Standard Test Methods for Evaluating Wet Braking Traction Performance of Passenger Car Tires on Vehicles Equipped with Anti-Lock Braking Systems[1]

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INTRODUCTION

These test methods cover procedures for measuring the wet braking performance of passenger car tires when tested on vehicles equipped with an anti-lock braking system (ABS). ABS operation is accomplished by the use of wheel rotation rate sensors that detect impending wheel lockup and controllable brake pressure regulators; both of these systems are connected to a control microprocessor. When potential lockup is detected for any wheel or pair of wheels, brake pressure is lowered to forestall the lockup and maintain wheel rotation. This process is repeated until the vehicle comes to a stop. The necessary lateral force to maintain vehicle control in an emergency braking situation is only possible when wheel rotation is maintained. Although there may be differences in the braking performance among the commercially available "vehicle-ABS" combinations, tires may be evaluated for their relative or comparative wet braking performance with any one "vehicle-ABS-driver" combination, by the methods as outlined in these test methods.

1. Scope

1.1 These test methods cover the measurement of two types of ABS vehicle behavior that reflect differences in tire wet traction performance when the vehicle is fitted with a series of different tire sets to be evaluated.

1.1.1 The stopping distance from some selected speed at which the brakes are applied.

1.1.2 The lack of control of the vehicle during the braking maneuver. Uncontrollability occurs when the vehicle does not follow the intended trajectory during the period of brake application despite a conscious effort on the part of a skilled driver to maintain trajectory control. Uncontrollability is measured by a series of parameters related to this deviation from the intended trajectory and the motions that the vehicle makes during the stopping maneuver.

1.1.3 Although anti-lock braking systems maintain wheel rotation and allow for a high degree of trajectory control, different sets of tires with variations in construction, tread pattern, and tread compound may influence the degree of trajectory control in addition to stopping distance. Thus vehicle uncontrollability is an important evaluation parameter for tire wet traction performance.

1.2 These test methods specify that the wet braking traction tests be conducted on two specially prepared test courses: *(1)* a straight-line (rectilinear) "split-μ" (μ = friction coefficient) test course, with two test lanes deployed along the test course (as traveled by the test vehicle); the two lanes have substantially different friction levels such that the left pair of wheels travels on one surface while the right pair of wheels travels on the other surface; and *(2)* a curved trajectory constant path radius course with uniform pavement for both wheel lanes.

1.3 As with all traction testing where vehicle uncontrollability is a likely outcome, sufficient precautions shall be taken to protect the driver, the vehicle, and the test site facilities from damage due to vehicle traction breakaway during testing.

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Standard precautions are roll-bars, secure mounting of all internal instrumentation, driver helmet, and secure seat belt harness, etc.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E274 Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire

E303 Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester

E501 Specification for Rib Tire for Pavement Skid-Resistance Tests

E524 Specification for Smooth Tire for Pavement Skid-Resistance Tests

E965 Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique

E1136 Specification for P195/75R14 Radial Standard Reference Test Tire

E1337 Test Method for Determining Longitudinal Peak Braking Coefficient of Paved Surfaces Using Standard Reference Test Tire

F457 Test Method for Speed and Distance Calibration of Fifth Wheel Equipped With Either Analog or Digital Instrumentation

F538 Terminology Relating to the Characteristics and Performance of Tires

F1046 Guide for Preparing Artificially Worn Passenger and Light Truck Tires for Testing

F1572 Test Methods for Tire Performance Testing on Snow and Ice Surfaces

F1650 Practice for Evaluating Tire Traction Performance Data Under Varying Test Conditions

F1805 Test Method for Single Wheel Driving Traction in a Straight Line on Snow- and Ice-Covered Surfaces

F1806 Practice for Tire Testing Operations–Basic Concepts and Terminology for Reference Tire Use

F2493 Specification for P225/60R16 97S Radial Standard Reference Test Tire

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *anti-lock braking system (ABS), n*—a collection of sensing and control hardware installed on a vehicle to prevent wheel lockup during brake application. **F538**

3.1.2 *candidate tire, n*—a test tire that is part of a test program. **F538**

3.1.2.1 *Discussion*—The term "candidate object" may be used in the same sense as *candidate tire*.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.3 *candidate tire set, n*—a set of candidate tires. **F538**

3.1.4 *control tire, n*—a reference tire used in a specified manner throughout a test program. **F538**

3.1.4.1 *Discussion*—A control tire may be of either type and typical tire use is the reference (control) tire in Practice F1650 that provides algorithms for correcting (adjusting) test data for bias trend variations (see Practice F1650 and Annex A1).

3.1.5 *reference tire, n*—a special tire included in a test program; the test results for this tire have significance as a base value or internal benchmark. **F538**

3.1.6 *spinout, n—in tire testing*, a type of uncontrollability defined by a loss of steering control due to rapid or substantial yaw, or both. **F538**

3.1.7 *standard reference test tire, (SRTT), n*—a tire that is used as a control tire or surface monitoring tire (for example, Specification E1136 and F2493 tires). **E1136, F1572, F1649, F1650, F1805, F1806, F2493**

3.1.7.1 *Discussion*—This is a Type 1 reference tire.

3.1.8 *stopping distance, n*—the path distance (rectilinear or curved) needed to bring a vehicle to a stop from some selected initial brake application speed. **F538**

3.1.9 *surface monitoring tire, n*—a reference tire used to evaluate changes in a test surface over a selected time period. **F538**

3.1.10 *test (or testing), n*—a procedure performed on an object (or set of nominally identical objects) using specified equipment that produces data unique to the object (or set). **F538**

3.1.10.1 *Discussion*—Test data are used to evaluate or model selected properties or characteristics of the object (or set of objects). The scope of testing depends on the decisions to be made for any program, and sampling and replication plans (see definitions below) need to be specified for a complete program description.

3.1.10.2 *split-μ test*—a wet traction or stopping distance test conducted on a test course with substantially different wet friction levels for the left and right tire test lanes. **F538**

3.1.10.3 *test run*—a single pass of a loaded tire over a given test surface. **F538**

3.1.10.4 *traction test—in tire testing*, a series of n test runs at a selected operational condition; a traction test is characterized by an average value for the measured performance parameter. **F538**

3.1.11 *test tire, n*—a tire used in a test. **F538**

3.1.12 *test tire set, n*—one or more test tires as required by the test equipment or procedure, to perform a test, thereby producing a single test result. **F538**

3.1.12.1 *Discussion*—The four nominally identical tires required for vehicle stopping distance testing constitute a test tire set. In the discussion below where the test tire is mentioned, it is assumed that test tire set may be substituted for test tire, if a test tire set is required for the testing.

