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Passenger cars — Steady-state circular driving behaviour — Open-loop test methods

Voitures particulières — Tenue de route en régime permanent sur trajectoire circulaire — Méthodes d'essai en boucle ouverte

Reference number
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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 4138 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 9, *Vehicle dynamics and road-holding ability*.

This third edition cancels and replaces the second edition (ISO 4138:1996), which has been technically revised.

Introduction

The dynamic behaviour of a road vehicle is a most important part of active vehicle safety. Any given vehicle, together with its driver and the prevailing environment, forms a unique closed-loop system. The task of evaluating dynamic behaviour is therefore very difficult since there is a significant interaction between these driver-vehicle-environment elements, each of which is complex in itself. A complete and accurate description of the behaviour of the road vehicle must necessarily involve information obtained from a number of tests of different types. Since they quantify only a small part of the complete vehicle handling characteristics, the results of these tests can only be considered significant for a correspondingly small part of the overall dynamic behaviour.

Moreover, insufficient knowledge is available concerning the relationship between overall vehicle dynamic properties and accident avoidance. A substantial amount of effort is necessary to acquire sufficient and reliable data on the correlation between accident avoidance and vehicle dynamic properties in general, and the results of these tests in particular. Therefore, it is not possible to use these methods and test results for regulatory purposes.

Finally, test conditions and tyres have a strong influence on test results. Only vehicle dynamic properties obtained under identical test and tyre conditions are comparable.

INTERNATIONAL STANDARD **ISO 4138:2004(E)**

Passenger cars — Steady-state circular driving behaviour — Open-loop test methods

1 Scope

This International Standard specifies open-loop test methods for determining the steady-state circular driving behaviour of passenger cars as defined in ISO 3833 and of light trucks, such behaviour being one of the factors comprising vehicle dynamics and road-holding properties. The open-loop manoeuvres included in these methods are not representative of real driving conditions, but are nevertheless useful for obtaining measures of vehicle steady-state behaviour resulting from several specific types of control inputs under closely controlled test conditions.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3833:1977, *Road vehicles — Types — Terms and definitions*

ISO 7401:2003, *Road vehicles — Lateral transient response test methods — Open-loop test methods*

ISO 8855:1991, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*

ISO 15037-1:1998, *Road vehicles — Vehicle dynamics test methods — Part 1: General conditions for passenger cars*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8855 and the following apply.

3.1
low-speed path radius
radius of the circular path transcribed by the origin of the vehicle axis system when the vehicle is operated at constant speed with a given fixed steering-wheel angle and with approximately zero lateral acceleration

4 Principle

4.1 Test methods

Three test methods are specified:

- Method 1, the constant-radius test method;
- Method 2, the constant steering-wheel angle test method;
- Method 3, the constant-speed test method.

Each method is presented with two variations and differs in requirements for testing space, driver skill, and instrumentation. Methods 1 and 3 depend upon the path-keeping ability of the driver to minimize instrumentation requirements. Method 2 uses fixed steering-wheel angle and calculates path radius from measures of inertial instruments.

4.2 Equivalence of test methods

The nature of any stable steady state is independent of the method by which it is achieved. Therefore, to obtain a desired set of steady-state equilibrium conditions of speed, steering-wheel angle and turn radius, it is possible to hold any one of them constant, vary a second and measure the third. Thus, a *constant-radius test method* (in which speed is varied and steering-wheel angle is measured), a *constant steering-wheel angle test method* (in which speed is varied and radius is calculated from variables of vehicle motion) or a *constant-speed test method* (in which radius is varied and steering-wheel angle is either measured or varied and the radius calculated from variables of vehicle motion) may be used. The conditions that are to be held constant, varied and measured or calculated are summarized in Table 1.

Table 1 — Test conditions

Test method	Constant	Varied	Measured or calculated
Constant radius	Radius	Speed	Steering-wheel angle
Constant steering-wheel angle	Steering-wheel angle	Speed	Radius
Constant speed with discrete turn radii	Speed	Radius	Steering-wheel angle
Constant speed with discrete steering-wheel angles	Speed	Steering-wheel angle	Radius

All three test methods will produce equivalent steady-state results, provided they span the same combination of speed-steer-radius steady-state conditions. Moreover, in principle, an equivalent to any of the methods can be obtained by cross-plotting a series of results from one to produce the results from another.

EXAMPLE Taking points at constant speed from a series of constant-radius tests run on different turn radii.

In practice, however, results obtained from tests conducted with different combinations of speed, steer and radius may differ due to differences in road-load throttle, aerodynamics, tyre slip and inclination angles at different steering angles, etc. Also, the steering system is non-linear in many vehicles and does not have a fixed overall steering ratio. Gradients obtained using one method at a given steady-state equilibrium condition can differ from those obtained using another because, while in one method lateral acceleration is controlled by changing speed, in another it is controlled by changing the steering-wheel angle. Practical considerations such as tyre heating during long test runs and failure to maintain true steady state also tend to affect test results.

5 Variables

5.1 Reference system

The provisions given in ISO 15037-1:1998, 3.1, apply.

5.2 Measurement

Measure the following variables:

a) longitudinal velocity (v_X);

b) lateral acceleration (a_Y);

c) steering-wheel angle (δ_H).

Alternatively, lateral acceleration may be determined from other motion variables (see 9.2).

NOTE The method chosen to determine lateral acceleration could require the measurement of additional variables (yaw velocity, vehicle roll angle, or sideslip angle) for use in the computation.

The following variables should also be measured:

- yaw velocity ($\mathrm{d}\psi/\mathrm{d}t$);
- sideslip angle (β) and/or lateral velocity (v_Y);
- longitudinal acceleration (a_X);
- vehicle roll angle (φ_V);
- steering-wheel torque (M_H).

In addition, front steer angle (δ_F) and rear steer angle (δ_R) may be measured.

6 Measuring equipment

6.1 Description

The variables selected for test purposes shall be measured using appropriate transducers and the data recorded on a multi-channel recording system having a time base. Typical operating ranges, and recommended maximum errors of the transducer and recording system, are given in ISO 15037-1 and Table 2.

Table 2 — Variables, their typical operating ranges and recommended maximum errors

Variable	Typical operating range	Recommended maximum error of the combined transducer/recorder system
Front steer angle	± 20°	± 0,2°
Rear steer angle	± 10°	± 0,1°
Steering-wheel torque	± 30 N · m	± 0,3 N · m
NOTE Increased measurement accuracy could be desirable for computation of some of the characteristic values given in 10.3.		

