
**Road vehicles — Test method
to evaluate the performance of
autonomous emergency braking
systems —**

**Part 1:
Car-to-car**

*Véhicules routiers — Méthode d'essai pour évaluer la performance
des systèmes automatiques de freinage d'urgence —*

Partie 1: Voiture à voiture

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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).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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*.

A list of all parts in the ISO 22733 series can be found on the ISO website.

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 capacity to avoid or mitigate a collision during potential accident is an important part of the performance of an autonomous emergency braking system. This document is intended to assess performance of an autonomous emergency braking system under defined test scenario only.

NOTE 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 enough and reliable data on the correlation between accident avoidance and vehicle dynamic properties in general and the results of these tests in particular.)

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Road vehicles — Test method to evaluate the performance of autonomous emergency braking systems —

Part 1: Car-to-car

1 Scope

This document specifies a method to evaluate the behaviour of a vehicle equipped with an autonomous emergency braking system (AEBS), or dynamic brake support (DBS) during several accident scenarios. Those accidents occur during a straight-line driving when the vehicle under test (VUT) approaches another vehicle in the same lane. Both vehicles are aligned in longitudinal axis to each other.

The most important part of the vehicle behaviour during these accidents scenarios is the capacity to avoid or mitigate the collision.

Systems requiring driver intervention are not in the scope of this document.

NOTE Depending on accidentology, only a part of the scenarios can be used for an evaluation of performance. AEB system evaluation based upon this document is limited to longitudinal accident scenarios.

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 8855:2011, *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*

ISO 19206-1, *Road vehicles — Test devices for target vehicles, vulnerable road users and other objects, for assessment of active safety functions — Part 1: Requirements for passenger vehicle rear-end targets*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8855, ISO 15037-1 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

AEB

autonomous emergency braking

braking applied automatically by the vehicle in response to the detection of a likely collision to reduce the vehicle speed and potentially avoid the collision

3.2

CCRs

car-to-car rear stationary

collision in which a vehicle travels forward towards another stationary vehicle and the frontal structure of the vehicle strikes the rear structure of the stationary vehicle

3.3

CCRm

car-to-car rear moving

collision in which a vehicle travels forward towards another vehicle travelling at constant speed and the frontal structure of the vehicle strikes the rear structure of the leading vehicle

3.4

CCRb

car-to-car rear braking

collision in which a vehicle travels forward towards another vehicle travelling at constant speed and then decelerates, and the frontal structure of the vehicle strikes the rear structure of the leading vehicle

3.5

DBS

dynamic brake support

system that further amplifies the driver braking demand in response to the detection of a likely collision to achieve a greater deceleration

3.6

EVT

equivalent vehicle target

vehicle target as defined in ISO 19206-1

3.7

FCW

forward collision warning

audiovisual warning provided automatically by the vehicle in response to the detection of a likely collision to alert the driver

3.8

peak braking coefficient

PBC

measure of tyre-to-road surface friction based on the maximum deceleration of a rolling tyre

Note 1 to entry: Measured using ASTM E1136-10, at a speed of 64,4 km/h, without water delivery.

3.9

TTC

time-to-collision

remaining time before the VUT strikes the EVT (3.6), assuming that the VUT and EVT travel at constant speed

3.10

VUT

vehicle under test

vehicle tested with a pre-crash collision mitigation or avoidance system on board

3.11

T_{AEB}

time when the AEB (3.1) system activates

Note 1 to entry: Activation time is determined by identifying the last data point where the filtered acceleration signal is below -1 m/s^2 , and then going back to the point in time where the acceleration first crossed $-0,3 \text{ m/s}^2$.

3.12

T_{FCW}
time when the audible warning of the *FCW* (3.7) starts

Note 1 to entry: The starting point is determined by audible analysis or video analysis.

3.13

V_{impact}
vehicle velocity at which the VUT hits the *EVT* (3.6)

3.14

V_{rel_impact}
relative speed at which the VUT hits the *EVT* (3.6) by subtracting the velocity of the *EVT* from V_{impact} (3.13) at the time of collision

4 Variables

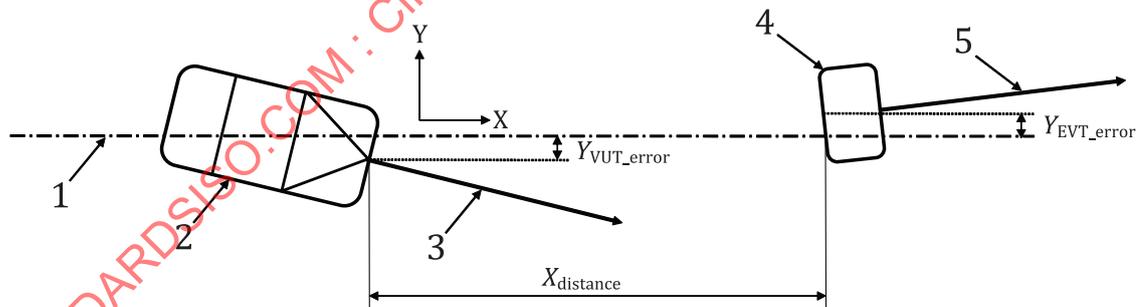
4.1 Reference system

The reference earth frame according to ISO 8855:2011, 2.8 is defined as:

- X axis: intended straight line path projected on the ground to front;
- Y axis: perpendicular to X axis on the ground to left;
- Z axis: perpendicular to the ground to the top.

