
**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*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 33, *Vehicle dynamics and chassis components*.

This fifth edition cancels and replaces the fourth edition (ISO 4138:2012), which has been technically revised.

The main changes compared to the previous edition are as follows:

- editorial changes,
- a third variation of the constant speed test method was added. This variation involves slowly increasing the steering wheel angle.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The main purpose of this document is to provide repeatable and discriminatory test results.

The dynamic behaviour of a road vehicle is a very important aspect of active vehicle safety. Any given vehicle, together with its driver and the prevailing environment, constitutes a closed-loop system that is unique. The task of evaluating the dynamic behaviour is, therefore, very difficult since the significant interactions of these driver-vehicle-environment elements are each complex in themselves. A complete and accurate description of the behaviour of the road vehicle involves information obtained from a number of different tests.

Since this test method quantifies only one 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 work 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. Consequently, any application of this test method for regulation purposes will need proven correlation between test results and accident statistics.

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

1 Scope

This document 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 documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 8855, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*

ISO 15037-1:2019, *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.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

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.

Methods 1 and 2 are presented with two variations and method 3 with three variations. The methods differ 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 turning radius, it is possible to hold any one of them constant, vary the second and measure the third. Thus, either 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	Variable	Measured or calculated	Variation
1	Radius	Speed	Steering wheel angle	With discrete test speeds
				With continuous speed increase
2	Steering-wheel angle	Speed	Radius	With discrete test speeds
				With continuous speed increase
3	Speed	Radius	Steering-wheel angle	With discrete turn radii
		Steering wheel angle	Radius	With discrete steering-wheel angles
				With slowly increasing steering-wheel angle

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 nonlinear 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 and, whereas 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 available size of the test area, 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 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 can 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, $d\psi/dt$;
- sideslip angle, β and/or lateral velocity, v_Y ;
- longitudinal acceleration, a_X ;
- vehicle roll angle, ϕ_V ;
- steering-wheel torque, M_H .

The front steer angle, δ_F , and rear steer angle, δ_R , may also 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.

6.2 Transducer installation

The transducer installation shall be in accordance with ISO 15037-1:2019, 5.2.

6.3 Data processing

The provisions given in ISO 15037-1:2019, 5.3, apply.

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	$\pm 20^\circ$	$\pm 0,2^\circ$
Rear-steer angle	$\pm 10^\circ$	$\pm 0,1^\circ$
NOTE Increased measurement accuracy can be desirable for computation of some of the characteristic values given in 10.3.		

7 Test conditions

Test conditions shall be in accordance with ISO 15037-1:2019, Clause 6. General data on the test vehicle shall be recorded as specified in ISO 15037-1:2019, 6.4.1. In addition, 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 could affect test results shall be recorded on the test report for general data (see ISO 15037-1:2019, Annex A).

8 Test procedure

8.1 Warm-up

The warm-up shall be carried out in accordance with ISO 15037-1:2019, 7.1.

8.2 Initial driving condition

The conditions shall be in accordance with ISO 15037-1:2019, 7.2.1 and 7.2.3, and with [8.3](#) to [8.6](#) as follows, according to which method and variation 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. A minimum of three repetitions is recommended.

For tests utilizing discrete increments of speed, radius or steering-wheel angle, all of the test data may be taken in one turning direction followed by all the data in the other turning 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 turning directions at each test speed/radius/steering-wheel angle.

The method chosen shall be noted on the test report, in the section on test-method-specific data for test conditions (see ISO 15037-1:2019, Annex B). At a minimum, data shall be taken at increments of lateral acceleration no larger than $0,5 \text{ m/s}^2$. [Annex C](#) provides general information for the test methods.

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 path of appropriate radius. A constant-radius (in plane) road will often 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 $\pm 0,5$ 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 $\pm 0,5$ m. The maximum rate of increase of lateral acceleration should be $0,1 \text{ m/s}^2/\text{s}$. The maximum permissible rate of increase of lateral acceleration shall be $0,2 \text{ m/s}^2/\text{s}$.

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 $\pm 1^\circ$ 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 pre-selected 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 With the exception that in this procedure the steering-wheel angle is maintained and the speed is varied, this procedure and the procedure given in 8.5.2.3 are the same.

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 is $0,1 \text{ m/s}^2/\text{s}$. The maximum permissible rate of increase of lateral acceleration shall be $0,2 \text{ m/s}^2/\text{s}$.

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 $0,5 \text{ m/s}^2$ lateral acceleration increments at the selected speed. An adjustable steering stop should be used, for maintaining constant steering-wheel angles when using the discrete steering-wheel angle method.

