



SURFACE VEHICLE RECOMMENDED PRACTICE

J2664™

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Superseding J2664 JUN2006

Trailer Sway Response Test Procedure

RATIONALE

SAE J2664 has been revised to comply with current SAE formatting, review policy and updated to SAE Recommended Practice based on its use in the industry.

FOREWORD

The need for a consistent test procedure to quantify trailer natural sway response has been recognized over the past few decades; significant development from several sources has been reported. The development of this document utilized these sources and input from industry professionals.

Attaching a trailer to any vehicle will change the dynamic characteristics of that vehicle. The dynamic characteristics affected include rotation about the pitch, roll, and yaw axes and translations in the longitudinal, lateral, and vertical directions. The manner in which the vehicle and trailer are loaded and connected (including weight-distributing equipment), along with characteristics of the specific tow vehicle and trailer, will alter the dynamic characteristics of the combination. A complete measurement of vehicle/trailer dynamic behavior will involve other tests not addressed by this document.

1. SCOPE

This SAE Information Report establishes a consistent procedure for measuring and analyzing the natural sway response of a particular trailer when attached to a particular vehicle under specific loading and operating conditions. This test procedure applies, but is not limited to, passenger cars, vans, light/medium-duty trucks as tow vehicles, and semitrailers with a Gross Vehicle Weight Rating (GVWR) of 11794 kg (26000 pounds) or less. Other applications include full trailers, tow dollies, tow bars, and the like. Other articulated vehicles can utilize this test procedure as long as the test does not exceed the linear behavior of the system. This test procedure does not apply to motorcycles towing trailers.

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2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

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

SAE J211-1 Instrumentation for Impact Test - Part 1 - Electronic Instrumentation

SAE J266 Steady-State Directional Control Test Procedures for Passenger Cars and Light Trucks

SAE J670E Vehicle Dynamics Terminology

SAE J684 Trailer Couplings, Hitches, and Safety Chains - Automotive Type

2.1.2 ISO Publications

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

ISO 9815 Passenger Car/Trailer Combinations - Lateral Stability Test

ISO 8855 Road Vehicles - Vehicle dynamics and road-holding ability - Vocabulary

2.2 Related Publications

2.2.1 SAE Publications

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

SAE J1441 Subjective Rating Scale for Vehicle Handling

SAE J2181 Steady-State Circular Test Procedure for Trucks and Buses

SAE 790186 Determination of Trailer Stability through Simple Analytical Methods and Test Procedures; Klein, Richard H. and Szostak, Henry T.

SAE 670099 Directional Control Dynamics of Automobile - Travel Trailer Combinations; Bundorf, R. Thomas

SAE 2001-01-0049 Minimizing Driver Demands and Data Acquisition Errors in Trailer Testing; Leonard, M. Mark, Tuskan, Steven M., and Johnson, Dutch

2.2.2 ISO Publications

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

ISO 612 Dimensions of Motor Vehicles and Towed Vehicles - Terms and Definitions

ISO 1176 Road Vehicles - Weights - Vocabulary

ISO 2416 Passenger Cars - Load Distribution

ISO 3833 Road Vehicles - Types - Terms and Definitions

ISO 4138	Road Vehicles - Steady State Circular Test Procedure
ISO 7401	Road Vehicles - Lateral Transient Response Test Method
ISO 7975	Braking in a Turn - Open Loop Test Procedure
ISO TR3888	Road Vehicles - Test Procedure for a Severe Lane-Change Maneuver
ISO TR8726	Road Vehicles - Open-Loop Response Test Method with Pseudo-Random Steering Input

2.2.3 Additional Related Publication

DOT HS-801-936 Handling Test Procedures for Passenger Cars Pulling Trailers - Volume II - Technical Report; Johnston, Donald E.; Zellner, John W.; and Ashkenas, Irvin L.

3. DEFINITIONS

The terminology used herein follows the standard definitions as found in SAE J670e. In addition, the following new definitions are required:

3.1 COMBINATION VEHICLE

Two or more vehicles with at least one common connection point between two vehicles. Typically, one of the vehicles is a trailer.

