SAE International®

# SURFACE VEHICLE RECOMMENDED PRACTICE

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# Measurement of Vehicle and Suspension Parameters for Directional Control Studies

RATIONALE

This document was revised to correct typographical and formatting errors in Equations 5-7, and minor typographical errors in some of the tables and figures.

## 1. SCOPE

The parameters measured according to this SAE Recommended Practice will generally be used in simulating directional control performance in the linear range. (The "linear range" is the steady-state lateral acceleration below which steering wheel angle can generally be considered to be linearly related to lateral acceleration.) But they may be used for certain other simulations (such as primary ride motions), vehicle and suspension characterization and comparison, suspension development and optimization, and processing of road test data.

This document is intended to apply to passenger cars, light trucks, and on-highway recreational and commercial vehicles, both non-articulated and articulated. Measurement techniques are intended to apply to these vehicles, with alterations primarily in the scale of facilities required. But some differences do exist between passenger cars and trucks, especially heavy trucks, such as differences in body/frame flexibility, suspension stiffness, and suspension friction. These will be addressed in this document or SAE J1574-2, where appropriate.

### 1.1 Purpose

The purpose of this document is to define the basic design requirements for test equipment and the test procedures to be employed in measuring certain vehicle characteristics generally required for directional control simulation. In addition, data processing procedures are provided so that data from different laboratories can be directly compared. The companion Information Report gives the rationale behind the Recommended Practice, where appropriate.

## 1.2 Assumptions and Limitations

The approach used to develop this document was to consolidate and document existing technology as embodied in equipment and procedures currently employed for routine tests. As a result, the assumptions and limitations of those practices must be acknowledged in this document.

The major assumptions stemming from this established document are:

a. Static-suspension characteristics (kinematic and elastic) are valid for simulation and suspension comparison purposes. This does not apply to shock-absorber characteristics required to determine ride and roll damping.

b. Phenomenological suspension descriptions, such as kinematic and elastic gradients, are valid for simulation and suspension comparison purposes.

c. Kinematic and elastic suspension characteristics measured for the inertial loads and suspension-roll angles associated with the linear range are valid for simulating vehicle behavior in the linear range.

d. Kinematic and elastic suspension characteristics associated with the linear range describe a system which may be approximated as linear. Therefore, they may be used in simulations using the principle of superposition and may be measured singly, with set points of other variables at zero or nominal value.

In addition to these broad assumptions, two other assumptions related to the use of this document must be stated. First, it is assumed that the vehicle description and preparation, as described in Section 3, will be performed prior to any of the tests described in subsequent sections. (The procedures described in Sections 4 through 10 may be performed somewhat independently of each other, once those in Section 3 are complete.) Second, the terminology of SAE J670e will be observed wherever possible.

The limitations associated with this document may be divided into those associated with the uses of the final data and the vehicle characteristics addressed. Limitations in both categories generally stem from the limitations of existing practices. Simulations which are not addressed are those involving lateral accelerations beyond the linear range, free control dynamics, combined lateral and longitudinal accelerations, accelerating and braking performance, or oscillations of any parts of the unsprung masses or steering system at frequencies above those associated with directional control. In addition, assumption 1.2b results in experimental procedures and suspension data which is not useful for multibody simulations such as ADAMS or DADS.

Vehicle and component characteristics which are not addressed are those not required for directional control simulation in the linear range. While this list is clearly quite long, some bear mentioning for the convenience of the user of this document. These are:

a. Suspension side view kinematic properties

b. Suspension steer and camber compliances resulting from longitudinal force, overturning moment, and rolling resistance moment

c. Kingpin and caster offsets

d. Characteristics of fifth wheels of articulated vehicles

e. Rotational inertias of wheels, tires, brakes, and driveline components

Tire force and moment characteristics (addressed in SAE J1106 and SAE J1107)

The first two of these may be addressed with methods analogous to those described in Sections 8 and 9.

In addition, certain other vehicle characteristics will not be addressed due to their relative newness and the associated absence of established experimental practice. Examples of less conventional chassis systems which will not be fully addressed are active and adaptive suspension systems, four-wheel steering, and speed-sensitive steering. However, procedures formally discussed may well be adapted to these less conventional systems. Such adaptation may be discussed when appropriate.

1.3 Characteristics Measured

The previous paragraphs covering purpose, scope, and assumptions and limitations have not explicitly listed the vehicle characteristics which will be addressed in this document. Table 1 does this, showing the section in which each is addressed and whether it is a suspension or total vehicle characteristic. In addition to this summary of variables measured, the list of variables for each section will be repeated in paragraph 1 of that section, in a different format, providing expected ranges for different vehicle types.

After reviewing Table 1, the reader may see that some of the variables listed are not directly required for vehicle simulation or data reduction. Such a variable may have been included in Table 1 because it is required in the documentation process or in the determination of another variable. In addition, some variables listed may be measured very simply, precluding the need for an in-depth measurement practice or discussion thereof.

1.4 Nature of Measurements

This document covers the measurement of a broad range of vehicle characteristics using an equally broad range of experimental practices. This paragraph briefly outlines the nature of these experimental approaches.

The measurements of Sections 3 (Vehicle Description and Preparation) and 4 (Measurement of Dimensional and Geometric Characteristics) generally involve only measurements of linear dimensions, to varying degrees of accuracy. Measurement devices range from steel tapes to micrometers and are generally available in most vehicle shops. In addition, a flat, planar reference surface (bed plate) and certain specialized tools are required for a few of the measurements. In general, vehicle loading and suspension trim are important.

The measurement of vehicle and component weights (Section 5) and center of gravity positions (Section 6) generally require the direct measurement of weight or force. Scales of varying load capacity are used for these measurements. The measurement of center of gravity positions also requires a specialized tilt table and the measurement of angular displacement. The measurement of component weights and center of gravity positions requires some vehicle disassembly.

The measurement of moments and products of inertia (Section 7) requires very specialized equipment for inducing lightly damped vehicle oscillations about a specified axis. These measurements are based on the measurement of natural frequency and restoring moment(s).

The measurements of Section 8 (Measurement of Suspension Kinematic Characteristics) generally require a prescribed steer or suspension displacement (ride or roll) and the measurement of steer or camber displacement. In some cases, equilibrium techniques can be used, allowing the indirect determination of a kinematic swing center. All of the measurements require very specialized facilities for providing the suspension or steering displacement, minimizing unwanted forces or moments, and allowing the determination of desired displacements.

TABLE 1 - CHARACTERISTICS MEASURED

| Variable | Section | Front Suspension | Rear Suspension | Total Vehicle |
|---|---|---|---|---|
| Dimensional and Geometric Characteristics: | | | | |
| axle spread, tandem axle | 4 | x | x | |
| dual spacing, dual axle | 4 | x | x | |
| fifth wheel position | 4 | | | x |
| pintle position | 4 | | | x |
| roadwheel dimensions | 4 | x | x | |
| stabilizer bar diameter | 4 | x | x | |
| steering wheel diameter | 4 | | | x |
| suspension or steering coordinates | 4 | x | x | |
| suspension alignment | 4 | x | x | |
| suspension trim height | 4 | x | x | |
| tire pressure | 4 | x | x | |
| tire tread depth | 4 | x | x | |
| wheel track | 4 | x | x | |
| wheelbase | 4 | | | x |
| Vehicle and Component Weights: | | | | |
| sprung weight | 5 | | | x |
| tire normal forces | 5 | x | x | |
| total vehicle weight | 5 | | | x |
| unsprung weight | 5 | x | x | |
| Center of Gravity Positions: | | | | |
| sprung cg position | 6 | | | x |
| total vehicle cg position | 6 | | | x |
| unsprung cg position | 6 | x | x | |
| Moments and Products of Inertia: | | | | |
| sprung mass pitch moment | 7 | | | x |
| sprung mass roll moment | 7 | | | x |
| sprung mass yaw moment | 7 | | | x |
| sprung mass roll-yaw product | 7 | | | x |
| total vehicle pitch moment | 7 | | | x |
| total vehicle roll moment | 7 | | | x |
| total vehicle yaw moment | 7 | | | x |
| total vehicle roll-yaw product | 7 | | | x |
| unsprung mass pitch moment | 7 | x | x | |
| unsprung mass roll moment | 7 | x | x | |
| unsprung mass yaw moment | 7 | x | x | |
| unsprung mass roll-yaw product | 7 | x | x | |
| Suspension Kinematic Characteristics: | | | | |
| overall steering ratio | 8 | x | | |
| ride camber coefficient | 8 | x | x | |
| ride caster coefficient | 8 | x | | |
| ride shock absorber travel ratio | 8 | x | x | |
| ride steer coefficient | 8 | x | x | |
| roll camber coefficient | 8 | x | x | |
| roll caster coefficient | 8 | x | | |
| roll center height | 8 | x | x | |
| roll shock absorber travel ratio | 8 | x | x | |

TABLE 1 - CHARACTERISTICS MEASURED (CONTINUED)

| Variable | Section | Front Suspension | Rear Suspension | Total Vehicle |
|---|---|---|---|---|
| roll steer coefficient | 8 | x | x | |
| Suspension Elastic and Coulomb Friction Characteristics: | | | | |
| aligning moment camber coefficient | 9 | x | x | |
| aligning moment steer coefficient | 9 | x | x | |
| lateral force camber coefficient | 9 | x | x | |
| lateral force defl. coefficient | 9 | x | x | |
| lateral force steer coefficient | 9 | x | x | |
| ride Coulomb friction | 9 | x | x | |
| ride rate | 9 | x | x | |
| roll Coulomb friction | 9 | x | x | |
| suspension roll rate | 9 | x | x | |
| wheel rate | 9 | x | x | |
| Shock Absorber Characteristics: | | | | |
| bushing spring rate | 10 | x | x | |
| damping coefficient | 10 | x | x | |
| ride damping | 10 | x | x | |
| roll damping | 10 | x | x | |
| shock absorber spring rate | 10 | x | x | |

Similarly, the measurement of suspension elastic and Coulomb friction characteristics (Section 9) generally requires a prescribed suspension displacement (ride or roll) or an externally applied load (lateral force or aligning moment) and the measurement of wheel displacement (linear or angular). Again, very specialized facilities are required to provide the desired displacement or load, to minimize unwanted displacements or loads, and to allow the determination of desired displacements. These measurements are generally made with the tires on the vehicle; the complete rationale for this is discussed in 9.2.2 of SAE J1574-2 for Section 9, Measurement of Suspension Elastic and Coulomb Friction Characteristics. Other brief references can be found in SAE J1574-2 for this section, paragraph 1.5, and the Recommended Practice for Section 9, 9.2.2.

Finally, the measurement of shock-absorber characteristics (Section 10) requires specialized equipment to stroke the shock absorber through a range of amplitudes and/or frequencies. Measurements of amplitude, frequency, and force are required.

In many of these measurements, equivalent, or nearly equivalent, methods may exist. Where possible, alternatives are discussed with some indication of their relative merits.

1.5 Use of SAE J1574-1 and SAE J1574-2

The purpose of this paragraph is to give the user of this document some insight into its structure and some suggestions for its effective use. Table 1 has indicated some of this structure. But, for convenience and reference for the following discussion, all of the sections of this document and SAE J1574-2 are given as follows:

1. Scope

2. References

3. Vehicle Description and Preparation

4. Measurement of Dimensional and Geometric Characteristics

5. Measurement of Vehicle and Component Weights

6. Measurement of Center of Gravity Positions

7. Measurement of Moments and Products of Inertia

8. Measurement of Suspension Kinematic Characteristics

9. Measurement of Suspension Elastic and Coulomb Friction Characteristics

10. Measurement of Shock Absorber Characteristics

This document covers vehicle description, vehicle preparation, recommended testing practices, and recommended data processing and presentation practices for the measurements listed previously. The companion Information Report (SAE J1574-2) gives the background and rationale for procedures presented in this document, if such background is appropriate. With one exception, it is written in parallel to SAE J1574-1, with the same paragraph numbers and titles. The two should be used together for complete understanding of the test procedures and the principles behind them.

Sections 4 through 10 are intended to provide test procedures which may be performed somewhat independently of each other, provided that the vehicle description and preparation of Section 3 are complete. Each of these seven sections is divided into the following five major paragraphs:

a. Variables Measured

b. Apparatus

c. Test Procedures

d. Data Processing and Presentation

e. Calibration Procedures

Each major paragraph may be subdivided further with decimal suffixes (e.g., 4.3.2.1).

This document will be easier to understand and use with reference to SAE J670e and SAE J1106 and SAE J1107.

1.6 Rationale

This document has been reaffirmed to comply with the SAE 5-Year Review policy.

## 2. REFERENCES

### 2.1 Applicable Documents

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

SAE J670 Vehicle Dynamics Terminology

SAE J874 Earthmoving Machines - Method for Locating the Center of Gravity

SAE J1106 Laboratory Testing Machines for Measuring the Steady State Force and Moment Properties of Passenger Car Tires

SAE J1107 Laboratory Testing Machines and Procedures for Measuring the Steady State Force and Moment Properties of Passenger Car Tires

SAE J1574-2 Measurement of Vehicle and Suspension Parameters for Directional Control Studies - Rationale

2.1.2 Tire and Rim Association

Available from Tire and Rim Association, Inc., 175 Montrose West Avenue, Suite 150, Copley, OH 44321.

Tire and Rim Association Yearbook

# 3. VEHICLE DESCRIPTION AND PREPARATION

## 3.1 General Vehicle Description

A general vehicle description entails both qualitative and quantitative information and is usually accomplished by using a standard form, designed for this purpose. Two such forms are presented at the end of this section. The first, Figure 1, is generally applicable to (non-articulated) passenger vehicles and light trucks. The second, Figures 2, 3, and 4, is more specifically applicable to heavy commercial vehicles, both articulated and non-articulated, including a trailer. Both allow for the description of a broad range of vehicle types. As such, either may be more lengthy than required for a given application and may best be used as a reference for a simpler form, more suited to vehicle types encountered in a specific laboratory.

## 3.2 Specific Measurements

The vehicle definition summarized in the following description forms includes, in addition to a general description, various dimensions and weights whose measurement is discussed in Sections 4 and 5. Those addressed in Section 4 are generally, but not entirely, physical dimensions of the vehicle or its parts. Those addressed in Section 5 are the static tire normal forces, among others. The measurement of overall steering ratio is addressed in Section 8. While accurate knowledge of overall steering ratio is generally required for directional control simulation and for data reduction of certain directional control tests, values for gear ratio or C factor (rack travel for each full revolution of the pinion) are generally not. It is common practice to use nominal values for these characteristics, if available, obtained from part numbers or independent sources, to more fully define the vehicle and/or check the directly measured overall steering ratio.

GENERAL DEFINITION

Year ____ Make ____ Model ____ Mileage ____
VIN ____ Fleet No. ____
Body Style ____ Body Code ____
Status: [ ] Production [ ] Pilot [ ] Prototype
[ ] Preprototype [ ] Development [ ] Pretest
[ ] Component [ ] Experimental
Options: [ ] Air Cond. [ ] Power Brakes [ ] Power Stg.

MAJOR DIMENSIONS

Wheelbase ____ mm
Front Track ____ mm Rear Track ____ mm

MASS

TIRE NORMAL FORCES
LF ____ kg RF ____ kg
LR ____ kg RR ____ kg

DRIVETRAIN

ENGINE
Configuration: Disp. ____ l Conf. ____ (L4,...)
Layout: [ ] Front [ ] Rear [ ] Transverse
Fuel: [ ] Gasoline [ ] Diesel [ ] Alcohol
Induction: [ ] Carburetor [ ] Fuel Inject. [ ] Turbocharged
[ ] Supercharged
POWER TRANSMISSION
Drive Wheels: [ ] FWD [ ] RWD [ ] Part 4WD
[ ] Full 4WD
Transmission: [ ] Manual [ ] Automatic Forward Gears __

FRONT SUSPENSION

SOLID AXLE
[ ] Leaf Spring [ ] Mult. Link [ ] Track Bar Other ____
INDEPENDENT
[ ] Uneq. A arm [ ] Strut [ ] Mult. Link Number Links __
Other ____
SPRINGS
[ ] Coil [ ] Torsion Bar [ ] Long. Leaf [ ] Trans. Leaf
[ ] Air Other ____
Material ____ Code ____
STABILIZER BAR
[ ] Link Type [ ] Strap Down [ ] Tubular Diameter ____ mm
Material ____ Code ____
SHOCK ABSORBERS
[ ] Air Pressure ___ kPa [ ] Selectable [ ] Adaptive
[ ] Active Code ____



FIGURE 1 - VEHICLE DEFINITION
(PASSENGER VEHICLES AND LIGHT TRUCKS (NONARTICULATED))

RIDE CONTROL
[ ] Level Control [ ] Active
REMARKS

______________________________________________

REAR SUSPENSION

SOLID AXLE
[ ] Leaf Spring [ ] 4 Link [ ] Track Bar [ ] Watt Linkage
Other ________

INDEPENDENT
[ ] Uneq. A arm [ ] Strut [ ] Mult. Link Number Links ___
Other ________

SPRINGS
[ ] Coil [ ] Torsion Bar [ ] Long. Leaf [ ] Trans. Leaf
[ ] Air Other ________
Material ______ Code ________

STABILIZER BAR
[ ] Link Type [ ] Strap Down [ ] Tubular Diameter ___ mm
Material ______ Code ________

SHOCK ABSORBERS
[ ] Air Pressure ___ kPa [ ] Selectable [ ] Adaptive
[ ] Active Code ________

RIDE CONTROL
[ ] Level Control [ ] Active
REMARKS

______________________________________________

STEERING

FRONT
Gear Type: [ ] Worm/Sector [ ] Rack and Pinion
Linkage Location: [ ] Ahead of W.C. [ ] Behind W.C.
Linkage Type: [ ] Parallelogram [ ] End Take Off [ ] Ctr. Take Off
Assist: [ ] Integral [ ] Linkage
[ ] Hydraulic [ ] Electric [ ] Electro-Hyd.
[ ] Conventional [ ] Engine Speed [ ] Vehicle Speed
Damper: [ ] Integral [ ] Linkage
Ratios: [ ] Linear [ ] Nonlinear
Overall ______ :1 Gear ________ :1 C-Factor ___ mm
Steering Wheel Dia.: Vertical ______ Horizontal _____

