INTERNATIONAL STANDARD

ISO 14792

Second edition
2011-03-15

Road vehicles — Heavy commercial vehicles and buses — Steady-state circular tests

Véhicules routiers — Véhicules utilitaires lourds et autobus — Essais sur trajectoire circulaire en régime permanent

Reference number
ISO 14792:2011(E)

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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 14792 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 9, *Vehicles dynamics and road-holding ability*.

This second edition cancels and replaces the first edition (ISO 14792:2003), of which it constitutes a minor revision.

Introduction

The main purpose of this International Standard 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 interaction of these driver-vehicle-environment elements are each complex in themselves. A complete and accurate description of the behaviour of the road vehicle must necessarily involve 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 require proven correlation between test results and accident statistics.

Road vehicles — Heavy commercial vehicles and buses — Steady-state circular tests

1 Scope

This International Standard specifies tests for determining the steady-state directional control response of heavy vehicles, one of the factors composing vehicle dynamics and road-holding properties. It is applicable to heavy vehicles, i.e. commercial vehicles, combinations, buses and articulated buses as defined in ISO 3833, covered by Categories M3, N2, N3, O3, and O4 of UNECE (United Nations Economic Commission for Europe) and EC vehicle regulations. These categories pertain to trucks and trailers with a maximum mass above 3,5 t and to buses and articulated buses with a maximum mass above 5 t.

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, *Road vehicles — Types — Terms and definitions*

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

ISO 15037-2:2002, *Road vehicles — Vehicle dynamics test methods — Part 2: General conditions for heavy vehicles and buses*

3 Test objectives

The general conditions for

- variables,
- measuring equipment and data processing,
- environment (test track and wind velocity),
- test vehicle preparation (tuning and loading),
- initial driving, and
- the reporting of general data and test conditions

of general significance, independent of the specific vehicle dynamics test procedure, shall be as specified in ISO 15037-2. They shall apply when vehicle dynamics properties are determined unless other conditions are required in the standard for the test procedure actually used.

Although this International Standard is intended for combination vehicles as well as for single-unit vehicles, Clauses 8 and 9, regarding data analysis, evaluation and presentation, deal only with the motion variables of the single-unit vehicle or of the first unit of combinations. Thus, in order to comply with this International Standard, the user shall meet the requirements for variables, measuring equipment and data handling only in as far as they apply to the single-unit vehicle or to the first unit of combinations. Nevertheless, users are encouraged to measure and analyse the motions of trailing units as appropriate to their particular purposes.

The primary objective of this test procedure is to determine the steady-state turning characteristics of heavy vehicles for both left- and right-hand turns.

The steady-state turning behaviour of unit vehicles which have more than two axles and/or dual or wide-base tyres, as is the case with most heavy vehicles, is known to be a strong function of both centripetal acceleration and path curvature[3][4]. To characterize the steady-state behaviour of these vehicles, it is therefore necessary to conduct turning tests on different radii turns as well as at varying levels of centripetal acceleration. Such a test program may be accomplished through a series of *constant radius* tests conducted at various radii, or through a series of *constant speed, variable-steer angle* tests conducted at different speeds. Indeed, it is desirable that both types of tests be conducted for a full characterization of the steady-state turning of these vehicles.

The constant radius test requires the test vehicle to be driven at a constant speed on a path of known, constant radius. The directional control response characteristics are determined from data obtained by repeating the procedure at successively higher speeds. To fully characterize the steady-turning of the vehicle, this procedure shall then be repeated for various radii. The procedure may be tailored to existing test track facilities by selecting circles or paths of appropriate radii.

The constant speed, variable-steer angle test requires the test vehicle to be driven at a constant speed and constant steer angle. The directional control response characteristics are determined from data obtained by repeating the procedure at successively greater steer angles. To fully characterize the steady-turning of the vehicle, this procedure shall then be repeated at various speeds.

4 Variables and reference system

The variables to be determined may be selected for test purposes from those given in ISO 15037-2 and shall be monitored using appropriate transducers. The variables relate to the intermediate axis system (X, Y, Z) (see ISO 8855).

For the purposes of this International Standard, the reference point shall be the centre of gravity of the vehicle unit.