3.2 CONNECTION POINT

The point of connection, e.g., generally a hitch ball or fifth wheel, where the trailer attaches to the tow vehicle. Measurement of the connection point is from the tow-vehicle rear axle, positive to the rear, to the centerline of the hitch ball or kingpin hole. (These measurements are required for the data forms in Appendix A.)

3.3 TRAILER SWAY

Oscillatory response to a disturbance of a combination vehicle characterized mainly by relative yaw motion between the tow vehicle and trailer. This is typically observed as an oscillatory turning and translational motion of the trailer at highway speeds.

3.4 ARTICULATION ANGLE (η)

The angle of the trailer's x-axis relative to the tow vehicle's x-axis in the x-y plane. Positive articulation angle for the trailer is to the left (driver) side of the tow vehicle. (Figure 1). Zero articulation angle is when the longitudinal axes of the tow vehicle and trailer are aligned.

3.5 TRAILER DAMPING RATIO

The ratio of the amount of equivalent viscous damping present in the trailer free response to that required for critical damping. Refer to SAE J670e – Damping Ratio. In practical application, this is a measure of how quickly trailer articulation settles out after an initial disturbance and with no further inputs.

3.6 WEIGHT-DISTRIBUTING HITCH

A mechanical device that connects the trailer to the tow vehicle and by means of leverage applied on both the trailer and towing vehicle structures, when properly adjusted, distributes the imposed vertical load at the hitch and coupling connection between structures of towing vehicle and trailer. (Refer to SAE J684). These devices are used to redistribute axle loads.

3.7 TONGUE WEIGHT

The static downward vertical force applied by the trailer to the tow vehicle at the connection point on level ground for a particular loading condition and connection point height with no weight distributing moment applied.

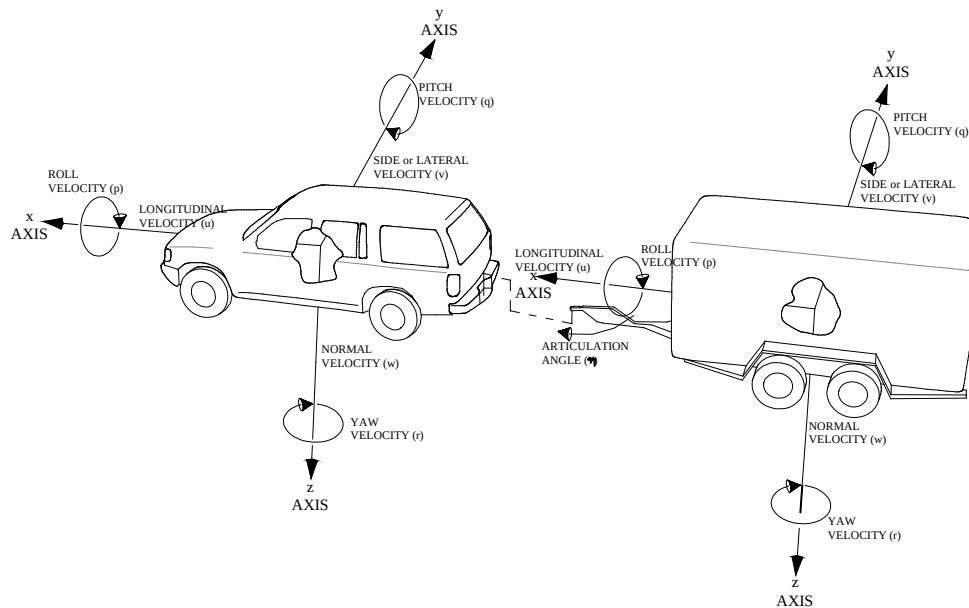


Figure 1 - Vehicle axis systems and articulation angle

4. INSTRUMENTATION AND RECORDING

The vehicle parameters in these tests shall be measured using appropriate transducers whose individual time histories are recorded on a multi-channel data recorder.