REAR
Gear Type: [ ] Worm/Sector [ ] Rack and Pinion
Linkage Location: [ ] Ahead of W.C. [ ] Behind W.C.
Linkage Type: [ ] Parallelogram [ ] End Take Off [ ] Ctr. Take Off
Actuation: [ ] Mechanical [ ] Hydraulic [ ] Electric
[ ] Electro-Hyd.
Displ. Reference: [ ] Front Wheels [ ] Vehicle Speed
REMARKS

______________________________________________

FIGURE 1 - VEHICLE DEFINITION
(PASSENGER VEHICLES AND LIGHT TRUCKS (NONARTICULATED)) (CONTINUED)

BRAKES

| | | | |
|---|---|---|---|
| FOUNDATION | | | |
| Brand ________ | | | |
| Assist: | [ ] Vacuum | [ ] Hydraulic | Other ________ |
| Front: | [ ] Disc | [ ] Drum | |
| Rear: | [ ] Disc | [ ] Drum | |
| ANTI-LOCK | | | |
| Brand ________ | [ ] Front | [ ] Rear | |
| REMARKS | | | |

TIRES AND WHEELS

| | | | |
|---|---|---|---|
| FRONT | | | |
| Brand ________ | Size ________ | Model ________ | Const. ________ |
| Status: | [ ] Production | [ ] Experimental | |
| Type: | [ ] Mud + Snow | [ ] Performance | Other ________ |
| Construction: | [ ] Steel Radial | [ ] Other Radial | [ ] Belted Bias |
| | [ ] Bias | Other ________ | |
| Tread: | [ ] New | [ ] Half Worn | [ ] Full Worn |
| | [ ] Shaved | Depth ______ mm | |
| Pressure: | Pressure ___ kPa | [ ] Cold | [ ] Hot |
| Rim: | Width ______ mm | Offset ______ mm | |
| REAR | | | |
| [ ] Same as Front | | | |
| Brand ________ | Size ________ | Model ________ | Const. ________ |
| Status: | [ ] Production | [ ] Experimental | |
| Type: | [ ] Mud + Snow | [ ] Performance | Other ________ |
| Construction: | [ ] Steel Radial | [ ] Other Radial | [ ] Belted Bias |
| | [ ] Bias | Other ________ | |
| Tread: | [ ] New | [ ] Half Worn | [ ] Full Worn |
| | [ ] Shaved | Depth ______ mm | |
| Pressure: | Pressure ___ kPa | [ ] Cold | [ ] Hot |
| Rim: | Width ______ mm | Offset ______ mm | |

FIGURE 1 - VEHICLE DEFINITION
(PASSENGER VEHICLES AND LIGHT TRUCKS (NONARTICULATED)) (CONTINUED)

## PART I: UNIT TRUCKS AND TRACTORS

### General

*Chassis Cab*

| | | | |
|---|---|---|---|
| Year ____________ | Make ____________ | Model ____________ | Millage ____________ |
| VIN ____________ | Fleet No. ________ | GVWR ____________ | GCWR ____________ |
| Status: | [ ] Production | [ ] Pilot | [ ] Prototype |
| | [ ] Pre-prototype | [ ] Development | [ ] Pretest |
| | [ ] Component | [ ] Experimental | |
| Cab Style: | [ ] COE | [ ] Cab Forward | [ ] Conventional |
| | [ ] Short Nose Conventional | | |
| Options: | [ ] Air Conditioning | [ ] Other ____________ | |

*Body*

| | | | |
|---|---|---|---|
| Year ____________ | Make ____________ | Model ____________ | ID No. ____________ |

Description ______________________________________________

*Loading* ______________________________________________

*Major Dimensions*[1]

| | | | |
|---|---|---|---|
| AF ________ mm | BA ________ mm | BBC ________ mm | BH ________ mm |
| BL ________ mm | CE ________ mm | CH ________ mm | FH ________ mm |
| FMH ________ mm | OL ________ mm | WB ________ mm | |

### Mass

*Tire Loads*

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Left Side: | ______ kg | ______ kg | ______ kg | ______ kg | ______ kg |
| Right Side: | ______ kg | ______ kg | ______ kg | ______ kg | ______ kg |

[1] Figure 2a identifies these and other dimensions.

FIGURE 2 - VEHICLE DEFINITION (UNIT AND ARTICULATED HEAVY TRUCKS)
PART I: UNIT TRUCKS AND TRACTORS

**Drivetrain**

*Engine*

| | | | |
|---|---|---|---|
| Make ______ | Model ______ | Displc ______ | Config ______ |
| Fuel: | [ ] Gasoline | [ ] Diesel | [ ] Alcohol |
| Stroke: | [ ] Two Stroke | [ ] Four Stroke | |
| Induction: | [ ] Carburetor | [ ] Fuel Injection | [ ] Turbocharged |

**Power Transmission**

*Transmission*

| | | |
|---|---|---|
| Make ______ | Model ______ | Number of Forward Gears ______ |
| [ ] Manual | [ ] Automatic | [ ] OD Range Selector |

*Full-Time Drive Axles*

| | | |
|---|---|---|
| Make ______ | Model ______ | Axle(s) No(s) ______ |
| [ ] Single Speed | [ ] Two Speed | [ ] Ratio(s) ______ |
| [ ] Inter-axle Diff. Lock | | |

*Selectable Drive Axles*

| | | |
|---|---|---|
| Make ______ | Model ______ | Axle(s) No(s) ______ |
| [ ] Single Speed | [ ] Two Speed | Ratio(s) ______ |
| [ ] Inter-axle Diff. Lock | | |

**Axles**

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Spacing from preceding axle (Sn)[1], mm: | | | | | |
| Make: | | | | | |
| Model: | | | | | |
| Load rating, kg: | | | | | |
| Axle width (AW)[1], mm: | | | | | |
| Track width (TW)[1], mm: | | | | | |
| Dual spacing (DS)[1], mm: | | | | | |
| Steering: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Self-Steering: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Drive: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Lift: | [ ] | [ ] | [ ] | [ ] | [ ] |

[1] Figure 2a identifies these and other dimensions.

FIGURE 2 - VEHICLE DEFINITION (UNIT AND ARTICULATED HEAVY TRUCKS)
PART I: UNIT TRUCKS AND TRACTORS (CONTINUED)

**Suspension No.** ____________

Includes Axle(s) No(s): ____________

Make: ________ Model: ________ Load Rating, kg: ____________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ____________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ____________

*Spring(s)*

Make ________ Model ________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ______ Length, mm ______
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ____________

Remarks ____________



**Suspension No.** ____________

Includes Axle(s) No(s): ____________

Make: ________ Model: ________ Load Rating: ____________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ____________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ____________

*Spring(s)*

Make ________ Model ________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ______ Length, mm ______
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ____________

Remarks ____________

FIGURE 2 - VEHICLE DEFINITION (UNIT AND ARTICULATED HEAVY TRUCKS)
PART I: UNIT TRUCKS AND TRACTORS (CONTINUED)

**Suspension No.** ____________________

Includes Axle(s) No(s): ________________

Make: __________ Model: __________ Load Rating, kg: ____________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ____________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ____________________

*Spring(s)*

Make __________ Model __________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ______ Length, mm ______
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ____________________

Remarks ____________________

**Suspension No.** ____________________

Includes Axle(s) No(s): ________________

Make: __________ Model: __________ Load Rating: ____________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ____________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ____________________

*Spring(s)*

Make __________ Model __________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ______ Length, mm ______
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ____________________

Remarks ____________________

FIGURE 2 - VEHICLE DEFINITION (UNIT AND ARTICULATED HEAVY TRUCKS)
PART I: UNIT TRUCKS AND TRACTORS (CONTINUED)

**Steering System**

Gear Make: ____________ Gear Model: ____________
Assist: [ ] Manual [ ] Integral Asst. [ ] Linkage Asst.
Gear Location: [ ] Frame [ ] Axle
[ ] Ahead of WC [ ] Behind WC

Ratios: Overall: ________ : 1 Gear: ________ : 1

Pitman Arm Length, mm ____________ Steering Arm Length, mm ____________

Ackerman wheelbase, mm ____________

Handwheel Dia, mm: Vertical ____________ Horizontal ____________

Remarks ____________________________________

**Brakes**

*Actuation*

[ ] Air
[ ] Hydraulic [ ] Vacuum Asst. [ ] Hydraulic Power

*Wheel Brakes*

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Make: | | | | | |
| Disc: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Drum: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Disc or Drum size: | | | | | |
| Wedge: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Wedge Angle, degrees: | | | | | |
| S-Cam: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Slack Length, mm: | | | | | |
| Automatic Slacks: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Air Chamber Type: | | | | | |
| Spring Brake: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Anti-lock: | [ ] | [ ] | [ ] | [ ] | [ ] |

Anti-Lock Make: ____________ Anti-Lock Model: ____________

Remarks ____________________________________

FIGURE 2 - VEHICLE DEFINITION (UNIT AND ARTICULATED HEAVY TRUCKS)
PART I: UNIT TRUCKS AND TRACTORS (CONTINUED)

**Tires and Wheels**

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| *Wheels* | | | | | |
| Make: | ____ | ____ | ____ | ____ | ____ |
| Spoke Style: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Disk Style: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Rim Size: | ____ | ____ | ____ | ____ | ____ |
| *Tires* | | | | | |
| Make: | ____ | ____ | ____ | ____ | ____ |
| Model: | ____ | ____ | ____ | ____ | ____ |
| Size and Load Range: | ____ | ____ | ____ | ____ | ____ |
| Tread Style: | ____ | ____ | ____ | ____ | ____ |
| Tread Condition | | | | | |
| New: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Half Worn: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Full Worn: | [ ] | [ ] | [ ] | [ ] | [ ] |
| Tread Depth, mm: | ____ | ____ | ____ | ____ | ____ |
| Pressure, kPa: | ____ | ____ | ____ | ____ | ____ |
| Taken: [ ] Hot or [ ] Cold | | | | | |

FIGURE 2 - VEHICLE DEFINITION (UNIT AND ARTICULATED HEAVY TRUCKS)
PART I: UNIT TRUCKS AND TRACTORS (CONTINUED)

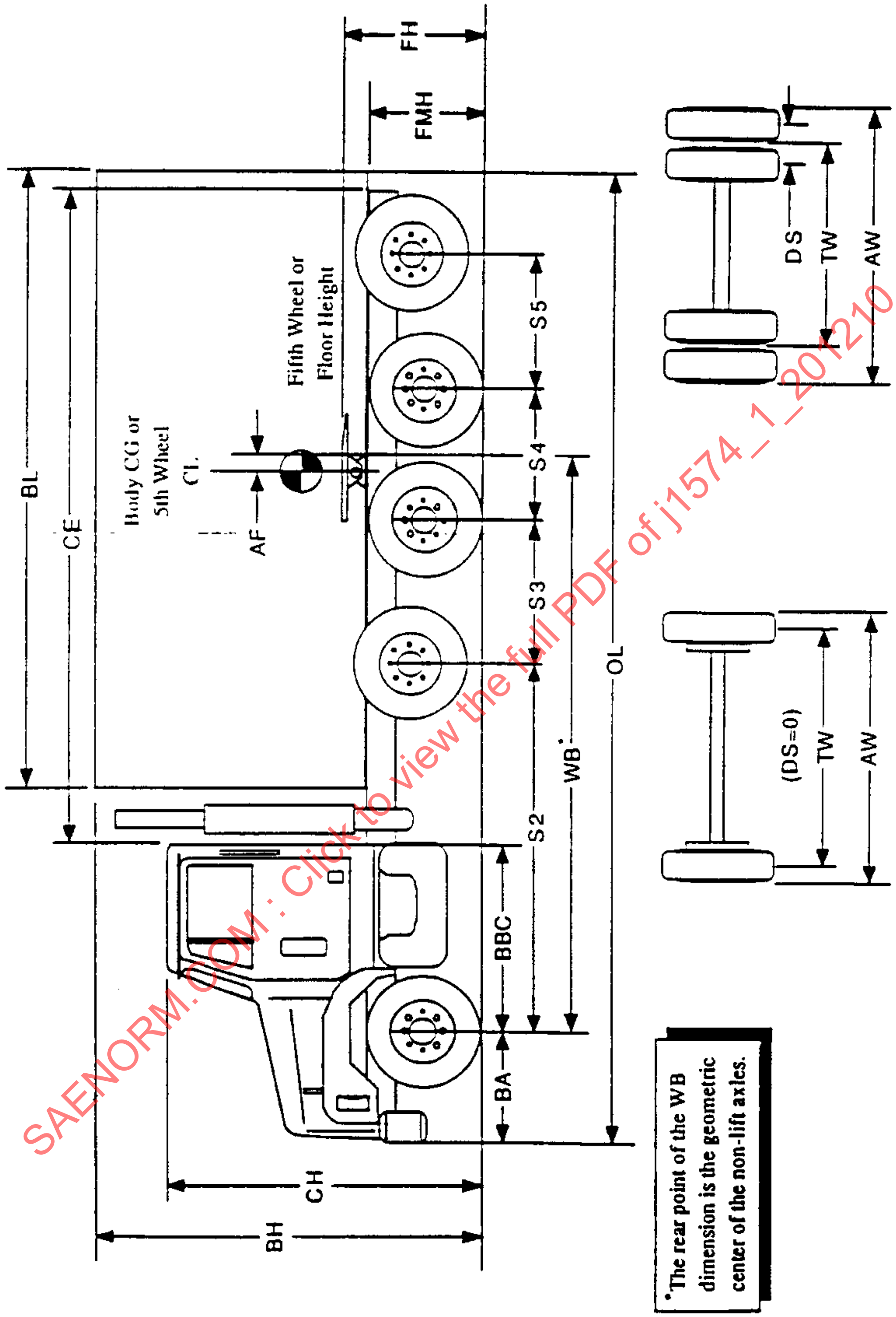




FIGURE 2A - DIMENSIONS FOR UNIT TRUCKS AND TRACTORS

**PART II: SEMITRAILERS**

**General**

| | | | |
|---|---|---|---|
| Year ____________ | Make ____________ | Model ____________ | Millage ____________ |
| VIN ____________ | Fleet No. __________ | GVWR ____________ | |
| Status: | [ ] Production | [ ] Pilot | [ ] Prototype |
| | [ ] Pre-prototype | [ ] Development | [ ] Pretest |
| | [ ] Component | [ ] Experimental | |
| Body Style: | [ ] Van | [ ] Liquid Tanker | [ ] Dry Bulk Tanker |
| | [ ] Flat Bed | [ ] Single Drop | [ ] Drop Center |
| Options: | [ ] Refrigeration | [ ] Other ____________ | |

*Loading* ____________________________________________

____________________________________________

*Major Dimensions*[1]

| | | | |
|---|---|---|---|
| BH _________ mm | BL _________ mm | BW _________ mm | FH _________ mm |
| KPS _________ mm | OH _________ mm | PH _________ mm | WB _________ mm |

**Mass**

*Tire Loads*

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Left Side: | _______ kg | _______ kg | _______ kg | _______ kg | _______ kg |
| Right Side: | _______ kg | _______ kg | _______ kg | _______ kg | _______ kg |

| Axle No. (from front): | 6 | 7 | 8 |
|---|---|---|---|
| Left Side: | _______ kg | _______ kg | _______ kg |
| Right Side: | _______ kg | _______ kg | _______ kg |

[1] Figure 3a identifies these and other dimensions.

FIGURE 3 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART II: SEMITRAILERS

**Axles**

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Spacing from kingpin or preceding axle (Sn)[1], mm: | | | | | | | | |
| Make: | | | | | | | | |
| Model: | | | | | | | | |
| Load rating, kg: | | | | | | | | |
| Axle width (AW)[1], mm: | | | | | | | | |
| Track width (TW)[1], mm: | | | | | | | | |
| Dual spacing (DS)[1], mm: | | | | | | | | |
| Self-Steering: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Lift: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |

[1] Figure 3a identifies these and other dimensions.

