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SURFACE VEHICLE RECOMMENDED PRACTICE

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

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.

The term "tilt table" refers to a device that rolls (rotates) the surface ("table") supporting a vehicle about a longitudinal axis. These devices may have one table that is larger than the vehicle's wheelbase (2.1.1) or a number of smaller tables, each large enough to support the wheels on an axle (2.1.2). In the case of multiple tables, the pivot axes should be aligned to fall on a common line. The important quality of the device is to maintain equal angles of tilt (within 0.1 degree if possible) under the wheels of all axles.

The test is conceptually very simple. The vehicle is driven onto the table (or tables) and then one side of the table is gradually elevated thereby placing the vehicle at a sequence of roll angles due to the tilting of the table.

When the table is at a tilt angle, the test simulates a nonvibratory steady turn. The "simulated" weight of the vehicle is the load perpendicular to the table surface, that is, the actual weight of the vehicle times the cosine of the angle of tilt. The "simulated" lateral acceleration force is the component of load horizontal to the table surface, that is, the actual weight of the vehicle times the sine of the tilt angle. The simulated lateral acceleration is the simulated lateral force divided by the simulated weight, that is, the tangent of the tilt angle. Thus, the static rollover threshold of the vehicle, in g's (1 g = the acceleration of gravity) of lateral acceleration, can be measured by determining the tangent of the tilt angle at which the vehicle just becomes unstable in roll.

1. Scope—The test procedure applies to roll coupled units such as straight trucks, tractor semitrailers, full trailers, B-trains, etc. The test is aimed at evaluating the level of lateral acceleration required to rollover a vehicle or a roll-coupled unit of a vehicle in a steady turning situation. Transient, vibratory, or dynamic rollover situations are not simulated by this test. Furthermore, the accuracy of the test decreases as the tilt angle increases, although this is a small effect at the levels of tilt angle used in testing heavy trucks. The test accuracy is accepted for vehicles that will rollover at lateral acceleration levels below 0.5 g corresponding to a tilt table angle of less than approximately 27 degrees. Even so, the results for heavy trucks with rollover thresholds greater than 0.5 g could be used for comparing their relative static roll stability.

1.1 Purpose—The purpose of this SAE Recommended Practice is to provide an interim test procedure for using tilt tables to measure a static rollover threshold for heavy trucks.

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 L. Laird, "Measurement of Heavy Vehicle Suspension Roll-Stability Properties, and a Method to Evaluate Overall Stability Performance," SAE Paper No. 881869.

2.1.2 C. Winkler, "Experimental Determination of the Rollover Threshold of Four Tractor-Semitrailer Combination Vehicles," University of Michigan Transportation Research Institute report No. UMTRI-87-31.

2.1.3 G. Box, W. Hunter, and J. Hunter, "Statistics for Experimenters," Part I: Comparing Two Treatments, Wiley Interscience.

2.1.4 C. Winkler and M. Hagan, "A Test Facility for the Measurement of Heavy Vehicle Suspension Parameters," SAE Paper No. 800906.

3. ***Vehicle Identification, Test Setup, and Instruments***—When preparing the test vehicle for testing, several vehicle factors (that play an important role in determining rollover threshold) need to be considered. These factors are:

a. Payload—its weight, center of gravity location, and how it is attached to the vehicle.
b. Tires—size, model, construction type, and pressure setting and wear state (Nomenclature and DOT identification number).
c. Suspension—model, size, type, and characteristics such as air spring height. (Height regulation valves should be deactivated [held at static values] during the actual tilt to avoid inflation/deflation of the air bag during the tilt. Cross coupling air lines from side to side may need to be deactivated. The investigation of active suspensions is beyond the scope of this procedure.)