3.1.13 *trajectory, n*—the rectilinear or curvilinear path of a vehicle during a stopping maneuver; it is defined by the center of gravity and the transient angular orientation of the vehicle. **F538**

3.1.13.1 *intended trajectory*—the intended or ideal path (rectilinear or curvilinear) to bring a vehicle to a stop, that is, under controlled angular orientation. **F538**

3.1.13.2 *orthogonal trajectory deviation*—the perpendicular deviation or distance from the center of the vehicle to the TGL at the end of a stopping test. **F538**

3.1.13.3 *trajectory guide line (TGL)*—the centerline marked on the test course pavement that constitutes the intended trajectory; it is used by the driver to guide or steer the vehicle on its intended path. **F538**

3.1.14 *uncontrollability, n*—any deviation of the vehicle from the intended trajectory (TGL) during or at the end of a test, or both. **F538**

3.1.14.1 *plowing—in tire testing*, a type of uncontrollability defined by a loss of steering control with no substantial vehicle yaw; the vehicle moves on a trajectory that is dictated by vehicle dynamics as determined by velocity, mass, and the available traction at each tire. **F538**

3.1.15 *yaw, n—in a vehicle*, the angular motion of a vehicle about its vertical axis through the center of gravity. **F538**

3.1.15.1 *yaw velocity*—the magnitude of the yaw (rotation or angular displacement); it may be measured by fore and aft, vehicle vs. pavement, velocity sensors. **F538**

4. Summary of Test Method

4.1 *Methods of Measurement*—These test methods are divided into two methods:

4.1.1 *Method A*—Rectilinear Trajectory Braking, and

4.1.2 *Method B*—Curvilinear Trajectory Braking.

4.1.3 With each method, one of three procedures (Procedure 1, 2, or 3) that vary in measurement sophistication may be used to evaluate stopping distance and vehicle uncontrollability.

4.1.4 Procedure 1 is the simplest, with manually recorded stopping distance and trajectory deviation measurements. Procedure 2 uses computer data acquisition and non-pavement-contact sensors to measure speed, stopping distance, and yaw velocity. Procedure 3 is the most comprehensive; it includes all the measurement capabilities of Procedure 2 in addition to the recording of steering wheel angle throughout the stopping maneuver. The measurement procedures for the performance parameters are more fully described in Section 11.

4.2 *Method A—Rectilinear Trajectory Braking*—This mode of braking traction testing is conducted by bringing the vehicle to a stop in an intended rectilinear trajectory or straight line motion, on a split-μ test course. The test may be conducted at a series of initial brake application speeds.

4.3 *Method B—Curvilinear Trajectory Braking*—This mode of braking traction testing is conducted by bringing the vehicle to a stop on a curvilinear trajectory (curved path) on a uniform test surface pavement. The test may be conducted at a series of initial brake application speeds.

NOTE 1—Vehicle uncontrollability may be experienced more abruptly and with greater frequency with Method B procedures. Therefore, when using Method B, precautions should be exercised to avoid any possible danger during testing. Testing shall begin with the lowest test velocities selected for any program and as higher velocities are approached, sufficient care shall be taken to avoid any danger to the driver, the vehicle, and any on-site facilities during traction breakaway conditions.

NOTE 2—Test speeds lower than 10 km/h are not recommended due to instrumentation insensitivity at this low speed.

4.4 These test methods contain four annexes and one appendix that give important information to assist in the meaningful evaluation of tire wet traction performance.

4.4.1 *Annex A1*—Interpretation of Results and Tire Design Feature Evaluation,

4.4.2 *Annex A2*—Techniques for Water Application and Control,

4.4.3 *Annex A3*—Selecting Path Radius and Test Speed for Method B Testing,

4.4.4 *Annex A4*—Measuring Orthogonal Trajectory Deviation (Procedure 1), and

4.4.5 *Appendix X1*—List of Instrumentation Suppliers.

5. Significance and Use

5.1 Braking traction is an important factor in vehicle control especially on wet pavements. These test methods permit an evaluation of tires for their relative or comparative performance on an ABS-equipped vehicle. See Annex A1 for background information for interpretation of results and meaningful evaluation of tire design features for their influence on wet traction performance.

5.2 Although stopping distance is important for vehicle control, the ability to steer the vehicle on a selected trajectory is equally or, in some instances, more important. The wet traction capability of tires influences both of these measured parameters since the tires are the link between the ABS and the pavement and provide the traction or tire adhesion level that permits the ABS to function as intended.

5.3 The absolute values of the parameters obtained with these test methods are highly dependent upon the characteristics of the vehicle, the design features of the ABS, the selected test pavement(s), and the environmental and test conditions (for example, ambient temperature, water depths, test speeds) at the test course. A change in any of these factors may change the absolute parameter values and may also change the relative rating of tires so tested.

5.4 These test methods are suitable for research and development purposes where tire sets are compared during a brief testing time period. They may not be suitable for regulatory or specification acceptance purposes because the values obtained may not necessarily agree or correlate, either in rank order or absolute value, with those obtained under other conditions (for example, different locations or different seasonal time periods on the same test course).

6. Test Vehicle

6.1 *Test Vehicle*—Any commercially available passenger vehicle equipped with an ABS may be used for the testing. However, it is important that the same vehicle (same model year, same version of ABS) be used for all tests in any testing program. Different vehicles may give different tire wet traction performance because of their varying handling, suspension, and ABS design parameters.

6.1.1 During testing with any selected vehicle, the vehicle test mass (driver, fuel, and instrumentation load) shall be maintained to a tolerance of ±2 %.

6.1.2 All tests in any program of tire comparisons shall be conducted with the same driver and in the shortest time period possible for any selected test program.

6.2 *Precautions in ABS Vehicle Use*—As with any complex test system, certain precautions shall be exercised in any testing program. ABS operation efficiency as a function of brake pad "break-in," pad operating temperature or fade, or both, pad drag, or any other ABS factor (all of which can change with time and use) should not be allowed to influence tire testing outcome. If there is any doubt about the influence of the above or any other ABS operating efficiency factor, a series of control tire stopping tests on a separate dry surface is recommended to quantify the influence of the suspected ABS operating factors. Follow the procedures as set forth in Practice F1650 for evaluating any significant time or other trend in ABS operation or efficiency, or both.

7. Test Instrumentation Requirements

7.1 The requirements for test instrumentation are given in terms of test instrument specifications rather than citing specific instruments that perform adequately. As new instrument design improves capability, the specifications can be revised. This avoids instrumentation obsolescence in these test methods. Appendix X1 provides a list of instrument suppliers that may be capable of meeting the specifications as set forth in these test methods.

7.2 *Procedure 1—Instrumentation:*

7.2.1 *Stopping Distance-Speed Measurement*—Equip the test vehicle with a system that provides the following capabilities.

7.2.1.1 A digital speed display for the driver, reading to ±1 km/h (0.6 mph).

7.2.1.2 A "test initiation system" that provides a signal received from the vehicle brake pedal movement or other suitable brake system component, to accurately indicate the start of the brake actuation process.

