

# SURFACE VEHICLE RECOMMENDED PRACTICE

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## A Test for Evaluating the Rearward Amplification of Multi-Articulated Vehicles

**Foreword**—This SAE Recommended Practice is intended as a guide toward a standard practice and is subject to change to keep pace with experience and technical advances.

This procedure involves a test course especially laid out to excite the rearward amplification tendencies of multi-articulated heavy trucks. The form of the course is illustrated in Figure 1. The test driver follows this course in performing the test.

The vehicle is instrumented to measure lateral accelerations at the tractor's front axle and at the center of gravity of the sprung mass of the last trailer. The lateral acceleration of the tractor is the input that excites the vehicle motion. This input is quantified by computing its root-mean-square (rms) value over the lateral maneuvering section of the test course.<sup>1</sup> The value of the input is obtained by multiplying the rms value of the input by the square root of 2 to provide an estimate of the amplitude of an equivalent sinusoid of lateral acceleration. The output is quantified by measuring the maximum absolute value of the lateral acceleration of the last trailer. The rearward amplification is the ratio of (a) the value of the output divided by (b) the value of the input.

Studies of various methods of processing the data have led to a technique that can be used to measure rearward amplification to within approximately 10% of the average value with a confidence of 90% that the true value lies within this band. This level of confidence can be obtained using the results from five repeats of the test. The following statement of this test procedure for evaluating obstacle evasion capability contains sections entitled:

1. Scope
  - 1.1 Purpose
2. References
3. Statement of the Test Procedure
  - 3.1 Test Course
  - 3.2 Vehicle Condition and Preparation
  - 3.3 Instrumentation Requirements
  - 3.4 Data Acquisition and Processing Requirements
  - 3.5 Requirements for Proper Execution of the Test Maneuver
  - 3.6 Analysis of the Test Data
  - 3.7 Interpretation of the Results

1. After investigating several possibilities for quantifying the input motion (including peak measured values of lateral acceleration, for example), it was found that the rms value of the lateral acceleration of the front axle of the tractor was a good indicator of the magnitude of the input, and when this rms value is used, the variability of the test results is less than that obtained using other possibilities

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FIGURE 1—LAYOUT OF THE TEST COURSE

The procedure, which is presented next, is intended to meet the following general requirements:

To be able to:

- a. Distinguish reliably between vehicles with different levels of performance in obstacle avoidance maneuvers.
- b. Perform the tests using reasonable instrumentation and data processing requirements.
- c. Attain repeatable results.
- d. Perform the tests correctly in a relatively easy manner.

**1. Scope**—The procedure applies to heavy vehicles weighing more than 11 800 kg (26 000 lb) and particularly to those vehicles having two or more articulation joints that allow rotation in a horizontal plane. The procedure pertains to the lateral directional response of multi-articulated vehicles in avoidance maneuvers performed at highway speeds without braking.

**1.1 Purpose**—This test procedure is intended to be used for determining the rearward amplification and dynamic offtracking qualities of multi-trailer commercial vehicles (heavy trucks and buses).

## **2. References**

**2.1 Applicable Publications**—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated, the latest revision of SAE publications shall apply.

**2.1.1 SAE PUBLICATION**—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J2180—A Tilt Table Procedure for Measuring the Static Rollover Threshold for Heavy Trucks

**2.1.2 FMVSS PUBLICATIONS**—Available from the Superintendent of Documents, U. S. Government Printing Office, Mail Stop: SSOP, Washington, DC 20402-9320.

FMVSS 105—Hydraulic Brake Systems

FMVSS 121—Air Brake Systems

## **3. Statement of the Test Procedure**

**3.1 Test Course**—The test involves the course illustrated in Figure 1. (Also see Appendix A.) The test driver is to follow this course in a manner that meets the requirements of 3.5. As shown in Figure 1, there is a straight section 91.5 m (300 ft) long, leading up to a maneuvering section that attains a 1.46 m (4.8 ft) lateral displacement in a longitudinal distance of 61 m (200 ft). After the "dynamic" maneuvering section, the course remains parallel to the original direction of travel for an additional 61 m (200 ft).