6.2 Transducer installation

The transducer installation shall comply with ISO 15037-1:1998, 4.2.

6.3 Data processing

The provisions given in ISO 15037-1:1998, 4.3 apply.

7 Test conditions

Test conditions shall be in accordance with ISO 15037-1:1998, Clause 5. General data on the test vehicle shall be recorded as specified in ISO 15037-1:1998, 5.4.1 and the following paragraph.

The tyre type, tyre brand, any special equipment on the test vehicle, any deviation in type or operating condition of components from the manufacturer's specification, the odometer reading at the beginning and end of the test, and any other condition that may affect test results shall also be recorded on the test report for general data (see ISO 15037-1:1998, Annex A).

8 Test procedure

8.1 Warm-up

The warm-up shall be carried out in accordance with ISO 15037-1:1998, 6.1.

8.2 Initial driving condition

The conditions shall be in accordance with ISO 15037-1:1998, 6.2.1 and 6.2.3, and the following (8.3 to 8.6), according to which of the three methods and their variations is used.

8.3 General test description

All necessary variables shall be recorded throughout the manoeuvre. Data shall be taken for both left and right turns.

For tests utilizing discrete increments of speed, radius or steering-wheel angle, all of the test data may be taken in one turn direction followed by all the data in the other turn direction, as experience has shown that this minimizes data scatter. However, to obtain more even tyre wear and reduced tyre heating, data may be taken in alternating turn directions at each test speed/radius/steering-wheel angle.

The method chosen shall be noted in the section for test method specific data on the test report for test conditions (see ISO 15037-1:1998, Annex B). At a minimum, data shall be taken at increments of lateral acceleration no larger than 0,5 m/s^2.

NOTE Where data vary rapidly with changes in lateral acceleration, it can be useful to decrease the speed/radius/steering-wheel angle increments.

The test should be repeated several times so that the results can be examined for repeatability and averaged.

Caution should be exercised during testing so that tyre heating is minimized as much as possible. Tyre heating is a particular concern for test methods using continuous speed increase, with attendant long periods of data acquisition, and for all test methods at high levels of lateral acceleration. The tyres should be cooled to normal operating temperatures between test runs.

8.4 Method 1 — Constant-radius

8.4.1 Description

This test method requires driving the test vehicle at several speeds over a circular path of known radius. The standard radius of the path shall be 100 m, but larger and smaller radii may be used, with 40 m as the recommended lower value and 30 m as the minimum.

The directional-control response characteristics are determined from data obtained while driving the vehicle at successively higher speeds on the constant-radius path. This procedure can be conducted in a relatively small area. The procedure can be adapted to existing test track facilities by selecting a circle or a path of appropriate radius. Often a constant-radius (in plane) road will suffice for a test facility.

The constant-radius test exists in two variations. In the first, the vehicle is driven on the circular path at discrete constant speeds. Data are taken when steady state is attained. The test can be run on any level constant-radius path of sufficient length to attain and hold on-radius steady state for at least a 3 s measurement period. In the second, the vehicle remains on the circle with a continuous, slow speed increase, during which data are taken.

8.4.2 Procedure

8.4.2.1 General

First, drive the vehicle on the desired circular path at the lowest possible speed. Record data with the steering-wheel and throttle positions fixed, so that the approximate Ackermann steer angle can be recorded.

Then, drive the vehicle at the next speed at which data are to be taken. Increase the level of the lateral acceleration and take data until it is no longer possible to maintain steady-state conditions.

8.4.2.2 With discrete test speeds

Drive the vehicle onto the circle at each test speed. After attaining steady state, in which the desired path radius is held within ± 0,5 m, the steering wheel and throttle positions shall be held constant for at least 3 s.

8.4.2.3 With continuous speed increase

Steadily increase the speed and record data continuously, for as long as the vehicle remains on the desired circular path within ± 0,5 m. The maximum rate of increase of lateral acceleration should be 0,1 $m/s^2/s$. The maximum permissible rate of increase of lateral acceleration shall be 0,2 $m/s^2/s$.

8.5 Method 2 — Constant steering-wheel angle

8.5.1 Description

This test method requires driving the test vehicle at several speeds with a single selected steering-wheel angle that is held fixed. The path radius is determined by computation: from horizontal velocity and yaw velocity, or from horizontal velocity and lateral acceleration. The test exists in two variations: a series of discrete test runs, or a single continuous test run. In the first, the steering-wheel angle is applied with the vehicle travelling at discrete speeds and is maintained until steady-state conditions are reached. In the second, the steering-wheel angle is held fixed while speed is increased continuously at a slow rate, up to the limit of control.

The standard steering-wheel angle shall provide a low-speed path radius of 30 m. Other radii may be used, with 20 m as the minimum. For testing to the limit of control with the standard initial condition, the path radius can increase to 100 m or more.

8.5.2 Procedure

8.5.2.1 General

First, drive the vehicle at the lowest possible speed to establish the steering-wheel angle for the selected low-speed path radius.

Then, drive the vehicle at successively higher speeds, with the steering-wheel angle held constant or mechanically fixed within ± 1° of the selected steering-wheel angle. Run the test through the desired range of lateral acceleration, or until the limits of test space, vehicle speed, or vehicle stability are reached.

8.5.2.2 With discrete test speeds

At each selected speed, the steering wheel shall be turned to the preselected steering-wheel angle and maintained until steady-state conditions, including speed and throttle, are attained. The steering-wheel angle and throttle position shall be held constant for at least 3 s.

NOTE This procedure is the same as that of 8.5.2.3, except that the steering-wheel angle is maintained and speed varied.

8.5.2.3 With continuous speed increase

The steering-wheel angle shall be held constant or mechanically fixed at the pre-selected steering-wheel angle while the vehicle speed is steadily increased. The maximum rate of increase of lateral acceleration should be 0,1 $m/s^2/s$. The maximum permissible rate of increase of lateral acceleration shall be 0,2 $m/s^2/s$.

8.6 Method 3 — Constant-speed

8.6.1 Description

This test method requires driving the test vehicle at one speed on circular paths of different radii, utilizing a range of steering-wheel angles. The directional-control response characteristics are determined from data plotted against lateral acceleration. This test method could require large test areas, depending on the combination of speed and lateral acceleration. The discrete turn radii method requires a number of marked circles or circular segments with different radii, sufficient in number to provide 0,5 m/s^2 lateral acceleration increments at the selected speed. An adjustable steering stop should be used, for maintaining constant steering-wheel angles in the discrete steering-wheel angle method.

