SAE International™ **SURFACE VEHICLE RECOMMENDED PRACTICE**

J2505 AUG2010

Issued 2003-06
Revised 2010-08

Superseding J2505 JUN2003

Measurement of Vehicle-Roadway Frictional Drag

RATIONALE

This document has been revised with editorial changes suggested during a review by the Accident Investigation and reconstruction practices committee

TABLE OF CONTENTS

SAE Technical Standards Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."
SAE reviews each technical report at least every five years at which time it may be reaffirmed, revised, or cancelled. SAE invites your written comments and suggestions.
Copyright © 2010 SAE International
All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.
TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: http://www.sae.org

SAE values your input. To provide feedback on this Technical Report, please visit http://www.sae.org/technical/standards/J2505_201008

1. SCOPE

This SAE Recommended Practice provides guidelines for procedures and practices used to obtain and record measurements and to analyze and present results of frictional drag tests of a vehicle with its brakes fully applied at a given roadway location. It is for use at accident sites and test sites and is applicable to straight-line stopping of vehicles such as passenger cars, light trucks and vans under fully braked conditions including locked-wheel skids for vehicles with a conventional braking system and for vehicles with full or partial antilock braking systems (ABS). The average deceleration resulting from a given series of tests is intended to be representative of a frictional drag factor for the conditions under which the test was conducted such as the type of vehicle, type and condition of tires, roadway material and roadway surface conditions. The frictional drag factor is intended to conform to use with the stopping distance formula (Fricke, 1990) as stated in Equation 1. **Two methods are included: Stopping Distance Method (measurement of the distance required to bring a vehicle to a complete stop from a known initial speed) and Average Acceleration Measurement (using acceleration measuring devices and data analysis to determine the average drag factor). The Recommended Practice applies to vehicles stopping in a fully braked condition. Values of roadway frictional drag obtained by other means do not necessarily agree or correlate (Lock, et al., 1982) with full vehicle testing and are not recommended.**

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this recommended practice to the extent specified herein. Unless otherwise specified, the latest version 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 724-776-4970 (outside USA), www.sae.org.

SAE J670 Vehicle Dynamics Terminology

2.1.2 NIST Publication

Available from National Institute of Standards and Technology, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, Tel: 301-975-6478, www.nist.gov.

Taylor, B. N., Guide for the Use of the International System of Units (SI), NIST SP 811, 1995

2.2 Related Publications

The following publications are for information purposes only and are not a required part of this document.

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

SAE J2909 Light Vehicle Dry Stopping Distance

SAE J299 SEP93 Stopping Distance Test Procedure

TSB 003 Rules for SAE Use of SI (Metric) Units

SAE Paper 940722 Uncertainty in Accident Reconstruction Calculations, Brach, R. M., 1994

SAE Paper 940918 Analysis of Accelerometer Data for Use in Skid-Stop Calculations, Robinson, E. L., 1994

2.2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E 274-93 Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire

ASTM E 445/E 445M-88 Test Method for Stopping Distance on Paved Surfaces Using a Passenger Vehicle Equipped with Full-Scale Tires

ASTM E 456-96 Standard Terminology for Relating to Quality and Statistics

ASTM E 503/E 503M-88 (1994) Test Methods for Measurement of Skid Resistance on Paved Surfaces Using a Passenger Vehicle Diagonal Braking System

ASTM F 403-86 (Reapproved 1993) Test Method for Tires for Wet Traction in Straight-Ahead Braking, Using Highway Vehicles

ASTM F 811-95 Practice for Accelerometer Use in Vehicles for Tire Testing

2.2.3 NIST Publication

Available from National Institute of Standards and Technology, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, Tel: 301-975-6478, www.nist.gov.

Taylor, B. N. and C. E. Kuyatt, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, NIST Technical Note 1297, US Dept of Commerce, 1994

2.2.4 Other Publications

Fricke, Lynn B., Traffic Accident Reconstruction, Vol 2, Traffic Accident Investigation Manual, Northwestern University Traffic Institute, 1990

Lock, J. R., D. L. Ivey, A. S. Jones, K. E. Barnes, O. J. Pendelton and T. Chira-Chavala, Pavement Condition Measurement for Safety Improvements, Vol 1, “Development of Procedures”, Final Report, Texas Transportation Institute, College Station, TX, 1982

3. DEFINITIONS

The following terms and acronyms are defined for use herein.