The lateral displacement of the course in the maneuvering section represents the motion of a point that is traveling at 88 km/h (55 mph) for 2.5 s with a lateral acceleration of the form  $-A[\sin(2\pi/2.5)]$  where  $t$  is time in seconds ( $t = 0$  at the beginning of the maneuvering section) and  $A = 0.15 g$ .

The test course should be laid out on a proving ground or other facility with adequate room to allow a heavy truck to reach 88 km/h (55 mph) (or its maximum speed on level ground if that speed is less than 88 km/h (55 mph)).

The facility must provide sufficiently large space to allow the driver to recover control of the vehicle in the event control is lost during the prescribed obstacle avoidance maneuver occurring on the maneuvering section. Additional course space is also required for the driver to steer and/or brake to exit from the maneuver.

The test course should be nearly level (planar with a uniform grade) in all directions with a maximum slope that is no greater than 1% in any direction.

Ambient wind conditions should be less than 24 km/h (15 mph). Surface and wind conditions should be entered into the data sheets for each test.

The skid number of the dry test surface shall exceed 56 when measured at 64 km/h (40 mph).<sup>2</sup> If available, the skid number of the surface should be recorded.

**3.2 Vehicle Condition and Preparation**—The results of this test are known to be sensitive to how the vehicle is loaded and the condition of its tires. Also there is a danger that unrestrained vehicles may rollover in this test.

The condition of the vehicle's tires needs to be controlled. If the vehicle is to be operated with bias ply tires, it should be tested with new (broken in) bias ply tires installed on the vehicle. Otherwise, the vehicle is to be tested with new radial ply tires.

The tires should be broken in with at least 50 miles of running. Also the tires should be exercised by driving through the test course at least five times before taking any data. (The test driver will probably need at least this many practice runs to become used to the vehicle and the test course.)

Tire wear should be less than 2 mm (3/32 in). That is, the tread depth should be no less than the new tire tread depth minus 2 mm. If the vehicle is tested at other states of tire wear, those tread depths shall be reported.

The tire inflation pressures shall be set at the manufacturer's recommendations or the Tire and Rim Association specifications for the tire loads involved. Tire condition and inflation pressure shall be recorded on the data sheets. The tires shall be identified on the data sheets. Ideally the cornering stiffness for the tires will have been measured and these values will be recorded to aid in identifying the vehicle. Identification of the tires is very important because the shear force capabilities of the tires (particularly cornering stiffness) may have a large influence upon the results of these tests.

Unless special test loads are specified, the vehicle should be uniformly loaded to the maximum weight that it is expected to carry. Ordinarily (unless otherwise specified) this will be at the GCWR with axle loads close to their GAWR. The height of the center of gravity (cg) of the test load should be set to a height specifically chosen for the test. (If practical, a tilt table test (SAE J2180) may be used to identify the rollover threshold of vehicles that are to be tested for rearward amplification.) The cg height and rollover threshold, if available, for the vehicle in the condition used in testing for rearward amplification shall be recorded on the data sheets. The axle loads and the payload's cg height shall also be recorded on the data sheets identifying the vehicle.

Since how the load is distributed is important, the load used in the test needs to be described carefully. Ideally this description will either give the dimensions and location of the load or the moments of inertia of the load about horizontal, lateral, and vertical axes through the center of gravity of the load plus the location of the center of gravity of the payload. To the extent feasible, the moments of inertia of the load used in testing should be representative of the intended load to be carried in service.

The fill level of tank vehicles is important. Vehicles with partially filled tanks may not perform as well as vehicles with full tanks. The fill level shall be recorded when testing tank vehicles.

(In summary, and to aid in defining and identifying the vehicle being tested, Appendix B provides a list of pertinent vehicle properties that should be described and included with the test results.)