The standard test speed is 100 km/h. If higher or lower speeds are selected, they shall be in 20 km/h increments.

8.6.2 Procedure

8.6.2.1 General

From an initial constant-speed driving condition, apply steering inputs of successively increasing magnitude and hold them constant or mechanically fixed within $\pm 1^\circ$ for 3 s after the measured vehicle motion variables reach steady state. Control the throttle in order to maintain constant speed within 3 % throughout the test run. Run the test through the desired range of lateral acceleration, or until the limits of test space, vehicle speed, or vehicle stability are reached.

8.6.2.2 With discrete turn radii

Drive the vehicle onto the circle at the pre-selected speed. After attaining steady state, the steering wheel and throttle position shall be held constant for at least 3 s.

8.6.2.3 With discrete steering-wheel angles

With the vehicle being driven at the pre-selected speed, apply a steering input and hold it constant for at least 3 s after the measured vehicle motion variables reach steady state. Control the throttle in order to maintain constant speed throughout the run.

NOTE It is possible to use the constant-speed test method with discrete steering-wheel angles to extract transient response measures comparable to those obtained from the step input method of ISO 7401:2003, if the steering input is applied in accordance with ISO 7401:2003, 8.1. However, since ISO 7401:2003, 8.1, requires a fixed throttle position versus the controlled throttle position in the constant-speed test method, the resulting transient response measured might not be identical to those obtained from ISO 7401:2003, 8.2.

9 Data analysis

9.1 General

The steady-state values for all measured variables shall be established as their average values during any time interval of 1 s to 3 s during which steady state is maintained. For each selected time interval, the limitations on path radius, steer angle, speed, rate of increase of lateral acceleration and/or throttle position specified in the description of the test procedure being followed shall be observed. In addition, for each selected time interval, the standard deviation of lateral acceleration shall not exceed 5 % of its mean value.

9.2 Lateral acceleration

Theoretically, steady-state characteristics should be determined as functions of centripetal acceleration, which is measured perpendicular to the path. Traditionally, these characteristics have been expressed as functions of lateral acceleration, which is measured perpendicular to the intermediate X-axis. At steady state, lateral acceleration and centripetal acceleration differ only by the cosine of the sideslip angle. In most cases, the vehicle sideslip angle is small, so lateral acceleration may generally be considered to be equal to centripetal acceleration. Where large values of vehicle sideslip angle are observed, or where greater accuracy is desired, centripetal acceleration may be corrected to obtain lateral acceleration.

Steady-state centripetal acceleration may be obtained by any one of the following three methods.

a) The product of yaw velocity and horizontal velocity:

$$\frac{\mathrm{d}\psi}{\mathrm{d}t} \times v_\mathrm{h}$$

b) The square of the horizontal velocity, divided by the path radius:

$$\frac{{v_\mathrm{h}}^2}{R}$$

c) The product of the square of the yaw velocity and the path radius:

$$\left(\frac{\mathrm{d}\psi}{\mathrm{d}t}\right)^2 \times R$$

The method used to determine lateral acceleration shall be noted in the test report.

9.3 Path radius

For the constant steering-wheel angle test method, path radius R (see ISO 8855:1991, 2.3.2) may be computed at steady state from longitudinal velocity, corrected for sideslip angle, divided by yaw velocity, corrected for vehicle roll angle.

10 Data evaluation and presentation of results

10.1 General

General data on the test vehicle shall be presented on a summary form using the general data test report contained in ISO 15037-1:1998, Annex A. The general test conditions shall be presented using the test conditions test report contained in ISO 15037-1:1998, Annex B.

10.2 Plotted results (see Annex A)

Measured data shall be plotted directly against lateral acceleration on figures, as follows:

a) steering-wheel angle data points for the constant-radius and constant-speed test methods on Figure A.1;

b) path radius data points for the constant steering-wheel angle test method on Figure A.2;

c) sideslip angle data points, if measured, on Figure A.3;

d) vehicle roll angle data points, if measured, on Figure A.4;

e) steering-wheel torque data points, if measured, on Figure A.5.

Curves may be fitted to the plotted points either freehand or by one of the many mathematical routines available. The method of curve fitting should be stated. This is particularly recommended where the process involves fitting smooth curves to experimental data for the purpose of evaluating the gradients. The type of curve and the method of fitting will influence the results obtained.

NOTE Within the context of an International Standard, it is not possible to recommend any one way as being better than another.

10.3 Evaluation of characteristic values

10.3.1 General

There are a number of ways to further process the data presented here. These have been developed as conventions over many years and each can be justified in its own way — for example, the division of steering-wheel angle data by a nominal overall steering ratio. The following specified variables represent, therefore, only examples for the evaluation of results, which describe vehicle steady-state behaviour. Any one of these methods may be used at the option of the user. If this evaluation is carried out, it will be necessary to determine the overall steering ratio. The method for determining the overall steering ratio is given in Annex B.

10.3.2 Evaluation of gradients — Differentiation

10.3.2.1 General

A common method of further treating basic experimental data is to derive the gradient of the curve fitted to the experimental points. The values of gradient thereby obtained are then plotted against the independent variable (in this case, lateral acceleration) to give a response graph.

As mentioned in 10.2, curves may be fitted to the experimental data either freehand or by a mathematical routine. If curve fitting is being done for the purpose of gradient evaluation, it is strongly recommended that the latter method be used; otherwise, the repeatability of the resulting gradients cannot be guaranteed. In addition, because each resulting curve will be described by a mathematical expression, it can be differentiated mathematically to produce the gradient as a continuous function of lateral acceleration.

NOTE It has been found that the characteristics of some vehicles have discontinuities in slope, which are not easily dealt with by standard curve fitting and differentiating techniques.

By this means, the following derived gradients can be obtained and plotted as functions of lateral acceleration. The gradients are plotted against lateral acceleration using the convention: lateral acceleration on the abscissa, with left turns positive, right turns negative; and the gradients on the ordinate with normal sign convention.

10.3.2.2 Steering-wheel angle gradient

See ISO 8855:1991, 6.3.4. This gradient is expressed by the following equation:

$$\frac{\partial\left(\delta_{\mathrm{H}}\right)}{\partial\left(a_Y\right)}$$

NOTE This gradient cannot be computed from the results obtained using the constant steering-wheel angle test method if the test is performed using only one steering-wheel angle.

