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Heavy commercial vehicles and buses — Vehicle dynamics simulation and validation — Lateral dynamic stability of vehicle combinations

Véhicules utilitaires lourds et autobus — Dynamique du véhicule simulation et validation — Stabilité latérale des véhicules articulés

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Foreword

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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).

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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*.

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

Since this test method quantifies only one small part of the complete handling characteristics, the results of this test can only be considered significant for a correspondingly small part of the overall dynamic behaviour.

Moreover, insufficient knowledge is available to correlate overall vehicle dynamic properties with accident prevention. A substantial amount of work is necessary to acquire sufficient and reliable data on the correlation between accident prevention and vehicle dynamic properties in general and the results of this test in particular. Consequently, proven correlation between test results and accident statistics is used for any application of this test method for regulation purposes.

Test conditions and tyres have a strong influence on test results. Therefore, only results obtained under comparable test and tyre conditions are comparable.

Heavy commercial vehicles and buses — Vehicle dynamics simulation and validation — Lateral dynamic stability of vehicle combinations

1 Scope

This document specifies a method for comparing simulation results from a vehicle model to measured test data for an existing vehicle combination's lateral stability according to driving tests as specified in ISO 14791. The comparison is made for the purpose of validating the simulation model for this type of test. A complete validation comprises the comparison for at least one tested vehicle and one variant of this vehicle, covered by a parameter variation in the vehicle model.

The document applies to heavy vehicles, including commercial vehicles, commercial vehicle combinations, buses and articulated buses as defined in ISO 3833 (trucks and trailers with maximum weight above 3,5 tonnes and buses and articulated buses with maximum weight above 5 tonnes, according to ECE and EC vehicle classification, categories M3, N2, N3, O3 and O4).

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 14791:2000, *Road vehicles — Heavy commercial vehicle combinations and articulated buses — Lateral stability test methods*

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 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8855, ISO 15037-2 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 http://www.electropedia.org/

3.1
simulation
calculation of motion variables of a vehicle from equations in a mathematical model of the vehicle system

3.2
basic vehicle parameters
parameters not subject to model fitting, which are directly and accurately measurable on the test vehicle

EXAMPLE Masses and dimensions.

3.3
estimated vehicle parameters
parameters that may be used for model fitting, which are typically hard to be determined

EXAMPLE Mass moment of inertia and tyre characteristics.

3.4
vehicle model validity range
basic vehicle parameters (3.2) which may be changed if the type of vehicle combination and tyre type are maintained

Note 1 to entry: For example, when wheel base is modified some of the estimated parameters may need to be updated accordingly.

4 Principle

The pseudo random and the single sine wave steering input according to ISO 14791 is used to determine lateral stability by calculating the rearward amplification (RA) and yaw damping (D) of heavy commercial vehicles and buses as defined in ISO 3833. Within this document, the purpose of the test is to demonstrate that a vehicle model can predict the vehicle behaviour within specified tolerances. The vehicle model is used to simulate a specific existing vehicle running tests as specified in ISO 14791. The maximum lateral acceleration in the first vehicle unit is limited to a conservative value to assure linear behaviour of the vehicle combination. The characteristic values from model results and physical testing are compared for validating the model. In this document a tolerance is given for when the model is valid. The tolerance depends upon the physical testing variation in repeatable results and the uncertainty in the input data to the model. The validated model can also be used for the single sine wave lateral acceleration input as specified in ISO 14791. The experimental variation sets the bounds within which the model is validated.

When the vehicle model is used outside its validity range, for example changing vehicle combination type or changing tyre parameters, a new validation is required. For proving good reliability of the simulation results, it is recommended to repeat the process of comparing simulation and measurement results for different vehicle parameters, for example laden conditions and vehicle longitudinal velocity.

5 Variables

The variables of motion used to describe the behaviour of the vehicle shall be related to the reference axis system (X, Y, Z) of the first vehicle unit (see ISO 8855) with the reference point as described in 3.1. The variables that shall be determined for conformance with this document are:

— longitudinal velocity, v_x;

— steering-wheel angle, δ_H;

— yaw velocity of the first vehicle unit and yaw velocity of each vehicle unit, ω_z;

— lateral acceleration of the front axle of the first vehicle unit at or below the height of the wheel centre, a_y.