This provision overrides the similar provision of ISO 15037-2.

Strictly speaking, the steady-state turning performance ought to be evaluated based on centripetal acceleration, a_{C}, rather than on lateral acceleration, a_{Y}, (see ISO 8855). In most practical situations, however, the difference between these two quantities is small and can be ignored. Nevertheless, in a few cases (e.g. long-wheelbase vehicles operating on small turning radii or any vehicle operating at large body sideslip angles), the difference could be appreciable. In these cases, measured lateral acceleration needs to be corrected for sideslip angle to determine centripetal acceleration. In any case, this document refers to centripetal acceleration throughout rather than to lateral acceleration.

5 Measuring equipment

The measuring and recording equipment shall be in accordance with ISO 15037-2.

6 Test conditions

The limits and specifications for ambient and vehicle test conditions shall be in accordance with ISO 15037-2.

7 Test procedures

7.1 General

The general test specifications shall be in accordance with ISO 15037-2.

7.2 Constant radius test

During this test procedure, the vehicle shall be steered such that it moves on a circular path at a constant speed. Repeat the procedure at successively faster speeds. The entire procedure should be repeated on paths of at least three different radii.

A standard radius of 100 m should be used for one of the paths. The radii of the other paths should span the largest range practicable. The significance of the results improves with increases in the range and number of radii. Whichever the radii chosen, the vehicle shall be steered such that the reference point of the first unit remains within 0,5 m of the intended circular path.

For each radius chosen, conduct the test at several speeds. The first speed shall be the slowest practical speed. Choose successive speeds such that the increments of centripetal acceleration are not more than 0,5 m/s^2. Where the data vary rapidly with centripetal acceleration, it could be useful to make smaller incremental changes.

7.3 Constant speed, variable-steer angle test

During this test procedure, the vehicle shall be driven at a constant speed and constant steer angle. Repeat the procedure at successively larger steer angles. The entire procedure should be repeated applying at least three different speeds.

The standard speed should be 50 km/h and additional speeds covering the broadest range practicable are also recommended. A test at a very slow speed is desirable. The significance of the results improves with increases in the range and number of speeds.

For each test run, maintain the average speed within a tolerance of $\pm$ 2 km/h of the selected speed. A deviation of the vehicle speed of $\pm$ 3 km/h from the selected speed is permissible.

For each test speed, conduct tests at several levels of constant steer angle. The first steer angle shall be the smallest practical deflection from the straight-ahead position. Choose successive steer angles such that the increments of centripetal acceleration are no more than 0,5 m/s^2. At slower speeds, where large changes of steer angle produce little change in centripetal acceleration, it could be useful to make smaller incremental changes.

7.4 Common test conditions

For each test, maintain the steering-wheel position and the vehicle speed as constant as possible during the acquisition of the data. Take data for at least 3 s at each steady-state centripetal acceleration. During this time period, the standard deviation of centripetal acceleration shall not exceed 0,25 m/s^2.

Take data for both left and right turns. All the data may be taken in one direction followed by all the data in the other direction. Alternatively, data may be taken successively in one direction and in the other for each acceleration level, going from the lowest to the highest. Note the method in accordance with Annex A.

The range of centripetal accelerations covered should be as large as is practicable. However, a careful estimation of the rollover limit of the test vehicle should be made prior to testing. Special care should be taken whenever centripetal acceleration of a test might exceed 75 % of this estimate. The use of anti-rollover outriggers should be considered for any testing approaching the rollover limit.

Sustained, steady-state turns at moderate and high lateral accelerations can heat the tyres of the test vehicle to unusually high temperatures. Since tyre temperature can influence tyre properties and, hence, test results, care should be taken that the tyres do not become too hot.

8 Data analysis

8.1 General

When analysing the data, the steady-state values for all the measured variables shall be established as the average values of these variables during the time over which steady state was maintained.

8.2 Steering-wheel angle

The maximum variation of the steering-wheel angle from the average value shall be reported.

8.3 Centripetal acceleration

Steady-state values of acceleration for each vehicle unit may be obtained from any of the following:

— the lateral acceleration corrected for slideslip angle;

— the product of the yaw velocity and the horizontal velocity;

— the square of the horizontal velocity divided by the path radius;

— the product of the square of the yaw velocity and the path radius.