2. For directions on measuring dry surface skid numbers, see Federal Motor Vehicle Safety Standard FMVSS 105 or 121. These measurements follow ASTM procedures for measuring skid number except that the pavement is not wetted.

Since an unconstrained vehicle may roll over in this maneuver, the test vehicle shall be equipped with outriggers. (Information on outriggers is presented in Appendix C.)

### 3.3 Instrumentation Requirements—Transducers—Transducers shall be provided for measuring:

- Forward Velocity (V) with an accuracy of  $\pm 0.5$  mph over a range from 80 to 100 km/h (50 to 60 mph).
- The time period of the maneuver (T) from the moment the front axle reaches the first plate of the maneuvering section until it reaches the last plate of the maneuvering section with an accuracy of  $\pm 0.03$  s for time periods ranging from 2.0 to 3.0 s. (The idea here is to provide an event recorder that will determine the start and the end of the maneuvering section. This has been done with a laser optical device mounted on the front axle. The device discerns marks placed on the pavement indicating where the dynamic section begins and ends. Any other scheme that records the times when the front axle enters and leaves the dynamic section of the course will suffice.)
- Lateral acceleration of the center of the front axle (AYX) with an accuracy of  $\pm 0.01$  g over a range from 0.0 to 0.2 g. (This accelerometer may be attached to the axle and need not be mounted on a stabilized platform.)
- Lateral acceleration of the center of mass of the sprung mass of the last semitrailer (AYT) with an accuracy of  $\pm 0.01$  g over a range from 0.0 to 0.5 g. This accelerometer may be mounted upon a stable platform to eliminate the influence of vehicle roll upon the measurement of lateral acceleration, or trailer roll angle may also be measured to compensate for gravitational effects of a rigidly mounted accelerometer.

Measurements from the transducers listed previously are sufficient to determine rearward amplification. The following instrumentation is needed to determine the quality of the driver's steering and to evaluate the level of transient high-speed (dynamic) offtracking.

The test course is marked by "plates" that have five sides and a point as illustrated in Figure 2. The point is placed on the test course. A water-jet attached at a selected point on the front axle may be used to mark the vehicle's path. (See Appendix D.) Alternatively, a laser system or some other system may be used to measure the distance from the vehicle's path to the desired path (the test course). The test driver shall be capable of following the desired path within 15.2 cm (6 in). Any test run that does not meet this requirement is unsatisfactory and must be rejected.

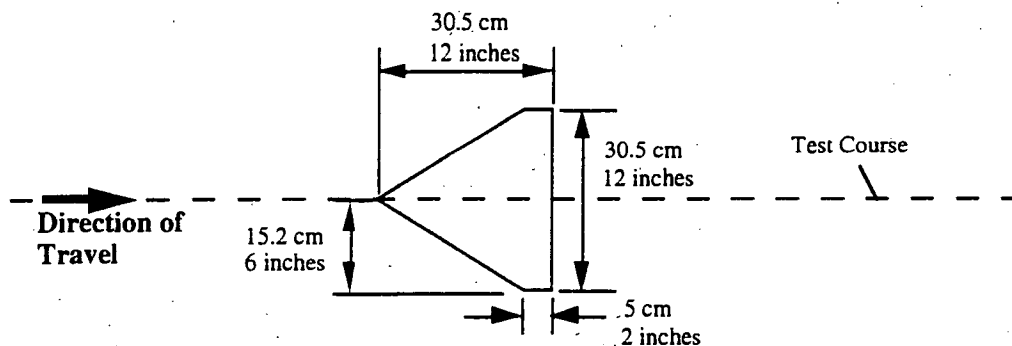


FIGURE 2—"HOME" PLATES USED TO MARK THE TEST COURSE

To determine transient high-speed offtracking, a water-jet or alternative device shall be attached to the rear axle of the last trailer at a point that corresponds to the selected point on the front axle. The distance from the path of this axle (as determined by the water mark, for example) from a line tangent to the test course at the end of the maneuvering section (1.46 m (4.8 ft) from the original direction of travel) is measured. If the last trailer overshoots the tangent line in the region from 15 m (50 ft) before the end of the maneuvering section to 15 m (50 ft) after the end of the maneuvering section, the maximum level of overshoot shall be recorded. If the last trailer's path does not overshoot in this region, the amount of "undershoot" at the end of the maneuvering section shall be recorded. (See Figure 3.)