7.2.1.3 A distance measuring system that measures the distance along the vehicle or trajectory path from either the point of brake application or a well established test initiation velocity obtained from the test initiation system, to the point where the vehicle comes to a stop. This system shall have a readout in units of distance traversed (metres, feet) and shall have an accuracy of ±0.1 m (±0.3 ft) in a typical stopping distance test.

7.2.2 *Orthogonal Trajectory Deviation*—Use a distance measuring system that can measure the perpendicular distance from the intended trajectory line (TGL) to the center of the vehicle in its final rest position after a test. The center of the vehicle is defined as the midpoint of the vehicle length and width dimension. The system shall have an accuracy of ±0.1 m (±0.3 ft). Annex A4 provides a recommended procedure for this measurement for both Methods A and B.

7.3 *Procedure 2—Instrumentation:*

7.3.1 *Data Acquisition and Recording System*—Provide a data acquisition system that has the necessary signal conditioning (A to D converter, etc.) to provide input to a digital computer to record and store the required test data. The data acquisition system shall provide recorded data at the rate of at least 100 data points per second per channel.

7.3.1.1 The data recording system shall have sufficient processing speed and data storage capability for operation at the data acquisition rate as specified in 7.3.1. Data processing (averaging, etc.) after a test run may be conducted by way of typical computer mathematical algorithms.

7.3.1.2 The following data channels (signals) shall be recorded during a test run: vehicle speed, km/h (mph); vehicle yaw (velocity), m/s (ft/s); and distance traveled after point of test initiation (or brake application), m (ft).

7.3.2 *Stopping Distance—Speed Measurement*—Equip the test vehicle with a non-pavement-contact sensor that provides the same specifications for vehicle speed (velocity) and stopping distance as defined in 7.2.1. Record the output from this sensor in the same way using a "brake actuation or other test initiation system" as described for Procedure 1 in 7.2.1.2.

7.3.3 *Trajectory Yaw Deviation*—The deviation from intended trajectory is assessed by the special processing of the yaw (velocity) of the vehicle. This velocity is obtained from a non-pavement-contact sensor or sensor system that provides a signal directly proportional to this velocity. For any test, the signal from this sensor shall be recorded from the point of brake application or other point of test initiation until the vehicle comes to rest. The accuracy of this velocity measurement shall be ±2 % or better.

7.4 *Procedure 3—Instrumentation:*

7.4.1 The instrumentation for stopping distance-speed measurement shall be as specified in 7.2.1, and the instrumentation for trajectory deviation shall be as specified in 7.3.3.

7.4.2 *Steering Wheel Rotation*—Equip the steering wheel of the test vehicle with a transducer that records the rotation of the wheel as the driver attempts to maintain vehicle control during the stopping maneuver. Record left and right rotations as specified in 7.3, as + and – values (signals), and the accuracy of the rotation recording shall be ±2° or better.

7.5 *Calibration of Instrumentation*—Calibrate the speed and distance measuring instrumentation by appropriate techniques in accordance with the manufacturer's instructions. Make special sensor calibration procedures by appropriate techniques as specified by the manufacturer. The calibration procedure for "fifth-wheels" shall be as a minimum, in accordance with Test Method F457.

8. Preparation of Test Pavement(s)

8.1 *Pavement Selection and Course Layout:*

8.1.1 *Method A—Straight Line Testing*—Lay out the test pavement (both lanes, see 8.2) with sufficient length to accommodate the stopping distance produced by the highest initial speeds and the poorest performing tires in any planned testing program. The length needed at any speed depends on the tires being tested, the water depths on the surface, and the friction levels of both the left and right sections (lanes) of the pavement. Allow sufficient area for vehicle recovery (spinout, plowing). Lay out the two lane test course so that tests may be conducted in either direction.

8.1.2 *Method B—Curvilinear Path Testing*—The path radius for a Method B test course must be selected. For any tire set and pavement, the cornering force required to negotiate a curved path varies as the second power of the speed and inversely with the radius of the curve. Annex A3 provides recommendations for selecting the path radius and other Method B test details.

8.1.2.1 *Configuration of Curved Test Course*—Three options are available for the configuration of the curved course: *(1)* full-circle, *(2)* half-circle, or *(3)* quarter-circle. With any of these options an approach lane may be used to enter the test course. The selection of one of the three options should be made on the basis of the selected path radius and the anticipated distance needed to bring the vehicle to a stop for the selected maximum speeds. For any configuration, the available stopping distance is a function of the path radius. Annex A3 provides some information for selecting initial braking actuation test speeds.

8.2 *"Split-μ" Surface Layout:*

8.2.1 There are two general approaches for this layout: *(1)* selection of different paving aggregate-binder combinations (low micro-macro texture vs. high micro-macro texture) in the initial construction of the test lanes of a wet traction test facility, or *(2)* the selection of a large area of high traction pavement and the treatment of a 3 to 4 m (9 to 12 ft) wide lane of this pavement to reduce the traction level. This treatment may consist of an epoxy paint or similar durable surface coating treatment to produce a modified surface with low friction level (low microtexture). Either of these approaches may be used.

8.2.2 With either Method A or B, the course layout should provide for a lateral or cross-slope of 1 to 2 % such that there is a lateral flow of water across the test lanes. The recommended direction of flow is from high to low friction level on the test surfaces if two lanes are used. All individual test surfaces (either lane) shall be of uniform composition, free of large cracks and foreign material or debris.

8.3 *Magnitude of "Split-μ" Pavement Friction (Traction) Level:*

8.3.1 The average friction level for both of the pavements as well as the differential friction level (high vs. low friction test lanes) are important test course factors.

8.3.2 The difference in friction coefficient between the high and the low test lanes expressed as a ratio [μ (hi)/μ (lo)] shall be 2.0 or greater. Recommended combinations are 0.50 versus 0.20 or 0.45 versus 0.15. The absolute value of the traction or friction coefficients will be a function of the measurement techniques as described in 8.3.2.1. If both Methods A and B are to be used in any test program, use the same friction measurement technique (same standard tire or slider) for both pavements on both test courses.

8.3.2.1 *Method A: Lane Friction Evaluation*—Friction measurements in both lanes may be conducted by using braking trailer tests in accordance with Test Method E274 for slide coefficient or Test Method E1337 for the more definitive peak coefficient value, with a standard test speed and standard test tire such as specified in Specifications E501, E524, or E1136, or in accordance with Test Method E303, the portable British Pendulum Tester, using a standard slider. Conduct sufficient braking trailer test runs (four to six) on each individual surface to obtain a well documented average value. If Test Method E303 is used, assess the friction level as the average of the measured values at ten or more marked and equally spaced locations along the wheel paths of each of the surfaces used for the testing.

8.3.2.2 *Method B: Friction Evaluation*—Friction evaluation for the pavement used for curvilinear path testing by braking trailer testing may not be feasible. If trailer testing cannot be conducted, use the technique in Test Method E303 as described in 8.3.2.1. At least one common friction evaluation method should be used for both Methods A and B testing.