It is recommended that the following variables are also determined:

— yaw angle of the first vehicle unit, ψ;

— lateral acceleration in the centre of gravity of each vehicle unit, a_y;

— articulation angles, $\Delta\psi$.

6 Minimum vehicle model parameters and requirements

6.1 General

In this document, the vehicle model shall be able to predict lateral dynamic behaviour in the linear range, well below physical limits of performance as specified in ISO 14791. The minimum level of complexity is a single-track model with lateral slip behaviour. This clause will define a minimum level of requirements for the model's parameters. More detailed vehicle models can be used but they shall show that they meet the parameter requirements as specified in this document.

6.2 Basic vehicle parameters

The basic vehicle parameters shall not have larger errors between the vehicle model and the physical vehicle combination than the errors shown in Table 1.

Table 1 — Parameters, typical usage ranges and recommended maximum estimation errors between vehicle model and physical vehicle combination

Basic vehicle model parameter	Recommended maximum error between model and physical vehicle combination
Axle and coupling positions with front axle as reference	±0,02 m
Axle and coupling loads	±100 kg
Vehicle unit mass	±200 kg

To receive an accurate centre of gravity position in longitudinal direction, each vehicle unit in the vehicle combination with significant vertical force in joint couplings between units, such as fifth wheel on tractor or converter dolly, shall also be measured separately on the weighting scale.

6.3 Estimated vehicle parameters

The critical vehicle parameters shall be within the error range as shown in Table 2. The recommended method for estimating the yaw inertia is to use evenly distributed payload on the load carrying vehicle units. In combination with chassis inertia, the total yaw inertia per vehicle unit can be derived with Steiner's theorem.

The lateral tyre characteristics are an important vehicle model parameter when calculating lateral dynamics. The nominal value is usually provided by tyre supplier or measured. The lateral tyre characteristics shall be normal load dependent to allow basic vehicle parameter change of axle load.

Table 2 — Estimated vehicle parameters, typical usage ranges and recommended maximum estimation errors between vehicle model and physical vehicle combination

Estimated vehicle parameter	Recommended maximum estimation error between model and physical vehicle combination
Yaw inertia per vehicle unit	±25 %
Cornering stiffness for one axle[a]	±25 %
Tyre road friction	±0,1
[a] For zero camber angle.	

To reduce the uncertainty of estimating yaw inertia, well defined loads, e.g. concrete blocks, should be used and be position-measured in the vehicle unit's reference frame.

7 Physical tests

7.1 General

An existing vehicle combination of interest shall be tested as specified in ISO 14791. The results should be reported as specified in ISO 14791. The tests shall be repeated to determine test result variability. The bounds of the test result variability are the first part of the tolerance used for validating the vehicle model.

The test conditions, the reference condition of the vehicle, and the loading condition described in ISO 15037-2 shall apply to this document. For the standard loading condition, the payload shall be evenly distributed. General data of the test vehicle shall be recorded as specified in ISO 15037-2:2002, Annex A. Test conditions of the test vehicle shall be recorded as specified in ISO 15037-2:2002, Annex B.

7.2 Test methods

7.2.1 General

In all of the proposed test manoeuvres, the recommended value of the maximum lateral acceleration of the first unit is 1,5 m/s^2, but it may be decreased for the purpose of limiting the response of the last unit to no more than 75 % of the estimated rollover limit and no more than 75 % of any tyre friction limit.

7.2.2 Pseudo random steer input

The test shall be conducted in accordance with ISO 14791 This test shall be repeated at least five times for each vehicle test speed. A steering machine may be used for the tests if human drivers are used.

When repeating the pseudo random steer input for about 12 minutes per test it is also recommended that the driver is changed. It is recommended that the test is repeated five times with multiple drivers to evaluate test variability and minimise driver influence on the input amplitude and frequency distribution.

7.2.3 Single sine wave input

This test shall be repeated at least five times for each steering frequency, starting from 0,2 Hz to 0,6 Hz with a step size of 0,05 Hz to evaluate test variability. A steering machine shall be used for the tests.

8 Simulation

8.1 General

To validate the accuracy of calculating lateral dynamics stability up to 1,5 m/s^2, the vehicle model as stated in Clause 6 is used to estimate rearward amplification and yaw damping.

8.2 Data recording

The output of the simulation model shall be at a frequency not less than that of the sampling rate of the physical tests.