10.3.2.3 Path curvature gradient

This gradient is expressed by the following equation:

$$\frac{\partial\left(\frac{1}{R}\right)}{\partial\left(a_Y\right)}$$

NOTE This gradient cannot be computed from the results obtained using the constant-radius test method if the test is performed using only one turn radius.

10.3.2.4 Sideslip angle gradient

See ISO 8855:1991, 6.3.7. This gradient is expressed by the following equation:

$$\frac{\partial\left(\beta\right)}{\partial\left(a_Y\right)}$$

10.3.2.5 Vehicle roll angle gradient

See ISO 8855:1991, 6.3.6.1. This gradient is expressed by the following equation:

$$\frac{\partial\left(\varphi_{\mathrm{V}}\right)}{\partial\left(a_Y\right)}$$

10.3.2.6 Steering-wheel torque gradient

See ISO 8855:1991, 6.3.5. This gradient is expressed by the following equation:

$$\frac{\partial\left(M_{\mathrm{H}}\right)}{\partial\left(a_Y\right)}$$

10.3.2.7 Steering-wheel/sideslip angle gradient

See ISO 8855:1991, 6.3.8. This gradient is expressed by the following equation:

$$\frac{\partial\left(\delta_{\mathrm{H}}\right)}{\partial\left(\beta\right)}$$

While, in theory, the steering-wheel/sideslip angle curve can be produced from the ratio of curves of steering-wheel angle and sideslip angle versus lateral acceleration, this method is likely to lead to significant errors. It is preferable to fit a curve directly to the steering-wheel angle versus sideslip angle data and to differentiate it with respect to sideslip angle to produce steering-wheel/sideslip angle gradient versus sideslip angle, and then to transform the latter variable into lateral acceleration by using the sideslip angle/lateral acceleration relationship given in 10.3.2.4.

NOTE 1 This curve is believed by some experts to relate strongly to the vehicle behaviour as perceived by the driver, i.e. the relationship between the steering-wheel input and the resulting vehicle sideslip angle.

NOTE 2 This gradient cannot be computed from the results obtained using the constant steering-wheel angle test method if the test is performed using only one steering-wheel angle.

10.3.3 Normalisation of results — Comparison of results from different vehicles

10.3.3.1 General

Gradients obtained by different methods at a given steady-state equilibrium condition may differ. This is because different test methods control lateral acceleration by different variables (speed, path radius or steering-wheel angle). Therefore, only data obtained by the same method and at the same speed and radius steady-state conditions are comparable.

10.3.3.2 Explanation

In any general case of a vehicle making a steady-state turn of given radius, the steer angle required will consist of two parts: that due to the Ackermann effect, which for a given radius is proportional to the wheelbase; and that due to the handling characteristics of the vehicle. In addition, the steering-wheel angle corresponding to the required steer angle will depend on the overall steering ratio.

Thus, there are three quantities to be taken into account in the general case:

a) wheelbase, l;

b) overall steering ratio, i_S;

c) steering-wheel angle gradient, $\partial(\delta_\mathrm{H})/\partial(a_Y)$.

The units of the steering-wheel angle gradient will be degrees per metres per second squared, and, by convention, a vehicle with zero steering-wheel angle gradient — that is to say one which needs no movement of its steering wheel when changing speed on a curve of constant radius — is defined as a neutral-steer vehicle. The steering-wheel angle of a neutral-steer vehicle becomes a function only of turn radius, steering ratio and wheelbase.

The steering-wheel angle gradient of any vehicle can be normalised by dividing the measured responses of the actual vehicle by the product of its wheelbase and steering ratio.

The practical benefits of doing this are that the steering-wheel angle gradient of vehicles of widely different sizes and steering ratios can be compared analytically by comparing their normalized measured responses.

Comparison of measurements that have not been normalised will not clearly show differences in steering-wheel angle gradient because they also contain the effects of differences in wheelbase and steering ratio.

In this particular procedure the numerical value of the product of wheelbase and steering ratio is the same as the product of the test radius and the steering-wheel angle, in radians, required at zero speed on that radius. This steering-wheel angle is the intercept of the curve in Figure A.1 with the zero lateral acceleration line and thus, the value of the product of steering ratio and wheelbase can be obtained without direct measurement.

10.3.4 Normalized steady-state properties

10.3.4.1 General

In the light of the explanation given in 10.3.3.2, it is now possible to define normalized steady-state properties that correspond to the non-normalized ones of 10.3.2. However, there does not appear to be any significance in normalized sideslip angle, roll angle or torque gradients, and therefore only normalized equivalents of steering-wheel/sideslip angle gradient are described.

10.3.4.2 Normalization with respect to steering ratio

This technique is useful for comparing results from vehicles of similar wheelbase. The procedure for measuring steering ratio is given in Annex B.

a) **Understeer gradient**

See ISO 8855:1991, 6.3.9. This gradient is determined by dividing the steering-wheel angle gradient by the steering ratio and subtracting the dynamic reference steer angle gradient:

$$\frac{\partial\left(\delta_{\mathrm{H}}\right)}{\partial\left(a_Y\right)} \times \frac{1}{i_{\mathrm{S}}} - \frac{\partial\left(\delta_{\mathrm{D}}\right)}{\partial\left(a_Y\right)}$$

In a constant-radius test (see 8.4), the dynamic reference steer angle gradient is zero, so the equation can be written as

$$\frac{\partial\left(\delta_{\mathrm{H}}\right)}{\partial\left(a_Y\right)} \times \frac{1}{i_{\mathrm{S}}}$$

Whereas, in a constant steering-wheel angle test (see 8.5), the steering-wheel angle gradient is not defined, and understeer can be found most directly from the path curvature gradient (see 10.3.2.3), as the product of the wheelbase and the path curvature gradient:

$$l \times \frac{\partial\left(\frac{1}{R}\right)}{\partial\left(a_Y\right)}$$

b) **Understeer/sideslip gradient**

This gradient is determined by dividing the steering-wheel/sideslip angle gradient (see 10.3.2.7), by the steering ratio:

$$\frac{\partial\left(\delta_{\mathrm{H}}\right)}{\partial\left(\beta\right)} \times \frac{1}{i_{\mathrm{S}}}$$

10.3.4.3 Normalization with respect to wheelbase — Stability factor

This technique yields response values that can be used to compare vehicles of widely different sizes. See ISO 8855:1991, 6.3.10.

The stability factor is determined by dividing the understeer gradient by the wheelbase.