8.4 *Trajectory Guide Line:*

8.4.1 For either Method A or Method B, a TGL shall be part of the test course layout. This shall be a highly visible (white or yellow) 10 to 12 cm (4 to 5 in) wide guide line located on the longitudinal juncture between the low and high friction level test lanes or in the center of the curved test course pavement.

8.5 *Application of Water to the Pavement:*

8.5.1 Continuously apply water to the pavement with a system of sprinklers that uniformly applies water to the course. Annex A2 outlines techniques for adjusting and controlling the water depth on the test course.

8.6 *Conditioning the Pavement:*

8.6.1 The microtexture of test pavements is subject to change due to weathering action and actual tire testing (see 12.1). Since wet traction should be evaluated on pavements of constant microtexture, such variations can cause problems in evaluation. To reduce or, if possible, avoid this complication, one or both of the following actions are recommended.

8.6.1.1 Condition the pavement by conducting 20 (or more) test runs at some selected speed to polish or condition the surface, using tires not involved in the test program. The pavement friction evaluation techniques described in 8.3 may be used for "before" and "after" conditioning testing.

8.6.1.2 Conduct the testing in accordance with the test plans as specified in Practice F1650. This practice gives data correction procedures for correcting any trends or transient changes in pavement or other test conditions by the use of control tires tested on a regular basis with the candidate tires.

9. Selection and Preparation of Test Tires

9.1 For ordinary comparative testing, each four-tire set should be of the same age (± few weeks) and have been stored under identical conditions up to the time of initial testing (see also 9.4).

9.2 Mount the tires on rims recommended by the appropriate tire standards organizations (for example, Tire and Rim Association, ETRTO, JATMA) by using conventional mounting procedures with proper bead seating techniques. Use a suitable type and volume of lubricant.

9.3 *Tire Break-In*—Three options available for tire "break-in" are: *(1)* a simple technique to remove any residue or protuberances, or both, on the tread surface; *(2)* a technique to produce a tread surface with a smooth matte finish characteristic of natural wear; and *(3)* on-vehicle operation to give the tire a dynamic "running-heat" history to approach an equilibrium tire shape in addition to some normal wear. The purpose of *(1)* and *(2)* is to avoid any condition that might potentially interfere with frictional grip to the pavement. Option *(3)* is selected on the basis that the lack of a dynamic "running-heat" history might influence performance.

9.3.1 *Option 1*—Trim away all protuberances (mold vent flash) with a suitable cutting tool. Vigorously wipe the surface of the tread with brush and a solvent comprised of 50 % hydrocarbon liquid (hexane) and 50 % ethanol. This will remove any typical mold release agents.

9.3.2 *Option 2*—Very lightly buff the tire in accordance with the procedures set forth in Guide F1046, removing approximately 0.2 mm of tread depth across the tread with no alteration of the profile.

9.3.3 *Option 3*—Break in the test tires on a suitable vehicle for 80 km (50 miles) at speeds of 95 to 115 km/h (60 to 70 mph) under routine interstate highway driving, without producing excessive wear during the break-in.

9.4 Prior to the start of testing, store the mounted tires under conditions that avoid direct sunlight and excessive temperature increases.

9.5 Adjust the tire inflation pressure to the values selected for the testing program.

10. Vehicle Preparation

10.1 Install the instrumentation as specified by the procedure selected for the testing. Ensure that all instrumentation is operating in accordance with specifications.

10.2 Ensure that the ABS is in normal operating condition.

10.3 Adjust the vehicle load (mass) as specified in 6.1.

11. Test Procedure

11.1 *Preliminary Actions*—Set up the watering system to apply water to the test surface for a period of at least 30 min prior to testing to make any adjustments needed and to allow the surface to become thoroughly saturated and stabilized.

11.2 Assemble all the sets of tires to be tested in any evaluation program or for daily testing. Select the test speeds to be used and the order in which the sets of tires will be tested. For any selected order, a test sequence is established with a control tire set tested at regular intervals among the selected candidate sets. Select the number of test runs or replicates for both control and candidate tires. A complete test for a tire set is comprised of *n* replicate test runs for each selected speed.

11.3 Select from Practice F1650 a test plan that specifies the frequency of control tire tests. This practice also gives the procedure for correcting for any variation or drift in testing conditions as well as the necessary calculations for evaluating the Traction Performance Index (TPI), that gives a comparative rating of all candidate tire sets tested (see 12.1).

11.4 *Methods A and B—Procedure 1:*

11.4.1 Conduct tests at a series of speeds in the range of 48 to 88 km/h (30 to 55 mph) or, if possible, a maximum speed above 88 km/h (55 mph). Conduct all testing in an "increasing speed" operation. Approach the test course at the selected initial brake speed. During the approach to the test course, ensure that all instrumentation is operating and that data will be acquired throughout the entire test run.

11.4.2 During the initial part of the run, center the vehicle on the TGL, begin the data acquisition process, and apply the brakes at a location on the test area of the wet pavement that has been previously selected and that is clearly marked. Maintain brake pressure throughout the run.

11.4.3 If the vehicle deviates from the intended trajectory during the run, attempt to steer the vehicle in a manner so as to regain control and maintain the intended trajectory. Continue with this until vehicle motion ceases.

11.4.4 At the termination of vehicle motion verify that data have been recorded as intended and record the stopping distance to the nearest 0.1 m (0.3 ft).

11.4.5 Measure the vehicle trajectory deviation, the perpendicular distance from the TGL to a selected reference point on the vehicle. See Annex A4 for details on the vehicle reference point(s) and recommendations for this procedure.

11.4.6 Repeat the operations as specified in 11.4.1-11.4.5 for the selected number of replicate runs at each speed. Repeat the same procedure for all selected speeds or other operational conditions, or both.

11.4.7 For each candidate set and for each repeated control set, test data shall be recorded in two tabulations, a raw data tabulation and a table of results.

11.4.7.1 *Raw Data Tabulation*—Tabulate the following in accordance with set identification: *(1)* the individual *n* values for stopping distances, SD1, and their average, SD1(av), in metres, and *(2)* the individual orthogonal trajectory deviations, TD1, and their average, TD1(av), in metres. The notation "1" indicates a Procedure 1 value.

11.4.7.2 *Table of Results*—Prepare a table of results and record all data with columns for: test sequence number (a sequential indication from 1 to *m*, of all the control tire and candidate tire tests (average of n runs) for any program with m total tests); set identification; speed; average test values (for all test runs) at any speed, SD1(av), TD1(av); and the standard deviation among the individual run values at any speed, designated STD(SD1) and STD(TD1).

11.4.7.3 Identify test sequence numbers or tests according to date and time of day. Prepare a separate table of ambient temperature and wind direction and velocity on an hourly basis. Both control and candidate set data shall be included in the table.