The standard test speed is 100 km/h for discrete turn radii and wheel angles and 80 km/h for a slowly increasing steering wheel angle. 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. Control the throttle smoothly 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.

NOTE To avoid rapid changes in throttle inputs, it is possible to choose to keep the throttle constant throughout the test. If so, this is noted in the test report.

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 shall be held constant or mechanically fixed within $\pm 1^\circ$ 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 or mechanically fixed within $\pm 1^\circ$ 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, if the steering input is applied in accordance with ISO 7401:2011, 10.1. However, since ISO 7401:2011, 10.1 requires a fixed throttle position versus the controlled throttle position of the constant-speed test method, there is a possibility that the resulting measured transient response is not identical to that obtained from ISO 7401:2011, 10.2.

8.6.2.4 With slowly increasing steering-wheel angle

With the vehicle being driven at the pre-selected speed, apply a slowly increasing steering input.

The increase in lateral acceleration should preferably not exceed $2 \text{ m/s}^2/\text{s}$.

The recommended steering wheel angle rate is $13,5^\circ/\text{s}$ up to a lateral acceleration of approximately 5 m/s^2 .

For high-slip manoeuvres (limit conditions) the steering wheel angle rate may be increased to $30^\circ/\text{s}$ up to a maximum of 180° .

The actual test speed and steering wheel angle rate used in the test is dependent on conflicting requirements of not exciting the transient response of the vehicle (not too fast), available test space and unrealistic heating of the tire (not too long test time). The user should balance these requirements, considering the recommendations in this document. The actual parameters used in the test should be noted in the test report.

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 the 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 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:

$$\frac{d\psi}{dt} \times v_h$$

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

$$\frac{v_h^2}{R}$$

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

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

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_p (defined in ISO 8855:2011, 5.3.3) may be computed at steady-state from longitudinal velocity, corrected for sideslip angle, divided by yaw velocity and 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 presented in ISO 15037-1:2019, Annex A. The general test conditions shall be presented using the test conditions test report presented in ISO 15037-1:2019, Annex B.

10.2 Plotted results (see also [Annex A](#))

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

- steering-wheel angle data points for the constant-radius and constant-speed test methods in [Figure A.1](#);
- path radius data points for the constant steering-wheel angle test method in [Figure A.2](#);
- sideslip angle data points, if measured, in [Figure A.3](#);
- vehicle roll angle data points, if measured, in [Figure A.4](#);
- steering-wheel torque data points, if measured, in [Figure A.5](#).

Curves may be fitted to the plotted points, either freehand or using 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 this document it is not possible to recommend any one way as better than any other.

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 the use of each can be justified in its own fashion, 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, a method for which is given in [Annex B](#) and shall be followed.

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, left turns positive, right turns negative, while the gradients on the ordinate are plotted using the normal sign convention.

10.3.2.2 Steering-wheel angle gradient

According to ISO 8855:2011, 12.3.1, the steering wheel angle gradient is expressed as the partial derivative of the steering wheel angle with respect to the lateral acceleration:

$$\frac{\partial \delta_H}{\partial a_Y}$$

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 as the partial derivative of the path curvature (inverse of the curve radius) with respect to the lateral acceleration:

$$\frac{\partial \frac{1}{R}}{\partial a_Y}$$

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

10.3.2.4 Sideslip angle gradient

According to ISO 8855:2011, 12.3.5, this gradient is expressed as the partial derivative of the sideslip angle with respect to the lateral acceleration:

$$\frac{\partial \beta}{\partial a_Y}$$

10.3.2.5 Roll angle gradient

According to ISO 8855:2011, 12.3.3, this gradient is expressed as the partial derivative of the vehicle roll angle with respect to the lateral acceleration:

$$\frac{\partial \phi_V}{\partial a_Y}$$

10.3.2.6 Steering-wheel torque gradient

According to ISO 8855:2011, 12.3.2, this gradient is expressed as the partial derivative of the steering wheel torque with respect to the lateral acceleration:

$$\frac{\partial M_H}{\partial a_Y}$$

10.3.2.7 Steering-wheel/sideslip angle gradient

This gradient is expressed by the following formula:

$$\frac{\partial \delta_H}{\partial \beta}$$

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 of [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 his/her 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 Normalization 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: the first part due to the Ackermann effect, which for a given radius is proportional to the wheelbase, and the second part 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 account of in the general case:

- a) wheelbase, l ;
- b) overall steering ratio, i_s ;
- c) steering-wheel angle gradient, $\partial\delta_H/\partial a_Y$.