4.1 Vehicle Parameters

The minimum vehicle data channels required to conduct the combination vehicle testing are listed in the first column of Table 1. A typical full-scale range for each data channel is provided in the second column. These are suggested ranges and an individual test protocol may require appropriate modification of the presented ranges.

Table 1 - Vehicle parameters to be measured

Vehicle Data Channel	Typical Full-Scale Range
Forward Speed	0 to 120 kph (75 mph)
Steering Wheel Angle	± 180 degrees
Trailer Articulation Angle	± 10 degrees

4.1.1 Additional Test Variables

Additional test variables of interest and their corresponding full-scale range are listed in Table 2.

Table 2 - Additional vehicle parameters that may be measured

Vehicle Data Channel	Typical Full-Scale Range
Tow Vehicle Lateral Acceleration	$\pm 1g$
Tow Vehicle Yaw Velocity	± 40 deg/s
Trailer Lateral Acceleration	$\pm 1 g$
Trailer Roll Angle	± 15 degrees
Trailer Yaw Velocity	± 40 deg/s

4.2 Transducers and Transducer Installation

The transducer type (potentiometer, accelerometer, etc.), and location shall be recorded and presented as part of the test documentation (Appendix E). Adherence to the manufacturer's installation recommendations should be followed. The transducer orientation for a given data channel may not produce an output that is consistent with the standard sign convention outlined in this document. However, an appropriate sign change should be made in post processing such that the standard sign convention is maintained in the final presentation of the data.

Transducer linearity and off-axis sensitivities are generally specified as a percent of full-scale range. Transducers with less than 3% full-scale error would be suitable instruments for use in the tests set forth in this document. There may arise applications where the operating range of the transducer is a fraction of its full-scale range. In this situation, it is recommended that the transducer non-linearity be less than 3% of its indicated reading, which may require calibration over the operating range. Proper transducer balancing (transducer zero adjustment) is often sufficient to handle thermal effects that might affect the data.

Transducer drift should be compensated for by taking "zero" recordings at appropriate intervals during the test program to allow for bias corrections to be completed. Procedurally, the instrument zeros should be recorded after driving the vehicle at a slow speed in a straight line and bringing it gently to a stop. To eliminate any surface inclination effects, the procedure should be performed in opposite directions at the same location, and the results averaged. Instrument zeros recorded before the test should be recorded after allowing sufficient time for transducer and signal conditioner warm-up, gyro spin-up, etc.

When used, the following transducers shall be installed to measure:

4.2.1 Forward Speed

The road speed along the longitudinal axis of the tow vehicle. Typical transducers are optical sensors, rolling fifth wheels, or GPS based systems.

4.2.2 Tow Vehicle Steering Wheel Angle

The steering wheel angle relative to the vehicle structure. Typical transducers are rotary potentiometers or digital shaft encoders that involve a mechanical coupling between the steering shaft and the steering column support structure.

4.2.3 Trailer Articulation Angle

The angle between the tow vehicle's x-axis and the trailer's x-axis, in the horizontal plane. Typical transducers used to measure articulation angle include string and rotary potentiometers.

4.2.4 Tow Vehicle Lateral Acceleration

The lateral acceleration of the tow vehicle at the approximate center of gravity and parallel to the test track surface. If the transducer is not mounted on a stabilized inertial platform, the lateral acceleration should be corrected for the tow vehicle roll angle in data processing. This can be accomplished by integration of the roll rate sensor.

4.2.5 Tow Vehicle Yaw Velocity

The angular rate of change of the tow vehicle's x-y plane about the z-axis. There are commercially available solid-state inertial rate sensors that are capable of making this measurement.

4.2.6 Trailer Lateral Acceleration

The lateral acceleration of the trailer at the approximate center of gravity and parallel to the test track surface. If the transducer is not mounted on a stabilized inertial platform, the lateral acceleration should be corrected for the trailer roll angle in data processing.