11.5 *Method A—Procedure 2:*

11.5.1 *Procedure 2: Stopping Distance*—For Procedure 2 testing, the same steps as outlined in 11.4.1-11.4.4 are to be followed. Stopping distance, designated SD2, ("2" indicates Procedure 2) is recorded from the output of the non-pavement-contact distance (and speed) measuring sensor in the same manner as in Procedure 1.

11.5.2 *Procedure 2: Trajectory Yaw Deviation*—The trajectory yaw deviation parameter, TYD2, is obtained from special calculations performed on the sequence or series of values of yaw velocity as recorded by the yaw velocity sensor (system) from the point of initial brake application or other initial point established by the test initiation system to the rest point of the vehicle after the test.

NOTE 3—The procedure to calculate TYD2 described in 11.5.2.1 is based on using the upper 20 percentile of the recorded yaw velocity values during any test run. This upper 20 % is used to concentrate on the higher values that may occur among the more numerous lower TDY2 values. The operation is essentially a filtering action, eliminating the lower values (background noise) and rendering the average of the upper 20 % a more sensitive parameter for comparison of vehicle uncontrollability.

11.5.2.1 *Calculation of TYD2*—The parameter TYD2, measured in m/s, is calculated from the series (or column) of values in spreadsheet format as follows. For each test run, sort the TYD2 values from high to low by the appropriate spreadsheet algorithm. Determine the total number of TYD2 values recorded during the test. Select the first 20 % of the total number of TYD2 values, starting at the upper end (high values) of the distribution. Calculate the average of this upper 20 %. This is designated as TYD2.

11.5.2.2 For Method A, the ideal value for TYD2 or TYD2(av) is zero, since for a perfectly rectilinear stop there would be no rotational or yaw velocity of the vehicle. Any deviation from zero indicates some degree of uncontrollability.

11.6 *Method B—Procedure 2:*

11.6.1 For Method B testing (curvilinear path testing) a rotational or yaw vehicle velocity exists as part of the normal generation of lateral force on an intended curved trajectory and a "perfectly controlled braking test" will produce a series of non-zero values of TYD2. There are two options for evaluating the TYD2 values for Method B testing.

11.6.1.1 *TYD2 Calculation: Option 1*—Perform the data analysis and calculations as outlined in 11.5.2, with the realization that a perfectly controlled circular path radius test will generate a non-zero TYD2(av). Any deviation from the circular trajectory will alter the TYD2 values compared to this base value. Tire sets may be evaluated on a comparative basis by the average values of TYD2(av) over the selected number of replicate test runs.

11.6.1.2 *TYD2 Calculation: Option 2*—Evaluate a baseline value of TYD2 by conducting a series of dry surface cornering tests or cornering-braking tests, or both, at each speed used in the wet traction evaluation program. Conduct these tests on a set of tires with excellent cornering capabilities. Obtain TYD2(av) values in the same manner as outlined in 11.5.2 for six or more runs at each speed and designate the average of the six runs as (ref) TYD2, a reference value. For any test run, TYD2 for Option 2 at any speed is related to the" as measured" TYD2 for a wet braking test, by the relationship shown in Eq 1:

$$TYD2 = \text{"as measured"}\ TYD2 - (\text{ref})TYD2 \tag{1}$$

where:

TYD2 = the single test run value of vehicle trajectory yaw deviation to be used for tire performance evaluation.

11.6.2 Prepare a table of results and record all data with columns for:

11.6.2.1 Test sequence number (a sequential indication from 1 to *m*, of all the tests for any program with *m* total tests),

11.6.2.2 Set identification,

11.6.2.3 Speed,

11.6.2.4 Average or test values at any speed, SD2(av), TYD2(av), and

11.6.2.5 standard deviation among the individual run values, designated STD(SD2) and STD(TYD2).

11.6.3 Identify test sequence numbers or tests according to date and time of day. Prepare a separate table of ambient temperature and wind direction and velocity on an hourly basis. Include both control and candidate set data in the table. Indicate in the table the option chosen for evaluating TYD2.

11.7 *Methods A and B—Procedure 3:*

11.7.1 Follow the test operations as specified for Methods A and B Procedure 2 as given in 11.5 and 11.6.

11.7.2 *Steering Wheel Angle (Rotation)*—Graphically display the trace of steering wheel angle versus time for the entire stopping distance test, from test initiation to the rest position of the vehicle. During the first two seconds after brake application, record the maximum steering wheel angle, SWA(2) (the "2" indicates seconds of elapsed time) that was required in the attempt to maintain vehicle control. Record the maximum angle, SWA(*m*), during the remainder of the stopping maneuver.

11.7.3 Prepare a table of results and other test information as given in 11.6.2. Add to this table columns for SWA(2) and SWA(*m*) and the average test values of these two parameters for all test runs at any speed.

12. Calculation for Wet Traction Performance

12.1 *Preliminary Control Set Data Review*—During any wet traction testing program, test results may be perturbed by a gradual polishing of the test surface as testing proceeds or by hourly or daily variations in water depth, or both. Pavement polishing is most pronounced in the initial stages of a test program if the pavement has not been used for testing in the recent past. Several days of testing usually polishes the pavement to an equilibrium state. If either of these perturbations exists a correction of candidate set performance data is required. The decision to correct data is based on the time or run sequence response of the control tire set parameters for each speed used in the test program. If a significant trend is found or if significant transient perturbations are found, corrections are made for candidate set traction performance parameters for that speed.

12.1.1 *Evaluating Data Perturbation or Drift, or Both*—Practice F1650 gives the procedures for determining if any drift or perturbation of testing conditions exists during the period of the testing program, and for correcting the wet braking traction performance parameters if significant perturbation or drift is found.

12.1.2 Tabulate all the corrected candidate traction performance parameter values in a format as outlined in 11.4.7.2, 11.6.2, and 11.7.3.

12.2 *Evaluating Absolute Braking Performance Parameters:*

12.2.1 *Stopping Distance*—Evaluate each candidate set wet traction performance for stopping distance on the basis of corrected parameter values (Corr)SD1(av), (Corr)SD2(av), or (Corr)SD3(av), or for no drift, the "as measured" values, for Method A or Method B, or both.

12.2.2 *Trajectory Deviation*—Evaluate each candidate set for wet traction performance for vehicle trajectory deviation on the basis of corrected parameter values, (Corr)TD1(av), (Corr)TYD2(av), or (Corr)TYD3(av), or if no drift was observed, the "as measured" values, for Method A or Method B, or both.

12.2.3 *Steering Wheel Angle*—If Procedure 3 was used, evaluate each set of candidate tires for wet traction steering controllability on the basis of corrected values (Corr)SWA(2) and (Corr)SWA(m), or if no corrections were required on the basis of "as measured" values, for Method A or Method B, or both.