FIGURE 3 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART II: SEMITRAILERS (CONTINUED)

**Suspension No.** ______________________

Includes Axle(s) No(s): ____________________

Make: ____________ Model: ____________ Load Rating, kg: ____________________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ________________________________________________________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ________________________________________________________________

*Spring(s)*

Make ____________ Model ____________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves _______ Length, mm _______
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ________________________________________________________________

Remarks ________________________________________________________________

**Suspension No.** ___________________________

Includes Axle(s) No(s): ____________________

Make: ____________ Model: ____________ Load Rating: ______________________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ________________________________________________________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ________________________________________________________________

*Spring(s)*

Make ____________ Model ____________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves _______ Length, mm _______
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ________________________________________________________________

Remarks ________________________________________________________________

FIGURE 3 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART II: SEMITRAILERS (CONTINUED)

**Suspension No.** ______________________

Includes Axle(s) No(s): ______________________

Make: ____________ Model: ____________ Load Rating, kg: ______________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ______________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ______________________

*Spring(s)*

Make ____________ Model ____________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ________ Length, mm ________
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ______________________

Remarks ______________________

**Suspension No.** ______________________

Includes Axle(s) No(s): ______________________

Make: ____________ Model: ____________ Load Rating: ______________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ______________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ______________________

*Spring(s)*

Make ____________ Model ____________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ________ Length, mm ________
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ______________________

Remarks ______________________

FIGURE 3 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART II: SEMITRAILERS (CONTINUED)

**Brakes**

*Actuation*

[ ] Air
[ ] Hydraulic: [ ] Vacuum Asst. [ ] Hydraulic Power

*Wheel Brakes*

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Make: | ____ | ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| Disc: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Drum: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Drum or drum size: | ____ | ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| Wedge: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Wedge angle, degree: | ____ | ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| S-Cam: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Slack length, mm: | ____ | ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| Automatic slacks: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Air chamber type: | ____ | ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| Spring brake: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Anti-lock: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |

Anti-lock make: ____________ Anti-lock model: ____________

Remarks ______________________________________________

______________________________________________________

FIGURE 3 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART II: SEMITRAILERS (CONTINUED)

**Tires and Wheels**

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| *Wheels* | | | | | | | | |
| Make: | | | | | | | | |
| Spoke style: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Disk style: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Rim size: | | | | | | | | |
| *Tires* | | | | | | | | |
| Make: | | | | | | | | |
| Model: | | | | | | | | |
| Size and load range: | | | | | | | | |
| Tread style: | | | | | | | | |
| Tread condition | | | | | | | | |
| New: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Half worn: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Full worn: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Tread depth, mm: | | | | | | | | |
| Pressure, kPa: | | | | | | | | |
| Taken: [ ] Hot or [ ] Cold | | | | | | | | |

FIGURE 3 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART II: SEMITRAILERS (CONTINUED)

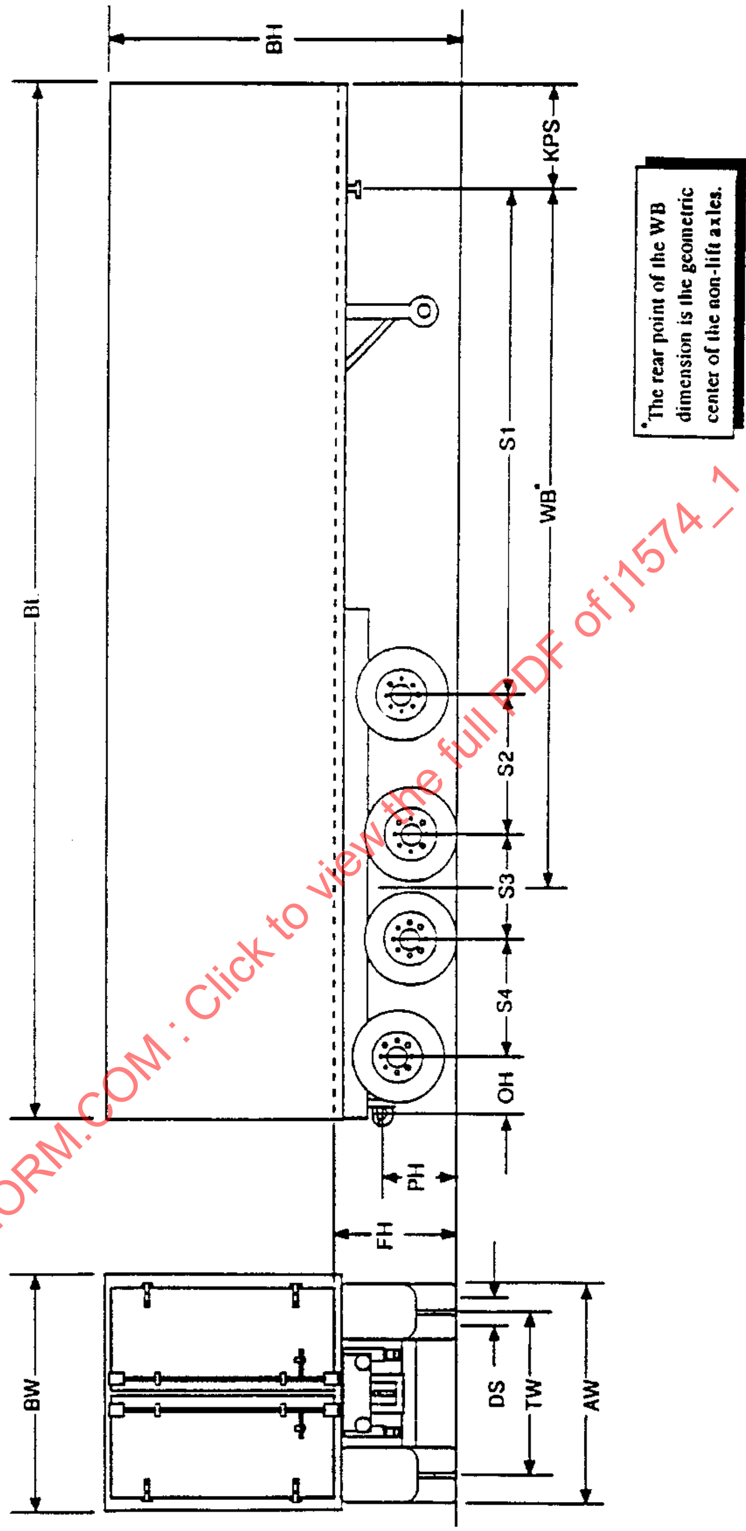




FIGURE 3A - DIMENSIONS FOR SEMITRAILERS

## PART III: CONVERTER DOLLIES

### General

Year ______________ Make ______________ Model ______________ Millage ______________
VIN ______________ Fleet No. ____________ GVWR ______________

Status: [ ] Production [ ] Pilot [ ] Prototype
[ ] Pre-prototype [ ] Development [ ] Pretest
[ ] Component [ ] Experimental

Style: [ ] A-Dolly [ ] B-Dolly
Other ______________________________________________

*Major Dimensions*

AF __________ mm OL __________ mm WB __________ mm FH __________ mm

### Mass

*Tire Loads*

| Axle No. (from front): | 1 | 2 | 3 |
|---|---|---|---|
| Left Side: | ________ kg | ________ kg | ________ kg |
| Right Side: | ________ kg | ________ kg | ________ kg |

### Axles

| Axle No. (from front): | 1 | 2 | 3 |
|---|---|---|---|
| Spacing from pintle hitch (S1)[1] or preceding axle (S2)[1], mm: | ________ | ________ | ________ |
| Make: | ________ | ________ | ________ |
| Model: | ________ | ________ | ________ |
| Load rating, kg: | ________ | ________ | ________ |
| Axle width (AW)[1], mm: | ________ | ________ | ________ |
| Track width (TW)[1], mm: | ________ | ________ | ________ |
| Dual spacing (DS)[1], mm: | ________ | ________ | ________ |
| Self-steering: | [ ] | [ ] | [ ] |

---

[1] Figure 4a identifies these and other dimensions.

FIGURE 4 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART III: CONVERTER DOLLIES

**Suspension**

Make: ______________ Model: ______________ Load Rating: ______________________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ______________________________________________________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ______________________________________________________________

*Spring(s)*

Make ______________ Model ______________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ________ Length, mm ________
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ______________________________________________________________

Remarks ______________________________________________________________

**Brakes**

*Actuation*

[ ] Air
[ ] Hydraulic [ ] Vacuum Asst. [ ] Hydraulic Power

*Wheel Brakes*

| Axle No. (from front): | 1 | 2 |
|---|---|---|
| Make: | ______ | ______ |
| Disc: | [ ] | [ ] |
| Drum: | [ ] | [ ] |
| Disc or drum size: | ______ | ______ |
| Wedge: | [ ] | [ ] |
| Wedge angle, degrees: | ______ | ______ |
| S-Cam: | [ ] | [ ] |
| Slack length, mm: | ______ | ______ |
| Automatic slacks: | [ ] | [ ] |
| Air chamber type: | ______ | ______ |
| Anti-lock: | [ ] | [ ] |

Anti-Lock Make: ______________________ Anti-Lock Model: ______________________

Remarks ______________________________________________________________
______________________________________________________________

FIGURE 4 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART III: CONVERTER DOLLIES (CONTINUED)

**Tires and Wheels**

| Axle No. (from front): | 1 | 2 | 3 |
|---|---|---|---|
| *Wheels* | | | |
| Make: | ______ | ______ | ______ |
| Spoke style: | [ ] | [ ] | [ ] |
| Disk style: | [ ] | [ ] | [ ] |
| Rim size: | ______ | ______ | ______ |
| *Tires* | | | |
| Make: | ______ | ______ | ______ |
| Model: | ______ | ______ | ______ |
| Size and load range: | ______ | ______ | ______ |
| Tread style: | ______ | ______ | ______ |
| Tread condition: | | | |
| New: | [ ] | [ ] | [ ] |
| Half worn: | [ ] | [ ] | [ ] |
| Full worn: | [ ] | [ ] | [ ] |
| Tread depth, mm: | ______ | ______ | ______ |
| Pressure, kPa: | ______ | ______ | ______ |

Taken: [ ] Hot or [ ] Cold

FIGURE 4 - VEHICLE DEFINITION (HEAVY TRUCKS - UNITS AND ARTICULATED)
PART III: CONVERTER DOLLIES (CONTINUED)

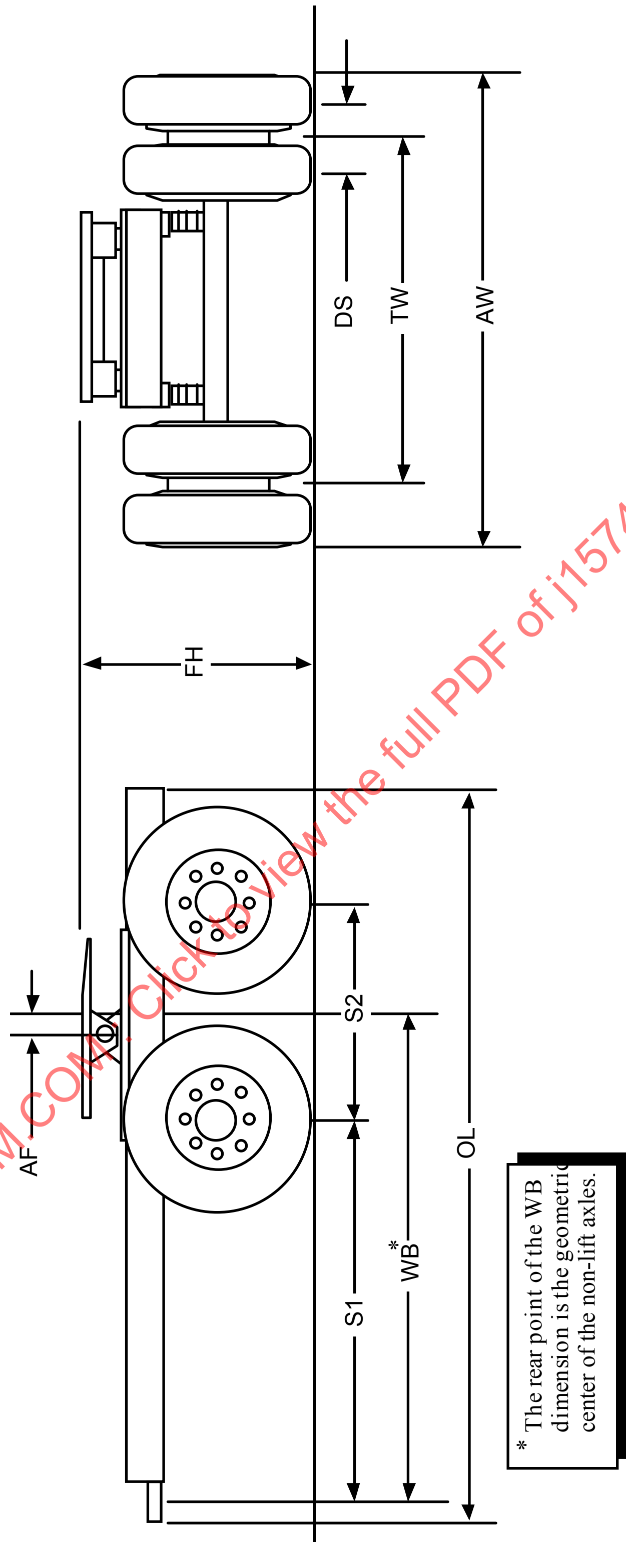


FIGURE 4A - DIMENSIONS FOR CONVERTER DOLLIES

**PART IV: FULL TRAILERS**

**General**

| | | | |
|---|---|---|---|
| Year ____________ | Make ____________ | Model ____________ | Millage ____________ |
| VIN ____________ | Fleet No. ____________ | GVWR ____________ | |
| Status: | [ ] Production | [ ] Pilot | [ ] Prototype |
| | [ ] Pre-prototype | [ ] Development | [ ] Pretest |
| | [ ] Component | [ ] Experimental | |
| Body Style: | [ ] Van | [ ] Liquid Tanker | [ ] Dry Bulk Tanker |
| | [ ] Flat Bed | [ ] Single Drop | [ ] Drop Center |
| Options: | [ ] Refrigeration | Other: ____________ | |

*Loading* ____________________________________________

____________________________________________

*Major Dimensions*[1]

| | | | |
|---|---|---|---|
| AF ________ mm | BH ________ mm | BL ________ mm | BW ________ mm |
| FH ________ mm | KPS ________ mm | OH ________ mm | PH ________ mm |
| WB ________ mm | WBD ________ mm | | |

**Mass**

*Tire Loads*

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Left Side: | ______ kg | ______ kg | ______ kg | ______ kg | ______ kg |
| Right Side: | ______ kg | ______ kg | ______ kg | ______ kg | ______ kg |

| Axle No. (from front): | 6 | 7 | 8 |
|---|---|---|---|
| Left Side: | ______ kg | ______ kg | ______ kg |
| Right Side: | ______ kg | ______ kg | ______ kg |

[1] Figure 5a identifies these and other dimensions.

FIGURE 5 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART IV: FULL TRAILERS

**Axles**

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Spacing from kingpin or preceding axle (Sn)[1], mm: | | | | | | | | |
| Make: | | | | | | | | |
| Model: | | | | | | | | |
| Load rating, kg: | | | | | | | | |
| Axle width (AW)[1], mm: | | | | | | | | |
| Track width (TW)[1], mm: | | | | | | | | |
| Dual spacing (DS)[1], mm: | | | | | | | | |
| Self-Steering: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Lift: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |

[1] Figure 5a identifies these and other dimensions.



FIGURE 5 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART IV: FULL TRAILERS (CONTINUED)

**Suspension No.** ____________________

Includes Axle(s) No(s): ____________________

Make: ____________ Model: ____________ Load Rating, kg: ____________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ____________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ____________________

*Spring(s)*

Make ____________ Model ____________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ________ Length, mm ________
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ____________________

Remarks ____________________

**Suspension No.** ____________________

Includes Axle(s) No(s): ____________________

Make: ____________ Model: ____________ Load Rating: ____________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ____________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ____________________

*Spring(s)*

Make ____________ Model ____________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ________ Length, mm ________
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ____________________

Remarks ____________________

FIGURE 5 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART IV: FULL TRAILERS (CONTINUED)

**Suspension No.** ____________________

Includes Axle(s) No(s): ____________________

Make: ____________ Model: ____________ Load Rating, kg: ____________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ____________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ____________________

*Spring(s)*

Make ____________ Model ____________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ________ Length, mm ________
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ____________________

Remarks ____________________



**Suspension No.** ____________________

Includes Axle(s) No(s): ____________________

Make: ____________ Model: ____________ Load Rating: ____________________

*Style—Single-Axle Suspensions*

[ ] Leaf Spring [ ] Air [ ] Lift
[ ] Other ____________________

*Style—Multi-Axle Suspensions*

[ ] Walking Beam [ ] Four Leaf [ ] Air [ ] Torsion Bar
[ ] Other ____________________

*Spring(s)*

Make ____________ Model ____________
[ ] Multi-Leaf [ ] Taper Leaf No. of Leaves ________ Length, mm ________
[ ] Air [ ] Torsion Bar [ ] Rubber Block
[ ] Other ____________________

Remarks ____________________

FIGURE 5 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART IV: FULL TRAILERS (CONTINUED)

**Brakes**

*Actuation*

[ ] Air
[ ] Hydraulic: [ ] Vacuum Asst. [ ] Hydraulic Power

*Wheel Brakes*

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Make: | ____ | ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| Disc: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Drum: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Drum or drum size: | ____ | ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| Wedge: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Wedge angle, degree: | ____ | ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| S-Cam: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Slack length, mm: | ____ | ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| Automatic slacks: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Air chamber type: | ____ | ____ | ____ | ____ | ____ | ____ | ____ | ____ |
| Spring brake: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Anti-lock: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |

Anti-lock make: ____________ Anti-lock model: ______________

Remarks ________________________________________________

________________________________________________________



FIGURE 5 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART IV: FULL TRAILERS (CONTINUED)

**Tires and Wheels**

| Axle No. (from front): | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| *Wheels* | | | | | | | | |
| Make: | | | | | | | | |
| Spoke style: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Disk style: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Rim size: | | | | | | | | |
| *Tires* | | | | | | | | |
| Make: | | | | | | | | |
| Model: | | | | | | | | |
| Size and load range: | | | | | | | | |
| Tread style: | | | | | | | | |
| Tread condition | | | | | | | | |
| New: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Half worn: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Full worn: | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] | [ ] |
| Tread depth, mm: | | | | | | | | |
| Pressure, kPa: | | | | | | | | |

Taken: [ ] Hot or [ ] Cold



FIGURE 5 - VEHICLE DEFINITION (HEAVY TRUCKS - UNIT AND ARTICULATED)
PART IV: FULL TRAILERS (CONTINUED)

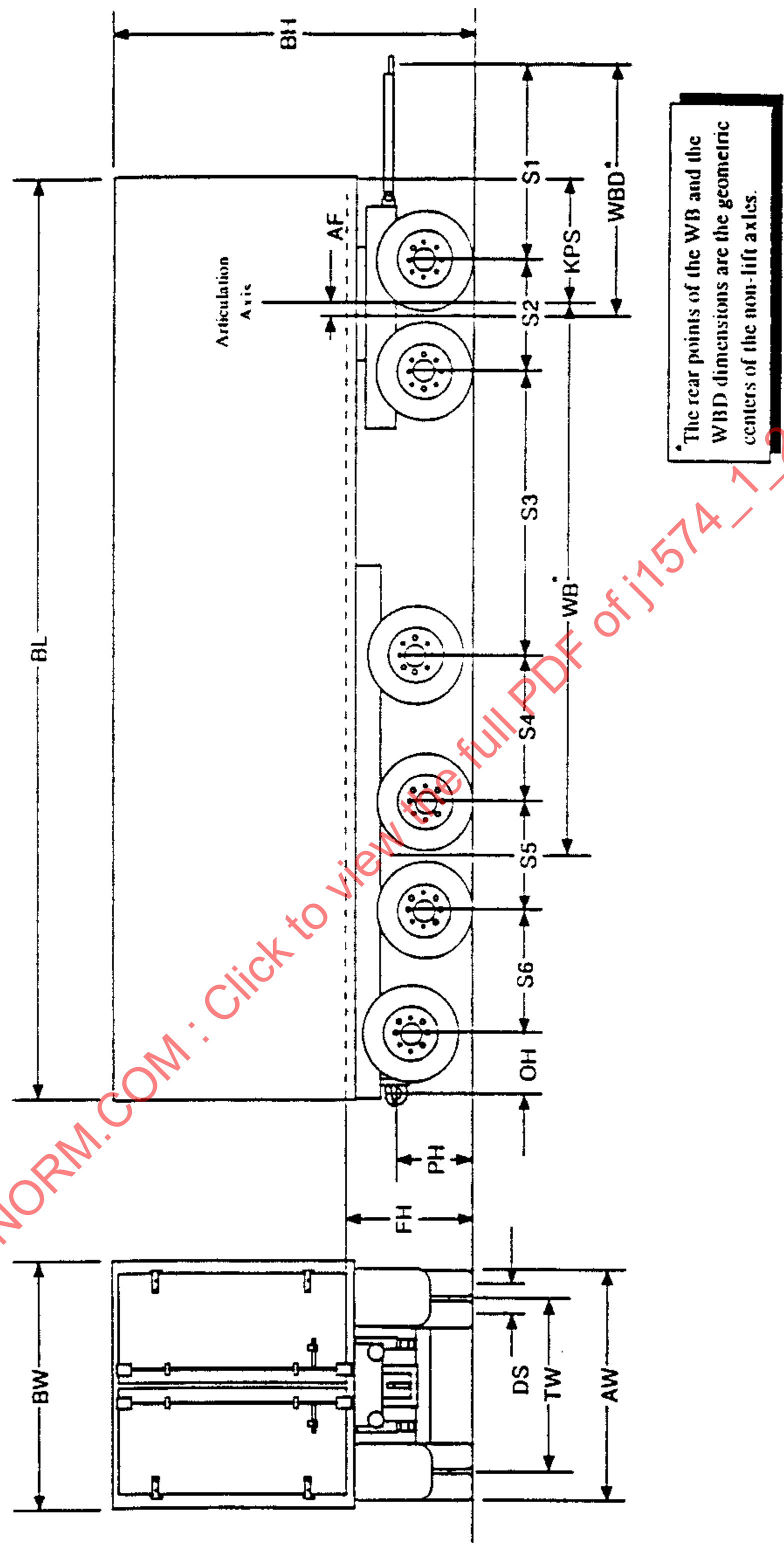




FIGURE 5A - DIMENSIONS FOR FULL TRAILERS

3.3 Vehicle Preparation

Preparation of the vehicle for most of the tests described in subsequent sections requires certain procedures. Those required for most tests are listed as follows. Others specifically required for a certain test will be discussed in the appropriate section.