10.3.4.4 Normalization with respect to sideslip angle gradient — Directional coefficient

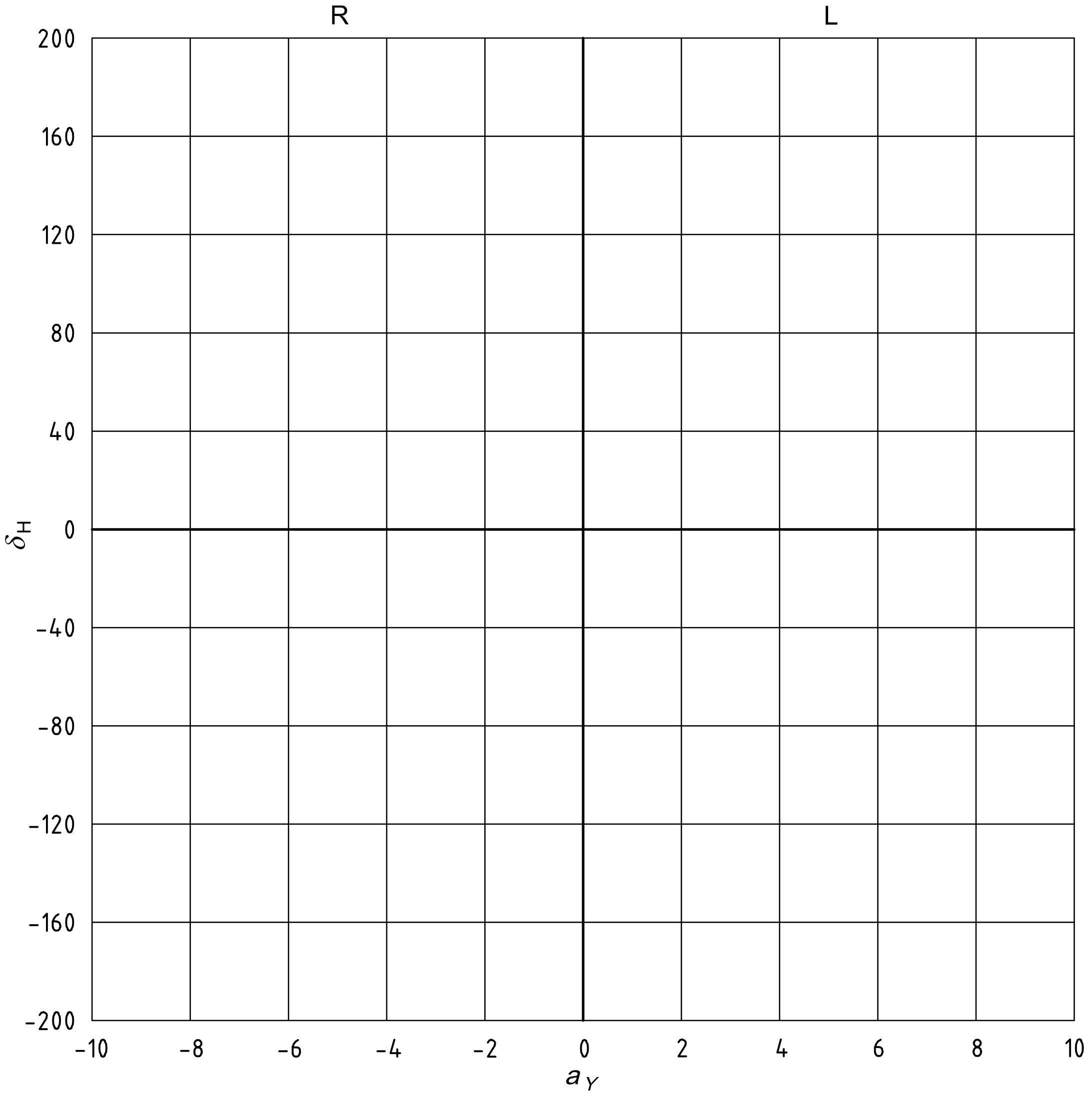
See ISO 8855:1991, 6.3.11.

The directional coefficient is determined by dividing the stability factor by the sideslip angle gradient.

Annex A
(normative)

Presentation of results

The characteristic values of the vehicle dynamic reaction shall be presented as functions of steady-state lateral acceleration in accordance with Figures A.1 to A.5.



Vehicle: ....

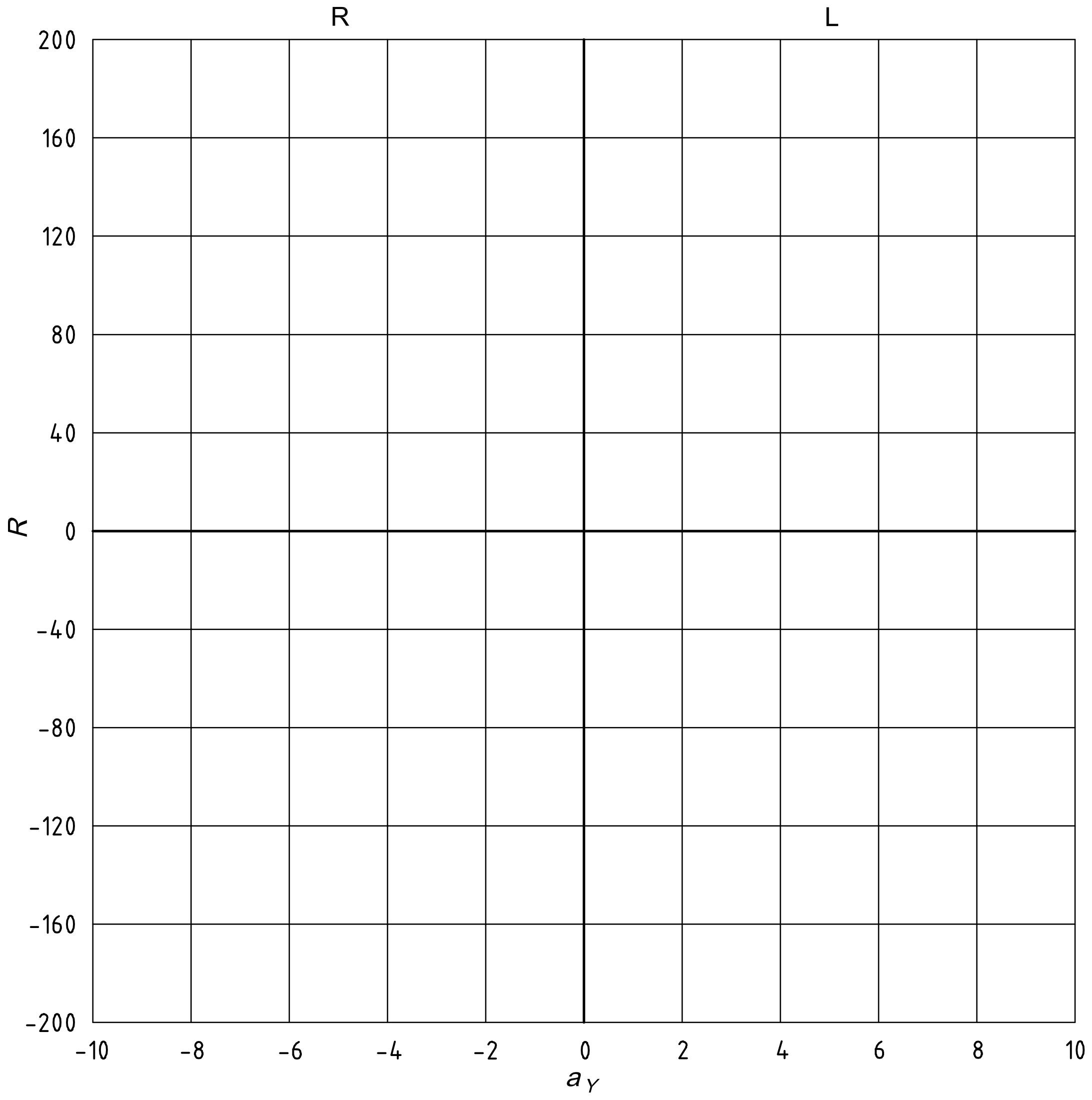
Turn radius (constant-radius test method): ....