8.4 Curvature of trajectory

Steady-state values of the curvature of trajectory of each vehicle unit may be obtained from any of the following:

— direct measurement of the radius of the path;

— yaw velocity divided by the horizontal velocity;

— centripetal acceleration divided by the square of horizontal velocity.

9 Data evaluation and presentation of results

9.1 General

General data and test conditions shall be presented in the test report in accordance with ISO 15037-2:2002, Annexes A and B. For every change in equipment of the vehicle (e.g. load), the general data shall be documented again.

Selected data shall be plotted on figures in accordance with Annex A as follows:

— steering-wheel angle versus centripetal acceleration, see Figure A.1;

— sideslip angle versus centripetal acceleration, see Figure A.2;

— vehicle roll angle versus centripetal acceleration, see Figure A.3;

— steering-wheel torque versus centripetal acceleration, see Figure A.4;

— other variables selected according to Clause 4 versus centripetal acceleration.

Polarities of data presentations shall be in accordance with ISO 8855.

Because of the influence of path curvature on steady-state turning of vehicles with more than two axles and/or dual or wide-base tyres, plots of these forms (see Annex A) are expected to be substantially different, depending on the radius (in the case of constant radius tests) or the velocity (in the case of constant velocity tests) at which they were conducted[3][4]. Therefore, the test condition shall be specified on the graph.

The base data points shall always be plotted. Curves may be fitted to the plotted points either freehand (but this is not recommended) or by one of the many mathematical routines available. The method that is chosen, however, could influence the results obtained. Therefore the method of curve fitting should be stated.

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.

9.2 Other evaluations and presentation of results

9.2.1 General

There are a number of ways of further processing the test data obtained by these standard test methods. Some have been developed as conventions over many years, while others have been recently introduced. In general, the underlying theories are well developed only for vehicles with conventional steering systems (i.e. steering only on the first axle). While these concepts can be useful for more complex vehicles, users should be cautious in their application.

Therefore, the following represents only examples of useful ways to evaluate and present test results so as to describe the steady-state turning behaviour of the test vehicle. Any one of these may be used at the option of the user.

9.2.2 Overall steering ratio

For certain of the evaluations that follow it will be necessary to determine the overall steering ratio of the test vehicle.

The overall steering ratio, i_S, as defined in ISO 8855, shall be determined for each vehicle test configuration over the range of steering-wheel angles used during the test.

The overall steering ratio in general will not represent the dynamic situation because of additional steering system deflections caused by compliances and geometric effects. It is, however, suitable for removing the effect of different steering system lever and gears 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.

9.2.3 Gradients — Differentiation

A common method of further treating basic experimental data is to derive the gradients of the curves fitted to the experimental data. The values of the gradients obtained may then be plotted against the independent variable (in this case, centripetal acceleration) to give a response graph.

Gradients of particular interest which can be derived and plotted include

— steering-wheel angle gradient;

— sideslip angle gradient;

— vehicle roll angle gradient; and

— steering-wheel torque gradient;

all of which are defined in ISO 8855.

As was the case with the basic data presentations of 9.1, the gradients described here (except for vehicle roll angle gradient) are expected to differ substantially, depending on the specific test condition under which the data were collected[3][4]. Accordingly, the gradients and the graphs in which they are displayed shall always include the test condition under which they were determined. For example, steering wheel gradient determined from a constant-velocity test conducted at 50 km/h should be designated as

$$\left[\frac{\partial \delta_H}{\partial a_c} \times \frac{1}{i_S} - \frac{\partial \delta_D}{\partial a_c}\right]_{\upsilon_X = 50\ \text{km/h}}$$

and a graph of this gradient as a function of centripetal acceleration should include notation indicating the 50 km/h test condition.

9.2.4 Understeer and stability gradients

It is common to evaluate the results of steady-state circular tests to determine the understeer/oversteer and open-loop stability characteristics of the test vehicle.