3.1 ABS

Antilock Braking System

3.2 Braking Distance, *d*

The straight line distance on a flat surface taken to bring a vehicle to rest by rapid full application of the braking system.

3.3 Fifth Wheel

An instrumented wheel device attached to a vehicle that provides kinematic data in the heading direction of the vehicle.

3.4 Frictional Drag

The total retarding force on a moving vehicle between its tires and the roadway surface, exerted as a result of brake application.

3.5 Frictional Drag Coefficient (Coefficient of Friction)

The ratio of the frictional drag force to the vehicle’s weight at a given speed, position or instant of time.

3.6 Frictional Drag Factor, *f*

The frictional drag coefficient averaged over a fully braked stop as calculated using the stopping-distance formula (see Equation 1).

3.7 Full Brake Application

The production of sufficient brake pedal force to cause wheels with conventional brakes to lock and/or for continual operation of an ABS system.

3.8 Skid Mark Length

The length of a visible tire mark on a roadway surface made under full brake application.

3.9 Test Weight

Total weight of the test vehicle, including onboard equipment and occupants, at the time of the tests.

3.10 Vehicle Reference Point

A point on the exterior of a vehicle whose position is to be noted and measured at various times and events during a test.

4. TEST CONDITIONS

4.1 Safety

The manner of conducting all activities covered by this recommended practice should ensure the safety of the test personnel, observers and the general public. All applicable professional practices and applicable governmental laws and regulations for conducting such tests are to be followed.

4.2 Vehicle

The vehicle used in the tests, including its features, equipment and condition, should be chosen as appropriate to the needs and intended use of the data. The braking system should be inspected prior to all tests and any unplanned or unintentional irregularities noted and corrected. If testing of any part of the vehicle under abnormal conditions is specifically intended, such conditions should not be a hazard to participants or the general public. The operator should be familiar with the vehicle, its condition and operation.

Vehicle descriptive and physical information should be recorded for each test as described in Section 7 and the example data sheet in Appendix A.

4.3 Initial Speed

The initial speed(s) chosen for testing should be representative of the conditions for which the data are to be applied. For example, if used for accident reconstruction purposes, speeds should simulate those of the subject conditions.

4.4 Roadway Environment

The roadway test site location and conditions should be chosen as appropriate to the needs and intended use of the data. The use of roadways and other locations accessible to the general public should be properly controlled. Weather conditions, roadway surface conditions including temperature, roadway geometry and other existing environmental conditions should be recorded (see attached data form) and any abnormalities noted. A sufficiently long portion of the roadway should be available to reach the test speed and to allow for controlled, aborted and abnormal stopping distances.

4.5 Testing Events

Extraordinary events that occur during testing, such as a significant change in vehicle heading, temporary lifting of a wheel or wheels from the roadway, brake fade, nonuniform wheel locking, different skid mark lengths from wheel to wheel, etc., should be noted. When possible, measurements of extraordinary events should be taken, such as a heading angle at rest different from the original value.

The consideration of potential error sources is left to the judgement and experience of the investigator.

5. MEASUREMENT OF VEHICLE-ROADWAY DRAG FACTOR BY BRAKING DISTANCE

5.1 Procedure

The vehicle should be brought to the steady desired initial speed. The brakes then should be rapidly actuated and sustained with sufficient force to maintain wheel lock and/or ABS system operation until the vehicle comes to rest. Any factors that can cause significant deviations from a straight line path and constant heading angle should be avoided. The roadway location corresponding to a vehicle reference point is to be marked at the time of brake system application, such as with a chalk gun triggered by brake system actuation. The speed at the time of brake pedal application at the mark point should be measured and recorded using appropriate instruments such as a radar gun, fifth wheel (side wheel) device, etc. The position of the vehicle reference point at the time of wheel lock can be marked in addition to or as an alternative to brake system application location if all wheels lock with reasonable simultaneity. The distance of travel, d, from the marked point to the vehicle reference position at rest is to be measured and recorded.

Measurement devices have an associated inaccuracy (for example, a 1% error in measuring 1.6093 km is 16.093 m [1 mile is 52.8 ft]). Experimental techniques, especially the act of coordinating a human observation and action with an event (starting and stopping a stop watch to time an event, reading a speed at an event such as wheel lock, etc.) have associated inaccuracies. A description of each measurement device and each experimental technique and a quantitative evaluation of their associated accuracies, precisions and variations should be reported.