Test speed (constant-speed test method): ....

Key

a_Y	lateral acceleration, m/s^2
δ_H	steering-wheel angle, degrees
R	right turn
L	left turn

Figure A.1 — Steering-wheel angle characteristic

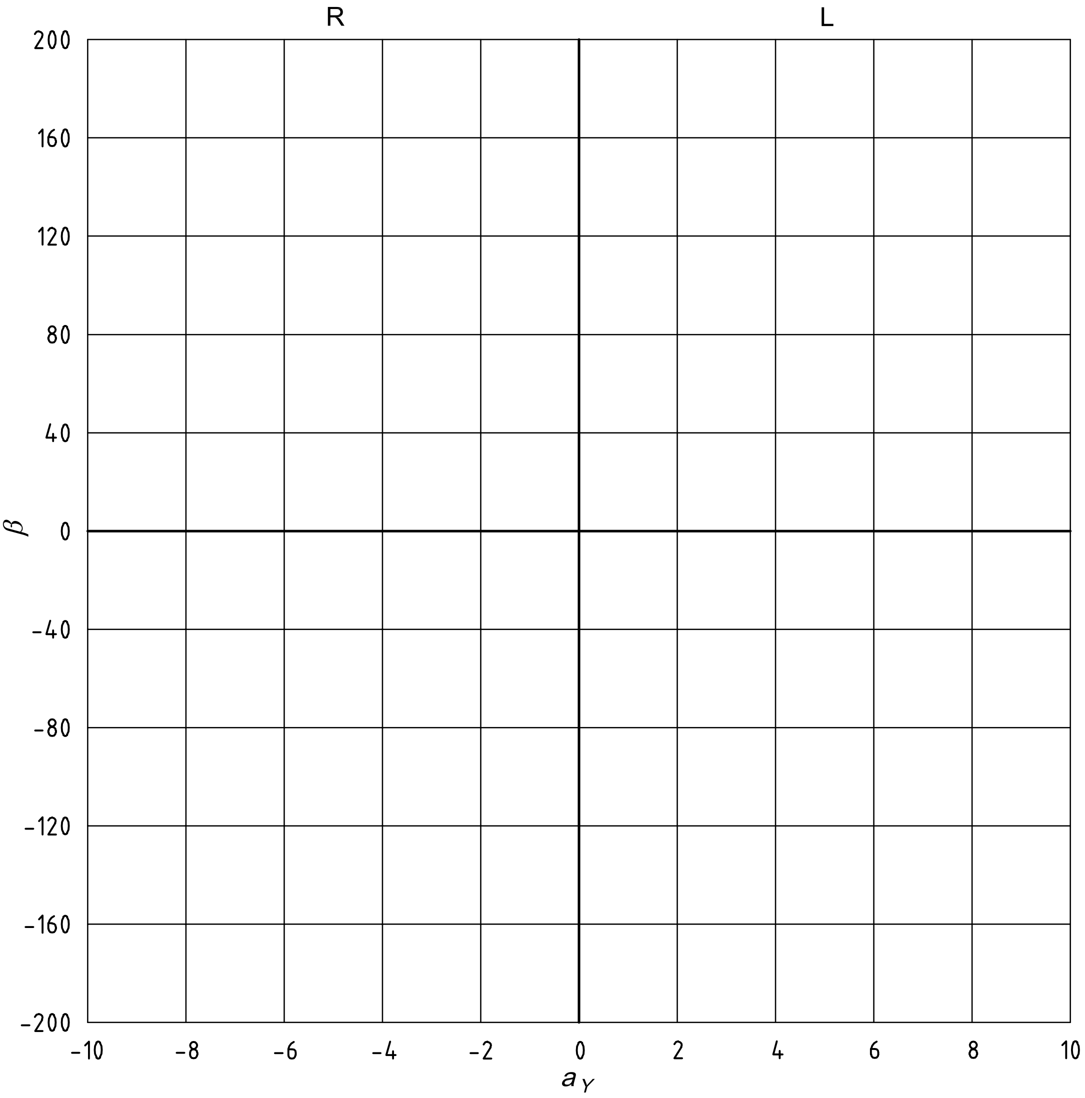


Vehicle: ....
Steering-wheel angle (constant steering-wheel angle test method): ....