In addition, the experimenter should note that the trailer(s) and the tractor comprise the "test vehicle." For articulated vehicles, all units that are roll coupled should be tested together. Each vehicle unit that is free to roll independently is tested separately. For example, since a fifth wheel provides roll coupling, a tractor and semitrailer combination comprise a single roll unit to be tested. Full trailers, of the type which are connected to their towing unit without roll coupling (such as through a pintle hitch), comprise a single roll unit to be tested.

(Individual testing of tractors and semitrailers is conceptually possible, but beyond the scope of this procedure. The roll stability properties of roll coupled units such as tractors and semitrailers generally have a highly nonlinear, synergistic relationship with one another. For example, it is very possible for two trailers, which show very similar results when coupled to one particular tractor, to show very dissimilar results when coupled to different tractors.)

All of the factors discussed previously can affect the rollover threshold. Care should be exercised in choosing realistic and repeatable test conditions. The test vehicle, including payload, tire, and suspension characteristics as listed previously, shall be identified and an adequate description shall be included with the results. This documentation is needed so that users of the results will understand the test conditions and not be misled since there are many possible choices of loading states, suspensions, and tires for heavy trucks.

(Also, the influences of stick-slip in the vehicle's compliant and coupling components should be taken into account. It can generally be expected that typical levels of hysteresis in suspensions and other elements of the vehicle will have minimal influence on measured roll stability [that is, the rollover threshold]. However, hysteresis may significantly influence other "events," such as initial wheel lift, which occurs prior to rollover at relatively low levels of tilt angle. Since hysteresis is difficult or practically impossible to control directly, the vehicle may be removed from the table in between tests and driven around to "randomize" or "equalize" the influences of hysteresis and stick-slip. Any procedures used to control stick-slip and hysteresis should be documented with the test results so that the test conditions can be understood. The number and sequence of left and right turns and the roughness of the road surface may influence the results at test angles below the rollover threshold. However, the influence on the rollover threshold is expected to be small and probably negligible.)

In addition to the previous test vehicle parameters, care should be taken to insure that the test vehicle is placed on the tilt table as straight as possible. The vehicle should be tested with all units in a straight line parallel to the tilt axis such that no axle centerline is off line by more than 25 mm (1 in). This provides a uniform test arrangement, even though various amounts of articulation may exist during turning maneuvers.

Rollover tests should be conducted at very low roll rates. The dynamic response of the test vehicle as it transitions the various "events" of the tilt table procedure is typically very slow. For example, when the vehicle begins to "fall" as the roll stability limit is reached, it accelerates very slowly. If table speed is too fast, the table can "chase" the vehicle, making precise identification of the moment of instability difficult. Similar problems can arise at each of the "events" occurring in the procedure. To avoid measurement errors which can result from the table "chasing" the vehicle, roll rates of 0.25 degree/s or less are desirable in the immediate vicinity of any "event" of interest, such as wheel lift off or the occurrence of suspension lash.

If the tilt table is located outdoors, note the wind conditions. Record wind condition (speed and direction). Do not test when wind speed exceeds 6 km/h (10 mph) and wind speeds less than 3 km/h (5 mph) are desirable. (A 6 km/h side wind on a stationary 14.4 m [48 ft] van semitrailer could produce a side force of approximately 1300 N [300 lb] which would be equivalent to an error of approximately 0.005 g in the rollover threshold for a semitrailer with a gross weight of 267 000 N [60 000 lb]. Since there is a velocity squared relationship between side force and wind velocity, a 3 km/h side wind would result in approximately 0.001 g of error in rollover threshold for this van semitrailer.)

Clearly, the vehicle needs to be restrained to keep it from rolling over or sliding down the table. Straps, chains, etc., can be used to catch the vehicle once rollover has started (see Figure 1). Restraints which can be adjusted under load are particularly desirable. A high-friction, ridged surface should also be used to provide enough friction force at the tire/table interface to keep the tires from sliding sideways. Even though the tire should not be resting against a vertical surface during the tests, it is good safety practice to have a constraining surface in place to hold the wheel in case it does slide sideways. An initial clearance of 75 to 100 mm (3 to 4 in) between the tires and the restraint is generally adequate to prevent contact in the normal conduct of a test.