a. Remove significant accumulations of dirt or mud. Clean parts requiring measurement or detailed identification.

b. Qualitatively determine that the vehicle represents design (e.g., OE) or a predetermined out-of-specification condition. This applies to option content, hardware configuration, and proper assembly of chassis parts.

c. Inspect all suspension and steering components for integrity and wear state. Measure state of wear which might affect vehicle performance or safety, as applicable. Replace as required.

d. Set tire pressures to manufacturer's recommended cold pressures (at 21 °C room temperature) plus 20 kPa, to reflect warm-up effects, or predetermined out-of-specification values.

e. Check all fluid levels (coolant, fuel, lubricants). Fill as required.

f. Set suspension alignment to manufacturer's recommended settings or predetermined out-of-specification settings.

g. Determine suspension trim heights at curb loading, if manufacturer's specifications for trim heights are available. In the measurements discussed in subsequent sections, it may be more appropriate to ballast the vehicle to proper tire normal forces or to proper suspension trim heights. This will be addressed in 3.1 (Vehicle Preparation) of each section.

4. MEASUREMENT OF DIMENSIONAL AND GEOMETRIC CHARACTERISTICS

4.1 Variables Measured

As discussed in Section 3, there are a number of vehicle characteristics which should be documented to fully define a test vehicle, either for future reference or for direct application to vehicle dynamics simulations. Many of these characteristics are qualitative, involving only notation of the size or configuration of certain components or the presence of certain options (power steering, automatic transmission). Others require measurement. They are shown in Table 2, with approximate ranges for each variable.

In the design of apparatus for measurements discussed in other sections of the document, the ranges of Table 2 should be used as the references for all size accommodation issues.

4.2 Apparatus

4.2.1 General Performance Requirements



Specific accuracy requirements for the measurement apparatus are discussed in 4.2.3 and Table 3. These comments are intended to outline the general performance requirements for these tools, focusing on those of a specialized nature.

Most of these measurements require only the determination of linear dimensions and do not require specialized test apparatus. General performance requirements for most of these measurement devices are simply encompassed in the measurement accuracy requirements of 4.2.3. But two specialized facilities are required for certain of the measurements. These are a precision surface plate and a wheel alignment facility, discussed as follows.

The precision surface plate, usually referred to as a “bed plate,” is required for measurements made in the vertical direction, specifically suspension or steering system coordinates or suspension trim heights. These measurements are sensitive to surface level and planarity. The measurements made in the horizontal direction are not particularly sensitive to surface level and planarity. For most production suspensions, the centers of tire contact move horizontally only a small fraction of any vertical movement, thereby making horizontal measurements involving the centers of tire contact relatively insensitive to the test surface. Specific requirements for level and planarity of surface plates are given in 4.2.3.

TABLE 2 - VARIABLES MEASURED

| Variable | Vehicle Type | Range |
|---|---|---|
| Linear Dimensions: | | |
| axle spread | 2,3 | 1200 to 1400 mm |
| dual spacing | 2,3 | 315 to 330 mm |
| fifth wheel height | 2 | 1000 to 1400 mm |
| fifth wheel to rear axle centerline (fifth wheel offset) | 2 | 0 to 650 mm |
| pintle height | 2,3 | 800 to 1100 mm |
| pintle overhang | 2,3 | 700 to 2700 mm |
| roadwheel diameter | 1 | 12.0 to 17.0 in |
| | 2,3 | 15.0 to 24.5 in |
| roadwheel offset | 1 | -150 to 150 mm |
| | 2,3 | -180 to 180 mm |
| roadwheel width | 1 | 4.0 to 11.0 in |
| | 2,3 | 6.0 to 14.0 in |
| stabilizer bar diameter | 1 | 0 to 40 mm |
| | 2 | 0 to 50 mm |
| | 3 | 0 to 50 mm |
| steering wheel diameter | 1 | 300 to 400 mm |
| | 2 | 500 to 600 mm |
| suspension or steering coordinates | 1 | 100 to 1000 mm |
| | 2,3 | 200 to 1000 mm |
| suspension trim heights | 1 | 0 to 500 mm |
| | 2,3 | 0 to 1000 mm |
| tire tread depth (new) | 1 | 5 to 10 mm |
| | 2,3 | 10 to 20 mm |
| wheelbase | 1 | 2100 to 3500 mm |
| | 2 | 3100 to 7000 mm |
| | 3 | 5600 to 12 500 mm |
| wheel track | 1 | 1100 to 1900 mm |
| | 2,3 | 1700 to 2200 mm |
| Suspension Alignment Values: | | |
| camber | 1 | -2.0 to 2.0 degrees |
| | 2,3 | -0.2 to 2.0 degrees |
| caster | 1 | 0.0 to 10.0 degrees |
| | 2 | 1.0 to 5.0 degrees |
| toe-in (per wheel) | 1,2,3 | 0.0 to 1.0 degrees |
| Other: | | |
| tire pressure (cold) | 1 | 140 to 725 kPa |
| | 2,3 | 300 to 950 kPa |

Vehicle Type: 1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers

TABLE 3 - TRANSDUCER REQUIREMENTS

| Variable | Type of Transducer | Typical Transducer | Veh. Type | Accuracy Percent[1] | Absolute |
|---|---|---|---|---|---|
| axle spread | linear disp. | steel tape | 2,3 | ±0.2 | |
| dual spacing | linear disp. | steel tape | 2,3 | ±0.2 | |
| fifth wheel to rear axle centerline | linear disp. | steel tape | 2 | ±0.2 | |
| pintle height | linear disp. | steel tape | 2,3 | ±0.2 | |
| pintle overhang | linear disp. | steel tape | 2,3 | ±0.2 | |
| roadwheel diameter | linear disp. | rim disk tape | 1,2,3 | ±0.5 | |
| roadwheel offset | linear disp. | steel scale | 1,2,3 | ±0.5 | ±0.2 mm |
| roadwheel width | linear disp. | steel scale, inside caliper | 1,2,3 | ±0.5 | |
| stabilizer bar dia. | linear disp. | vernier caliper, micrometer | 1,2,3 | ±0.2 | |
| steering wheel dia. | linear disp. | steel tape, steel scale | 1,2,3 | ±0.2 | |
| susp. or steering coordinates | linear disp. | vernier scale, CMM | 1,2,3 | ±0.2 | ±0.5 mm |
| suspension trim heights | linear disp. | steel tape, vernier scale, CMM | 1,2,3 | ±0.2 | ±0.5 mm |
| tire tread depth | linear disp. | tread depth gage | 1,2,3 | ±5.0 | ±0.2 mm |
| wheelbase | linear disp. | steel tape | 1,2,3 | ±0.2 | |
| wheel track | linear disp. | steel tape | 1,2,3 | ±0.2 | |
| camber | angular disp. | alignment facility | 1,2,3 | ±5.0 | ±0.05 degrees |
| caster | angular disp. | alignment facility | 1,2,3 | ±10.0 | ±0.50 degrees |
| toe-in (per wheel) | angular disp. | alignment facility | 1,2,3 | ±10.0 | ±0.02 degrees |
| tire pressure | pressure | pressure gage | 1,2,3 | ±0.5 | |

1. Measurement accuracy, as a percentage of actual reading, should be no worse than that listed. For those variables which may have values near zero, absolute measurement accuracy should be no worse than the absolute value shown.

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers



The need to measure suspension alignment values usually arises from the need to document the test vehicle or verify that it meets design intent. Camber can be measured with a precision inclinometer and a vertical reference. However, standard and more convenient practice for this and the measurement of caster and toe-in is the use of a commercial wheel alignment facility. This approach also allows the effects of wheel lateral runout to be conveniently removed. These measurements should be made to the level of accuracy stated in Table 3. (In some cases, specifically requested alignment accuracy may be more stringent than these.) Commercial wheel alignment equipment, properly maintained and calibrated, is usually sufficiently accurate for this purpose.

4.2.2 General Configurations

Transducers for the measurement of linear dimensions are those found in most industrial laboratories or shops. Most linear measurements discussed in this Section can be made with a flexible steel tape. In some cases, a plumb line or level may be helpful in obtaining the projection from a point in question. Dimensions of parts can be determined with either calipers and a precision scale or with a micrometer. Tire tread depth is most conveniently determined with a tread depth gage. This is a specialized internal depth gage proportioned and calibrated for this function.

The measurement of suspension or steering coordinates usually requires more specialized equipment. Traditional methods rely on the surface plate as a vertical position reference and a designated point on the vehicle, such as the front axle centerline, as the horizontal reference. Vertical measurements are made with adjustable pointers and vernier scales. An additional, small surface plate is helpful. Horizontal measurements are made with flexible steel tapes on the surface plate. The horizontal position of a component is established with a plumb line. In laboratories where such measurements are made frequently, the traditional methods are too time consuming. Computerized coordinate measurement machines (CMMs), or theodolites relying on computerized triangulation, are preferable tools in such cases.

Surface plates are commercially available and may be simple or complex in their design and installation. They are often made of steel and may have grooves designed for attaching other test apparatus. But, for this discussion, such details are not particularly significant and a surface plate will simply be defined as a flat, essentially undeformable surface meeting the requirements of 4.2.3. Wheel alignment facilities are also commercially available and vary widely in configuration. They provide for support of the vehicle on its tires on level, coplanar supports, which may be adjusted to accommodate different wheelbases and wheel tracks. Supports for the tires of an axle allow steer and track change with minimal friction. Various methods for transducing steer and camber, often optical, are used by different manufacturers.

Tire pressure is determined with a tire pressure gage, with a range appropriate for the pressures in question.

### 4.2.3 Performance Requirements

Since most of the tools required for these measurements are transducers, the performance requirements for each can be summarized by the expected magnitude of the variable to be measured and the required accuracy to which it must be measured. The expected magnitudes are shown in Table 2. (Experience at a given laboratory may indicate ranges of variables smaller than those of Table 2.) The required accuracy for each variable is shown in Table 3.

Performance requirements for the bed plate are encompassed by specifications for level and planarity, assuming that the plate is essentially rigid and large enough for the vehicles in question. The plate should be level within ±0.05 degree and should be planar within ±0.5 mm over its area.

## 4.3 Test Procedures

### 4.3.1 Vehicle Preparation

Prepare the vehicle in accordance with the guidelines of Section 3 (see 3.3). (Determination of wheel alignment and tire pressure are covered as follows.) For the measurements of this section, it should be set to curb suspension trim heights. Curb trim heights should be obtained from the vehicle manufacturer's literature (owner's manual or shop manual). They most uniquely define suspension trim heights if expressed as a dimension between a point on the suspension and another point on the sprung mass near the suspension. However, they may also be expressed as a dimension between a point on the sprung mass and the ground plane. The former should be used when possible. In certain cases (e.g., special request), it may be necessary to ballast or remove parts from the vehicle to achieve different, predefined, trim heights.

### 4.3.2 Test Procedures

#### 4.3.2.1 Measurement of Linear Dimensions

For the purposes of this discussion, measurement of the linear dimensions listed in Table 2 or 3 can be divided into those which require that the vehicle be on a surface plate and those which do not. In the latter category are: roadwheel dimensions, stabilizer bar diameter, steering wheel diameter, and tire tread depth. The remainder, and majority, do require a surface plate and will be addressed first. Order of measurement is not important so the procedures as follows will address measurements in the order of Tables 2 and 3.

To determine these dimensions:

a. Drive or roll the vehicle onto the bed plate. Return the steering to the straight ahead position and roll the vehicle forward and backward at least one tire circumference each way to remove any effects of turning or handling on wheel tracks and suspension trim heights.

b. Ballast and/or remove mass from vehicle to obtain desired curb suspension trim heights.

c. Repeat rolling process again and recheck trim heights. Repeat until desired trim heights are obtained, within manufacturer's tolerances.

d. Measure axle spread horizontally between the wheel centers of all tandem axle suspensions. Average values on opposite sides of a suspension.

e. Measure dual spacing horizontally between the centers of tire contact of all dual axles. Average values on opposite sides of an axle.

f. Measure the horizontal distance between the tractor fifth-wheel pivot and the center of the rear axle (at the center of the axle spread).

g. Measure the (three) coordinates of any steering or suspension points desired. Measure consistently with an established coordinate system and record the origin and axes of this system. Average values on opposite sides of the vehicle.

h. Measure the suspension trim heights established in 4.3.2.1c, above, to the accuracy requirements of Table 3. Average values on opposite sides of the vehicle.

i. Measure the wheelbase horizontally between wheel centers (or to the center of the axle spread). Average values on opposite sides of the vehicle.

j. Measure wheel tracks horizontally between centers of tire contact on each axle.

The measurement of the remaining linear dimensions does not require that the vehicle be on a surface plate. However, it may be convenient to leave it there if this has been done. To determine these dimensions:

a. Common practice is to not measure roadwheel diameter, but rather to use the nominal value from the tire size. If there are reasons to actually make this measurement, the wheel should be removed from the vehicle and the tire from the wheel for the measurement. The measurement should be made in accordance with the guidelines of the Tire and Rim Association Yearbook.

b. Measure roadwheel offset with the tire removed. It should be measured parallel to the spin axis between the wheel and mounting planes. Record the direction of the offset (wheel plane inside or outside of mounting plane) as well. A true reference surface, usually a steel plate, allows direct measurement of offset with scales or calipers. Half of the external wheel width, compared to the height of the mounting surface above the reference plate, gives the offset.

c. Measure roadwheel width with the tire removed. It should be measured between the bead seats, parallel to the spin axis, in accordance with the guidelines of the Tire and Rim Association Yearbook.

d. Measure stabilizer bar diameter at least three locations along the center, torsional, section, and average the readings.

e. Measure steering wheel diameter (to the outside of the rim) horizontally and vertically and average the values.

f. Measure tire tread depth at crown and shoulders of tire at two circumferential locations which are 180 degrees apart. Measure to the groove bottoms, avoiding the treadwear indicator bars. Average the six readings.

#### 4.3.2.2 Measurement of Wheel Alignment

Mount the test vehicle on the alignment facility according to the manufacturer's recommendations. Check the suspension trim heights again and ballast as required. Lock the steering wheel in the straight ahead position and measure camber, caster (if applicable), and toe-in values. If required, adjust to manufacturer's recommended values.

#### 4.3.2.3 Measurement of Tire Pressure

Measure tire pressure under “cold” conditions, which means at normal room temperature (21 °C). Prior to measurement, vehicle (and tires) should be allowed to fully equilibrate to this temperature. This is most conveniently accomplished by measuring pressure after measuring the linear dimensions discussed previously. If required, pressures should be adjusted to manufacturer's recommended values.

### 4.4 Calibration Procedures

Measurement devices discussed in the last section should be purchased, maintained, and calibrated to provide the accuracy outlined in 4.2. Generally, any laboratory quality steel tapes, scales, or micrometers will have sufficient inherent accuracy without periodic calibration. However, they may be compared to a higher standard if such questions arise. Suspension alignment equipment should be installed and calibrated according to the manufacturer. Camber and toe-in may be calibrated with a precision inclinometer or protractor. Tire pressure gages are available in a wide range of accuracy. All should be either calibrated with a dead weight laboratory gage calibration device or compared periodically to a properly calibrated reference gage.

## 5. MEASUREMENT OF VEHICLE AND COMPONENT WEIGHTS

### 5.1 Variables Measured

Certain vehicle and component weights should be measured to document the test vehicle and to provide information for simulation or comparison. In addition, the determination of the horizontal position of the vehicle's center of gravity, discussed in the next section of this document, generally requires knowledge of the vertical ground reaction force at each center of tire contact. (This will be referred to as “normal force” and generally treated as a scalar quantity, assumed positive.) Measurement of these individual loads will be addressed here, to avoid redundancy. The requirement to measure each of these loads is discussed further in 5.1 of SAE J1574-2.

The variables to be measured fall into the broad categories of total vehicle weight (sum of tire normal forces), unsprung weight (of each suspension), and sprung weight (total minus total of unsprung weights). Table 4 shows approximate expected ranges for these weights, at curb loading condition. In addition, expected ranges for individual tire normal forces are shown as an aid in scale selection. (For tandem axles, the term “tire normal force” will be assumed to represent the sum of tire normal forces at the end of an axle.) If measurements are to be made at higher loading conditions, the total and sprung weights should be increased by the expected vehicle payload.