The understeer gradient of the simple, four-wheel vehicle is defined as the difference between the gradient of the reference front-wheel steer angle and the dynamic reference steer angle gradient (see ISO 8855):

$$\left[\frac{\partial \delta_H}{\partial a_c} \times \frac{1}{i_S} - \frac{\partial \delta_D}{\partial a_c}\right]$$

where

δ_D is the dynamic reference steer angle, equal to the wheelbase divided by the path radius (i.e. l/R). See ISO 8855.

NOTE In the equations and expressions given in this clause, the character “1” (non-italicized) is unity, while the character “l” (italicized) is wheelbase.

The radius is positive in turns to the left and negative in turns to the right.

To first order, this gradient is a single-valued function of centripetal acceleration for four-wheeled vehicles and therefore may be determined from the test data. The appropriate method is to plot the function (δ_H/i_S — l/R) versus a_c and to mathematically fit a smooth curve to the plot. The gradient may then be determined by differentiating the mathematical expression for the curve. It is also common and useful to include lines of constant velocity and lines of constant path curvature on the same plot to produce the so-called handling diagram[2][3][4]. Four-wheeled vehicles are considered understeer when this gradient is positive, neutral steer when it is zero, and oversteer when it is negative. Furthermore, the open-loop yaw stability of this simple vehicle is ensured whenever the value of the gradient is greater than the quantity: [—l/υ_X^2][2].

However, for vehicles with more than two axles and/or dual or wide-base tyres, the use of a wheelbase defined only by vehicle geometry yields more complex results in this analysis. When such a value is used, this gradient depends to first order on the test condition at which it is evaluated and is therefore expected to vary substantially depending on the test procedure. This also implies that the handling diagram will have a different curve for each test condition. Moreover, it is the gradients determined at constant velocity which are appropriate for evaluating stability of the lead unit (i.e. in relationship to the quantity [—l/υ_X^2], and which are therefore called the stability gradients. The stability gradients determined at constant radius are the understeer gradients, as they are most appropriate for determining understeer/oversteer of the vehicle[3][4].

Therefore, these gradients and the data plots with which they are associated shall always include notation indicating the test condition. For example, the stability gradient determined from constant-velocity tests at 50 km/h should be designated as

$$\left[\frac{\partial \delta_{\mathrm{H}}}{\partial a_{\mathrm{c}}} \times \frac{1}{i_{\mathrm{S}}} - \frac{\partial \delta_{\mathrm{D}}}{\partial a_{\mathrm{c}}}\right]_{\upsilon_X = 50\ \mathrm{km/h}}$$

and its associated graphs should include notation indicating the 50 km/h test condition.

9.2.5 Equivalent wheelbase

There is a special wheelbase, called the equivalent wheelbase, which, when used in the preceding analysis, provides a clearer understanding of the steady-state turning characteristics of more complex vehicles.

To first order, a unit vehicle equipped with more than two axles and/or dual or wide-base tyres has steady-state turning behaviour similar to a simple, four-wheel vehicle with an *equivalent wheelbase* (designated l_{e})[3][4]. Determining the understeer/oversteer and stability gradients of these more complex vehicles based on the equivalent wheelbase rather than on a geometric wheelbase therefore provides a clearer and simpler understanding of the vehicle's understeer/oversteer and stability characteristics.

Because of nonlinearities in the test vehicle, equivalent wheelbase may vary as a function of centripetal acceleration. Nevertheless, the equivalent wheelbase determined for a_{c} of approximately zero may be adequate for the entire operating range.

There are at least two ways to determine equivalent wheelbase from steady-state circular test data.

By definition, equivalent wheelbase is the value, which when used instead of wheelbase, results in the equality (to first order) of all understeer gradients (i.e. gradients determined from constant radius data) and stability gradients (i.e. gradients determined from constant velocity data)[3][4]. Therefore, one method for determining equivalent wheelbase is as follows.

— Estimate (guess) a value for l_{e}.

— Plot on a single graph the function ($\delta_{\mathrm{H}}/i_{\mathrm{S}}$ — l_{e}/R) versus a_{c} for each of the constant-velocity and constant-radius tests conducted.

— Compare the slopes of the several curves at $a_{\mathrm{c}} = 0$.

— Repeat the process until the value of l_{e}, which results in the best consistency of slopes at $a_{\mathrm{c}} = 0$, is found.