8.3 Documentation

The simulation shall be documented to the extent needed to reproduce the simulated tests. This should include at least:

— test method and corresponding test conditions used for validation;

— name and version number of the simulation model;

— name and version number of the tyre model;

— internal name of vehicle model;

— list and contents of input files used.

In addition, document the changes of the estimated parameters for model validation tuning.

9 Comparison of simulation and physical tests

9.1 General

The averaged curves evaluated from the measurement data described below are used to calculate upper and lower boundaries for comparing the measurement results with the respective simulation.

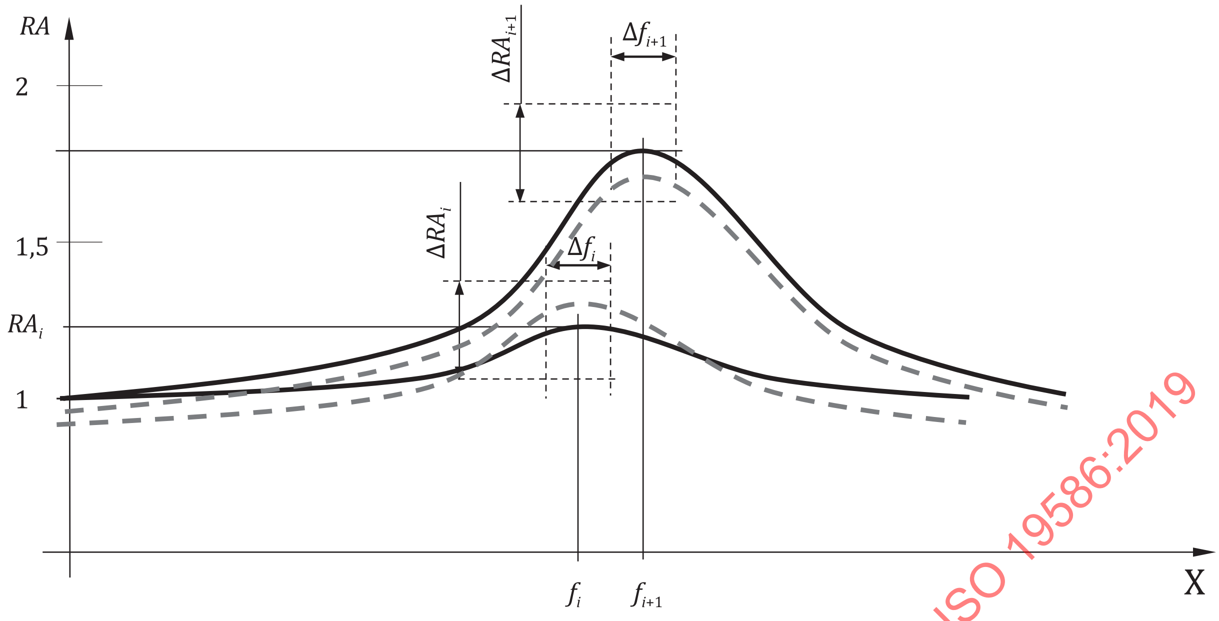
9.2 Characteristic values

9.2.1 Rearward amplification (RA)

The rearward amplification characteristic value can be derived from either the pseudo random steer input or single sine wave steer input measurement data. It is recommended to use the pseudo random steer input data to improve frequency content.

9.2.1.1 Pseudo random steer input for deriving RA

The pseudo random steer input gives a typical result curve as shown in Figure 1. From the physical tests an average is calculated. This will be the baseline for comparison with the simulated results. The simulation results and the tolerance of a physical test validation are also shown in Figure 1. Table 3 shows recommended tolerances for validating *RA* by using pseudo random input.



Key

X frequency

NOTE *RA* in yaw velocity is a function of frequency for a vehicle combination containing three vehicle units *i*.