Table 1 lists accuracy requirements for the instrumentation and the test set-up that are aimed at achieving 0.01 g accuracy in determining rollover threshold.

4. ***Test Procedure***—A basic rollover test consists of very gradually increasing the angle of the table, at a rate not to exceed 0.25 degree/s, and recording the angles at which:

a. The vehicle becomes unstable and starts to rollover
b. Wheels lift off
c. Suspension lash is encountered
d. The fifth wheel separates (if it does before rollover)

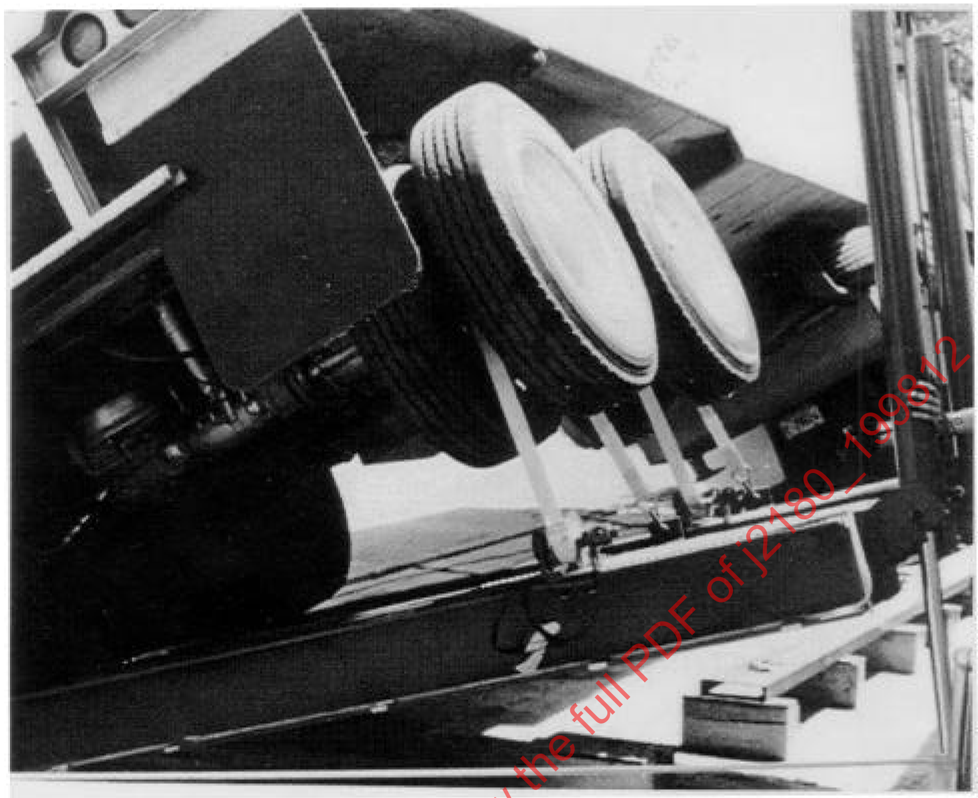

FIGURE 1—ILLUSTRATION OF STRAPS USED TO RESTRAIN THE VEHICLE FROM ROLLOVER

TABLE 1—TILT TABLE ACCURACY REQUIREMENTS

Tilt angle measurement	±0.1 degree
Vehicle-to-pivot axis alignment	Vehicle centerline parallel to pivot axis with ±25 mm at each axle
Tilt rate	≤0.25 degree/s in the vicinity of any event of interest
Pivot axis alignment	
Overall:	Horizontal ±0.25 degree
Multiple axle tables:	Co-linear ±2.5 mm
Tilt angle alignment at each axle[1]	±0.1 degree
Pretest suspension setting (Hysteretic effects)	Nominally centered; no special requirement for rollover threshold measurement
Wind disturbance acceleration	≤0.003 g magnitude (nominally 4.5 km/h wind speed)

1. Reflects on required table stiffness and/or the alignment of individual axle tables

To begin testing, a preliminary test should be performed to (1) adjust the anti-rollover constraints, and (2) learn approximately when wheels lift, lash is encountered, and rollover occurs.