It can also be shown that, at conditions where both velocity and centripetal acceleration approximate zero, equivalent wheelbase is equal to the inverse of path curvature gain[4]. That is, for small angles:

$$l_{\mathrm{e}} = \frac{\partial \delta_{\mathrm{H}}}{\partial^{1/\mathrm{R}}} \frac{1}{i_{\mathrm{S}}} \text{ for } \upsilon_X = a_{\mathrm{c}} = 0$$

Therefore, equivalent wheelbase can also be determined from the steady-state circular data taken at very low speed. These can be either the data taken from a single constant-velocity test at low speed, or the set of initial, low-speed data points from a series of constant-radius tests. In either case, the data points (for $\upsilon_X = 0$ and $a_{\mathrm{c}} = 0$) should be plotted in the form of a graph of the function $\delta_{\mathrm{H}}/i_{\mathrm{S}}$ versus $1/R$. A straight line should be fitted to the data points. The slope of the line is taken to be the equivalent wheelbase.

Investigators are encouraged to use both methods for determining equivalent wheelbase.

For either method, results tend to be rather sensitive to i_{S}. Care should be taken to determine an accurate value of i_{S} for use in these analyses.

Annex A
(normative)

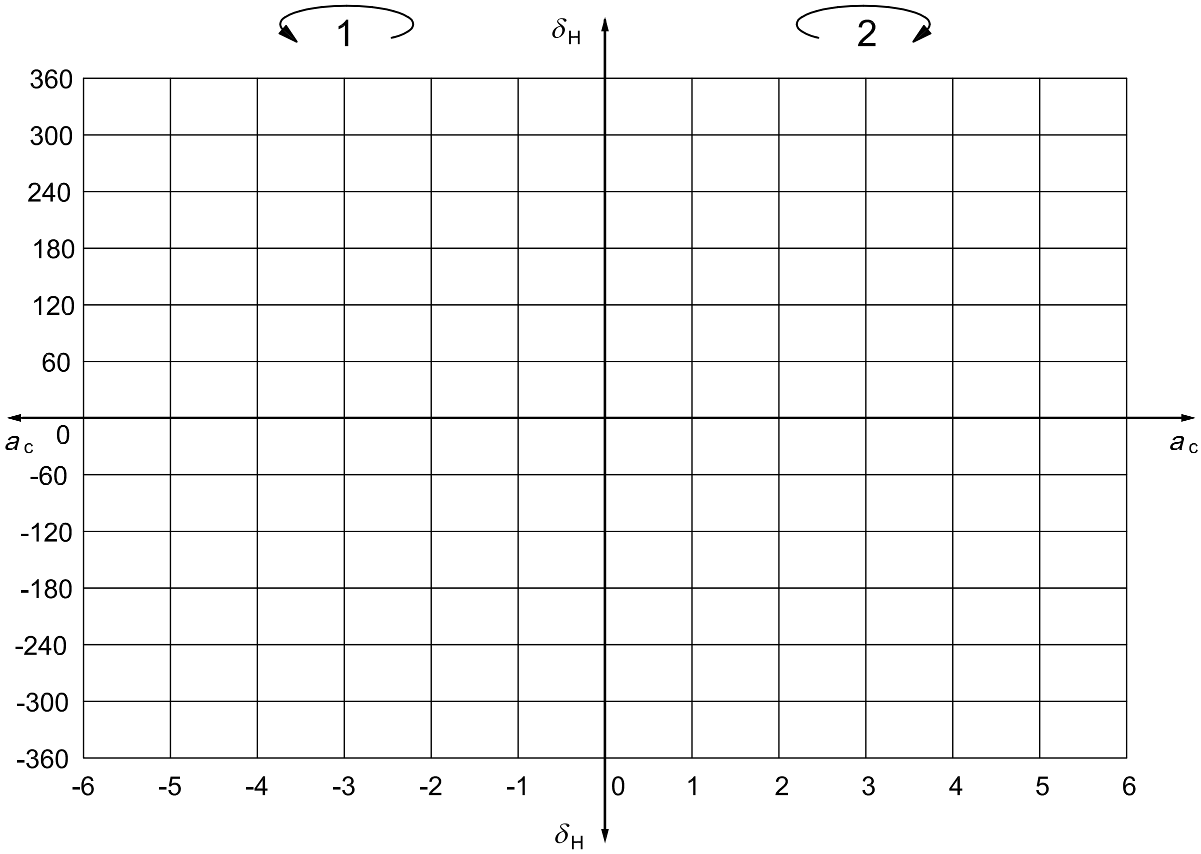
Test report — Presentation of results

The test results shall be presented as shown in Table A.1.