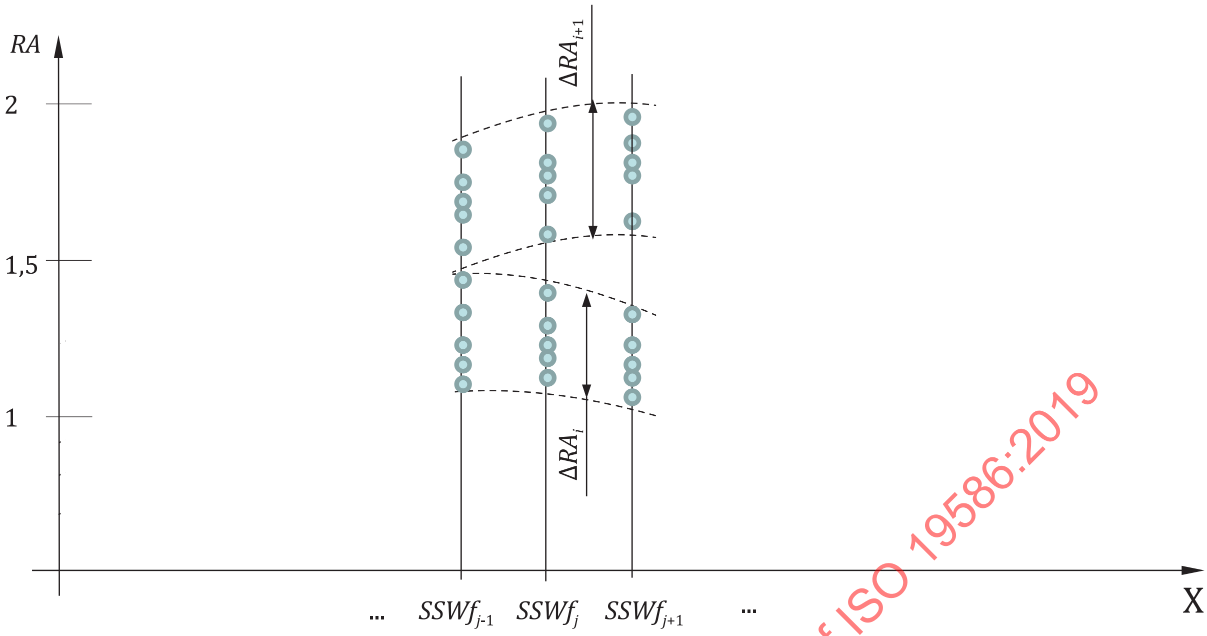
Figure 1 — Illustration of physical test averages (solid black) and simulation results (grey dashed line)

Table 3 — Tolerances of characteristic values for validation of *RA* by pseudo random steer input simulation and physical testing results

Tolerance of characteristic value	Recommended tolerance between simulation and physical testing
ΔRA_i for unit *i* and *i* + 1	±15 % of maximum
Δf_i for unit *i* and *i* + 1	±10 % at maximum

9.2.1.2 Single sine wave steer input for deriving RA

The single sine wave steer input can also be used to determine the *RA* of the vehicle combination. Typical simulated results are shown in Figure 2. The physical tests conducted for each single sine wave (SSW) period frequency is shown as circles in Figure 2. Table 4 shows recommended tolerances for validating *RA* by using single sine wave steer input.



Key

X sine period frequency

NOTE 1 *RA* in yaw velocity is a function of frequency for a vehicle combination containing three vehicle units *i*. Circles illustrate physical tests of the vehicle combination which is the basis for variability of the results.

Figure 2 — Illustration of simulated results from SSW

Table 4 — Tolerances of characteristic values for validation of *RA* by single sine wave steer input simulation and physical testing results

Tolerance of characteristic value	Recommended tolerance between simulation and physical testing
ΔRA_i for unit *i* and *i* + 1	±15 % of maximum
Δf_i for unit *i* and *i* + 1	±0,05 Hz

NOTE 2 The tolerance in Table 4 includes test variability and sensor errors.