5.2 Data Preparation and Analysis

Each test run produces corresponding values of initial speed, v_0, and distance to rest, d. Using consistent units, the frictional drag factor, f, is calculated with the formula

$$f = \frac{v_0^2}{2gd\cos\theta} - \tan\theta \qquad \text{(Eq. 1)}$$

where:

g is the acceleration of gravity and θ is a constant grade angle. For a level roadway θ = 0; for an up grade θ is positive and for a down grade θ is negative. Calculation of the frictional drag factor, f, by any method other than Equation 1 (such as when a vehicle is not brought to rest) should be documented. For grade angles less than about 0.17 rad (10 degrees, 17.6% grade), the root-mean-square uncertainty of the frictional drag coefficient computed by Equation 1 can be estimated using the formula

$$\Delta f = \sqrt{\left(\frac{2f}{v_0}\right)^2 \Delta v_0^2 + \left(\frac{f}{d}\right)^2 \Delta d^2 + \Delta\theta^2} \qquad \text{(Eq. 2)}$$

Δv_0, Δd and Δθ are variations of the initial speed, distance, and roadway grade angle, respectively, corresponding to measurement devices and procedures. Note that when any of the denominators in the terms of Equation 2 is small compared to the variations, the uncertainty is large. The results of an uncertainty analysis by Equation 2 or other established technique, should be part of any report of measurement results.

6. MEASUREMENT OF VEHICLE-ROADWAY DRAG USING ACCELERATION MEASURING INSTRUMENTS

This methodology is to be employed to determine frictional drag factor with the use of an acceleration measurement system such as an on-board accelerometer and signal processing equipment.

6.1 Instrumentation

The instrumentation employed, including transducer and data acquisition package, should be chosen as appropriate to the needs and intended use of the data. . Proper instruments, their calibration and the analysis of data and information from existing literature should always be taken into account

6.1.1 Identification

Transducer and data acquisition system manufacturer, model numbers, calibration dates, number of channels, and pertinent scaling factors and calibration factors are to be identified and recorded. Instrument data acquisition factors and calibration inputs are to be identified and recorded.

6.1.2 Mounting Location

Normally, acceleration transducer(s) should be located as close as feasible to the vehicle center of gravity. When otherwise specified, equipment should be located and mounted according to manufacturer's specifications. The transducer mounting location is to be identified and recorded in accordance with the SAE recommended vehicle inertial reference system, SAE J670.

6.1.3 Signal Conditioning and Data Recording

Sampling rate, data resolution, number of channels, and data filtering should be chosen according to the needs and intended use of the data. All values should be identified and recorded. All data channels should be referenced to a common time base.

6.1.4 Calibration

Calibration of the data acquisition system should be chosen as appropriate to the needs and intended use of the data and according to the manufacturer's recommended procedures. Calibration methodology is to be identified, followed and recorded. Correction factors, if used, are to be identified and recorded.

6.2 Procedures

The vehicle should be brought to the desired initial speed followed by rapid, full brake application. Full brake system actuation should be maintained to ensure wheel lock and/or full ABS operation until the vehicle comes to rest or reaches a desired speed reduction.

6.3 Data Presentation

All recorded data are to be reported with a common time base. Data should be presented graphically with plotting scales of sufficient size to clearly illustrate data values. Data may also be presented in a tabular format with values reported at time intervals sufficient to characterize a signal's time history with reasonable accuracy. Irrespective of reporting methodology, data from all channels are to be identified and recorded from the time when the transducer produces a significant acceleration signal to when the vehicle comes to rest.

6.3.1 Averaging Procedures

The determination of the effective vehicle-roadway frictional drag factor may be based on an averaging procedure using the acceleration-time history or acceleration-position history recorded during the test, The time period, t_1 to t_2 (see Figure 1), or acceleration threshold, or the displacement interval, x_1 to x_2 (Robinson, 1994), over which the acceleration is averaged is to be documented and reported. The averaging methodology, including any weighting of the data, is to be described and identified to allow subsequent duplication by others.