12.3 *Evaluating Comparative Braking Performance:*

12.3.1 Using the control or some other tire set as a reference standard, the relative performance of various candidate tire sets may be evaluated on an index basis compared to this reference standard as 100. Refer to Practice F1650 for details on calculating the Traction Performance Index (TPI). The usual approach for TPI is a calculation that relates improved performance to a higher index value. This approach is used in Eq 2, Eq 3, and Eq 4 for the TPI calculations.

12.3.2 *TPI—Stopping Distance*—Calculate the TPI(SD), the stopping distance performance index, in accordance with Eq 3, using corrected parameter or as measured parameter values as appropriate:

$$TPI(SD) = [SDi(av)\ reference/SDi(av)\ candidate] \times 100 \quad (2)$$

12.3.3 *TPI—Trajectory Deviation*—Calculate the TPI (TD), the trajectory deviation performance index, in accordance with Eq 3, using the appropriate (TD or TYD) corrected parameter or "as measured" parameter values:

$$TPI(TD) = [TDi(av)\ reference/TDi(av)\ candidate] \times 100 \quad (3)$$

12.3.4 *TPI—Steering Wheel Angle*—Calculate TPI(SW), the steering wheel angle controllability index, using either SWA(2) or SWA(m), or both, in accordance with Eq 4, using the appropriate corrected or as measured parameter values:

$$TPI(SW) = [SWA(2)(av)\ reference/SWA(2)(av)\ candidate] \times 100 \quad (4)$$

12.4 Tabulate all the corrected candidate TPI values in accordance with the format outlined in 11.4.7.2, 11.6.2, and 11.7.3.

13. Report

13.1 When tire performance data are reported using these test methods, the designation format shall be: F 1649-A(p), F 1649-B(p), or F 1649-AB(p), where F1649 is the ASTM designation number for these test methods; A represents Method A only used; B represents Method B only; AB represents Methods A and B used; and p represents the procedure number used, that is, 1, 2, or 3.

13.2 Report the following information in addition to the test method designation:

13.2.1 Test vehicle used, gross vehicle load (mass),

13.2.2 Tire inflation pressure, kPa (psi),

13.2.3 Method(s) used: A or B, or A and B,

13.2.4 Procedure used: 1, 2, or 3,

13.2.5 Instrumentation used,

13.2.6 Test speeds used,

13.2.7 Pavement friction (traction) coefficients; each lane, ASTM method used,

13.2.8 Type of watering system used, average water depths, if measured,

13.2.9 Tire break-in used: Option 1, 2, or 3, and

13.2.10 Method used to calculate TYD2, Option (1 or 2), if Procedure 2 or 3 used,

13.2.11 Performance parameter values at each speed, as measured or corrected:

13.2.11.1 Method A or B—Procedure 1—SD1(av), TD1(av), SD and TD indexes,

13.2.11.2 Method A or B—Procedure 2—SD2(av), TYD2(av), SD and TYD indexes, and

13.2.11.3 Method A or B—Procedure 3—SD3(av), TYD3(av), SWA(2)(av), SWA(m)(av), and SD, TYD and SWA index(es).

13.2.12 Number of individual runs used to obtain parameter averages in 13.2.11,

13.2.13 Indicate the vehicle reference point technique for measuring TD1, Annex A4, or other technique, and

13.2.14 A statement that the ABS was in normal operating condition.

14. Precision and Bias

14.1 *Precision*—No precision data presently exists for these test methods. Programs to evaluate precision may be organized at a later date.

15. Keywords

15.1 anti-lock braking system; plowing; spinout; split-μ testing; stopping distance; tire wet traction; vehicle uncontrollability

ANNEXES

(Mandatory Information)

A1. INTERPRETATION OF RESULTS AND TIRE DESIGN FEATURE EVALUATION

A1.1 *Interpretation of Traction Performance Results*:

A1.1.1 *Control Tire Testing*—As the control sets are tested sequentially they will respond to changes in pavement friction level and to changes in ambient conditions. The major ambient change is the water depth, which is influenced by the wind velocity and wind direction as these factors affect the sprinkler patterns and the velocity of water flow (effective water depth) down the 1 to 2 % slope.

A1.1.1.1 *Precaution on Extended Control Tire Testing*—If control tires are tested for an extended period, especially on aggressive highly textured pavement in addition to lower textured pavement, the treadwear of the tires may change their traction characteristics and thus invalidate their role as a reference tire. These altered characteristics are most important for high speed, smooth pavement, and deep water testing. Tread depth and other wear behavior should be monitored to avoid this problem.

A1.1.2 Examine the control tire plots of SDi(av), TDi(av), or TYDi(av), and SWA(2) versus test sequence number at the highest and lowest test speeds for differences in trend line shape (peaks, valleys, plateaus). If substantial variations appear in the high speed testing these may be related to variations in water depth; for example, low SDi(av) will correspond to low water depth. Low speed testing trend variations caused by water depth variations are nonexistent to minimal. If the same trend variations appear in both the low speed and high speed testing, factors other than water variations are at work.

A1.1.3 *Candidate Tire Sets*—Examine the test results for the candidate tire sets on the basis of their relative performance over the selected speed range of the program. Frequently the TPI as well as absolute parameter values will change low speed versus high speed. The performance will be influenced by the type of tire design variations among the candidate sets.

A1.1.4 The absolute and comparative performance of candidate sets may be influenced by such criticality factors (see A1.2) as pavement texture, speed, and water depth. If substantially different absolute performance or TPI values are obtained under such varied test conditions, special emphasis should be given to the traction performance under highly critical test conditions.

A1.2 *Tire Design Feature Evaluation*:

A1.2.1 *Influence of External Test Conditions*—Tire wet traction performance has been shown to depend on the external conditions used to evaluate performance.[3] These external conditions may be described in terms of a concept called the "degree of criticality" of the testing. Criticality is defined at low and high degrees in Table A1.1.

A1.2.2 A low "degree of criticality" test is typically conducted at a low speed on highly textured pavement at minimal water depth where the traction demand rate, called for in an attempt to maintain vehicle control, is at a low level. A high "degree of criticality" condition is typically a high speed test, on a low textured low friction level pavement with water depths of 1.5 or 1.5+ mm where the traction demand rate is high.

A1.2.3 As tire design features are varied, the influence of the design change may be different at the two degrees of criticality as described in A1.2.2. Since high criticality conditions represent situations where the greatest margin of wet traction performance is required, and where the probability of loss of control is greatest, special emphasis should be placed on this for tire evaluation.

A1.3 *Tire Design Features*—There are two major tire design categories in wet traction performance: those designated as "geometry-shape," for example, tread pattern geometry (groove void level) variations, aspect ratio (or inverse tread width); and those with variations in tread "compound properties," for example, hardness and hysteresis loss or tan δ.