As the tilt table test proceeds, the various axles of the vehicle will lift off at different times. As the test proceeds further, axles which lift early may clear the table surface by distances exceeding 0.3 m prior to the vehicle becoming unstable. To establish proper adjustment of constraints, start the initial tilt with all constraints adjusted to allow only a few centimeters of wheel lift. As the tilt proceeds and individual constraints become taught, lower the table and adjust constraints to provide freedom to roll as required. Continue this procedure up to the tilt angle at which the vehicle becomes unstable. Allow only the minimum unconstrained roll motion needed to clearly identify the occurrence of instability.

NOTE—(SAFETY) Most loaded heavy trucks will become unstable when all axles other than the front axle have lifted off. That is, usually the vehicle will become unstable even though the front axle has not lifted. In some cases, instability may occur with more than just the front axle still in contact. Right at the point of instability, the vehicle is "balanced" on the verge of rollover and very little constraint force is required to restrain the vehicle. However, as the vehicle rolls beyond the point of instability, required restraint force increases rapidly. In the process of adjusting axle constraints, care should be exercised to carefully observe whether or not the point of instability has been reached, even though some axles have not lifted off. If the vehicle is allowed to roll well beyond the point of instability, danger of failure of the restraint straps or chains increases quickly.)

It may be possible to identify the approximate tilt angle for each event of interest in the same tilt in which the constraints are adjusted. If not, a second preliminary tilt may be conducted to identify these angles.

Several test runs may be necessary to obtain a statistical distribution of rollover threshold values for a particular test vehicle (2.1.3). The total number of test runs will be dependent on the test objective as well as the accuracy required. As an example, multiple test vehicles may be tested to compare their rollover thresholds. Sufficient test turns will be needed to determine if a statistically significant difference exists between the test vehicles. However, if only a "general idea" of the rollover threshold value is required, three test runs will suffice.

Between each test run, the vehicle may be removed from the table and "equalized" as mentioned previously. The vehicle should be tilted in both directions. Because of asymmetries in mass, geometry, and system stiffness, the results for rolling to the left and to the right can be expected to differ.

5. Data Presentation and Analysis—The fundamental result from this test is the "rollover threshold." This performance measure is equal to the tangent of the table angle corresponding to the initiation of rollover. For example, if the vehicle had a rollover threshold of 0.4 g, the angle of the tilt table at the initiation of rollover would be the arctangent of 0.4 or 21.8 degrees. The rollover threshold shall be reported for all test runs.

Other factors such as table angles when wheel lift off, suspension lash, and fifth wheel separation occur are useful to help determine their relative influence on the test vehicle's rollover threshold. It is recommended that these events be tabulated as a function of the tangent of the table angle for all of the tests run.

Also, experimenters may want to measure and record angles at various cross members of the vehicle such as at the axles, at the front bumper of the tractor, or at points on the bed of the trailer. (See 2.1.1 for discussion of these types of measurements.) These angles can be useful for comparisons with experimental or theoretical results obtained in other tests or analyses. For comparisons with theoretical concepts, it is useful to plot the simulated lateral acceleration (i.e., the tangent of the table angle) versus the roll angle measured from the angle of the tilt table to the angle of the rolled lateral axis of the main sprung mass of the unit undergoing the test. (See Figure 2 for an example test result in which the rollover threshold is 0.34 g.)