6.3.2 Integration Procedures

The determination of the effective vehicle-roadway frictional drag factor may be based on integrating and averaging the acceleration history recorded during the test. Integration using automatic data analysis features of the instrumentation should be identified if used. Other integration methodologies may be chosen, but must provide sufficient accuracy for the needs and intended use of the data and are to be described and reported in sufficient detail to allow duplication of results by subsequent investigators.

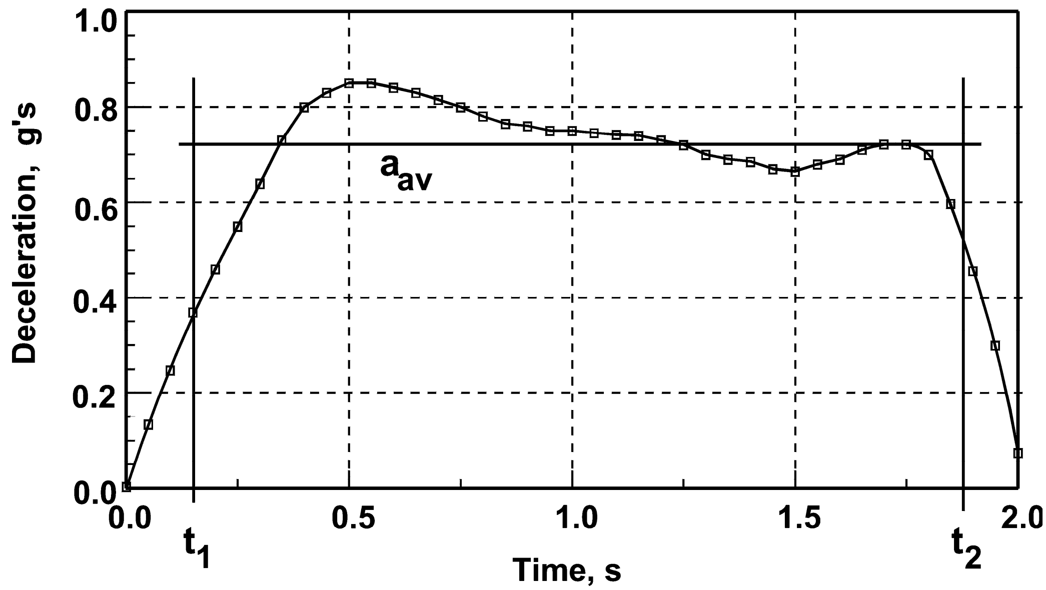


FIGURE 1 - DECELERATION TIME HISTORY ILLUSTRATING THE AVERAGE VALUE COMPUTED OVER THE TIME INTERVAL FROM t_1 TO t_2.

7. RECORD KEEPING, DATA ANALYSIS, AND REPORTING

7.1 Record Keeping

All pertinent information related to the taking of measurements of vehicle-roadway frictional drag is to be recorded. Sufficient information is to be documented to allow independent verification by others of the measurements and results. Documentation can include written records, photography and video. The following categories of descriptive information are to be included in the record keeping process:

7.1.1 Testing Environment

Date, time, location, weather, ambient temperature and relative humidity roadway surface material, surface condition and roadway geometry.

7.1.2 Vehicle and Allied Equipment

Manufacturer’s identification, physical characteristics and condition of pertinent equipment such as tire type(s) and manufacture, inflation pressure, etc.

7.1.3 Measurement Method Equipment Identification, Settings, Calibrations, Accuracy and Precision

Participants and observers in the measurement, analysis and reporting process are to be identified. An example data sheet is provided in Appendix A.

7.2 Data Acquisition and Analysis

When planning experiments, generally there are 2 basic types of variables to be considered. One type includes those to be held fixed and the other includes those to be given controlled changes. Variations in the fixed variables from run to run occur and can be beyond the control of a careful experimenter. These variations lead to what is referred to as “experimental error”. A properly conducted experiment is planned not only to reduce all uncontrolled variation, but the measurement process is designed so that the uncontrolled variation can be estimated. The most common way of doing this is through the use of repeated measurements.

When controlled variables are intentionally changed from experiment to experiment, their magnitude of change should span the largest possible range of interest of that variable and should be sufficient to outweigh any uncontrolled variation. When the number of controlled variables is high, combinations of their values for individual experimental runs should be chosen according to established techniques from the field of design of experiments.