The characteristic values of vehicle dynamic reaction shall be presented as functions of the steady-state centripetal acceleration as shown in Figures A.1 to A.4.

Table A.1 — Test results

Test number	**1**	**2**	**3**	**...**	**...**
Test type Constant radius or speed					
Speed, km/h Intended Average Maximum deviation from average					
Radius, m Intended Average Maximum deviation from average					
Steer angle, degrees Average Maximum deviation from average					
Centripetal acceleration, m/s^2 Average Standard deviation					
Other selected variables [variable 1], [units], average [variable 2], [units], average [variable 3], [units], average **...** **...** **...**					



Key

δ_H steering-wheel angle, in degrees

a_c centripetal acceleration, in m/s^2

1 left turn

2 right turn

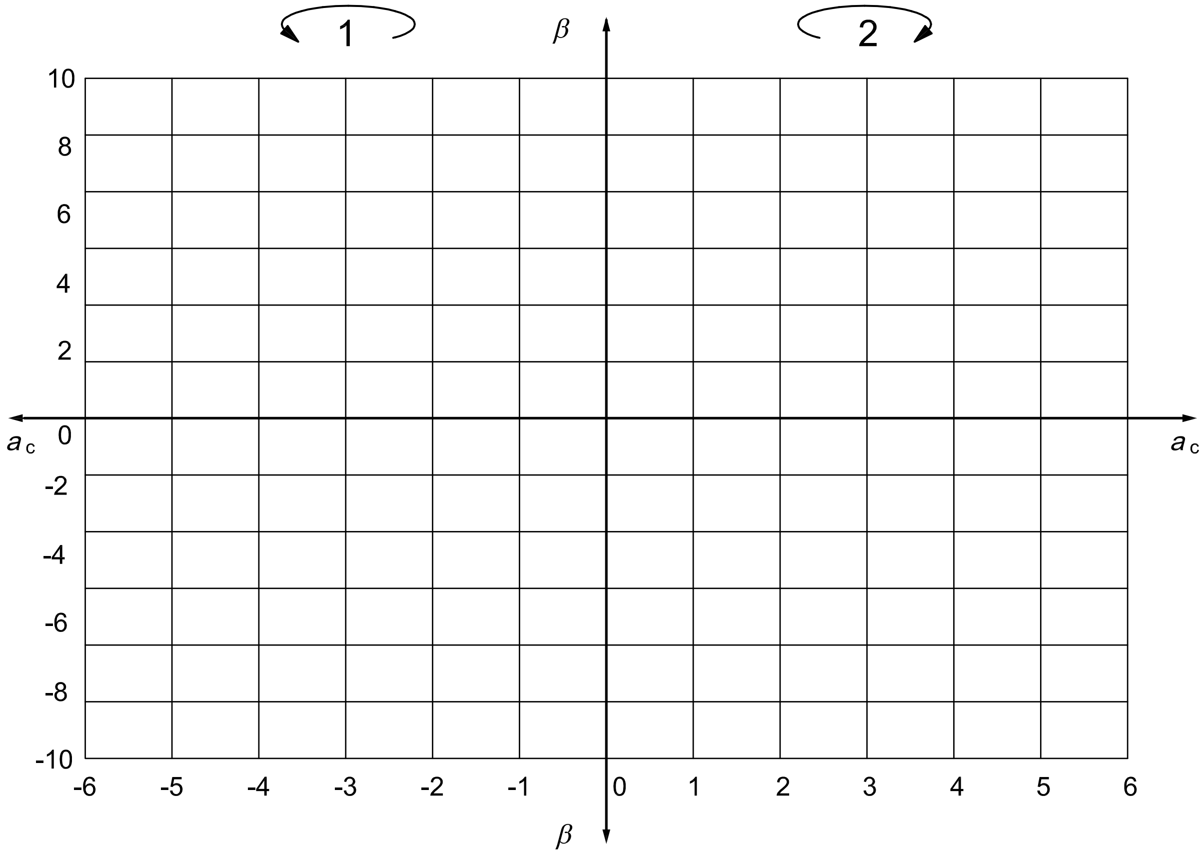
Vehicle: ....