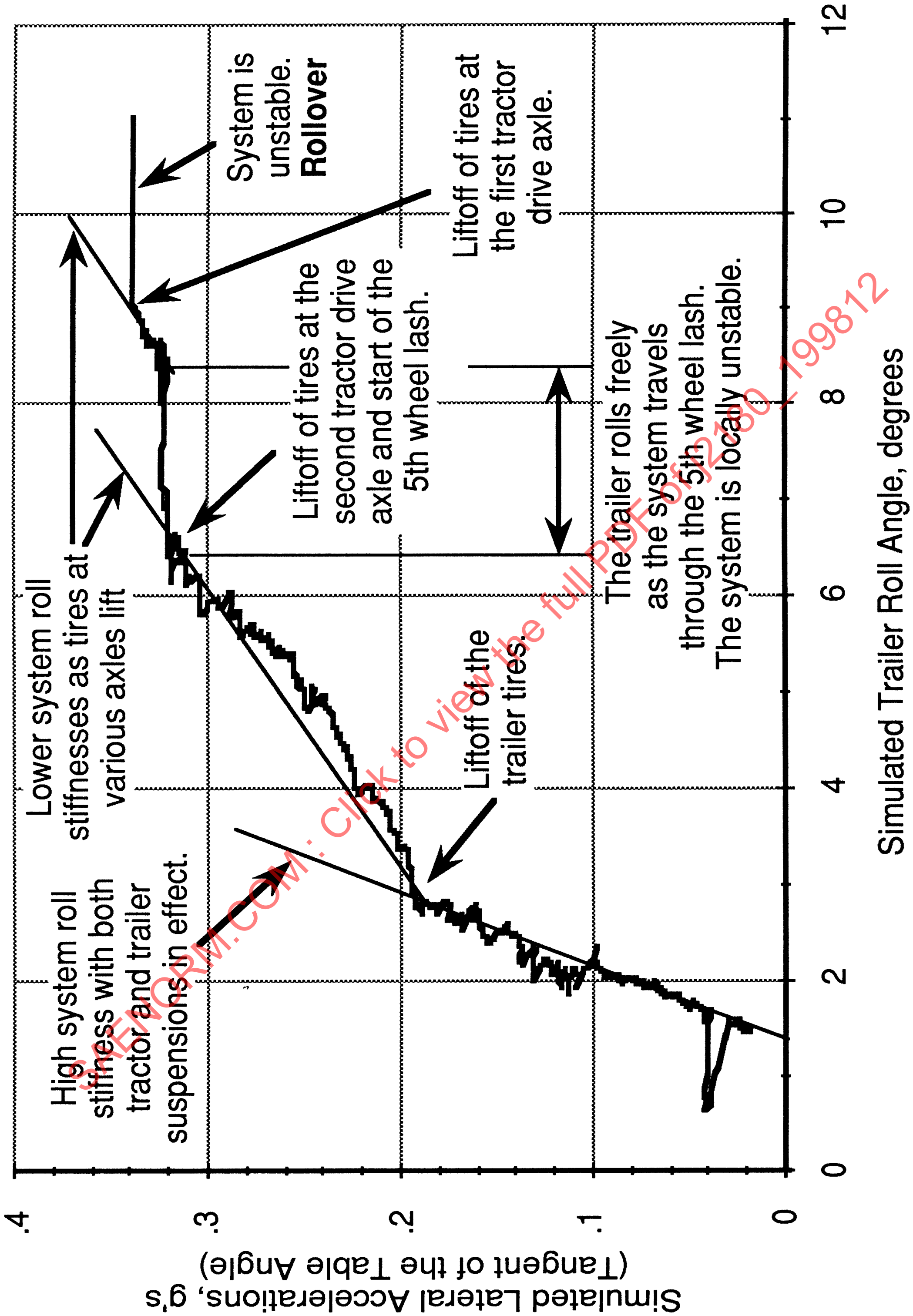

FIGURE 2—PLOT OF TRAILER ROLL ANGLE VERSUS SIMULATED LATERAL ACCELERATION FROM A TILT TABLE TEST OF A LOADED, FIVE-AXLE TRACTOR SEMITRAILER COMBINATION