The units of the steering-wheel angle gradient will be degrees per m/s^2 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 turning radius, steering ratio and wheelbase.

The steering-wheel angle gradient of any vehicle can be normalized 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 normalized 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 shown 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 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 the steering ratio is given in [Annex B](#).

a) Understeer gradient

This gradient is determined by dividing the steering-wheel angle gradient by the steering ratio and subtracting the dynamic reference steer angle gradient:

$$\frac{\partial\delta_H}{\partial a_Y} \times \frac{1}{i_s} - \frac{\partial\delta_D}{\partial a_Y}$$

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

$$\frac{\partial\delta_H}{\partial a_Y} \times \frac{1}{i_s}$$

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:

$$l \times \frac{\partial \frac{1}{R}}{\partial a_Y}$$

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:

$$\frac{\partial \delta_H}{\partial \beta} \times \frac{1}{i_S}$$

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.

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

The directional coefficient is determined by dividing the stability factor by the sideslip angle gradient. See ISO 8855.

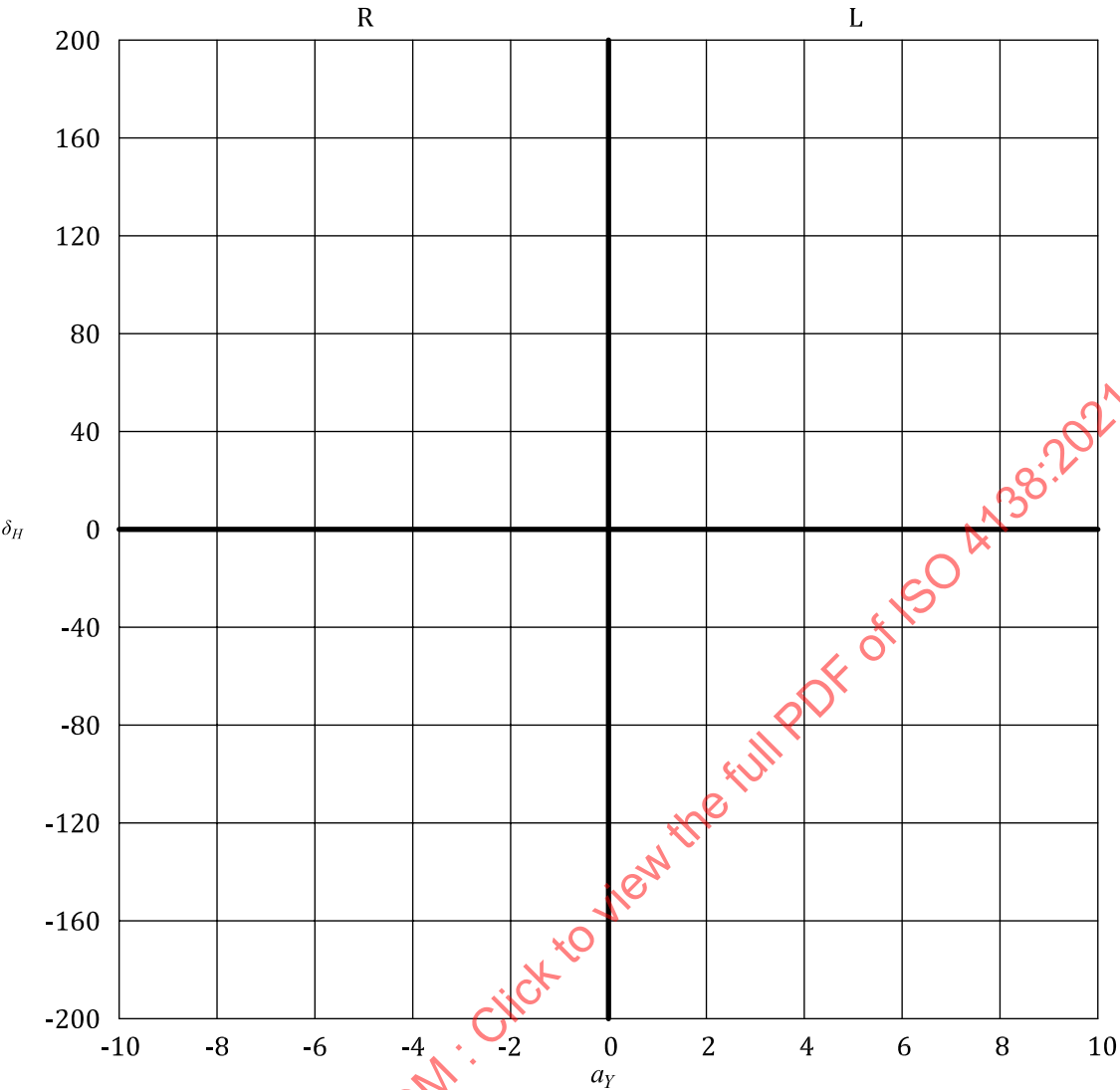
Annex A

(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](#).