Radius (for constant radius test): .... m

Speed (for constant velocity test): .... km/h

Curve fitting method: ....

Figure A.1 — Steering-wheel angle characteristic



Key

β sideslip angle, in degrees

a_c centripetal acceleration, in m/s^2

1 left turn

2 right turn

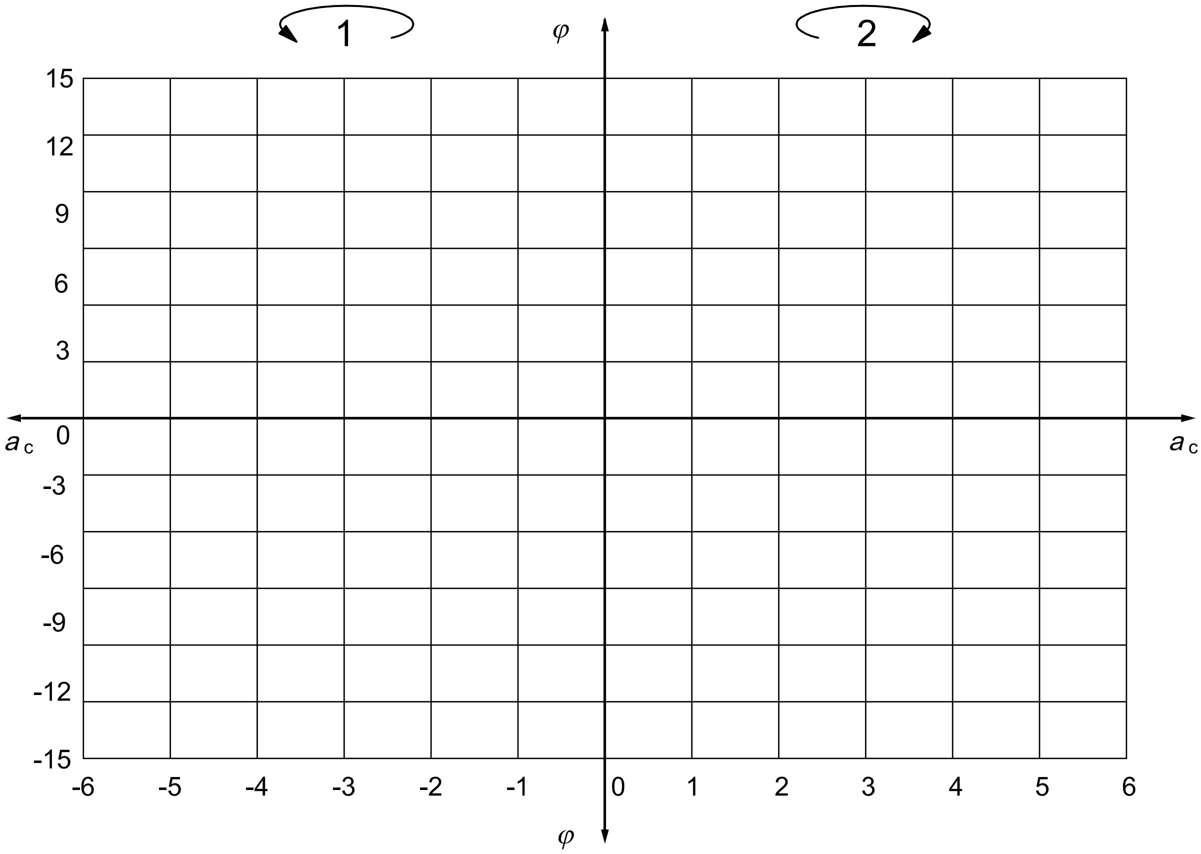
Vehicle: ....

Radius (for constant radius test): .... m

Speed (for constant velocity test): .... km/h

Curve fitting method: ....

