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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 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.

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ISO 19586 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 33, *Vehicle dynamics and chassis components, WG 6 Heavy commercial vehicles and buses*.

Introduction

The main purpose of this standard 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 difficult, 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 must 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, any application of this test method for regulation purposes will require proven correlation between test results and accident statistics.

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 International Standard specifies a method for comparing simulation results from a mathematical 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 tool for this type of test. A complete validation should comprise the comparison for at least one tested vehicle and one variant of this vehicle, covered by a parameter variation in the vehicle model.

The standard 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, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

ISO 8855:2011, *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 purpose of this standard, the terms and definitions given in ISO 8855:2011, ISO 15037-2:2002 and the following apply.

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

3.2
vehicle configuration
fundamental vehicle characteristic influencing the vehicle dynamics, e.g. number axles, axle types (e.g. independent suspension or rigid axle), number and type of the vehicle units

3.3
basic vehicle parameters
longitudinal axle positions, coupling positions, axle and coupling loads, and vehicle unit mass

3.4
estimated vehicle parameters
lateral tyre characteristics and yaw inertia of each vehicle unit

3.5
vehicle model validity range
basic vehicle parameters can be changed if the type of vehicle combination and tyre type are maintained

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 (YD) of heavy commercial vehicles and buses as defined in ISO 3833. Within this International Standard, the purpose of the test is to demonstrate that a mathematical 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 characteristic values from mathematical model results and physical testing are compared for validating the model. In this standard 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 mathematical model. The validated model can also be used for the single sine wave lateral acceleration input as specified in ISO 14791.

When the vehicle model is used outside its validity range, e.g. 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, e.g. 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 8855:2011) with the reference point as described in 3.1. The variables that shall be determined for compliance with this International Standard are:

— longitudinal velocity, v_X;

— steering-wheel angle, δ_H;

— yaw velocity of the first vehicle unit and yaw velocity of each vehicle unit, $\dot{\psi}$;

— 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 Mathematical Vehicle Model Parameters and Requirements

6.1 General

In this ISO standard the mathematical 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 section will define a minimum level of requirements for the mathematical model's parameters. More detailed vehicle models can be used but they shall show that they meet the parameter requirements as specified in this ISO standard.

6.2 Basic vehicle parameters

The basic vehicle parameters shall not have larger errors between the mathematical model and the physical vehicle combination than 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 loads	± 100 kg
Vehicle unit mass	± 200 kg

To receive 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. 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 need to 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*	± 25 %
Tyre road friction	± 0.1
* For zero camber angle.	

NOTE 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 Field 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 15037-2:2002 shall apply to this International Standard. 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, see Annex A.

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

This test shall be repeated at least five times for each vehicle test speed. A steering machine may be used for the tests.

NOTE When repeating the pseudo random steer input for about 12 minutes per test it is also recommended that the driver is changed.

7.2.3 Single sine wave input

This test shall be repeated at least five times for each steering frequency, starting from 0.2 to 0.6 Hz with a step size of 0.05 Hz. 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 mathematical vehicle model as stated in section 6 is used to estimate rearward amplification and yaw damping.

8.2 Data recording

Data recording from simulation shall have at least the same resolution as field test recording.

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 tool

— Name and version number of the tire model

— Internal name of vehicle model

— List and contents of input files used

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

9 Comparison of simulation and field 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)

Two approaches for deriving the characteristic value rearward amplification, the pseudo random steer input and the single sine wave steer input, where the recommended approach is the pseudo random steer input method.