4.2.7 Trailer Roll Angle

The trailer roll angle with respect to the road surface for the purpose of compensating the trailer lateral acceleration. Typical transducers to measure roll angle include rate sensors (requires integration of acquired data), string potentiometers, and height sensors.

Roll angle with respect to the road surface can be determined by:

- a. Integrating the trailer roll rate measurements. Drift and/or offsets should be removed from the data prior to data processing. Commercially available solid-state inertial rate sensors are capable of making these measurements.
- b. Angular measurement transducer in the roll gimbal of a sideslip trolley.
- c. Measurement of changes in the vertical distance to the ground from reference points on either side of the trailer, by non-contacting, height measuring transducers.
- d. Measurement of wheel jounce and rebound motion with respect to the sprung mass, taking into account suspension linkage factors. (This method will not account for tire deflections.)

4.2.8 Trailer Yaw Velocity

The angular rate of change of the trailer's x-y plane about the z-axis. There are commercially available solid-state inertial rate sensors that are capable of making this measurement.

It is not always practical or possible to measure some vehicle parameters directly. The tow vehicle lateral acceleration is one example. In the event that the accelerometer is not placed on a gyro-stabilized platform, the data should be corrected for roll angle. The data channel that is presented shall indicate when it is a corrected measurement, and the approach should be clearly stated.

4.3 Data Recording

Typical vehicle response time constants in handling tests are on the order of 1 second (1 Hz). The sampling rate for vehicle parameter measurements is recommended to be 100 Hz to capture adequate waveform information.

Discrete digital sampling of an analog transducer to obtain a time-based data record is the current state-of-the-art in data acquisition. Discrete sampling can and often will introduce aliased signals in the data that are artificially introduced if the pre-sampled signal is not first passed through an analog anti-aliasing filter. Proper filtering of transducer output signals prior to discrete sampling is required to prevent the creation of an aliased signal. It is recommended that a fourth-order Bessel (linear phase) filter at 40 Hz be used as the analog anti-aliasing filter when used with 100 Hz acquisition rate.

Another issue to consider in the setup of the instrumentation that utilizes discrete digital sampling is the measurement resolution that results from sampling by an Analog-to-Digital (A/D) converter. The reader should be aware that there is a trade-off between full-scale-range and count resolution. SAE J211-1, section 9.2, recommends that the count resolution (engineering unit per count) be less than 0.2% of the full-scale range. As an example, a 10-bit (1024 bits) data acquisition system that measures a bipolar parameter such as a string potentiometer used for trailer articulation angle ($\pm 10^\circ$ full-scale), will have a count resolution of 0.0195 degrees per count ($10^\circ / 512$ bits), which is approximately 0.2% of full-scale range. Therefore, in this example a data acquisition system with a 10-bit or higher A/D converter will meet or exceed the minimum digital resolution.

5. TEST CONDITIONS

5.1 General

All tests should be carried out within the standard test conditions outlined in 5.2 through 5.7. Any deviations from the standard test conditions shall be documented.

5.2 Test Condition Recording

The conditions and specifications of the tow vehicle and trailer under test shall be entered on the Tow Vehicle and Trailer Specification sheets. (Appendices A & B)

The as-tested condition of each vehicle shall be recorded on the appropriate Test Conditions Sheet: the tire size, type, brand information, inflation pressure, and tread depth; any special equipment; any deviation from manufacturers specifications in type or operating condition of components; tongue height and weight; all axle loads with the test trailer attached; the odometer reading at the beginning and end of test. Any other condition that is anticipated to affect test results shall also be recorded on the Test Conditions Sheets. (Appendices C & D)

The instrumentation transducers used, their locations in the tow vehicle and trailer, and all other significant instrumentation information shall be entered on the Instrumentation Information Sheet. (Appendix E)

5.3 Test Surface and Environment

All tests shall be carried out on a uniform hard surface which is free of contaminants and which has a gradient of not more than 1.5% in the longitudinal direction relative to test vehicle travel and 2% in the lateral direction. A smooth, dry pavement of asphalt or concrete or a high friction test surface is recommended. The effect of ambient wind should be considered at all test speeds; ambient wind speed should normally not exceed 7 m/s (15 mph). Surface and wind data should be noted on the Trailer/Environment Test Condition Sheet. (Appendix D)