Key

a_Y	lateral acceleration, m/s^2
R	path radius, m
R	right turn
L	left turn

Figure A.2 — Path radius characteristic

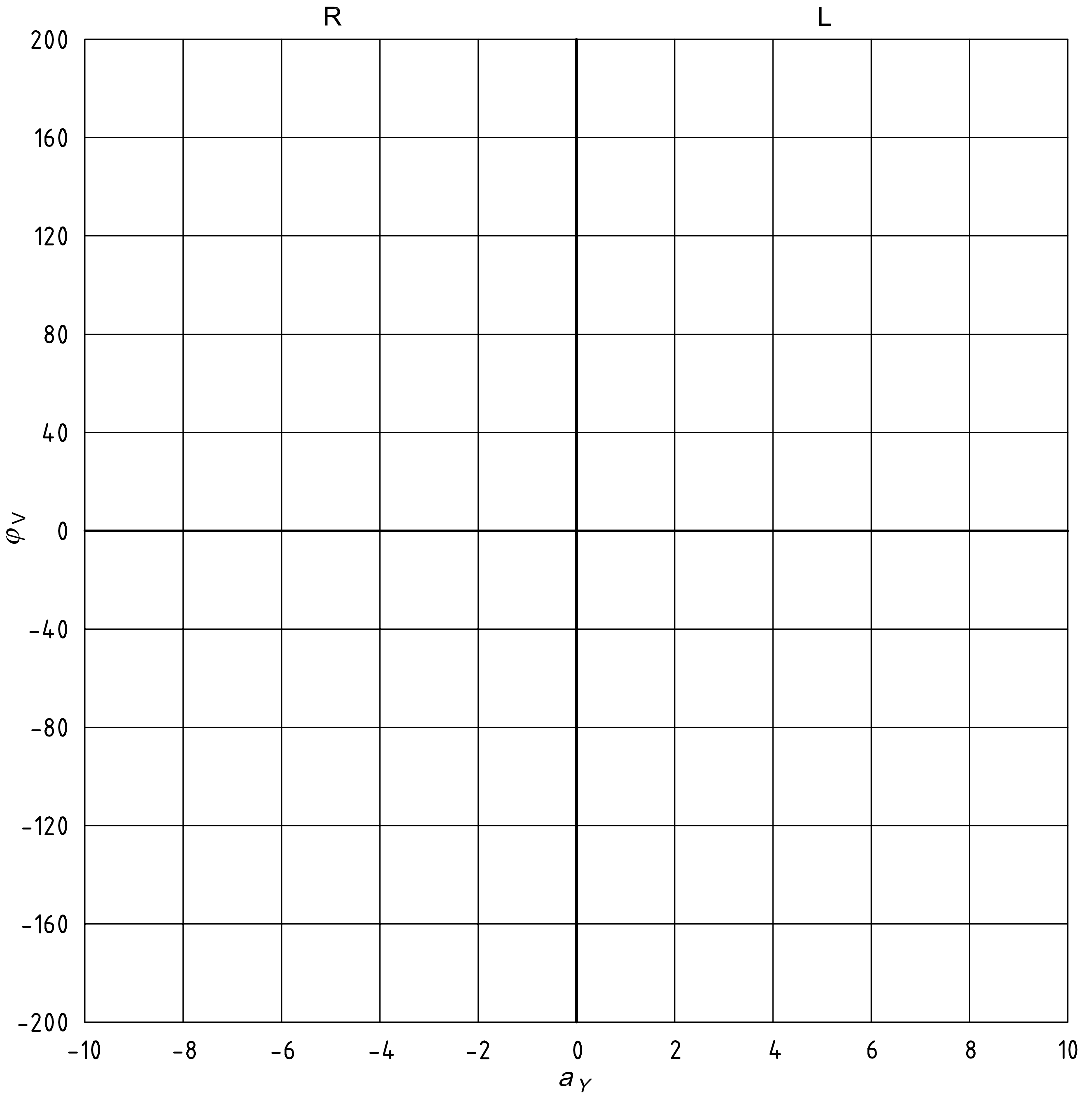


Vehicle: ....
Turn radius (constant-radius test method): ....
Steering-wheel angle (constant steering-wheel angle test method): ....
Test speed (constant-speed test method): ....

Key

a_Y	lateral acceleration, m/s^2
β	sideslip angle, degrees
R	right turn
L	left turn