A1.3.1 *Tire "Geometry-Shape" Features*—Wet traction performance responds to changes in "geometry-shape" features in a way that depends on criticality; changes that improve performance at a high criticality often decrease performance at a low criticality and vice versa. Varying tire design features such as aspect ratio and tread pattern void level strongly influence performance at high speeds and at conditions of high traction demand rate that are characterized by high interfacial slip velocity between the tread elements of the rotating tire and the pavement. Thus for meaningful Method A tire evaluation the highest possible initial brake application speed(s) that present(s) no safety problems should be selected. For Method B the same selection should be made along with the lowest

TABLE A1.1 "Degrees of Criticality" Defined

Degree of Criticality	Speed	Pave Texture[A]	Water Depth	Traction Demand Rate
Low	32 to 48 km/h (20 to 30 mph)	High (2.0, 2.0+ mm)	Low (<0.5 mm)	Low
High	90, 90 + km/h (55, 55+ mph)	Low (0.5, <0.5 mm)	High (1.5, 1.5+ mm)	High

[A] Pavement texture depths in mm given for Sand Patch technique, see Test Method E965.

[3] Veith, A. G., "Tires—Roads—Rainfall—Vehicles: The Traction Connection," *ASTM Special Technical Publication, Frictional Interaction of Tire and Pavement*, W. E. Meyer and J. D. Walter, eds., 1983, pp. 3–40.

possible path radius values that can be used on the same safety and vehicle cornering capability basis.

A1.3.2 *Tire Tread Compound Features*—Compound hardness variations have an influence similar to the geometry-shape features; the influence of an increase in hardness is different at a low versus high criticality. Hysteresis variations have their maximum influence at low to moderate speeds at all interfacial slip conditions. Thus if compound evaluation is important, intermediate speeds should be selected in addition to the higher speeds as recommended for meaningful evaluation of "geometry-shape" features.

A2. TECHNIQUES FOR WATER APPLICATION AND CONTROL

A2.1 *Water Depth*—The maintenance of controlled water depths is an important factor for tire testing, especially for test speeds of 72 to 80 km/h (45 to 50 mph) and higher (see Annex A1). Water depths are usually established by adjusting the supply line pressure in addition to sprinkler or other flow adjustments.

A2.1.1 The most accurate method for setting and controlling water depths is the use of an accurate water depth meter. If a depth meter is available this shall be used to measure the water depths at several locations in the vehicle wheel zones at least twice daily. If a water depth meter is not available, the uniformity of water application to the test surface shall be controlled by the adjustment of water supply line pressure and the adjustments in A2.2 or A2.3. The pressure or other indicator shall be monitored twice daily.

A2.2 *Above-Surface Sprinklers*—The most common above the surface ("rain bird" type) sprinklers are mounted on a 10 cm (4 in.) diameter aluminum water supply pipe laid out along the edge of the test course. The sprinklers shall be spaced equally along the length of the course and the sprinkler spray pattern carefully adjusted to give a uniform depth of water on the test surface as evaluated by careful observation.

A2.2.1 Wind direction and velocity influence the volume and location of the water applied by the sprinklers, and adjustments shall be made for any change in wind direction and velocity during testing. The pipe and sprinklers shall be located far enough from the test lanes to prevent the vehicle from coming into contact with them during any potential vehicle trajectory deviation.

A2.2.2 For Method A, the sprinklers should be located on the high friction side of the test course at a position where they will not interfere with the test but is close enough to give good watering. For Method B the sprinklers should be located on the inner side of the curved test course.

A2.3 *Trickle Sprinklers*—This technique uses a series of holes in the water supply pipe laid out along the edge of the course. The water from each orifice impinges on the surface adjacent to the pipe on the high side of the sloped test surface and thus allows for water flow across the surface. This type of watering technique is not as sensitive to wind velocity and direction as the sprinkler technique. The adjustment and control of water depth shall be conducted on the basis of the number of holes and the water supply pressure.

A2.3.1 The success of uniform water application for both techniques, but especially for the trickle sprinkler technique, is the existence of a very uniformly graded test surface (both lanes) without hills and valleys which produce water depth variations along the test surface.

A2.4 *Other Watering Methods*—Other watering methods that do not apply water to the test surface continuously (for example, watering truck applications) shall not be used because of the periodic variations of water depth that produce inherent test result variation.

A3. PATH RADIUS AND TEST SPEEDS FOR METHOD B TESTING

A3.1 *Introduction*—This annex gives some background information on how test speed and path radius influence the evaluation of tires for wet traction performance. Method B testing, which involves the generation of tire traction forces in both the lateral and longitudinal directions, has the potential to evaluate tires for their wet traction performance at a high degree of criticality (see Annex A1 for definition of criticality). Reduced to its simplest terms, the degree of criticality is determined by the magnitude and velocity of the slip motion of tread elements against the pavement as the tire generates (or attempts to generate) the required traction forces to maintain vehicle control.

A3.2 *Establishing the Degree of Criticality*—The degree of criticality is determined by the test speeds and inversely by the path radius in a Method B test.

A3.2.1 *Path Radius*—Recommended path radii are 80, 100, or 120 m (262, 327, or 393 ft). These represent radii that can be laid out on a reasonably sized test facility. The smaller the radius the greater the degree of criticality of the testing for any selected speed.

A3.2.2 *Initial Speeds for Brake Application*—Initial brake application speeds can reasonably range from 48 to 90 km/h (30 to 55 mph) or higher if possible. The higher the speed, the greater the degree of criticality.

A3.2.3 The ability to corner and to develop controlled braking action on any radius curve at any speed is a function of the tires, the pavement texture (friction coefficient), and for higher speeds, the water depth.

A3.3 *Typical Required Cornering Traction*—Table A3.1 gives the required steady state traction level to corner on a 100 m (327 ft) path radius curve at a series of speeds. The required traction is defined as the "*g*" level for cornering and is given in terms of the ratio of the tire tractive force divided by the tire load (four-tire average for the vehicle).

A3.3.1 If the tires cannot develop this magnitude of (vehicle average) traction coefficient or g level under the given conditions of pavement texture (friction level) and water depth, the vehicle will deviate from the intended path trajectory (spinout, plowing). The listed *g* levels are thus the required minimum values for maintaining vehicle control for simple cornering.

TABLE A3.1 Magnitude of "*g*" as a Function of Speed

Velocity		*g*-Level[A]
48 km/h	(30 mph)	0.19
64	(40)	0.33
72	(45)	0.42
80	(50)	0.51
88	(55)	0.62

[A] Pavement texture depths in mm given for Sand Patch technique, see Test Method E965.

A3.3.2 If the available (reserve) tire traction to maintain steady state cornering is less than the demand level of traction to maintain any desired level of braking action, the vehicle may experience instability or trajectory deviation as well as increased stopping distance. Thus brake application, under any of the conditions in Table A3.1, will lower the available tire traction and move the steady state cornering condition into a region of higher criticality.