In the design of apparatus for measurements discussed in other sections of this document, the ranges of Table 4 should be used as the references for all load accommodation issues.

TABLE 4 - VARIABLES MEASURED

| Variable | Vehicle Type | Range |
|---|---|---|
| Primary: | | |
| front tire normal force[(1)] | 1 | 1400 to 6500 N |
| | 2 | 10 000 to 25 000 N |
| | 3 | 5700 to 15 000 N |
| rear tire normal force[(1)] | 1 | 1400 to 6500 N |
| | 2 | 10 000 to 25 000 N |
| | 3 | 5700 to 15 000 N |
| front unsprung weight | 1 | 400 to 1800 N |
| | 2 | 4300 to 6400 N |
| rear unsprung weight | 1 | 400 to 1800 N |
| | 2,3 | 7800 to 13 000 N |
| Derived: | | |
| sprung weight | 1 | 7200 to 17 000 N |
| | 2 | 38 000 to 62 000 N |
| | 3 | 13 000 to 42 000 N |
| total vehicle weight | 1 | 8000 to 20 000 N |
| | 2 | 50 000 to 80 000 N |
| | 3 | 25 000 to 60 000 N |

1. For tandem axle suspensions, properties are defined for each side of the entire suspension. For dual tire axles, properties are similarly defined for each side of the suspension and therefore for each pair of tires.

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers

## 5.2 Apparatus

### 5.2.1 General Performance Requirements

Determination of horizontal center of gravity position generally requires the measurement of individual tire normal forces. Assuming this is done, scales must be capable of measuring the tire normal forces shown in Table 4 and accommodating suspensions or suspension parts having the weights shown in Table 4. These measurements must meet the accuracy requirements of Tables 5A and 5B, as well. Generally, these accuracy requirements require at least a second set of scales to measure unsprung weights. (Experience at a given laboratory may indicate ranges of variables smaller than those of Table 4.)

### 5.2.2 General Configurations

Scale configuration is minimally defined by the tire normal force and component weight ranges of Table 4 and the size requirements of Table 2. However, practical considerations of ease of use and cost significantly influence scale configuration. Ramps are sometimes used for driving the vehicle onto the scale(s), but laboratories which must measure the weights (tire normal forces) of many vehicles generally use scales which are flush with the floor or approach roadway, allowing the vehicle to be easily driven on and off the scale.

In measuring tire normal forces, if a single, small scale is used, either the scale or vehicle must be moved so that the normal force of each tire or tandem pair can be measured successively. If multiple scales are used, readings can be taken simultaneously. In either case, the tire support surfaces must be coplanar and level. These requirements are given in 5.2.3 and discussed in 5.2.3 of SAE J1574-2 for this section. Such scale(s) must provide for proper positioning of the vehicle's tire(s) on the scales such that scale accuracy is not impaired. Scale readout mechanisms are generally determined by convenience and cost considerations. Common approaches are large, analog gages or digital meters, often with automatic printouts of individual tire normal forces.

Scales for suspensions and suspension parts should be chosen according to the size of the parts, the load ranges of Table 4, and the accuracy requirements of Tables 5A and 5B.

Many types of scales exist for measuring static weight. They will not be discussed in any detail in this document. Basic types utilize mechanical, hydraulic, or pneumatic balance, or elastic transducers.

### 5.2.3 Performance Requirements

Overall measurement accuracy requirements for the variables of Table 4, with the addition of longitudinal and lateral weight distribution, are shown in Table 5A. Scale (the only transducer) accuracy requirements are shown in Table 5B. In addition, requirements for level and planarity are also shown. Lack of level and planarity can affect apparent total weight, individual tire normal forces, and horizontal position of the vehicle center of gravity. As a result, overall measurement accuracy will be worse than the scale accuracy. Overall accuracy requirements and the effects of scale error, level, and planarity on overall measurement accuracy are discussed in 5.2.3 of SAE J1574-2.

## 5.3 Test Procedures

### 5.3.1 Vehicle Preparation

Refer to 3.3 for general vehicle preparation. The vehicle should be ballasted to appropriate axle loads, if necessary. These may be the manufacturer's curb axle loads or other predetermined axle loads. Ballast should be centered laterally, unless a specific loading condition is being simulated. The resultant changes in suspension trim height, if small, will not affect the horizontal position of the vehicle's center of gravity.

TABLE 5A - MEASUREMENT ACCURACY REQUIREMENTS

| Variable | Vehicle Type | Accuracy Percent[1] | Absolute |
|---|---|---|---|
| Primary: | | | |
| front tire normal force | 1,2,3 | ±1.0 | |
| rear tire normal force | 1,2,3 | ±1.0 | |
| front unsprung weight | 1,2,3 | ±0.2 | |
| rear unsprung weight | 1,2,3 | ±0.2 | |
| Derived: | | | |
| sprung weight | 1,2,3 | ±0.2 | |
| total vehicle weight | 1,2,3 | ±0.2 | |
| longitudinal weight distribution | 1,2,3 | ±0.2 | |
| lateral weight distribution | 1,2,3 | ±0.2 | |

1. Measurement accuracy, as a percentage of actual reading, should be no worse than that listed. For those variables which may have values near zero, absolute measurement accuracy should be no worse than the absolute value shown.

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers

TABLE 5B - TRANSDUCER ACCURACY REQUIREMENTS

| Variable | Type of Transducer | Typical Transducer | Veh. Type | Accuracy Percent[1] | Absolute |
|---|---|---|---|---|---|
| front tire normal force | force | scale | 1,2,3 | ±0.2 | |
| rear tire normal force | force | scale | 1,2,3 | ±0.2 | |
| front unsprung weight | force | scale | 1,2,3 | ±0.2 | |
| rear unsprung weight | force | scale | 1,2,3 | ±0.2 | |
| scale level, side view | | | 1,2,3 | | ±0.2 degree |
| scale level, front view | | | 1,2,3 | | ±0.2 degree |
| scale planarity | | | 1 | | ±2.0 mm |
| | | | 2,3 | | ±5.0 mm |

1. Measurement accuracy, as a percentage of actual reading, should be no worse than that listed. For those variables which may have values near zero, absolute measurement accuracy should be no worse than the absolute value shown.

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers



### 5.3.2 Test Procedures

#### 5.3.2.1 Measurement of Total Vehicle Weight

The following steps should be followed in measuring the total vehicle weight:

a. Check functioning of the scales, and set or record zero as required.

b. Position vehicle on the scale(s), and record scale reactions.

c. Determine tire or axle loads, or total vehicle weight, as appropriate, by correcting scale reactions with the scale zeros.

#### 5.3.2.2 Measurement of Vehicle Component Weights

To measure the vehicle unsprung weights, each must be removed from the vehicle and weighed separately. This involves the following steps:

a. Remove suspension components to be measured from the vehicle. Fasteners and bushings attaching parts to the sprung mass should be set aside and all others loosely mounted on the appropriate components.

b. Clean components and remove extraneous material.

c. Check functioning of the scale, and set or record zero as required.

d. Place each component on the scale and record scale reaction.

e. Correct scale reaction with the scale zero.

f. Repeat steps a through e for other vehicle components of interest.

5.4 Data Processing and Presentation

5.4.1 Determination of Total Vehicle Weight

Determine the total vehicle weight by adding tire or axle loads as required.

5.4.2 Determination of Unsprung Weights

Determine each suspension's unsprung weight by adding the weight of all unsprung parts of that suspension. Use all or half of the weight of each component, in accordance with the discussion of 5.3.2.2 of SAE J1574-2.

5.4.3 Determination of Vehicle Sprung Weight

Determine the sprung weight by subtracting the sum of unsprung weights from the total vehicle weight.

5.5 Calibration Procedures

5.5.1 Calibration of Weight Scales

Calibrate the scales with dead weights which are sufficiently close to reference standards in accuracy to ensure test accuracy consistent with that of Table 5. The weights should include the range of values of the components to be measured.

6. MEASUREMENT OF CENTER OF GRAVITY POSITIONS

6.1 Variables Measured

Variables measured are total vehicle and unsprung mass center of gravity (cg) positions. From these, the sprung mass cg position can be calculated. Total vehicle cg horizontal position is determined from individual tire normal forces, whose measurement is discussed in Section 5.

The vehicle total center of gravity location is referenced to the following mutually perpendicular reference planes:

a. XY Plane - The horizontal plane on which the vehicle rests without penetration (the road plane)

b. XZ Plane - The vehicle longitudinal plane of symmetry

c. YZ Plane - A transverse vertical plane through the front axle centerline (fifth wheel mount center for commercial trailers)

The following positive coordinates will be recognized:

a. X—Longitudinal distance behind the YZ plane (Note that this is inconsistent with SAE and ISO sign conventions but is expedient, along with the definition of the YZ plane, above.)

b. Y—Lateral distance to the right of the XZ plane

c. Z—Height above the XY plane

The unsprung mass component parts cg locations are reported as described previously or by optional use of a local coordinate system with X coordinate referenced to the axle centerline and Y and Z coordinates as defined previously. Table 6 gives typical values for the variables measured, at curb loading condition.

TABLE 6 - VARIABLES MEASURED

| Variables | Vehicle Type | Range |
|---|---|---|
| Primary: | | |
| table angle | 1 | 0 to 25 degrees |
| | 2,3 | 0 to 15 degrees |
| table restoring moment | 1 | 0 to 6000 N·m |
| | 2,3 | 0 to 30 000 N·m |
| unsprung mass cg x position | 1 | –100 to 100 mm |
| (local coordinates) | 2,3 | –200 to 200 mm |
| unsprung mass cg y position | 1 | –5 to 5 mm |
| | 2 | –20 to 20 mm |
| | 3 | –10 to 10 mm |
| unsprung mass cg z position | 1 | 250 to 450 mm |
| | 2,3 | 375 to 575 mm |
| vehicle lateral displacement (tilted) | 1 | 0 to 10 mm |
| | 2,3 | 0 to 30 mm |
| Derived: | | |
| total vehicle cg x position | 1 | 850 to 1600 mm |
| | 2 | 1400 to 3400 mm |
| | 3 | 3200 to 7500 mm |
| total vehicle cg y position | 1 | –25 to 25 mm |
| | 2 | –100 to 100 mm |
| | 3 | –50 to 50 mm |
| total vehicle cg z position | 1 | 450 to 700 mm |
| | 2 | 750 to 1400 mm |
| | 3 | 700 to 1500 mm |
| sprung mass cg x position | 1 | 800 to 1680 mm |
| | 2 | 1250 to 3400 mm |
| | 3 | 2500 to 7500 mm |
| sprung mass cg y position | 1 | –30 to 30 mm |
| | 2 | –125 to 125 mm |
| | 3 | –65 to 65 mm |
| sprung mass cg z position | 1 | 475 to 775 mm |
| | 2 | 825 to 1675 mm |
| | 3 | 775 to 1800 mm |

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers

## 6.2 Apparatus

### 6.2.1 General Performance Requirements

Since the measurement of individual tire normal forces, which allows determination of the vehicle's horizontal cg position, was discussed in Section 5, only the measurement of the vehicle's vertical cg position will be addressed in this section. The apparatus for this determination must be able to accommodate the vehicle dimensions of Table 2 and the vehicle weights of Table 4, as modified for the vehicle types measured at a given laboratory. It must also allow measurements to the accuracy requirements of Table 7.

### 6.2.2 General Configurations

Vehicle center of gravity can be measured in a number of different ways. Five methods are described in detail in the Center of Gravity Test Code - SAE J874, with apparatus configurations for each. They are:

a. Suspension Method

—vehicle suspended by cable and slings

—cg hung beneath successive suspension points

—cg x, y, and z coordinates measured

b. Null Point Method

—vehicle on platform supported by two knife edges

—cg balanced successively above each knife edge

—cg x, y, and z coordinates measured

c. Platform Support Reaction Method

—vehicle on platform supported by three or four load cells

—ramp on platform required to determine cg z coordinate

—cg x, y, and z coordinates measured

d. Weight Reaction Method

—vehicle supported by a scale under each wheel, as discussed in Section 5, of this document

—cg x and y coordinates measured

e. Balance Method

—vehicle on platform supported by one knife edge

—cg x and y coordinates measured

The methods are described as pertaining to construction and industrial vehicles or machinery, but the apparatus may be sized to apply to passenger cars, light trucks, or suspension components as well. The suspension method is also a simple approach for determination of suspension component part cg location due to the relative ease of scaling equipment to the size of the part.

The last two methods do not provide for cg height determination but can be used in concert, with expansion of the latter, to determine all three cg coordinates. This approach is the basis of this document, with the weight reaction method having been discussed in the last section. The last method is expanded with the vehicle on a platform (table), supported at several tilt angles by a pivot or knife edge and a moment reaction and measurement scheme. The moment reaction and measurement is usually provided by a single scale or load cell. This allows determination of cg height, as discussed as follows. It is assumed that such a tilt table has been designed and balanced so that its simulated road plane and center of gravity lie on its pivot axis.

The tilt-table configuration should be such as to rigidly support the test vehicle with the suspension in the proper vertical position for the vehicle load condition of interest. Provision should be made for at least four adjustable jack stands or height blocks which are to be placed between the chassis and the table. Additional provision should be made for tie-down rods, cables or clamps to hold the chassis in firm contact with the stands. The table should have a horizontal pivot axis, oriented longitudinally or laterally for roll or pitch displacement. A range of 15 to 25 degrees tilt table rotation (Table 6) should be provided, in six to eight incremented steps. The tilt table pivot should be a knife edge or a shaft supported in low-friction bearings with all drag, including seal drag, reduced to allow restoring moment determination to the accuracy requirement of Table 7.

The table pivot axis could be oriented along any axis in a horizontal plane, with any orientation theoretically capable of allowing accurate measurement of center of gravity height. A longitudinal or lateral orientation is presumed in this discussion due to the added convenience provided for locating the vehicle and measuring its lateral displacement. The longitudinal orientation provides the minimum edge of table displacement for a given angular displacement and may thus be a more convenient orientation within a given laboratory space. Otherwise, there is no advantage of one orientation over the other.

The tilt-table protractor can be a purchased or a fabricated device; however, a precision spirit level protractor is recommended. Vehicle mass shift relative to the table pivot axis is measured by a small displacement transducer. A dial-type displacement indicator is a readily available device with the required accuracy. Other required machinist's scales, height probes, etc., are also generally available standard devices.

The scale for lightweight components may also serve in measurement of the tilt table restoring moment with the proper length moment arm, variable height support structure, and isolation from off-axis inputs. A suitable force transducer may also be used in measurement of restoring moment, in place of the scale.

6.2.3 Performance Requirements

Accurate measurement of several variables is required. Measurement of wheelbase, wheel tracks and trim heights is covered in Section 4 of this document, and separate measurement of individual tire normal forces, total vehicle weight, and unsprung masses is covered in Section 5. This discussion assumes these variables to have been measured to the accuracy requirements of Tables 3 and 5A and 5B, as applicable. The overall measurement accuracy requirements are shown in Table 7A. These requirements are discussed further in 6.2.3 of Section 6 of SAE J1574-2.

For simplicity, an accuracy requirement for table restoring moment is given, even though this is not usually measured directly. If the restoring moment is determined by measuring a restoring force acting through moment arm(s), all of these measurements in aggregate should allow the determination of restoring moment to 0.2%. This is also discussed further in SAE J1574-2.

The accuracy requirements shown in Table 7A for cg x and y positions stem from the weight distribution requirements of Table 5A. The accuracy requirement for the measurement of longitudinal weight distribution, in Table 5A, is 0.2%. As a result, the total vehicle cg x position can only be determined to about 0.5%. (This is because the cg x position is known to 0.2% of the wheelbase and to 0.4% of a half wheelbase, roughly its own value, using the axis system of 6.1. As a result, 0.5% is used in Table 7A.) Therefore, the accuracy requirement of sprung mass cg x position is also stated to the same 0.5% value. Since the unsprung mass cg x position, in local coordinates, can be zero, its accuracy requirement is stated in the absolute sense, as 0.2% of the wheelbase, again referencing Table 5A. Since all cg y positions can be zero, in either axis system, all related accuracy requirements are stated in the absolute sense, as 0.2% of the average wheel track.

The method used for determining center of gravity height, discussed in SAE J1574-2, eliminates the need to know the lateral position of the cg of the vehicle and table. As a result, these are not included in Table 7A. It is assumed that these centers of gravity will be placed (laterally) near the table pivot, to avoid a large restoring moment offset. Even though the static cg lateral position is not required, the lateral movement of the vehicle's cg as a function of table angle is required and is included in Table 7A.

Table 7B shows the same accuracy requirements as above, with the addition of types of typical transducers. Again, restoring moment is shown as the variable transduced for simplicity. Restoring force can be measured with a load cell or static load scale.

TABLE 7A - MEASUREMENT ACCURACY REQUIREMENTS

| Variable | Vehicle Type | Accuracy Percent(1) | Absolute |
|---|---|---|---|
| Primary: | | | |
| table angle | 1,2,3 | ±0.1 | |
| table restoring moment | 1,2,3 | ±0.2 | |
| unsprung mass cg x position (local coordinates) | 1,2,3 | | Note 1 |
| unsprung mass cg y position | 1,2,3 | | Note 2 |
| unsprung mass cg z position | 1,2,3 | ±0.5 | |
| vehicle lateral displacement (tilted) | 1,2,3 | ±10.0 | |
| Derived: | | | |
| total vehicle cg x position | 1,2,3 | ±0.5 | |
| total vehicle cg y position | 1,2,3 | | Note 2 |
| total vehicle cg z position | 1,2,3 | ±0.5 | |
| sprung mass cg x position | 1,2,3 | ±0.5 | |
| sprung mass cg y position | 1,2,3 | | Note 2 |
| sprung mass cg z position | 1,2,3 | ±0.5 | |

1. Measurement accuracy, as a percentage of actual reading, should be no worse than that listed. For those variables which may have values near zero, absolute measurement accuracy should be no worse than the absolute value shown.

Notes:
1. 0.2% of wheelbase.
2. 0.2% of average wheel track.

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers

TABLE 7B - TRANSDUCER ACCURACY REQUIREMENTS

| Variable | Type of Transducer | Typical Transducer | Veh. Type | Accuracy Percent[1] | Absolute |
|---|---|---|---|---|---|
| table angle | angular disp. | protractor, inclinometer | 1,2,3 | ±0.1 | |
| table restoring moment | moment | load cell | 1,2,3 | ±0.2 | |
| vehicle lateral disp. (tilted) | linear disp. | dial indicator | 1,2,3 | ±10.0 | |

1. Measurement accuracy, as a percentage of actual reading, should be no worse than that listed. For those variables which may have values near zero, absolute measurement accuracy should be no worse than the absolute value shown.