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

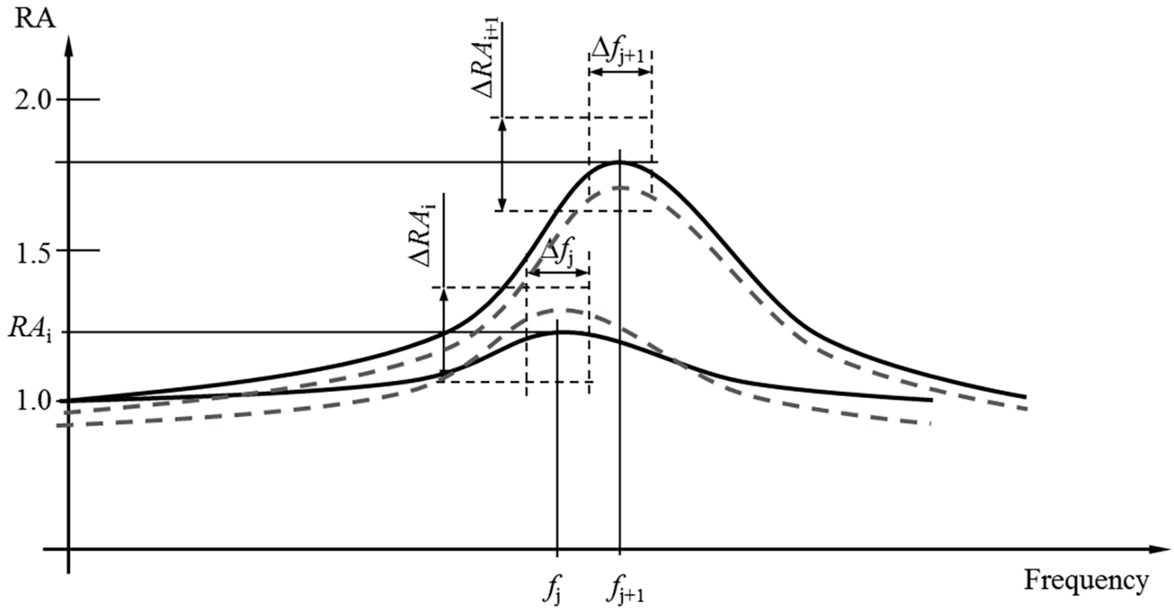

Figure 1 — Illustration of field test averages (solid black) and simulation results (grey dashed line). RA in yaw velocity as a function of frequency for a vehicle combination containing three vehicle units i.

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.

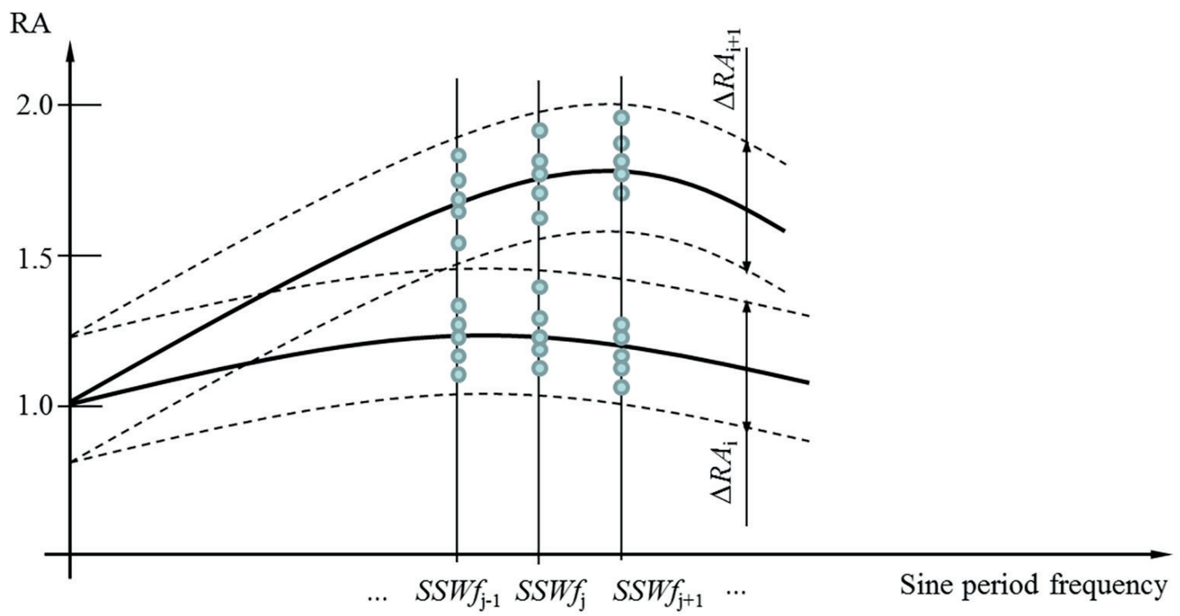

Figure 2 — Illustration of simulated results from SSW. RA in yaw velocity as a function of frequency for a vehicle combination containing three vehicle units i. Circles illustrate physical tests of the vehicle combination which is the basis for the black solid line.