5.4 Tires Preparation/Condition

The test may be performed with tires in any state of wear so long as a minimum of 1.5 mm (2/32") of tread depth remains over the entire tread surface, excluding wear bars. However, for standard conditions, tires with less than 20% wear should be used. New tires shall run for 50 to 200 km (30 to 150 miles) in the range of approximate test speeds in the appropriate position on the tow vehicle or trailer without excessive harsh use prior to recorded tests.

For a standard tow vehicle and standard trailer condition, tires shall be inflated to the cold pressure specified by the tow vehicle or trailer manufacturer for the test loading configuration at the ambient temperature of the testing area. The tolerance for setting the cold pressure is ± 5 kPa (1 psi) for pressures up to 250 kPa (36 psi), and $\pm 3\%$ for pressure above 250 kPa.

Tire wear state and inflation pressure may influence test results. Therefore tire wear state, break-in procedure, testing sequence, and inflation pressure shall be recorded on the Test Conditions Sheet (Appendix C & D), and any non-standard conditions shall be specifically noted therein.

5.5 Operating Components

Operating components and adjustments that may influence test results (for example: wheel rims, springs and suspension parts, steering system, wheel alignment, hitch, and coupler) should be inspected to ensure that they meet the manufacturers' or other appropriate specifications. All instrumentation and ballast shall be secured, both for safety and to prevent shifts in the tow vehicle and trailer centers of gravity.

5.6 Attachment and Equipment Procedures

The attachment of the trailer to the tow vehicle should be done in accordance with the appropriate instructions. The hitch should be installed on the tow vehicle in accordance with the manufacturer's instructions. Any weight-distributing equipment should be installed and adjusted in accordance with the appropriate instructions; presence of such a device and its adjustment shall be recorded on the Test Condition – Trailer/Environment Specification Sheet. (Appendix D). The source and identification of all instructions followed and any deviations from the instructions shall be identified on the Test Conditions sheets or Test Trailer Specification sheet (Appendices B, C & D).

5.7 Loading and Weight Distribution Conditions

Loading of both the tow vehicle and trailer will depend on the objectives of the specific test program. Loading of the equipment should be within the ratings of the manufacturers. The tow vehicle and trailer axle loads in the test condition shall be weighed before and after the weight-distributing equipment is applied. No axle load should exceed its Gross Axle Weight Rating (GAWR).

5.7.1 Tow Vehicle Loading

In general, the location of the ballast should be chosen to achieve desired axle loads, center of gravity location, and inertial properties of the tow vehicle. Ballast added shall be securely attached to prevent any movement during the test. Location and amount of ballast shall be recorded (Appendix C).

5.7.2 Trailer Loading

In general, the location of the ballast should be chosen to achieve desired axle loads, tongue weight, center of gravity location, and inertial properties of the trailer. Ballast added shall be securely attached to prevent any movement during the test. Location and amount of ballast shall be recorded (Appendix D).

5.7.3 Weight Distributing Hitch Adjustment

Mounting of the weight-distribution hardware should be done in accordance with the appropriate instructions. Various methods are commonly used to adjust weight-distributing hitches. These methods include making adjustments to the weight distributing hardware in order to achieve desired vehicle attitudes or axle loads. For purposes of this document, the amount of weight distributing shall be quantified using axle load measurements. The methodology is described in the following paragraphs.

An appropriate scale or scales shall be used to measure individual axle loads for the vehicle combination as if they were on a flat, level road surface. To facilitate this, the axle load measurements should be recorded using a platform scale in a flat roadway, or individual wheel scales concurrently with blocks of equal height to ensure all tire contacts are in a common level plane. This will prevent pitch angle differences between the tow vehicle and trailer that will influence the moment applied by the weight distributing hardware.