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers



## 6.3 Test Procedures

The following procedures pertain in general to all methods, vehicle sizes and components. Reference is specifically made to the tilt table method, however.

### 6.3.1 Vehicle Preparation

Refer to 3.3 for general vehicle preparation. The vehicle should not be ballasted but should be prepared to curb load. If the gas tank cannot be completely filled, the vehicle should be tested with the tank completely drained. Seats should be adjusted to the centers of travel, both horizontally and vertically and windows should be closed. Noncurb loading conditions are not recommended and are not covered in this document but are discussed further in SAE J1574-2.

### 6.3.2 Test Procedures

#### 6.3.2.1 Measurement of Total Vehicle Center of Gravity Position

The following steps should be followed in measuring the total vehicle center of gravity position:

a. Determine that all measuring devices have been properly calibrated, that any weight scales are reading zero in the unloaded condition and that external influences, such as wind blowing through open doors, are eliminated.

b. Place the vehicle on the locked (at zero angle) tilt table or platform with the tilt pivot axis approximately in the vehicle longitudinal plane of symmetry.

c. Check tire pressures and adjust the vehicle trim heights.

d. Secure the vehicle chassis to the table or platform in a rigid and safe manner, at the design trim heights, so as to permit tilt angles of up to 25 degrees (15 degrees for commercial vehicles). Record trim heights at body, frame, or suspension locations, both front and rear.

e. Make all reference measurements at zero tilt angle.

f. Any extra jacks, blocks, or beams required for vehicle support that are not included in the table set-up balance operation (see 6.4.3) must be weighed and their cg height(s) above the table pivot must be measured.

g. Set up a displacement indicator to measure lateral displacement of the side of the vehicle (relative to the table) at the approximate longitudinal and vertical cg location.

h. Starting at the maximum angle, increment tilt angles to zero using only the restoring moment from the measuring transducer or scale and moment arm system to hold the table in the tilted position. Return table to approximate starting angle by incrementing tilt angles upward. (Cycling the table through its extreme positions prior to taking moment, angle and deflection measurements may be required to “set” the system for repeatable results.)

i. Read and record overturning moment, tilt angles, and vehicle lateral displacement for each tilt angle.

6.3.2.2 Measurement of Unsprung Center of Gravity Positions

It is assumed that all unsprung parts of a suspension have been weighed in accordance with the recommendations of Section 5. Further, it is assumed that the center of gravity of each part or subassembly can be determined using either the suspension or null point method. The following steps should be followed in measuring each suspension's unsprung center of gravity position:

a. Remove all unsprung parts from the vehicle. (See discussion in 5.3.2.2 of SAE J1574-2 for Section 5.)

b. Determine and record the coordinates of the center of gravity of each part, relative to the local coordinate system for that suspension, as defined in 6.1.

6.4 Data Processing and Presentation

6.4.1 Determination of Total Vehicle Center of Gravity Position

The measurement of individual tire normal forces, discussed in Section 5, allows the determination of the vehicle horizontal (X and Y components) center of gravity position while the tilt-table measurements of this section allow the determination of its vertical (Z component) center of gravity position. These will be discussed as follows. The governing equations for the horizontal position are given for a four-wheeled vehicle, but could be developed, by analogy, for a vehicle with more axles.

The vehicle longitudinal cg position is determined from wheel or axle loads by solving a planar statics problem with the vehicle in side view. Vertical forces act at the center of gravity and through the wheel centers and moments can be summed about any point in the vehicle. Using the front wheel center as a summing point to solve for the distance from front wheel centerline to cg, the equation for this dimension is shown in Equation 1:

$$a = [P_3 + P_4]L/[P_1 + P_2 + P_3 + P_4] \quad \text{(Eq. 1)}$$

In this expression, the variable names are the same as used in 5.2.3 of SAE J1574-2 for Section 4, namely:

a horizontal distance from total vehicle center of gravity to front wheel centerline
L wheelbase
$P_1$ left front tire normal force
$P_2$ right front tire normal force
$P_3$ left rear tire normal force
$P_4$ right rear tire normal force

The vehicle lateral cg position is determined using the same methods. The equation for its position relative to the vehicle centerline was given in 5.2.3 and is repeated in Equation 2:

$$c = [(P_2 - P_1)(T_f/2) + (P_4 - P_3)(T_r/2)]/(P_1 + P_2 + P_3 + P_4) \quad \text{(Eq. 2)}$$

In this equation, $T_f$ and $T_r$ are the front and rear wheel tracks, respectively.

The total vehicle center of gravity height is determined using the equation developed in 6.2.3 of SAE J15742. It relates the problem variables in a y = mx + b form. To determine the center of gravity height:

a. For each tilt angle, calculate the variable as shown in Equation 3:

$$M/(W\cos\theta) - Y_{SH} \qquad \text{(Eq. 3)}$$

where:

M = table restoring moment (N·m)
W = total weight of vehicle, plus weight of hardware to secure vehicle to tilt table (N)
$Y_{SH}$ = lateral shift of vehicle center-of-gravity relative to table axis, due to tilt (m)

b. Using linear regression methods, determine the slope of the relationship between the previous variable and the value tanθ, where θ is the table-tilt angle. This is the height of the vehicle, plus attachment hardware, above the pivot axis. Convert to mm units.

c. Using principles of statics, determine the height of center-of-gravity of attachment hardware above table pivot axis, at zero tilt angle.

d. Again using principles of statics, determine vehicle center-of-gravity height by correcting value determined in step b for attachment hardware.

6.4.2 Determination of Unsprung Center of Gravity Positions

Unsprung center of gravity positions are determined for each suspension using principles of statics with the positions of the centers of gravity of all of the parts (or subsystems) of that suspension. This should be done for all three coordinate directions. All of the weight of a part should be used in the moment balance if it is entirely supported by the wheel and tire. Half of the weight of the part should be used if it is jointly supported by the wheel and tire and by the sprung mass. (See discussion in 5.3.2.2 of SAE J1574-2 for Section 5.)

6.4.3 Determination of Vehicle Sprung Center of Gravity Position

Determine the vehicle sprung center of gravity position, using the known coordinates of the total vehicle mass and unsprung masses. The moment balances should assume that the unsprung mass and sprung mass moments about a given axis balance that of the total vehicle mass. This approach can be used three times to solve for the coordinates of the vehicle sprung mass. These should be expressed in the coordinates of 6.1.

6.5 Calibration Procedures

6.5.1 Weight Scales

Weight scales, if used, should be calibrated as specified in Section 5.

6.5.2 Restoring Moment Transducer

The moment measuring device should be calibrated with a range of balance weights (and a moment arm length) of known accuracy. Care should be exercised to load scale platforms in the same manner and to the same load as they will be used. Off-axis and grossly off-center loading (on scale platform) should be avoided. Hysteresis should be well within the accuracy requirement of Table 7B.

### 6.5.3 Tilt Table or Platform

The table with all accessory equipment attached in normally used positions including all stands, blocks, cables, transducers, etc., must be statically balanced about the pivot axis. Check for pivot hysteresis. It should be small enough that the restoring moment can be measured to the accuracy requirement of Table 7B. If restoring moment is measured using a force transducer, then the table moment arm(s) should be measured to allow determination of restoring moment consistent with the accuracy requirements of Table 7B.

### 6.5.4 Precision Protractor

A laboratory grade spirit level protractor should be calibrated to a National Institute of Standards and Technology.

### 6.5.5 Dial Indicator Displacement Devices

Use gage blocks or a micrometer head to check. Check for hysteresis.

## 7. MEASUREMENT OF MOMENTS AND PRODUCTS OF INERTIA

### 7.1 Variables Measured

In order to perform simulations of transient directional control responses and rigid body ride motions, certain moments, and products of inertia of the vehicle are required. The simplest directional control simulations require total vehicle yaw moment of inertia while the simplest ride simulations require sprung mass pitch moment of inertia. More complex directional control simulations generally require sprung mass roll and yaw moments of inertia and the roll-yaw product of inertia, as well as the yaw moment of inertia for the unsprung mass.

This document will assume that the six aforementioned inertia properties must be determined. The sprung mass inertial properties can be determined by:

a. Measurement of total vehicle and unsprung mass inertial properties with calculation of sprung mass inertial properties

b. Measurement of sprung and unsprung mass inertial properties with correction for one half of parts attached to both sprung and unsprung masses (see discussion in 5.3.2.2 in SAE J1574-2 for Section 5) and with calculation of total vehicle yaw inertia

Both of these approaches are cumbersome. The first will be the approach discussed in this document, primarily for parallelism with the weight measurement procedures of Section 5. This allows some procedures to be performed in parallel. In addition, determination of the inertial properties of the total vehicle allows the measurement of unsprung mass inertial properties to be omitted in cases when approximations of unsprung mass inertial properties are sufficiently accurate.

Approximate values for variables measured directly and indirectly are shown in Table 8. The oscillation period limits are arbitrary, selected to limit windage effects. All inertia values are referenced to the total vehicle center of gravity for consistency, even though sprung and unsprung values might be measured or reported with respect to a different origin. In general, the total vehicle inertias are based on measured values for small and large vehicles in each class and the corresponding sprung and unsprung values are scaled from them, based on experimentally observed trends. The unsprung inertias shown are for the sum of all suspensions, even though measurements would be made on a suspension by suspension basis. The acceleration and moment limits are based on an oscillation amplitude of 2 degrees.

TABLE 8 - VARIABLES MEASURED

| Variable | Vehicle Type | Range |
|---|---|---|
| Primary: | | |
| total vehicle pitch period | 1,2,3 | 0.2 to 0.5 s |
| total vehicle roll period | 1,2,3 | 0.2 to 0.5 s |
| total vehicle roll acceleration | 1,2,3 | 3.0 to 20.0 degrees/s$^2$ |
| total vehicle yaw period | 1,2,3 | 0.2 to 0.5 s |
| total vehicle yaw reaction moment | 1 | 0 to 25 N·m |
| | 2 | 0 to 125 N·m |
| | 3 | 0 to 350 N·m |
| unsprung mass pitch period | 1,2,3 | 0.2 to 0.5 s |
| unsprung mass roll period | 1,2,3 | 0.2 to 0.5 s |
| unsprung mass roll acceleration | 1,2,3 | 3.0 to 20.0 degrees/s$^2$ |
| unsprung mass yaw period | 1,2,3 | 0.2 to 0.5 s |
| unsprung mass yaw reaction moment | 1 | 0 to 5 N·m |
| | 2 | 0 to 15 N·m |
| | 3 | 0 to 35 N·m |
| Derived: | | |
| sprung mass pitch moment of inertia | 1 | 750 to 7500 kg-m$^2$ |
| | 2 | 11 000 to 41 000 kg-m$^2$ |
| | 3 | 34 000 to 113 000 kg-m$^2$ |
| sprung mass roll moment of inertia | 1 | 150 to 900 kg-m$^2$ |
| | 2 | 2500 to 2900 kg-m$^2$ |
| | 3 | 5600 to 9200 kg-m$^2$ |
| sprung mass yaw moment of inertia | 1 | 900 to 7500 kg-m$^2$ |
| | 2 | 11 000 to 41 000 kg-m$^2$ |
| | 3 | 34 000 to 113 000 kg-m$^2$ |
| sprung mass roll-yaw product of inertia | 1 | –65 to 65 kg-m$^2$ |
| | 2 | –315 to 315 kg-m$^2$ |
| | 3 | –900 to 900 kg-m$^2$ |
| total vehicle pitch moment of inertia | 1 | 1000 to 10 000 kg-m$^2$ |
| | 2 | 15 000 to 55 000 kg-m$^2$ |
| | 3 | 45 000 to 150 000 kg-m$^2$ |
| total vehicle roll moment of inertia | 1 | 200 to 1200 kg-m$^2$ |
| | 2 | 2300 to 8300 kg-m$^2$ |
| | 3 | 6800 to 23 000 kg-m$^2$ |
| total vehicle yaw moment of inertia | 1 | 1200 to 10 000 kg-m$^2$ |
| | 2 | 15 000 to 55 000 kg-m$^2$ |
| | 3 | 45 000 to 150 000 kg-m$^2$ |
| total vehicle roll-yaw product of inertia | 1 | –75 to 75 kg-m$^2$ |
| | 2 | –350 to 350 kg-m$^2$ |
| | 3 | –1000 to 1000 kg-m$^2$ |
| unsprung mass pitch moment of inertia | 1 | 250 to 2500 kg-m$^2$ |
| | 2 | 3800 to 14 000 kg-m$^2$ |
| | 3 | 11 000 to 38 000 kg-m$^2$ |
| unsprung mass roll moment of inertia | 1 | 50 to 300 kg-m$^2$ |
| | 2 | 600 to 2100 kg-m$^2$ |
| | 3 | 1700 to 5800 kg-m$^2$ |
| unsprung mass yaw moment of inertia | 1 | 300 to 2500 kg-m$^2$ |
| | 2 | 3800 to 14 000 kg-m$^2$ |
| | 3 | 11 000 to 38 000 kg-m$^2$ |

TABLE 8 - VARIABLES MEASURED (CONTINUED)

| Variable | Vehicle Type | Range |
|---|---|---|
| unsprung mass roll-yaw product of inertia | 1 | –10 to 10 $kgm^2$ |
| | 2 | –35 to 35 $kgm^2$ |
| | 3 | –100 to 100 $kgm^2$ |

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers

## 7.2 Apparatus

### 7.2.1 General Performance Requirements

The measurement of these moments and products of inertia involves the low-frequency oscillation of the vehicle or unsprung masses about a low friction pivot and the measurement of period and, possibly, reaction moment. Various configurations may be employed, as discussed in 7.2.2. In general, they must provide a low friction pivot of known location and a linear reaction moment of known rate. Measurement of products of inertia requires either the reorientation of the pivot axis (or reorientation of the vehicle) or the measurement of out-of-plane moments. The measurement of period is also required. Specific accuracy requirements for these apparatus and transducers is given in Table 9. In addition, they must accommodate vehicles of a size and weight expected at a given laboratory, as outlined in Tables 2 and 4.

Measurement apparatus must be capable of determination of yaw moment of inertia about a vertical axis through the total center of gravity, of roll moment of inertia about a longitudinal axis contained in the vehicle plane of symmetry, of pitch moment of inertia about a lateral axis perpendicular to the vehicle's plane of symmetry, and of roll-yaw product of inertia relative to the previously defined roll and yaw axes. The exact location of these axes is not constrained and usually depends on the simulation application. It is common practice to measure one or more moments of inertia about axes convenient for testing and to calculate corresponding inertias about other axes using inertia transformation theory. As a result, discussion of measurement of these inertias will be general with regard to axis location.

### 7.2.2 General Configurations

Roll and pitch inertia measurements are usually made with the same method and apparatus by turning the vehicle or pivot axis 90 degrees after the first measurement is made. In general, principal inertias, or inertias about axes passing near the center of gravity, are sought. (This may be less true for trucks, with roll axes well below their centers of gravity.) Assuming that inertia about an axis through or near the center of gravity is sought, best practice is to measure the inertia about this axis, thus eliminating an additional $m \cdot R^2$ effect. This requires some form of linear restoring spring, since a compound pendulum will not work for a pivot axis through the center of gravity, or will have limited restoring effect for an axis near the center of mass.

Common practice is to provide a pivot axis somewhat above or below the center of gravity, in conjunction with linear restoring springs. The pivot axis can be displaced laterally, in which case only one set of restoring springs is required, with the likelihood that the pivot axis to center-of-gravity distance is increased somewhat. Knife edges or an air bearing are often used as pivots.

Yaw inertia is commonly measured one of two ways. The first utilizes a vehicle support bearing with a vertical degree of freedom, thus allowing single degree of freedom yaw oscillation. As discussed previously, greatest accuracy is obtained with the pivot axis near the center of gravity. Restoring moments are usually provided by linear springs. The second method utilizes a multifilar pendulum in which the vehicle rests on a horizontal platform suspended by three or four long, vertical cables. With this method, the vehicle must be rigidly attached to the platform and its center of gravity must be midway from the cables. If it is not, then two degree of freedom, coupled vibration will result, preventing the accurate determination of yaw moment of inertia. Assuming that a very low-friction bearing is available, the support bearing method is superior, since it does not require exact positioning of the vehicle center-of-gravity and since it guarantees single degree of freedom oscillation. Both methods will be addressed in the document.

Product of inertia measurements can be performed two ways. One is to measure “roll” and “yaw” moments of inertia about two sets of axes which have been rotated about a common pitch axis. These four moments of inertia define a section of the vehicle's ellipsoid of inertia, defined by Equation 4:

$$1 = I_{xx}x^2 + I_{zz}z^2 + 2I_{xz}xz \quad \text{(Eq. 4)}$$

Knowledge of the moments of inertia and degree of coordinate rotation allows determination of the roll-yaw product of inertia. A more direct method is to provide for single degree of freedom oscillation about a fixed axis while measuring the pivot reactions, thus allowing the determination of reaction moments about axes perpendicular to the pivot axis. (The measurement of all pivot reactions for three mutually perpendicular axes, with successive oscillations about each, allows the determination of all six moments and products of inertia.) Roll-yaw product of inertia is determined by measuring yaw reaction moment during roll oscillation, or vice-versa. This method will be the one discussed in this document.

### 7.2.3 Performance Requirements

Overall measurement accuracy requirements for the variables of Table 8 are shown in Table 9A. Transducer accuracy requirements are shown in Table 9B. (Note that, in the interests of space, “moment” and “product” are used for “moment of inertia” and “product of inertia.”)

Table 9B shows the most stringent accuracy requirements with the addition of types of typical transducers. Period can also be measured by transducing displacement, velocity, or acceleration, recording as a function of time, and determining the elapsed time for a number of cycles. In addition, roll acceleration can also be measured by transducing displacement or velocity, recording as a function of time, and taking first or second derivatives. Table 9B assumes the use of accelerometers to directly transduce roll acceleration.