Figure A.2 — Sideslip angle characteristic



Key

φ roll angle, in degrees

a_c centripetal acceleration, in m/s^2

1 left turn

2 right turn

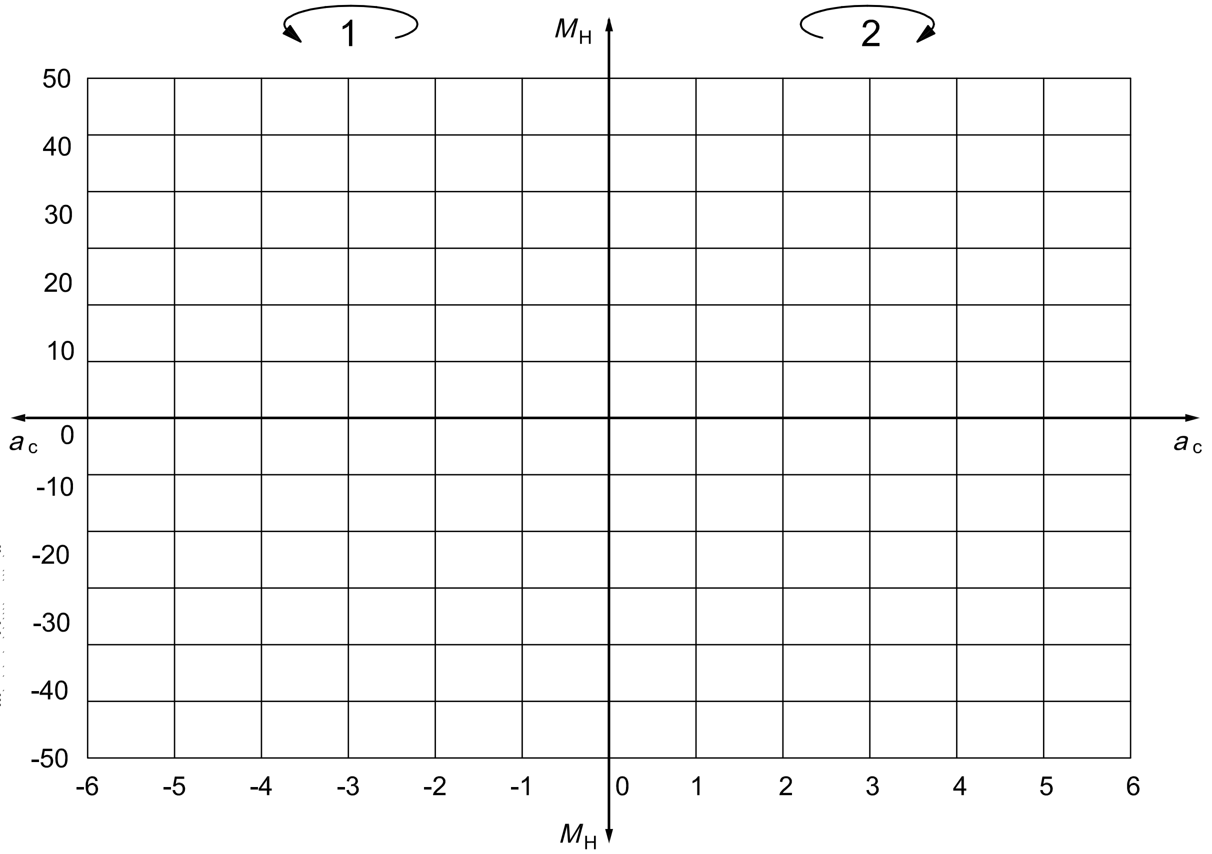
Vehicle: ....

Radius (for constant radius test): .... m

Speed (for constant velocity test): .... km/h

Curve fitting method: ....

Figure A.3 — Roll angle characteristic



Key

M_H steering-wheel torque, in N·m

a_c centripetal acceleration, in m/s^2

1 left turn

2 right turn

Vehicle: ....

Radius (for constant radius test): .... m

Speed (for constant velocity test): .... km/h

Curve fitting method: ....

Figure A.4 — Steering-wheel torque characteristic

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ICS 43.080.01

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