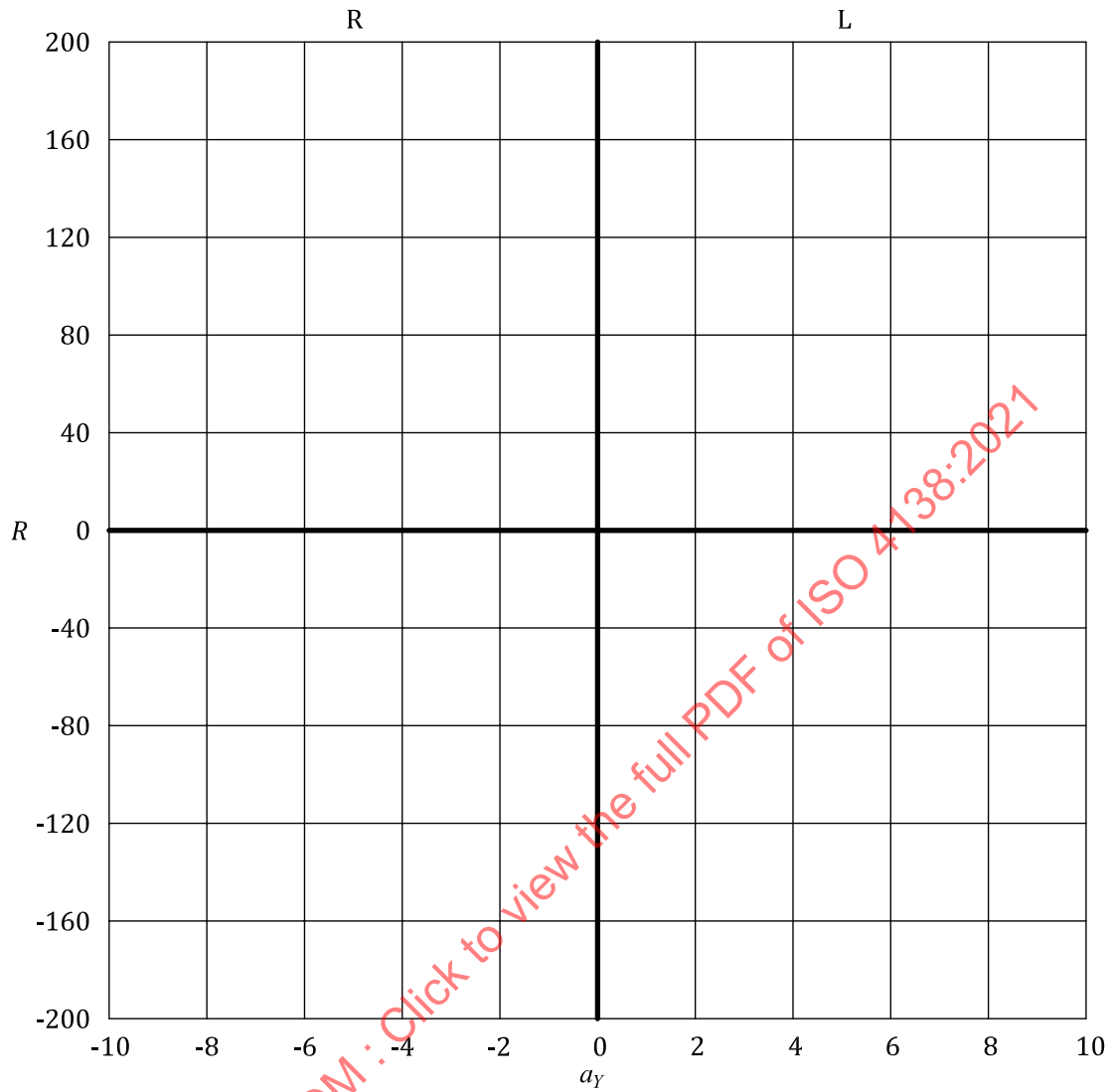
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Vehicle:
Turning radius (constant-radius test method):
Test speed (constant-speed test method):