## 7.3 Test Procedures

### 7.3.1 Vehicle Preparation

Prepare the vehicle in accordance with the guidelines of 3.3. The vehicle should not be ballasted to particular tire normal forces, since various methods of ballasting may not give unique inertial properties. It should be trimmed to the same suspension trim heights for which the center-of-gravity was determined in Section 6. The fuel tank should be drained (in order to avoid the introduction of higher harmonics in the oscillatory tests) but other fluid reservoirs should be topped up.

### 7.3.2 Test Procedures

The discussion in 7.2.2 outlines basic methods used in determining moments and products of inertia. The paragraphs below outline more specific test procedures, based on the fundamental methods outlined in 7.2.2. It is assumed that vehicle and unsprung weights and centers of gravity have been determined in accordance with the procedures of Sections 5 and 6.

While these procedures are discussed in two paragraphs as follows, time is generally saved by measuring all of the total vehicle inertial properties at one time and all of the unsprung mass inertial properties at another.

TABLE 9A - MEASUREMENT ACCURACY REQUIREMENTS

| Variable | Vehicle Type | Accuracy Percent[1] | Absolute |
|---|---|---|---|
| Primary: | | | |
| total vehicle pitch period | 1,2,3 | ±1.0 | |
| total vehicle pitch spring rate | 1,2,3 | ±1.0 | |
| total vehicle roll period | 1,2,3 | ±1.0 | |
| total vehicle roll spring rate | 1,2,3 | ±1.0 | |
| total vehicle roll acceleration | 1,2,3 | ±2.5 | |
| total vehicle yaw period | 1,2,3 | ±1.0 | |
| total vehicle yaw spring rate | 1,2,3 | ±1.0 | |
| total vehicle yaw reaction moment | 1,2,3 | ±2.5 | |
| unsprung mass pitch period | 1,2,3 | ±1.0 | |
| unsprung mass pitch spring rate | 1,2,3 | ±1.0 | |
| unsprung mass roll period | 1,2,3 | ±1.0 | |
| unsprung mass roll spring rate | 1,2,3 | ±1.0 | |
| unsprung mass roll acceleration | 1,2,3 | ±2.5 | |
| unsprung mass yaw period | 1,2,3 | ±1.0 | |
| unsprung mass yaw spring rate | 1,2,3 | ±1.0 | |
| unsprung mass yaw reaction moment | 1,2,3 | ±2.5 | |
| Derived: | | | |
| sprung mass pitch moment | 1,2,3 | ±2.0 | |
| sprung mass roll moment | 1,2,3 | ±2.0 | |
| sprung mass yaw moment | 1,2,3 | ±2.0 | |
| sprung mass roll-yaw product | 1,2,3 | ±10.0 | |
| total vehicle mass pitch moment | 1,2,3 | ±2.0 | |
| total vehicle mass roll moment | 1,2,3 | ±2.0 | |
| total vehicle mass yaw moment | 1,2,3 | ±2.0 | |
| total vehicle mass roll-yaw product | 1,2,3 | ±5.0 | |
| unsprung mass pitch moment | 1,2,3 | ±2.0 | |
| unsprung mass roll moment | 1,2,3 | ±2.0 | |
| unsprung mass yaw moment | 1,2,3 | ±2.0 | |
| unsprung mass roll-yaw product | 1,2,3 | ±10.0 | |

1. Measurement accuracy, as a percentage of actual reading, should be no worse than that listed. For those variables which may have values near zero, absolute measurement accuracy should be no worse than the absolute value shown.

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers

TABLE 9B - TRANSDUCER ACCURACY REQUIREMENTS

| Variable | Type of Transducer | Typical Transducer | Veh. Type | Accuracy Percent[1] | Absolute |
|---|---|---|---|---|---|
| period | time | stopwatch | 1,2,3 | ±1.0 | |
| roll acceleration | acceleration | accelerometer | 1,2,3 | ±2.5 | |
| yaw reaction moment | moment, force | load cell | 1,2,3 | ±2.5 | |

1. Measurement accuracy, as a percentage of actual reading, should be no worse than that listed. For those variables which may have values near zero, absolute measurement accuracy should be no worse than the absolute value shown.

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers



7.3.2.1 Measurement of Total Vehicle and Unsprung Mass Pitch and Roll Moments and Roll-Yaw Products of Inertia

Measurement techniques for pitch and roll moments of inertia are virtually identical since the same apparatus is usually used with the vehicle or unsprung mass turned at right angles. (There may be some cases in which this is not practical.) In addition, pivot reactions which allow the determination of product of inertia are recorded simultaneously. Therefore, the test techniques for pitch and roll moments and roll-yaw products of inertia will be discussed together. These methods assume that the total vehicle pitch and roll inertias are measured first and that the unsprung masses are subsequently removed for determination of their pitch and roll moments of inertia. The sprung mass pitch and roll moments of inertia are later determined by computation.

To measure total vehicle pitch and roll moments of inertia and roll-yaw product of inertia, the following major steps should be followed:

a. Adjust trim heights to the values recorded in the center of gravity position measurements. Secure suspension trims in this position to prevent either jounce or rebound travel. If body trim height dimensions were used in the center of gravity position determination, record suspension trim heights. Measure positions, relative to known body, frame, or suspension references, of hardware used to secure suspensions.

b. Place vehicle on inertia measurement test platform and secure. Measure positions of hardware, blocks, or other apparatus used to secure the vehicle to the platform. Attachment should be made directly to the frame or body; the vehicle should not rest on its tires.

c. If the inertia measurement test platform (and vehicle) is not already mounted on the pitch or roll pivots, do so. Record the position of the vehicle center of gravity (or other references which allow its determination) relative to the pivot axis. Attach restoring springs, and pivot reaction load cells, if necessary.

d. Allow the platform and vehicle to equilibrate and zero, or record equilibrium voltages (loads) of, the load cells and displacement transducers, if used.

e. Prepare data recording systems for load cells, and platform displacement, if used.

f. Perform a trial oscillation to check for sinusoidal waveform in the load cell (and platform displacement, if available) time history. Correct, if necessary. Common error sources are lash between vehicle and platform, between platform and pivot, between pivots and load cells, or oscillations of major vehicle subsystems, such as drivetrain. Record positions of any wedges or hardware used. Also determine the smallest possible amplitude which will give 30 to 40 sinusoidal cycles.

g. Excite roll or pitch oscillations and record displacement for 30 to 40 cycles as a function of time. If displacement is not transduced, count and time the elapsed time of the oscillations so that period may be calculated. Repeat this procedure three times.

h. If roll inertia was measured, repeat steps b through g for pitch inertia, or vice-versa. Note that load cell readings are not required when measuring pitch inertia, since pitch-yaw product of inertia is not required.

i. Weigh hardware used to secure suspensions, to secure the vehicle to the test platform, or to correct subsystem oscillations.

j. Measure dimensions and position of fuel tank(s) and “H points” of seats.

Two broad approaches may be used to measure unsprung mass moments and products of inertia. Both require removal of all unsprung mass components. In the first, the suspension is remounted on a lightweight fixture such that it is at the same trim height as it was when the total vehicle inertial properties were measured. The inertial properties of the suspension and fixture and of the fixture alone are measured and the suspension inertial properties of the suspension are determined by subtracting those of the fixture. In the second, suspension part coordinates are determined which uniquely define each part's position in the vehicle. The inertial properties of each part are measured and transformed to the vehicle inertial reference axes. In both cases, the inertial properties of parts which can be considered both sprung and unsprung are treated according to the 50/50 rule, discussed in 5.3.2.2 of SAE J1574-2 for Section 5. The second approach will be considered less cumbersome and discussed in this document.

To measure unsprung mass pitch and roll moments of inertia, the following major steps should be followed:

a. Prior to removing hardware used for maintaining suspension trim heights, measure coordinates of reference points on each suspension part, which will uniquely define its position in the vehicle.

b. Remove all unsprung parts from the test vehicle.

c. Disassemble to the subassembly or part level, as required, to measure unique inertial properties for each.

d. Measure a sufficient number of inertial properties for each part or subsystem, in a local coordinate system, to allow determination of pitch and roll moments and roll-yaw product in the vehicle inertial reference frame. Generally, it is easiest to utilize symmetry to determine principal moments and axes of inertia, although this is sometimes not possible. Measurements should be made on smaller analogs of the vehicle pitch, roll, or yaw test apparatus. Record inertial properties and orientation of local reference system to vehicle reference system.

7.3.2.2 Measurement of Total Vehicle and Unsprung Mass Yaw Moments of Inertia

Generally, the steps outlined above may be used in measuring total vehicle and unsprung mass moments of inertia, although some differences may exist. Since a product of inertia is not measured, load cells are not required. Also, if a multifilar pendulum is used, then the vehicle and supporting platform must be equidistant from the support cables, as discussed in 7.2.2. Care should also be used with a multifilar pendulum to excite only yaw oscillations, with negligible swinging.



7.4 Data Processing and Presentation

7.4.1 Determination of Total Vehicle and Unsprung Mass Pitch and Roll Moments and Roll-Yaw Products of Inertia

Moments of inertia may be easily calculated using very basic vibration theory and knowledge of the period and restoring spring rate. Products of inertia may be calculated nearly as easily, but require more advanced theory and knowledge of the yaw reaction moment and roll acceleration.

Pitch or roll moment of inertia may be obtained from the measured period and the equation for the natural frequency of a single degree of freedom oscillation. For torsional vibrations, this relationship is shown in Equation 5:

$$f = (57.3k/I)^{1/2}/(2\pi) \quad \text{(Eq. 5)}$$

where:

- f = natural frequency (Hz)
- I = moment of inertia ($N{\cdot}ms^2/rad$)
- k = spring rate ($N{\cdot}m/deg$)

Since the period (T) is the reciprocal of the natural frequency, the moment of inertia is shown in Equation 6:

$$I = 57.3T^2k/(4\pi^2) \qquad \text{(Eq. 6)}$$

This relationship can be used to determine the pitch or roll moments of inertia of either the total vehicle or any of the unsprung masses.

Sprung mass pitch or roll moments of inertia may be determined by subtracting the unsprung mass pitch or roll moments of inertia from the total vehicle pitch or roll moment of inertia. The unsprung moments of inertia must first be transformed to equivalent inertias about the axis for which the total vehicle moment of inertia was measured, using the parallel axis theorem. This theorem (derived in texts on dynamics) states that the moment of inertia about an arbitrary axis is the sum of the centroidal moment of inertia about an axis parallel to the desired axis and the product of the mass and the square of the distance between the axes. It may be necessary to use the parallel axis theorem successively to transform the measured unsprung moments of inertia to equivalent inertias about the desired total vehicle axes.

Determination of the roll-yaw product of inertia requires knowledge of the dynamics of a rigid body rotating about a fixed axis. In the roll inertia test, oscillation occurred about the vehicle longitudinal (x) axis and the reaction moment was measured about the vehicle vertical (z) axis. For this special case, texts on dynamics show that the yaw moment is shown in Equation 7:

$$M_z = I_{xz}\dot{\omega}_x + I_{xy}\omega_x^2 \qquad \text{(Eq. 7)}$$

where:

- $I_{xz}$ = roll-yaw product of inertia
- $I_{xy}$ = roll-pitch product of inertia
- $M_z$ = yaw reaction moment
- $\omega_x$ = roll velocity
- $\dot{\omega}_x$ = roll acceleration

Both roll velocity and roll acceleration vary sinusoidally. At maximum displacement, roll acceleration will be a maximum and roll velocity will be zero. Determination of the yaw reaction moment at this point in time allows determination of the roll-yaw product of inertia from the relation in Equation 8:

$$I_{xz} = M_z / \dot{\omega}_x \qquad \text{(Eq. 8)}$$

The maximum roll acceleration must be determined from transduced time histories of displacement, velocity, or acceleration. Roll acceleration should be converted to $rad/s^2$ for direct use in Equation 8.

Unsprung roll-yaw products of inertia may be determined similarly. They may then be subtracted from the total vehicle roll-yaw product of inertia, properly observing transformation of product of inertia between local and global (vehicle) coordinate systems, to obtain the sprung mass roll-yaw product of inertia.

7.4.2 Determination of Total Vehicle and Unsprung Mass Yaw Moments of Inertia

Yaw moment of inertia of both the total vehicle and unsprung masses may be determined in a manner analogous to that used for roll and pitch moments of inertia. Again, the period and restoring spring rate must be known and inertia transformation, using the parallel axis theorem, will be required. The torsional spring rate for a multifilar pendulum, in N·m/degrees, is shown in Equation 9:

$$k = R^2W/(57.3L) \quad \text{(Eq. 9)}$$

where:

L = length of each cable (m)
R = distance from vehicle/platform cg to each cable (m)
W = weight of vehicle and support platform (N)

7.5 Calibration Procedures

Before inertia values can be derived from the direct measurements discussed, a number of values must be available. These must be determined through direct measurement or calibration. The required values are: stopwatch or recorder timing accuracy, spring rate and locations, cable length, accelerometer sensitivity and locations, load cell sensitivity and load cell locations, tare mass, and tare inertia. These measurements or calibrations should be made using accepted laboratory techniques, as applicable. Measurement of tare inertia is accomplished by simply testing the support structure as the test vehicle or unsprung mass would be. Accuracies should be consistent with the accuracy requirements of Tables 9A and 9B for period, spring rate, roll acceleration, and yaw reaction moment.



8. MEASUREMENT OF SUSPENSION KINEMATIC CHARACTERISTICS

8.1 Variables Measured

Kinematic suspension characteristics are those which describe the motion of the unsprung masses relative to the sprung mass, as a result of relative motion. The rigid body ride and roll motions of the vehicle and the rotation of the vehicle steering wheel constitute the basic system inputs associated with these steering and suspension characteristics. Such kinematic characteristics are required to simulate basic directional control characteristics of the vehicle, or quantify those characteristics which influence this behavior. Shock absorber travel ratios are used in simulating roll and rigid body ride dynamics. These variables are shown in Table 10 with approximate ranges. Ranges for input displacements are generally of magnitudes associated with lateral accelerations in the vehicle's “linear range.”

In order to fully describe a vehicle, as discussed in Section 3, it is sometimes desirable to measure the overall ratio (for worm and sector) or “C factor” (for rack and pinion) of the steering gear. Such measurements are not specifically covered in this document, but may be performed using methods discussed in this section.

8.2 Apparatus

8.2.1 General Performance Requirements

The test apparatus must be capable of accommodating vehicles of sizes and weights defined in Tables 2 and 4 of Sections 4 and 5 of this document, or of a subset of these vehicles, if appropriate for a given laboratory. More specifically related to the above kinematic characteristics, the test techniques and associated equipment must be capable of attaining results of the accuracies outlined in Tables 11A and 11B. A more detailed discussion of accuracy requirements is addressed in 8.2.3 of SAE J1574-2.

Measurements can be accomplished by utilizing either a displacement motion analysis (by providing a continuous displacement of suspension ride travel, roll displacement, or steering wheel angle and measuring the corresponding displacement of interest) or equilibrium techniques (by applying a known force(s) to the system and measuring the reaction forces at system equilibrium).

TABLE 10 - VARIABLES MEASURED

| Variable | Vehicle Type | Range |
|---|---|---|
| Primary: | | |
| camber angle change | 1 | –10 to 10 degrees |
| | 2,3 | –5 to 5 degrees |
| caster angle change | 1,2 | –2.5 to 2.5 degrees |
| steering wheel steer angle | 1 | –100 to 100 degrees |
| | 2,3 | –200 to 200 degrees |
| roadwheel steer angle | 1,2,3 | –5 to 5 degrees |
| shock absorber displacement | 1,2,3 | –50 to 50 mm |
| suspension lateral displacement | 1,2,3 | –20 to 20 mm |
| suspension ride displacement | 1,2,3 | –50 to 50 mm |
| suspension roll displacement | 1,2,3 | –2.5 to 2.5 degrees |
| tire lateral force(1) | 1 | 300 to 1700 N |
| | 2,3 | 1500 to 3800 N |
| tire normal force change(1) | 1 | –1500 to 1500 N |
| | 2,3 | –6500 to 6500 N |
| Derived: | | |
| overall steering ratio | 1 | 10:1 to 30:1 |
| | 2,3 | 20:1 to 40:1 |
| ride camber coefficient | 1 | –0.1 to 0 degrees/mm |
| | 2,3 | –0.05 to 0 degrees/mm |
| ride caster coefficient | 1,2,3 | 0 to 0.05 degrees/mm |
| ride shock absorber travel ratio | 1,2,3 | 0.5:1 to 1.0:1 |
| ride steer coefficient | 1,2,3 | 0 to 0.015 degrees/mm |
| roll camber coefficient | 1,2,3 | 0 to 1.0 deg/degrees |
| roll caster coefficient | 1,2,3 | 0 to 0.5 deg/degrees |
| roll center height | 1 | –25 to 500 mm |
| | 2,3 | 450 to 800 mm |
| roll shock absorber travel ratio | 1,2,3 | 0.5:1 to 1.0:1 |
| roll steer coefficient | 1 | 0 to 0.15 deg/degrees |
| | 2,3 | 0 to 0.25 deg/degrees |

1. For tandem axle suspensions, properties are defined for each side of the entire suspension. For dual tire axles, properties are similarly defined for each side of the suspension and therefore for each pair of tires.

Vehicle Type:
- 1 = passenger vehicles and light trucks
- 2 = heavy trucks
- 3 = commercial trailers

8.2.2 General Configurations

The apparatus for determining these kinematic characteristics may vary considerably in exact configuration but not as much in general configuration. All characteristics can be determined by utilizing a displacement as input (suspension ride, suspension roll, or steering wheel displacement) and measuring a dependent displacement as output. The kinematic coefficient required is the rate of change of the dependent displacement with respect to the input displacement. Roll-center height may alternately be measured using principles of static equilibrium. As a result, the test apparatus must be capable of providing:

a. Suspension ride displacement

b. Suspension roll displacement

c. Steering wheel displacement

It may optionally provide lateral force input for the measurement of roll center height.

The apparatus must be capable of providing each of these displacement inputs in the absence of any others and in the absence of any tire forces other than normal force. Thus, apparatus for ride displacement input must provide for parallel wheel motion in the absence of roll. Tire support pads must remain coplanar and reduce all tire forces to levels much less than the normal force, which must remain normal to the original road plane. This is generally accomplished by designing low-friction tire support pads into the same rigid structure. The low friction supports may be mechanical, hydraulic, or pneumatic. The ride motion may be imposed by grounding the vehicle sprung mass and moving the roadwheels, or vice versa. The same apparatus is generally used to impart suspension roll, in which case the net ride motion, at the wheel centers, must remain zero. In both cases, the steering wheel should be locked to eliminate uncontrolled steering input. Steering input at the steering wheel is usually done by hand, with ride and roll motions constrained to zero.