7.3 Computation and Unit Conversion

The SI system of units is the primary system to be used for the publication of data. If desired, a dual set of units can be used. All conversions of units should be in accordance with conversion factors established and published by recognized organizations, such as the National Institute of Standards and Technology (NIST SP 811). All data analysis and computation should be carried out to completion without rounding and using a reasonable precision such as associated with electronic calculators and computers. All final values from computations used for tabulation and reporting should be rounded to have the number of significant figures no greater than the original data values, calibration value(s) or unit conversion factors used in the computation procedures.

7.4 Data Analysis

There usually are several aspects to the treatment and analysis of data. One includes the transformation of raw data into usable information, such as for the conversion of instrument readings using calibration constants, calculation of a drag coefficient from distance and speed values, etc. Another is the calculation of various statistical quantities. Another is the use of methods of statistical inference to permit the drawing of conclusions, such as the assessment of significant differences. In all cases, the calculations should follow the procedures presented in 7.3, and the use of accepted methods from the field of statistical analysis.

A principal objective of conducting experiments is to estimate one or more physical quantities such as frictional drag, speed, distance, etc. Estimation of these measured quantities may be the desired end of the measurements but in some cases, particularly when comparisons and/or decisions are required, statistical inference is employed. In all cases, two distinct aspects of estimation play a role. These are the determination of the best estimate of the value of a physical quantity by its mean (average) value and the other is the determination of the amount of variation of the physical quantity by its standard deviation or range. When a measurement of a physical quantity, x, is repeated its average, $\bar{x}$, is calculated using the formula:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad \text{(Eq. 3)}$$

and the standard deviation, s, can be obtained from the variance, s^2, calculated from the formula

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2 = \frac{1}{n-1}[(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_n - \bar{x})^2] \quad \text{(Eq. 4)}$$

where each x_i is one of the n independently measured values of a variable x and the symbol Σ indicates a summation over all n independently measured values of x_i.

7.5 Documentation and Reporting

The primary purposes of a technical report are to document the results of experiments and data analysis and to inform others of the methods used, the results obtained and the conclusions drawn. This should be done in a clear and concise fashion. Documentation should contain the information described in 7.1, all measured data, its analysis (7.4) and all inferences and conclusions. Important assumptions should be stated. When used, the work of others should be given proper credit and citation. Long, detailed documentation of data, derivations, etc., should be placed in appendices.

8. NOTES

8.1 Marginal Indicia

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 ACCIDENT INVESTIGATION AND
RECONSTRUCTION PRACTICES COMMITTEE

APPENDIX A – EXAMPLE VEHICLE-ROADWAY FRICTIONAL DRAG MEASUREMENT DATA SHEET

APPENDIX A.

VEHICLE-ROADWAY FRICTIONAL DRAG MEASUREMENT DATA SHEET

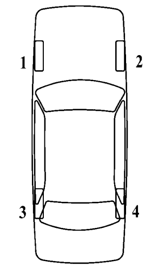
Vehicle Information

Make________________________ Model__________________________ VIN___________________________

Odometer Reading_________________ Test Wt: Front_________ Rear_____________ Total________________

Tire

Position	Type & Size	Tread Depth	Inflation Pressure	DOT Number
1				
2				
3				
4				



Service Braking System: Front _________________________ Rear____________________________

Apparent Condition____

Abnormal Conditions____

____

Environment

Location____ Date____________ Time:________begin_______end

Air: Temperature_________________ Humidity_________________ Dew Point Temp_________________

Sky/Sun_______________________ Wind____________________ Precipitation____________________

Roadway: Material_________________________ Forward Slope (grade):________ Cross Slope________________

Lane __________________________ Direction____________________ Path____________________

Surface: Preparation______________ Condition____________________ Temperature_____________

Dry/Wet________________ Moisture_____________________

Personnel and Equipment

Measuring Equipment (distance, speed, acceleration, force, etc) _______________________________________

____

____

____

Personnel____

Test Data

Run No.	Test Speed	Braking Distance/ Marked Distance	Peak Accel/ Skid Length	Average Accel/ Frictional Drag	Vehicle Yaw at Rest

Notes:____

____

____

____

____

FIGURE A1 – EXAMPLE VEHICLE-ROADWAY FRICTIONAL DRAG MEASUREMENT DATA SHEET