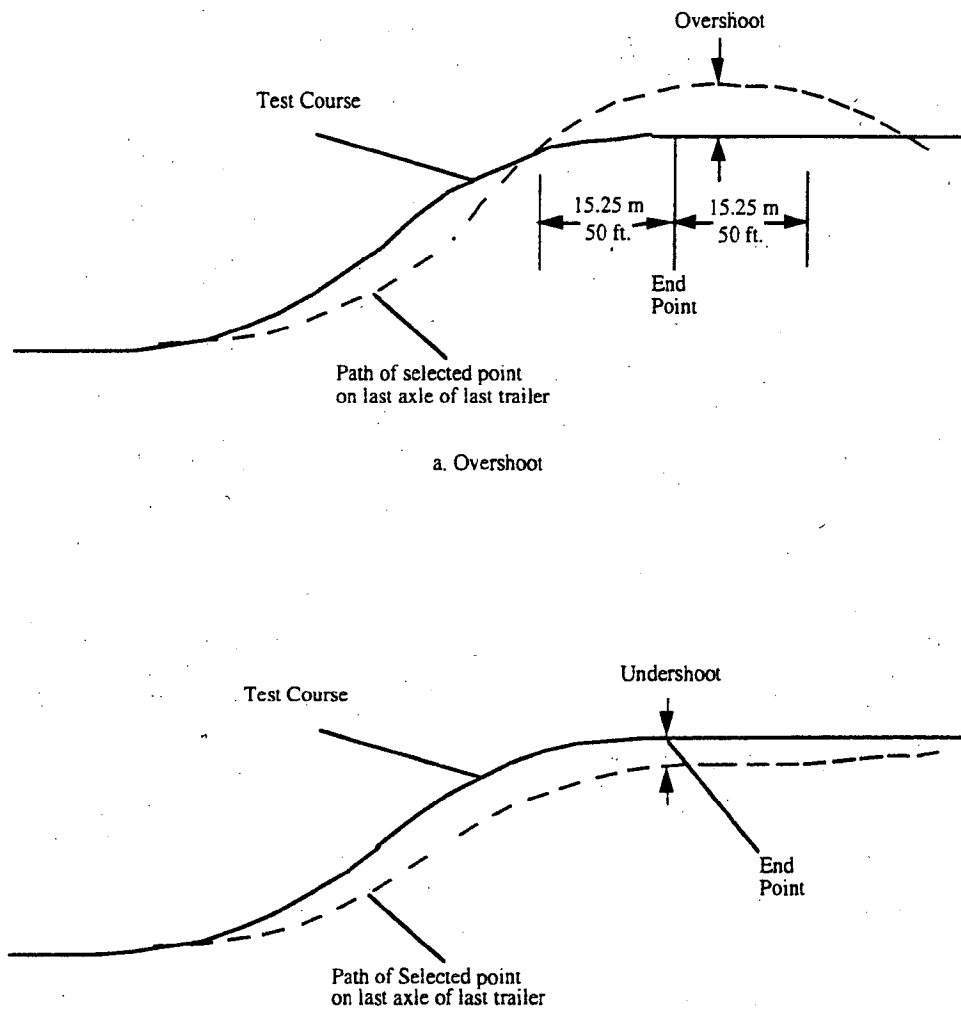


FIGURE 3—TRANSIENT HIGH-SPEED OFFTRACKING: OVERSHOOT AND UNDERSHOOT