If the equilibrium method is used to define the roll center height, then a method to apply a lateral force to the wheel plane at a known height must also be available. This, in turn, requires a restraint mechanism for the vehicle sprung mass. (See SAE J1574-2 for 9.2.2 for a more complete discussion of sprung mass grounding issues.) This method also requires simultaneous measurement of lateral and normal force, while ride, roll, and steering wheel steer motions are zero.

In order to determine all of the “derived” kinematic coefficients in Table 10, changes in all of the “primary” variables must be measured. Suspension ride and roll displacement are determined by transducing the vertical displacement of each of the wheel centers, relative to a datum fixed in the sprung mass. Common transducers are linear potentiometers or LVDTs. Steering wheel displacement is measured relative to the sprung mass, usually with a rotary potentiometer.

Roadwheel steer and camber (inclination) angles are generally transduced from a rigid plate attached to, and parallel to, the wheel plane. Linear or angular displacement transducers may be used, with linear transducers having the advantage of providing for the simultaneous measurement of lateral displacement of the wheel. With linear displacement transducers, steer angle change is measured by mounting the transducers in a plane parallel to the road plane, while camber angle change is measured by mounting them in a vertical plane perpendicular to the wheel plane. Measurements must assure that steer angle (angle between the intersection of the wheel and road planes and a line in the road plane parallel to the vehicle's longitudinal axis) and inclination angle (angle between the wheel plane and a perpendicular to the road plane) are measured correctly and not contaminated by each other or wheel displacements.

Wheel center lateral displacement is generally measured with linear displacement transducers, in conjunction with the measurement of steer or camber. However, a single displacement transducer may also be used, if attached to the wheel center. Shock absorber travel is also measured with a linear displacement transducer attached to parts functionally representing the ends of the shock absorber or strut.

In this discussion, the measurement of caster (change) will be assumed to be represented by the measurement of angular rotation of the knuckle about a transverse, horizontal axis. This equivalence assumes that the kingpin axis remains fixed in the knuckle during ride and roll motions. This angular displacement is best measured with an inclinometer, which may provide either a visual readout or electrical output. In most cases it is easiest to mount the inclinometer to the roadwheel, or to an attached plate which is parallel to the wheel plane, and to lock the brakes. This ensures that the roadwheel and knuckle rotations are the same.

Measurement of roll center height with the equilibrium technique requires the measurement of lateral and normal forces, and the position of each relative to vertical and lateral references. Forces are measured with load cells.

Test turnaround time and data processing convenience require data recording device(s), although manual data recording might be justified for a single set of these tests. The availability of such recording device(s) will be assumed, whether strip chart recorders, X-Y recorders, or continuous electronic recording devices. Data may be taken continuously or at a series of fixed displacements, provided that continuously varying inputs are very slow, to approximate steady-state conditions. "Instantaneous" displays of input and output variables, in X-Y form, are not required but are very useful in identifying measurement errors or vehicles which do not represent design intent.

In summary, the equipment listed as follows is required to measure all of the kinematic coefficients of Table 10. Generally, the measurement of a given coefficient will only require a subset of this list.

a. Ride displacement mechanism for sprung or unsprung mass (with low friction tire turn pads)

b. Roll displacement mechanism for sprung or unsprung mass (with low friction tire turn pads)

c. Low friction tire turn pads

d. Steering wheel displacement mechanism (optional)

e. Steering wheel displacement lock

f. Ride displacement transducer(s)

g. Roadwheel lateral displacement transducer(s)

h. Steering wheel angle transducer

i. Roadwheel steer angle transducer(s)

j. Camber angle transducer(s)

k. Inclinometer(s)

l. Brake locking mechanism (optional)

m. Shock absorber displacement transducer(s)

n. Lateral force input mechanism

o. Lateral force transducer

p. Normal force transducer

q. Sprung mass restraint mechanism

r. Data recording device(s)

8.2.3 Performance Requirements

Overall measurement accuracy requirements for the variables of Table 10 are shown in Table 11A. Rationale for these requirements are discussed in SAE J1574-2, 8.2.3.

Table 11B shows the accuracy requirements of Table 11A, with the addition of types of typical transducers. Steer and camber angle may also be measured with displacement transducers spanning a known distance.

TABLE 11A - MEASUREMENT ACCURACY REQUIREMENTS

| Variable | Vehicle Type | Accuracy Percent[1] | Absolute |
|---|---|---|---|
| Primary: | | | |
| camber angle | 1,2,3 | ±1.0 | |
| caster angle | 1,2,3 | ±9.0 | |
| steering wheel steer angle | 1,2,3 | ±0.5 | |
| roadwheel steer angle | 1,2,3 | ±1.0 | |
| shock absorber displacement | 1,2,3 | ±4.0 | |
| suspension lateral displacement | 1 | ±1.5 | ±0.01 mm |
| | 2,3 | ±1.5 | ±0.02 mm |
| suspension ride displacement | 1,2,3 | ±0.8 | |
| tire lateral force | 1,2,3 | ±1.0 | |
| tire normal force | 1,2,3 | ±1.3 | |
| Derived: | | | |
| overall steering ratio | 1,2,3 | ±1.5 | |
| ride camber coefficient | 1 | ±2.0 | ±0.01 degrees/mm |
| | 2,3 | ±2.0 | ±0.02 degrees/mm |
| ride caster coefficient | 1 | ±10.0 | ±0.01 degrees/mm |
| | 2,3 | ±10.0 | ±0.02 degrees/mm |
| ride shock absorber travel ratio | 1,2,3 | ±5.0 | |
| ride steer coefficient | 1 | ±2.0 | ±0.0002 degrees/mm |
| | 2,3 | ±2.0 | ±0.0004 degrees/mm |
| roll camber coefficient | 1,2,3 | ±2.0 | ±1.0% |
| roll camber coefficient | 1,2,3 | ±2.0 | ±2.0% |
| roll caster coefficient | 1,2,3 | ±10.0 | ±1.0% |
| roll center height | 1,2,3 | ±2.5 | ±2.5 mm |
| roll shock absorber travel ratio | 1,2,3 | ±5.0 | |
| roll steer coefficient | 1,2,3 | ±2.0 | ±0.25% |
| suspension roll displacement | 1,2,3 | ±1.0 | |

1. Measurement accuracy, as a percentage of actual reading, should be no worse than that listed. For those variables which may have values near zero, absolute measurement accuracy should be no worse than the absolute value shown.

   Vehicle Type:
   1 = passenger vehicles and light trucks
   2 = heavy trucks
   3 = commercial trailers

TABLE 11B - TRANSDUCER ACCURACY REQUIREMENTS

| Variable | Type of Transducer | Typical Transducer | Veh. Type | Accuracy Percent(1) | Absolute |
|---|---|---|---|---|---|
| camber angle | angle, disp. | rotary pot., LVDT | 1,2,3 | ±1.0 | |
| caster angle | angle | inclinometer | 1,2,3 | ±9.0 | |
| steering wheel angle | angle | rotary pot. | 1,2,3 | ±0.5 | |
| roadwheel steer angle | angle, disp. | rotary pot., LVDT | 1,2,3 | ±1.0 | |
| shock absorber disp. | displacement | linear pot., LVDT | 1,2,3 | ±4.0 | |
| suspension lat. disp. | displacement | LVDT | 1,2,3 | ±1.5 | ±0.01 mm |
| suspension ride disp. | displacement | LVDT | 1,2,3 | ±0.8 | |
| tire lateral force | force | load cell | 1,2,3 | ±1.0 | |
| tire normal force | force | load cell | 1,2,3 | ±1.3 | |

1. Measurement accuracy, as a percentage of actual reading, should be no worse than that listed. For those variables which may have values near zero, absolute measurement accuracy should be no worse than the absolute value shown.

Vehicle Type:
1 = passenger vehicles and light trucks
2 = heavy trucks
3 = commercial trailers



## 8.3 Test Procedures

### 8.3.1 Vehicle Preparation

The vehicle should be prepared to the guidelines of 3.3. Neither tire normal forces nor suspension trim heights need be set prior to actual testing. Tests will be run at fixed trim heights, generally curb or design trim heights. These must be known and clearly defined prior to testing.

### 8.3.2 Test Procedures

#### 8.3.2.1 Measurement of Overall Steering Ratio

A measurement of the change of steering wheel angle versus the change of roadwheel steer angles, over a range of ±5 degrees of roadwheel steer angle, is normally sufficient to obtain the overall steering ratio required for linear range simulation. The following basic steps should be followed to measure overall steering ratio:

a. Place a low friction tire turn pad under each of the steered wheels.

b. Measure power steering vehicles with the power steering system operative.

c. Mount a steer angle transducer at each steered wheel. Install the steering wheel angle transducer.

d. Ensure that the vehicle is at the desired trim condition.

e. Prepare recorders and zero as required.

f. Turn steering wheel through a displacement equivalent to about 5 degrees of roadwheel steer angle and return to straight ahead. If immediate data display is available, record steering wheel and roadwheel angles. Display data for each wheel in X-Y format and check for improper vehicle mounting, invalid instrumentation, or inappropriateness of test vehicle. Correct as required.

g. Turn the steering wheel first to the right (to eliminate steering system lash) and then back to center (to the left). While recording steering wheel and steered wheel angles, turn the steering wheel to the left, stopping at approximately 5 degrees (toe-out) of the left steered wheel. Reverse steering wheel rotation stopping at approximately 5 degrees (toe-out) of the right steered wheel. Repeat the cycle twice by again turning to the left (5 degrees toe-out) and then to the right (5 degrees toe-out). Return the steered wheels to the straight ahead position.

This test may also be conducted by manually recording the steering wheel and roadwheel angles using protractors (or similar device) attached to the steering wheel and the roadwheels (or tire turn pads). This method requires incremental measurements of steering wheel and roadwheel angles over the desired range of roadwheel travel. Recorders and angular displacement transducers are not required, but protractors for the steering wheel and roadwheels are. The steering wheel protractor should be graduated in degrees and the roadwheel protractors should be graduated in degrees and minutes.

This method employs basically the same procedure as described previously, with the exception that the data is manually transcribed at every 0.50 degree of roadwheel angle. The advantage of this procedure is that the equipment required is minimal and relatively inexpensive. The disadvantages are that the resolution of the data is dependent on the number and interval of the data points taken, and that the accuracy becomes more sensitive to test operator error.

8.3.2.2 Measurement of Ride Camber Coefficients

Ride camber coefficients are determined by measuring the change of tire inclination angle with ride displacement. The following basic steps should be followed to measure ride camber coefficients:

a. Rigidly secure the vehicle to the ride displacement mechanism (Note: One or both axles may be cycled in ride depending on the ride displacement mechanism used.)

b. Lock the steering wheel so that the test wheel(s) are in a straight ahead position.

c. Mount a camber angle transducer and a ride displacement transducer at each test wheel.

d. Ensure that the vehicle is at the desired trim position.

e. Prepare recorders and zero as required.

f. Cycle suspension(s) through the normal range of suspension travel and return to the desired trim position. If immediate data display is available, record ride travel and camber angle. Display data for each wheel in X-Y format and check for improper vehicle mounting, invalid instrumentation, or inappropriateness of test vehicle. Correct as required.

g. Again cycle suspension(s) through the normal range of suspension travel and return to the desired trim position, while recording data. Repeat two times.

8.3.2.3 Measurement of Ride Caster Coefficient

Ride caster coefficients are determined by measuring the change in caster angle with ride displacement. Caster angle change is measured by measuring the rotation of the knuckle(s) about a transverse, horizontal axis. Since the inclinometer is also sensitive to any angular changes about the Y axis of the test wheel or vehicle, it is important that any extraneous rotation of the vehicle with respect to its initial orientation be avoided. The procedures are the same as those outlined above for ride camber coefficients, except that changes in caster angles, rather than changes in camber angles, are measured. The equipment is also the same, with the substitution of inclinometer(s) for camber angle transducer(s). If the inclinometer(s) is mounted to the roadwheel, the brakes must be locked.

8.3.2.4 Measurement of Shock Absorber Travel Ratios in Ride

Shock absorber travel ratios in ride are determined by measuring the change in length of each shock absorber with ride displacement, using a linear displacement transducer. The procedures are the same as those outlined in 8.3.2.2 for ride camber coefficients, except that changes in shock absorber lengths, rather than changes in camber angles, are measured. The equipment is also the same, with the substitution of displacement transducer(s) for camber angle transducer(s).

8.3.2.5 Measurement of Ride Steer Coefficients

Ride steer coefficients are determined by measuring the change in roadwheel steer angle with ride displacement. The procedures are the same as those outlined in 8.3.2.2 for ride camber coefficients, except that changes in steer angles, rather than changes in camber angles, are measured. The equipment is also the same, with the substitution of steer angle transducer(s) for camber angle transducer(s).

8.3.2.6 Measurement of Roll Camber Coefficients

Roll-camber coefficients are determined by measuring the change of tire inclination angle with suspension roll displacement. Suspension roll displacement is defined by the front or rear view rotation, relative to the sprung mass, of a line connecting wheel centers. For independent suspensions, this requires the determination of both vertical and lateral wheel center coordinates, and thus the use of both vertical and lateral displacement transducers. For solid axle suspensions, it is not necessary to measure wheel center lateral coordinates, since a line connecting wheel centers may be assumed to be of constant length. The following basic steps should be followed to measure roll camber coefficients:

a. Rigidly secure the vehicle to the roll displacement mechanism. (Note: One or both axles may be cycled in roll depending on the roll displacement mechanism used.)

b. Lock the steering wheel so that the test wheel(s) are in a straight ahead position.

c. Mount a camber angle transducer, a ride displacement transducer, and a lateral displacement transducer at each test wheel.

d. Ensure that the vehicle is at the desired trim position.

e. Prepare recorders and zero as required.

f. Cycle suspension(s) through the normal range of suspension roll travel and return to zero roll displacement. If immediate suspension roll calculation (see 8.4.6) and data display is available, record ride travel, lateral displacement, and camber angle. Display inclination angle versus suspension roll, in X-Y format, for each wheel and check for improper vehicle mounting, invalid instrumentation, or inappropriateness of test vehicle. Correct as required.

g. Again cycle suspension(s) through the normal range of suspension roll travel and return to the desired trim position, while recording data. Repeat two times.

8.3.2.7 Measurement of Roll Caster Coefficient

Roll caster coefficients are determined by measuring the change in caster angle with roll displacement. Caster angle change is measured by measuring the rotation of the knuckle(s) about a transverse, horizontal axis. Since the inclinometer is also sensitive to any angular changes about the Y axis of the test wheel or vehicle, it is important that any extraneous rotation of the vehicle with respect to its initial orientation be avoided. The procedures are the same as those outlined above for roll camber coefficients, except that changes in caster angles, rather than changes in camber angles, are measured. The equipment is also the same, with the substitution of inclinometer(s) for camber angle transducer(s). If the inclinometer(s) is mounted to the roadwheel, the brakes must be locked.

8.3.2.8 Measurement of Roll-Center Heights

Roll-center heights can be determined by using either the displacement or the equilibrium technique. The displacement technique is based on measuring the simultaneous lateral and vertical displacements of the centers of tire contact during vehicle roll. This displacement data defines an arc which represents the path of the center of tire contact. A perpendicular line to the tangent of each arc at zero roll angle points to the swing center. The height of the intersection of a pair of such perpendiculars is the roll center height. If wheel center displacement is transduced, then inclination angle and loaded radius must also be measured to determine the path of the center of tire contact.

An alternate displacement test procedure, applicable to independent suspensions only, can also be used. Measurements of the vertical and lateral displacements of the centers of tire contact (with respect to the sprung mass) during vehicle ride motion describe an arc which represents the path of center of tire contact. The perpendiculars to the tangent of each arc at a given vehicle trim height intersects at the height of the suspension roll center. An approximation to this technique can be made if it is assumed that swing centers are symmetrically located. Then only a measurement of track change versus suspension travel is required to calculate roll center height. Neither of these alternate techniques will be covered in the procedures outlined as follows:

The equilibrium technique is based on measuring the simultaneous lateral and normal forces on the wheel while suspension roll is held to zero. The lateral force may be input and transduced at any known location on the wheel or through the tire support pad and the normal force may be transduced at any known location, generally through the tire support pad. If each side of an independent suspension is tested separately, then the rate of change of normal force with lateral force, along with their locations, provides sufficient information to solve a statics problem which defines that suspension's swing center. As with the displacement technique, the height of the intersection of lines connecting the centers of tire contact and the swing centers defines the height of the roll center. If both sides of a suspension are tested together, then the lateral forces must be applied to both sides simultaneously. The rate of change of tire lateral load transfer with lateral force, along with their locations, provides sufficient information to solve a statics problem which defines the roll center height.

The normal force change, which results from the application of lateral force, will cause a change in suspension trim, as measured at the wheel center. Since suspension roll is defined using the wheel center positions and since it is to be held to zero, it is necessary to measure wheel center vertical positions and adjust the heights of the wheel pads to maintain zero suspension roll. This requires either a servo control system in the roll displacement mechanism or the use of discrete steps in load application and manual adjustment of the roll displacement mechanism or tire support pads.

The following basic steps should be followed to measure roll-center height using the displacement technique:

a. Rigidly secure the vehicle to the roll displacement mechanism. (Note: One or both axles may be cycled in roll depending on the roll displacement mechanism used.)

b. Lock the steering wheel so that the test wheel(s) are in a straight ahead position.

c. Mount a ride displacement transducer and a lateral displacement transducer at each test wheel. Also mount a camber angle transducer, if required to correct displacement data for center of tire contact position.

d. Ensure that the vehicle is at the desired trim position.

e. Prepare recorders and zero as required.

f. Cycle suspension(s) through the normal range of suspension roll travel and return to zero roll displacement. If immediate center of tire contact path calculation and data display is available, record ride travel and lateral displacement. Display center of tire contact path, referenced to the road plane (at zero roll), and check for improper vehicle mounting, invalid instrumentation, or inappropriateness of test vehicle. Correct as required.

g. Again cycle suspension(s) through the normal range of suspension roll travel and return to the desired trim position, while recording data. Repeat two times.