A3.4 Testing experience[3] has shown that for any set of commercial or development tires (intended for similar vehicle application), the variation in wet traction performance among the set may be at a minimum (potentially no really significant differences) under low and possibly intermediate criticality test conditions, or both, and conversely the variation in performance may be a maximum for test conditions at a high degree of criticality.

A4. MEASURING ORTHOGONAL TRAJECTORY DEVIATION (PROCEDURE 1)

A4.1 This annex gives a recommended technique, applicable to both Methods A and B testing, for measuring the deviation or distance of the test vehicle from the trajectory guide line (TGL) at the termination of a stopping distance test for Procedure 1.

A4.2 *Vehicle Reference Point and Vehicle Measuring Brackets*:

A4.2.1 *Reference Point*—The reference point for calculating the deviation is the center of the vehicle, that is, the center point on the longitudinal (front-rear) centerline of the vehicle. The distance from the TGL to this reference point is calculated from measurements made using reference brackets at the front and rear of the vehicle.

A4.2.2 *Measuring Brackets*—Two brackets that each contain two centering holes, one above the other, for the insertion of a straight rod about 1 m long (3 ft), are attached to the front and rear bumpers. The brackets are carefully mounted on the bumpers coincident with the longitudinal centerline of the vehicle so that the axis that passes through the center of each of the two holes is completely vertical to the pavement. The rod (in a vertical orientation) is inserted into both of the holes and the lower end of the rod is allowed to contact the pavement below the bracket. This point on the pavement, both front and rear, establishes two measuring points on the pavement for trajectory deviation. See Fig. A4.1 for a sketch of a typical measuring bracket. The bracket hole dimensions for the rod depend on the diameter of the rod; a typical hole diameter might be slightly greater than 12.5 mm (0.5 in.) for a 12.5 mm (0.5 in.) diameter rod. Fig. A4.2 illustrates the vehicle center reference point and the two measurement bracket locations.

A4.3 *Trajectory Deviation Measurement—Method A*:

A4.3.1 After the vehicle comes to rest, mark the front and rear measuring points on the pavement with a small plate such that the perpendicular distance measurement from the TGL may be made with an accuracy of 0.1 m (4 in.). The vehicle may then be moved. Using a measuring wheel or a steel tape, measure the deviation or perpendicular distance from the center of the TGL to each of the measuring points on the pavement. The 90° angle to the TGL can be ensured by the use of a wooden or plastic jig that has two 1.5 m (4.5 ft) arms accurately fixed at 90° to each other. One of these arms is placed coincident with the centerline of the TGL and the other arm used to establish the perpendicular axis for distance measurement.

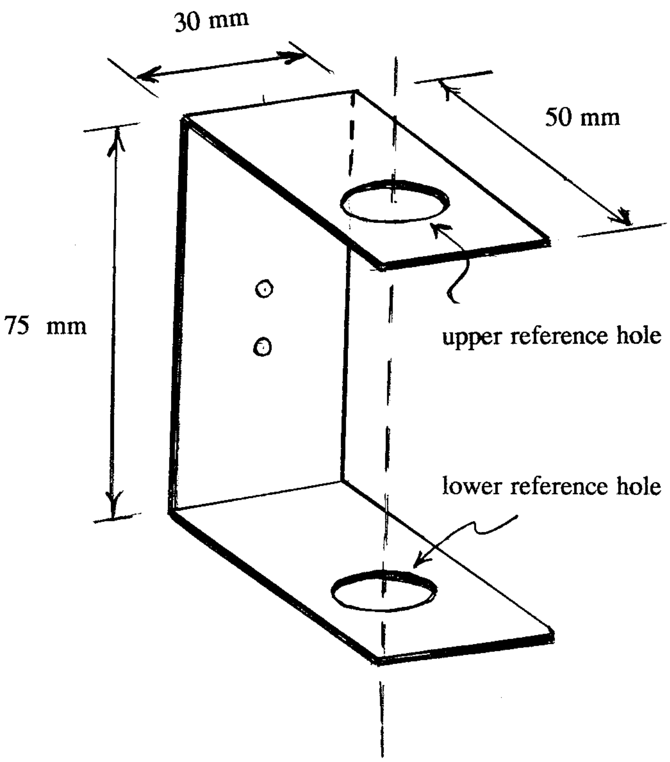

FIG. A4.1 Vehicle Bracket (Schematic View, With Typical Dimensions)

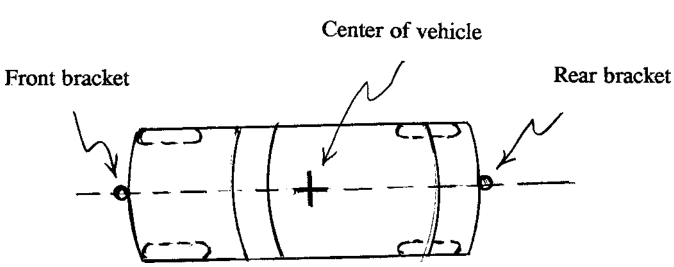

FIG. A4.2 Top View Schematic of Vehicle

A4.3.2 The Method A vehicle orthogonal trajectory deviation (distance), TD1(A) in m (ft), is given in Eq A4.1. It is the average of the front and rear perpendicular distance from the TGL to each of the measuring points:

$$TD1(A) = [d(f) + d(r)]/2 \quad (A4.1)$$

where:

d(f) = perpendicular distance from TGL to front bracket point, m (ft), and
d(r) = perpendicular distance from TGL to rear bracket point, m (ft).

A4.4 *Trajectory Deviation Measurement—Method B*:

A4.4.1 On the curvilinear course used for Method B, a distance measurement, perpendicular to TGL also using the front and rear brackets, and rear bracket measurement points (on the pavement) may be made with the assistance of a thin cable or line that is anchored at the center of path curvature for the test surface. Using the cable, which is coincident with the radius of the curve when stretched taut, the distance along the cable is measured from the center of curvature to the front and rear bracket measurement points. Method B orthogonal trajectory deviation (distance), TD1(B) is given in Eq A4.2:

$$TD1(B) = [\{td(f) + td(r)\}/2] - R \quad (A4.2)$$

where:

td(f) = total distance, center of curvature (path radius) to front vehicle bracket, m (ft),
td(r) = total distance, center of curvature (path radius) to rear vehicle bracket, m (ft), and
R = radius of curvature of test course, m (ft).

APPENDIX

(Nonmandatory Information)

X1. LIST OF INSTRUMENT SUPPLIERS

(1) Datron Technology Ltd., 6 Potters Lane, Kiln Farm, Milton Keynes, MK11 3HE, United Kingdom, http://www.datrontechnology.co.uk.

(2) Labeco, 156 E. Harrison Street, Mooresville, IN 46158, http://www.labeco.com.

(3) Link Engineering Co., 13840 Elmira Ave., Detroit, MI 48227, http://www.linkeng.com/en/Homepage.aspx.