configuration it represents. If the post-test vehicle weight differs by more than 25 pounds (11.3 kg) from the ETW, the coefficients of mechanical drag (A_m, B_m, and C_m) must be adjusted analytically to represent the vehicle at ETW. To adjust the coefficients of mechanical drag, multiply them by the ratio of the ETW to the post-test vehicle test weight (M_{VEH}) using compatible units.

8.3 Vehicle Ballasting

The vehicle shall be ballasted, if necessary, with the ballast distributed in such a way that the ballast does not create unrepresentative ride heights or vehicle attitude.

8.4 Vehicle Preconditioning

Precondition the test vehicle and tires by driving for a nominal 30 minutes at 80 km/h (50 mph). This preconditioning period may be used to calibrate instrumentation. If data collected during the preconditioning period shows that the vehicle's tire and driveline temperatures are not sufficiently stabilized, additional preconditioning at 80 km/h (or 50 mph) is allowed.

8.5 Active Devices

Active devices that are not driver controlled may behave differently during the coastdown test than during emissions testing or normal drive conditions. Examples of these active devices are active grill shutters, active suspension height, and active aerodynamic features. For non-regulatory testing, exercise good engineering judgment to ensure road load results are representative of actual use. For U.S. regulatory testing, manufacturers shall seek EPA approval under 40 CFR §86.1840 for determining the settings for coastdown testing.

9. COASTDOWN TEST

9.1 Vehicle Condition

Vehicle windows and vents must be closed. For safety reasons, it is recommended that the vehicle's headlights be turned on. Air-conditioning, if used, should be in the re-circulation mode and its use recorded. Accessories may be used. Use of accessories that affect engine speed shall be noted and duplicated during any subsequent dynamometer adjustments. Brakes shall not be retracted or removed.

9.2 Test Runs

A minimum of five valid test runs is required in each direction (ten total). Additional test runs may be conducted. However, all valid test runs must be included in the analysis.

9.3 Procedure

The test runs shall begin immediately following preconditioning. At the start of each test run, accelerate the vehicle to a vehicle speed of 125 km/h (or 77.7 mph). After vehicle has stabilized at 125 km/h (77.7 mph), 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), stop the recording equipment, engage the transmission and prepare for the next test run, which shall be in the opposite direction. Normal brake applications are allowed between test runs as necessary during the coastdown test procedure to ensure that no unrepresentative brake drag conditions exist. The procedure shall not include preconditioning between test runs, and shall be conducted so that the time and driving distance between test 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" test runs are permitted. In a split test run, data is first collected for the high-speed portion, 125 to "X" km/h (77.7 to "X" mph), in each direction; then low-speed data is collected, "X" + 15 to 15 km/h ("X" + 9.3 to 9.3 mph). The process is then repeated until five complete 125 to 15 km/h (77.7 to 9.3 mph) test run pairs have been completed.

9.3.2 Testing on Oval Tracks

It is recommended that the test procedures in this document be performed on a straight track. In the event that both sides of an oval track must be used, the results must be equivalent to those when tested on a straightaway with alternating passes over the same road surface. The following considerations must be taken into account:

- Test runs must be performed on the straight portions of the track.
- Similar wind conditions (magnitude, direction) shall exist on each straightaway (free of blockages).
- Equal and opposite grade shall exist on each straightaway, or the correction for gravitational drag in 11.5 must be applied.
- Vehicle speed between runs shall not exceed 80 km/h (50 mph).
- Both straightaways shall have surfaces that adhere to the conditions outlined in 7.4. In addition, the test runs shall be performed in a lane with a minimal amount of bank.

9.4 Lane Changes

While collecting data, lane changes are prohibited.

9.5 Traffic Considerations

During the test runs, vehicles moving in the same direction as the test vehicle may influence the aerodynamic behavior of the test vehicle if they come within 200 m (656 feet) either leading or trailing. This includes passing another vehicle or being passed in the same direction. If this occurs, the specific run may be invalid. Being passed by a vehicle in the adjacent traffic lane moving in the opposite direction on the same roadway during the test will cause a momentary change in the local wind vector but should not affect the final resolved force equation.

9.6 Invalid Runs

Identify any test runs (and the corresponding paired run) that are to be excluded from the analysis due to circumstances that render the test run as noncompliant (e.g., brake application, lane changes, equipment malfunction, etc.).

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 and end of each test run. Items may be recorded manually or by the data logging system:

a. Run number (method of identifying each run)

b. Start time

c. Ambient temperature

d. Ambient pressure

e. Ambient humidity

f. Run direction

g. Track surface temperature

10.2 Test Run Data

The following data shall be measured and recorded at a frequency of at least 5 Hz 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 speed and direction (yaw angle) relative to the vehicle

d. Ambient temperature

10.3 End of Test Data

Upon conclusion of the test runs, weigh the vehicle (including driver and all instrumentation) in order to determine its test vehicle mass (M_{VEH}). For regulatory testing, see 8.2 to determine if analytical correction of coastdown data is required. Determine average ambient temperature, average wind speed, peak wind speeds, and average barometer pressure during the test portion.