Figure A.3 — Sideslip angle characteristic

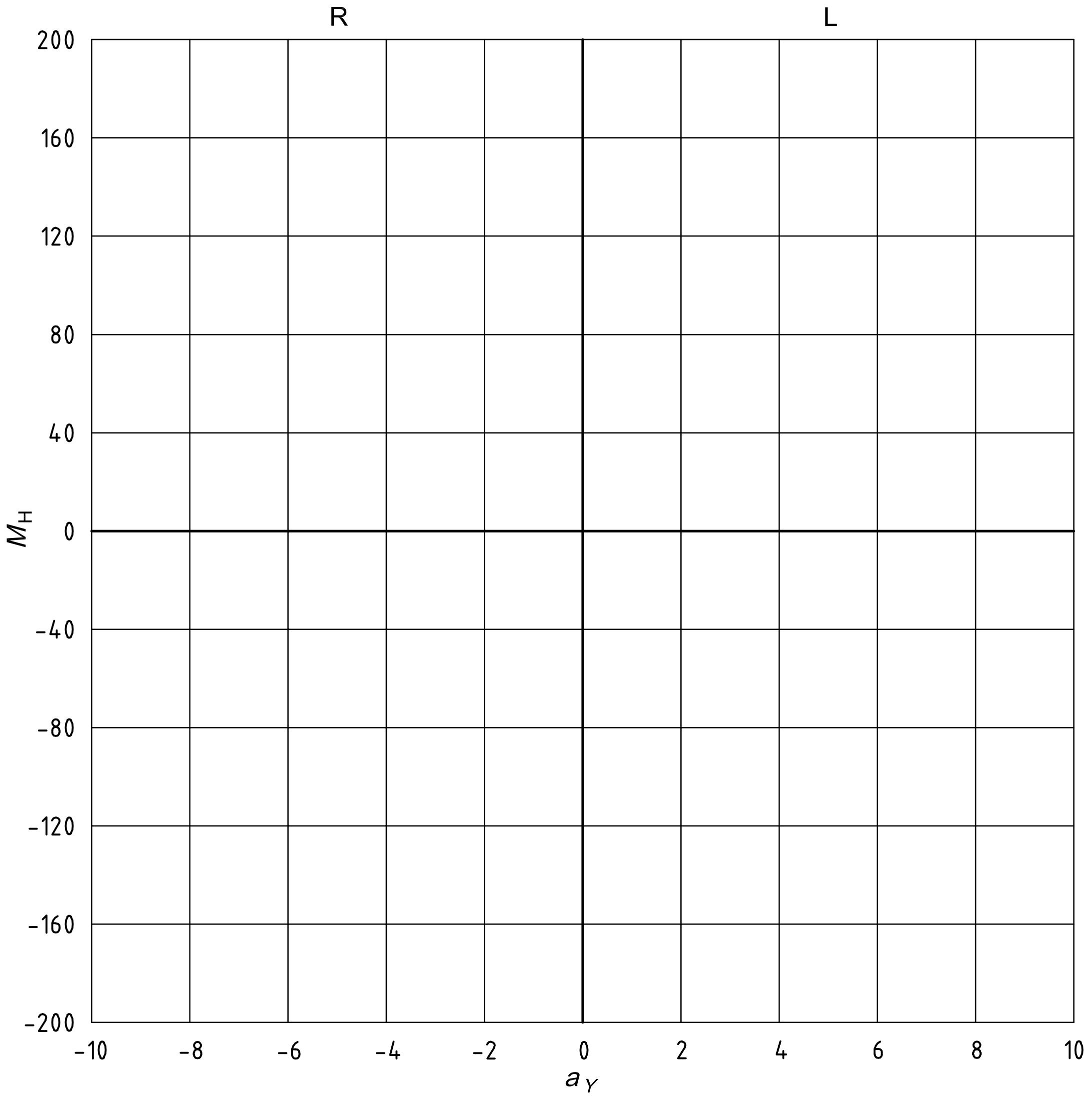


Vehicle: ....
Turn radius (constant-radius test method): ....
Steering-wheel angle (constant steering-wheel angle test method): ....
Test speed (constant-speed test method): ....

Key

a_Y	lateral acceleration, m/s^2
φ_V	vehicle roll angle, degrees
R	right turn
L	left turn

Figure A.4 — Vehicle roll angle characteristic



Vehicle: ....
Turn radius (constant-radius test method): ....
Steering-wheel angle (constant steering-wheel angle test method): ....
Test speed (constant-speed test method): ....

Key

a_Y	lateral acceleration, m/s^2
M_H	steering-wheel torque, N·m
R	right turn
L	left turn

Figure A.5 — Steering-wheel torque characteristic

Annex B
(normative)

Determination of overall (static) steering ratio

B.1 Steering systems

Understeer gradients are stated in terms of the difference in cornering compliances between the front and rear road-wheel “axles”. However, cornering compliances include deflections of the steering system due to elastic deformations. In order to include steering-system compliances, understeer is determined from measurements taken at the steering wheel. Steering-wheel angles are referred to the road wheels by the overall steering ratio, i_S.

Overall steering ratio (see ISO 8855:1991, 4.1.5.8) is a variable which describes the geometric relationship between steering-wheel angle and average road-wheel angle, measured under conditions of zero aligning moment and lateral force. If the steering system is significantly non-linear, each measured steering-wheel angle must be used together with a plot of average road-wheel angle versus steering-wheel angle to obtain the corresponding road-wheel steer angle. Steer angle gradients are obtained from a plot of road-wheel steer angle versus lateral acceleration.

B.2 Vehicles with four-wheel steering

Current four-wheel steering systems can be divided into three general types: rear steer having a programmed relationship to steering-wheel angle; rear steer programmed according to lateral acceleration; and rear/front steer ratio programmed according to speed or other, more complex, relationships. The first type creates a combined net-effect front/rear steering ratio, which is in general non-linear. The second type can be treated as only an additional source of (usually negative) rear wheel compliance steer. However, the third type must be considered as a separate control input. For steady-state testing of this third type of vehicle it could be necessary to disable the rear steering so as to measure basic response parameters, then by additional testing with rear steer enabled, determine the rear-steer control algorithm, and measure its effect on steady-state response parameters. Alternatively, tests of vehicles with systems of the third type may be conducted by holding the state that affects the rear steer ratio constant during the test. For example, vehicles with a speed-varying rear steer ratio may be tested using the constant-speed test method. Repeat tests at several different speeds would define the vehicle characteristics at different operating conditions.

B.3 Measurement

The overall steering ratio shall be determined for each vehicle test configuration over the range of steering-wheel angles used during the test.

The overall steering ratio will not, in general, represent the dynamic situation because of additional steering-system deflections caused by compliance and geometric effects. It is, however, suitable for removing the effect of different steering-system lever and gear ratios from comparisons of measurements from different vehicles. The compliance and geometric effects referred to above are then quite properly regarded as part of the vehicle handling characteristics.

Annex C
(informative)

General information — Theoretical basis for the test methods

The path curvature of an automobile in steady-state turning at a given speed (i.e. in a given state of steady-state equilibrium) is determined by speed, steering-wheel angle, wheelbase, and the elastic and kinematic characteristics of the front and rear steering systems, suspensions and tyres.

In the absence of kinematic and compliance steer effects — for example, at very low speeds — the low-speed path radius is defined geometrically by wheelbase and by front- and rear-wheel steer angles. At increasing speed, steady-state turning results in centrifugal force, which produces kinematic and compliance steer and camber. When expressed in degrees per metre per second squared of lateral acceleration and lumped together, these “cornering compliances” produce steer angles and tyre slip angles in front and rear that modify the low-speed path radius. Cornering compliances subtract from the front and rear Ackermann steer angles. Cornering compliances greater in the front than in the rear increase path radius from the Ackermann condition, and produce understeer; while cornering compliances greater in the rear than in the front reduce path radius, causing oversteer. The difference between the total front and rear cornering compliance is called the understeer gradient, expressed in degrees per metre per second squared. Similarly, the change in steering-wheel angle required to maintain a given radius with increasing lateral acceleration is called steering-wheel angle gradient, the change in roll angle with lateral acceleration is called roll angle gradient, etc.

The test procedures specified by this International Standard are designed to be used to measure these various vehicle steady-state properties.

The sensitivities of the vehicle's responses to steering wheel inputs are called yaw velocity gain (degree per second per degree of steering-wheel movement), lateral acceleration gain (metres per second squared per degree of steering-wheel motion), sideslip gain, etc. These can be calculated from the vehicle speed, steering-wheel angle, steering ratio, wheelbase and understeer gradient, or they can be obtained directly from measured data.

Bibliography

[1] ISO 1176:1990, *Road vehicles — Masses — Vocabulary and codes*

[2] ISO 2416:1992, *Passenger cars — Mass distribution*

[3] SAE J266, *Steady-State Directional Control Test Procedures for Passenger Cars and Light Trucks*1)

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1) Society of Automotive Engineers standard.

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