- Key**
- a_Y lateral acceleration, m/s²
 - δ_H steering-wheel angle, (degrees)
 - R right turn
 - L left turn

Figure A.1 — Steering-wheel angle characteristic values



Vehicle:

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

Test speed (constant-speed test method):

Key

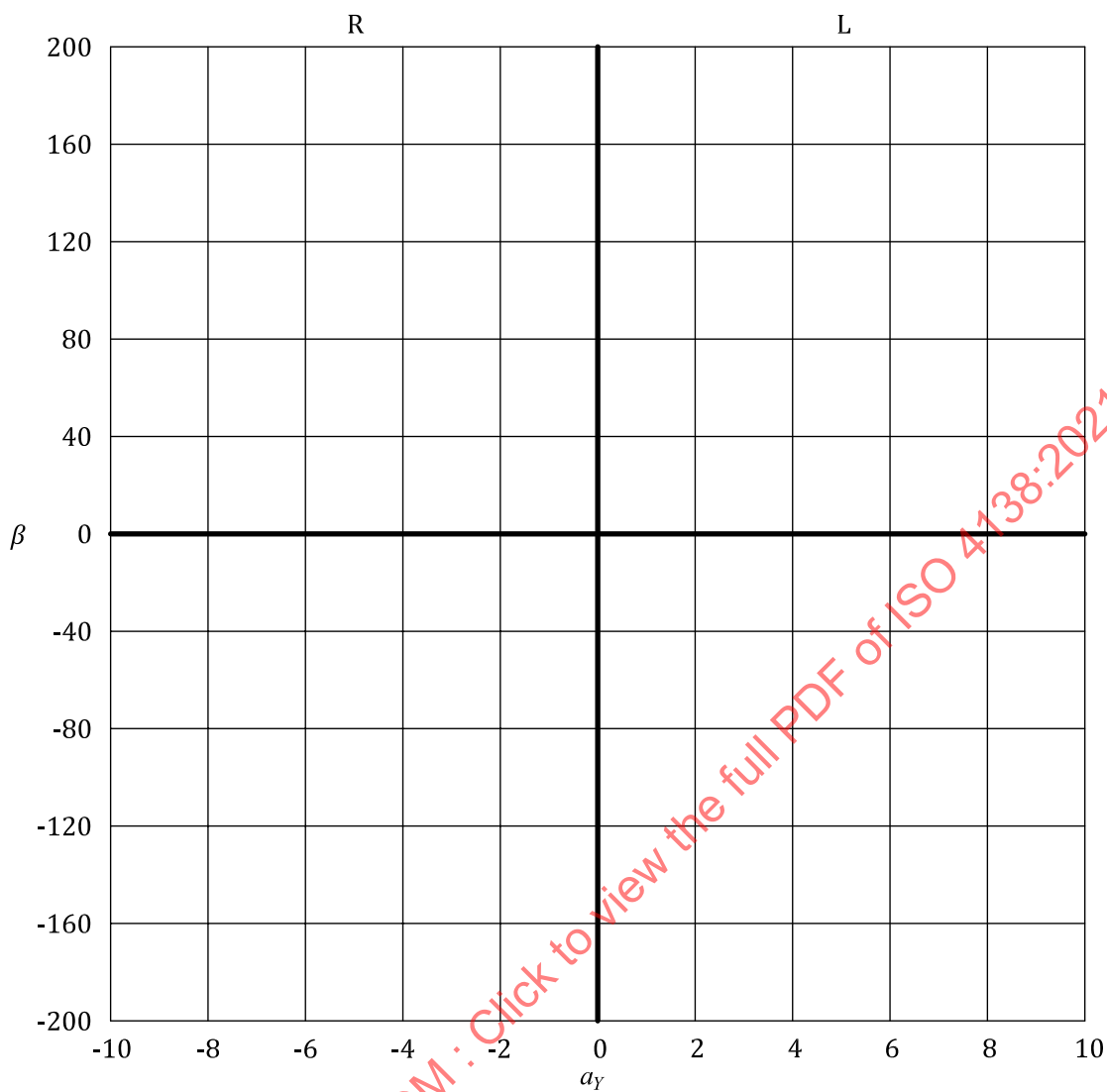
a_y lateral acceleration, m/s^2

R path radius, m

R right turn

L left turn

Figure A.2 — Path radius characteristic values



Vehicle:
Turning 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/s²
 - β sideslip angle (degrees)
 - R right turn
 - L left turn

Figure A.3 — Sideslip angle characteristic values