10.4 Data Recording Option

Data may be recorded continuously, i.e., 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 4:

$$-M_{TE}(dV/dt) = D_{mech} + D_{aero} + D_{grav} \quad \text{(Eq. 4)}$$

11.3 Mechanical Drag

Although mechanical drag consists of separate elements representing tire and front and rear axle frictional losses (including transmission losses), it can be modeled as a three-term polynomial with respect to vehicle speed (V). See Equation 5:

$$D_{mech} = A_m + B_m V + C_m V^2 \quad \text{(Eq. 5)}$$

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

The aerodynamic drag coefficient, $C_d(Y)$, is modeled as a five-term polynomial with respect to yaw angle (Y). See Equation 6:

$$C_d(Y) = a_0 + a_1 Y + a_2 Y^2 + a_3 Y^3 + a_4 Y^4 \quad \text{(Eq. 6)}$$

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 speed (V_r) to determine the aerodynamic drag (D_{aero}). See Equations 7 and 8:

$$D_{aero} = (1/2)\rho A V_r^2 C_d(Y) \quad \text{(Eq. 7)}$$

$$D_{aero} = (1/2)\rho A V_r^2 (a_0 + a_1 Y + a_2 Y^2 + a_3 Y^3 + a_4 Y^4) \quad \text{(Eq. 8)}$$

11.5 Gravitational Drag

For test tracks that are not level, the gravitational drag (D_{grav}) is the component of the test vehicle weight acting in the longitudinal direction. The value is positive when it is acting opposite to the 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. Grade is positive if elevation increases with distance travelled. See Equation 9:

$$D_{grav} = M_{VEH} g(dh/ds) \quad \text{(Eq. 9)}$$

11.6 Final Form of the Equation of Motion

$$-M_{TE}(dV/dt) = A_m + B_m V + C_m V^2 + (1/2)\rho A V_r^2 (a_0 + a_1 Y + a_2 Y^2 + a_3 Y^3 + a_4 Y^4) + M_{VEH} g(dh/ds) \quad \text{(Eq. 10)}$$

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 $F = F_0 + F_1 V + F_2 V^2$ 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. The user must select calibration techniques appropriate for the wind conditions encountered as well as the instruments used. One technique that may be used involves taking vehicle speed (V), relative wind speed (V_r), and yaw angle (Y) measurements during the warm-up phase of the test procedure. Paired runs in alternate directions at a constant 80 km/h (50 mph) 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. Appendix C describes the procedure used in the sample program referenced in 2.2.3.

12.2 Derive Second by Second Observations

From the periodic data collected during the coastdown runs, determine values for V, (dV/dt), V_r, 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_{TE}, dV/dt, V, ρ, A, V_r, Y, M_{VEH}, g, and dh/ds.

12.4 Identify Outliers

For each time series data point, calculate a predicted force based on the regression and compare to the measured value of M_{TE}(dV/dt). "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 to smooth the 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 wind speeds less than +5 km/h (3.1 mph) to avoid backwind conditions, restrict data analysis to vehicle speeds from 115 to 15 km/h (71.5 to 9.3 mph).

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_{TE}, dV/dt, V, ρ, A, V_r, Y, M_{VEH}, g, and dh/ds.

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

Calculate road load force coefficients by evaluating Equation 10 at zero wind speed ($V = V_r$), zero yaw angle (Y = 0), and zero grade (dh/ds = 0). Correct the final results for instrument drag (if known), correct to standard ambient temperature and pressure conditions of 20 °C (68 °F), 98.21 kPa (29.00 in-Hg). Mechanical drag terms (A_m, B_m, and C_m) 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]. See Equations 11 through 13:

$$F_0 = A_m[1 + 0.0081\,(T - 20)] \quad \text{(Eq. 11)}$$

$$F_1 = B_m[1 + 0.0081\,(T - 20)] \quad \text{(Eq. 12)}$$

$$F_2 = C_m[1 + 0.0081\,(T - 20)] + (1/2)\rho A a_0[(273 + T)\,/\,293]\cdot[98.21/\,\text{Baro}] \quad \text{(Eq. 13)}$$

13. NOTES

13.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE SAE LIGHT-DUTY VEHICLE PERFORMANCE AND ECONOMY MEASUREMENT STANDARDS COMMITTEE

APPENDIX A

A.1 EQUATION OF MOTION

The equation of motion is based on the following assumptions:

a. The tire slip angles developed in the presence of aerodynamic side forces and yawing moments have a negligible effect on tire drag. (Data is analyzed only for yaw angles of from -20 to +20 degrees, thus minimizing any potential effect.)

b. The contribution of the vehicle slip angle to the aerodynamic yaw angle is negligible.

c. The variation of the aerodynamic drag coefficient over the speed range of the procedure is negligible.

d. The variation of the mechanical drag contribution with speed can be adequately modeled with no more than a second-order polynomial in speed.

e. The reduction in mechanical drag (primarily tire rolling resistance) due to aerodynamic lift is very small and is disregarded.

f. The variation of the aerodynamic drag coefficient with yaw angle can be adequately modeled with a fourth-order polynomial in yaw angle.

g. The sensitivity (variation) of the aerodynamic drag coefficient (due) to the turbulence levels and nonuniformities which are introduced into the relative airstream when winds are present is negligible.

h. The aerodynamic drag forces can be adequately modeled with a quasi-steady relation which is evaluated using instantaneous freestream relative airspeeds and freestream yaw angles inferred from data measured with a boom-mounted anemometer situated at the mid-height of the vehicle. This requires that the dynamic responses of the anemometer and the vehicle be similar and/or that the test data be properly filtered, and that the anemometer measurements be corrected to account for the modifications of the freestream relative airspeed and freestream yaw angle produced by the interference of the vehicle on the flow field at the anemometer location.