9.2.2 Yaw damping and zero damping speed

9.2.2.1 Single sine wave steer input for deriving yaw damping

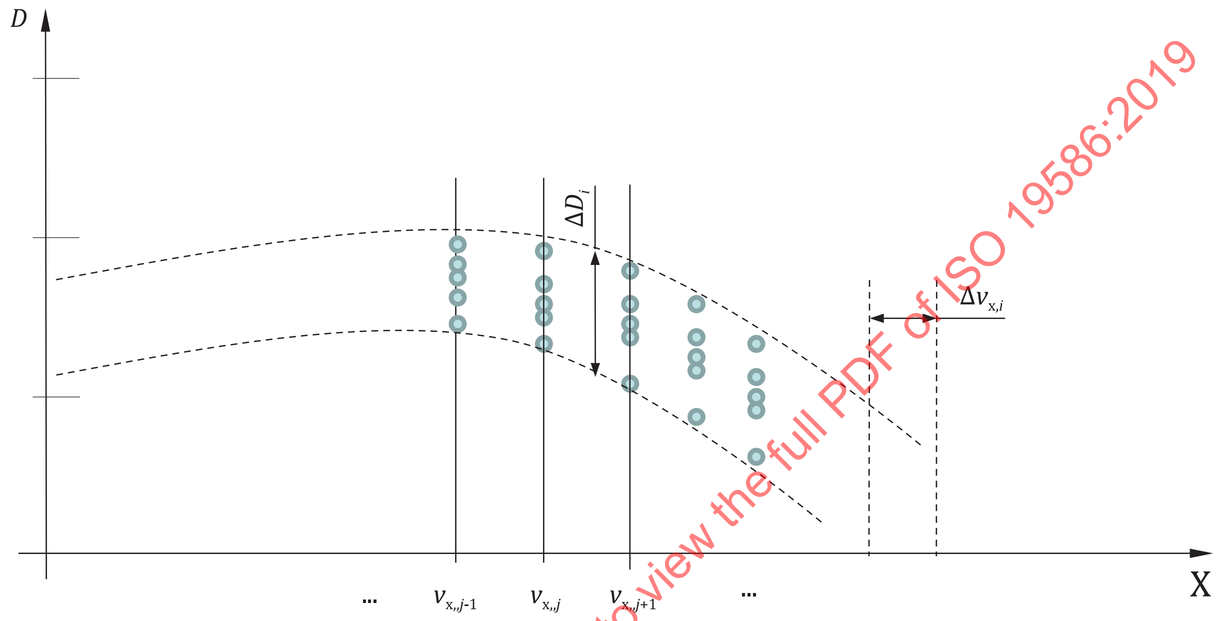
The yaw damping, *D*, shall be determined in accordance with ISO 14791:2000, 8.4 using single sine wave steer input data. For validation of the model, an average yaw damping value between each pair of vehicle units shall be calculated from five constant speed test repetitions at the steering input frequency which resulted in the largest rearward amplification. Table 5 shows the recommended tolerance between the averaged physical and the simulation yaw damping values.

Table 5 — Tolerances of characteristic values for validation of yaw damping by single sine wave steer input simulation and physical testing results

Tolerance of characteristic value	Recommended tolerance between simulation and physical testing
ΔD_i for unit *i* and *i* + 1	±30 % of average

9.2.2.2 Single sine wave steer input for deriving zero damping speed (optional)

Determination of the zero damping speed is optional. The average yaw damping, *D*, is calculated as described in 9.2.2.1 for a series of incremental longitudinal velocities, recommended to be between 30 km/h and 90 km/h in steps of 5 km/h. The averaged physical and the simulation yaw damping characteristic variations with longitudinal velocity shall be compared as shown Figure 3 and the zero yaw damping speeds determined in accordance with ISO 14791:2000, 8.4 . If the zero damping speed is not reached in the tests, the linear regression method with its requirements according to ISO 14791 shall be used. The recommended tolerance between the physical and simulation zero damping speeds is given in Table 6.



Key

X longitudinal velocity

NOTE Yaw damping of articulation angle or yaw velocity is a function vehicle's longitudinal velocity. Circles illustrate physical tests of the vehicle combination.

Figure 3 — Illustration of average physical results and simulated results from single sine wave input between two vehicle units

Table 6 shows recommended tolerances for validating zero damping speed by using single sine wave steer input.

Table 6 — Tolerances of characteristic values for validation of yaw damping by single sine wave steer input simulation and physical testing results

Tolerance of characteristic value	Recommended tolerance between simulation and physical testing
Zero damping speed for unit *i* and *i* + 1	±10 km/h

10 Validation process

In the first step, the comparison of measurement and simulation results described in 9.2.1 and 9.2.2 shall be conducted for the initial values of the model parameters, taken from measurement or design data.

If the validation results are not within the tolerance boundaries specified in 9.2.1 and 9.2.2, estimated vehicle parameters may be modified within feasible boundaries, as specified in 6.3.