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 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 shall be evaluated according to Clause 8.4 in ISO 14791 by using the single sine wave steer input. For model validation purposes, the yaw damping YD calculation of the test results shall be conducted for the steering input frequency which resulted in the largest RA. An average yaw damping is calculated from the five repetitions at the constant vehicle speed. Table 5 shows recommended tolerances for validating simulated YD between each vehicle unit i by using articulation angle from the using single sine wave steer input with one constant longitudinal velocity.

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
ΔYD_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)

The zero damping speed is optional. However, the yaw damping shall be evaluated according to Clause 8.4 in ISO 14791 by using the single sine wave steer input. The test shall be conducted for different vehicle longitudinal velocities and repeated five times for the steering input frequency which resulted in the largest RA. The steps in longitudinal velocity are recommended to be 5 km/h, starting at 30 km/h to 90 km/h. The average results from field testing shall be compared according to Figure 3. The example shows the YD between two vehicle units which also reach zero damping speed within the studied speed variation. However, it is not certain that zero damping speed is to be found for the operational longitudinal velocity of the vehicle combination. Model validation can then be conducted by

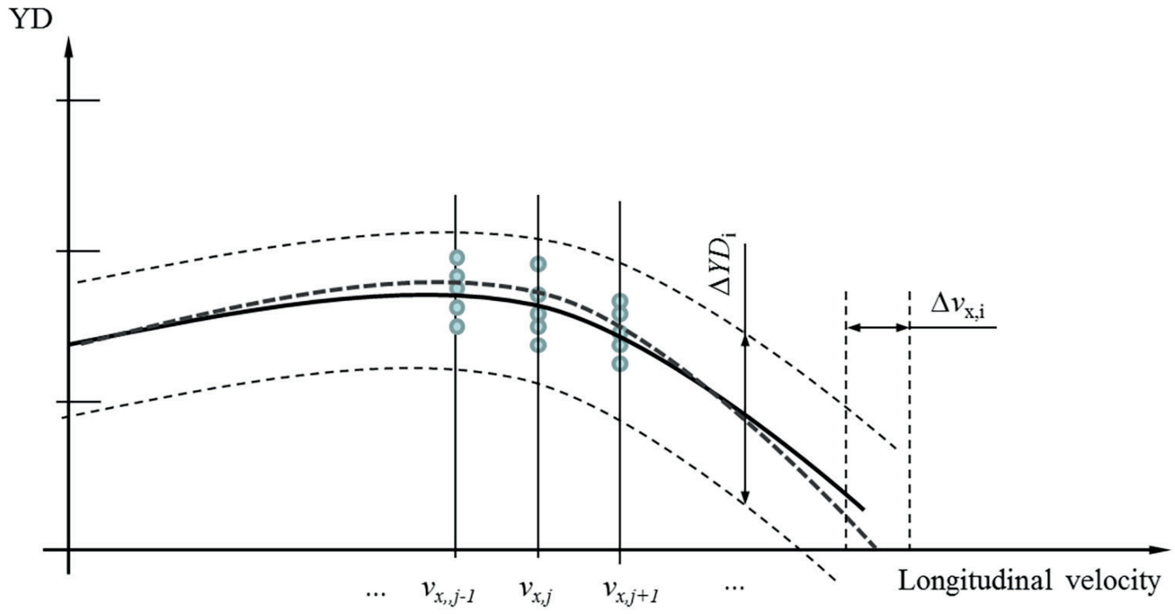

Figure 3 — Illustration of average physical results and simulated results from single sine wave input between two vehicle units. Yaw damping of articulation angle or yaw velocity as a function vehicle's longitudinal velocity. Circles illustrate physical tests of the vehicle combination.

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 clause 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 clause 9.2.1 and 9.2.2, estimated vehicle parameters may be modified within feasible boundaries, as specified in clause 6.3.

With the estimated vehicle parameters gained through this validation process, the comparison of measurement and simulation should then be repeated for a change in basic vehicle parameters, e.g. for a different loading condition or a different wheelbase. The repetition serves to prove that the validated simulation model is able to predict the influence of parameter changes upon the vehicle behavior for this test.

Annex B shows a principle of this validation process.

Annex A
(normative)

Test report – General data and test conditions

A.1 General data

The test report for general data shall be as given in ISO 15037-2:2002, Annex A.

A.2 Test conditions

The test report for test conditions shall be as given in ISO 15037-2:2002, Annex B.

Annex B
(informative)

Principle of comparing simulation and test results