4.2 Lateral offset

The lateral offset is determined as the lateral distance between the centre of the front of the VUT and the centre of the rear of the *EVT* when measured in parallel to the intended straight-lined path as shown in [Figure 1](#).



Key

- 1 intended straight-lined path
- 2 VUT
- 3 VUT path
- 4 EVT
- 5 EVT path

Figure 1 — Coordinate system and notation

The lateral offset is defined as $Y_{VUT_error} + Y_{EVT_error}$.

The origin is an arbitrary point on X axis. The Y_{VUT} and Y_{target_error} are measured in the reference frame and the Y_{target_error} is identical to Y_{EVT_error} .

4.3 Variables to be measured

Table 1 lists all relevant variables to be measured. All dynamic data shall be sampled and recorded at a frequency of at least 100 Hz. EVT and VUT data shall be synchronized by using the differential GPS (DGPS) time stamp of the EVT.

Table 1 — Variables to be measured

	Variable	Symbol
Time	CCRs and CCRm: T_0 equals TTC = 4 s	T_0
	CCRB: T_0 when EVT starts decelerating	
	T_{AEB} , time when AEB activates	T_{AEB}
	T_{FCW} , time when FCW activates	T_{FCW}
	T_{impact} , time when VUT impacts EVT	T_{impact}
Position	Position of the VUT during the entire test	X_{VUT}, Y_{VUT}
	Position of the EVT during the entire test	X_{EVT}, Y_{EVT}
Speed	Speed of the VUT during the entire test:	V_{VUT}
	— V_{impact} , speed when VUT impacts EVT	V_{impact}
	— V_{rel_impact} , relative speed when VUT impacts EVT	V_{rel_impact}
	Speed of the EVT during the entire test	V_{EVT}
Yaw velocity	Yaw velocity of the VUT during the entire test	$\dot{\psi}_{VUT}$
	Yaw velocity of the EVT during the entire test	$\dot{\psi}_{EVT}$
Acceleration	Acceleration of the VUT during the entire test	A_{EVT}
	Acceleration of the EVT during the entire test	A_{EVT}

An example of a test report is given in Annex B.

5 Equivalent vehicle target

The equivalent vehicle target (EVT) shall meet the requirements as defined in ISO 19206-1.

6 Measuring equipment and data processing

6.1 General

The test conditions on measurement equipment and data processing shall be in accordance with ISO 15037-1:2019, Clause 6, unless otherwise specified below.

6.2 Description

VUT and EVT shall be equipped with data measurement and acquisition equipment to sample and record data with an accuracy of at least:

- VUT and EVT speed to 0,1 km/h;
- VUT and EVT lateral and longitudinal position to 0,03 m;
- VUT and EVT yaw rate to 0,1°/s;
- VUT and EVT longitudinal acceleration to 0,1 m/s²;
- steering wheel velocity to 1,0°/s.

6.3 Transducer installation

The transient vehicle pitch changes shall not adversely affect the measurement of the velocity and distance variables for the chosen transducer system.

6.4 Calibration

All transducers shall be calibrated according to the manufacturer's instructions. The transducer manufacturer's recommended application software and firmware version shall be used. If parts of the measuring system can be adjusted, such calibration shall be performed immediately before the beginning of the tests.

6.5 Data processing

Filter the measured data as follows:

- position and speed are not filtered and are used in their raw state;
- acceleration with a 12-pole phaseless Butterworth filter with a cut-off frequency of 10 Hz;
- yaw rate with a 12-pole phaseless Butterworth filter with a cut-off frequency of 10 Hz;
- force with a 12-pole phaseless Butterworth filter with a cut-off frequency of 10 Hz.

7 Test conditions

7.1 General

The test conditions shall be in accordance with ISO 15037-1:2019, Clause 6, unless otherwise specified below.

7.2 General data

General data on the test vehicle and test conditions shall be recorded as specified in ISO 15037-1:2019, 6.4.1.

7.3 Test track

Conduct tests on a dry (no visible moisture on the surface), uniform, solid-paved surface with a consistent slope between level and 1 %. The test surface shall have a minimal peak braking coefficient (PBC) of 0,9.

The surface shall be paved and shall not contain any irregularities (e.g. large dips or cracks, manhole covers or reflective studs) that may give rise to abnormal sensor measurements within a lateral distance of 3,0 m to either side of the theoretical path line and with a longitudinal distance of 30 m beyond the position of VUT/EVT at the end of the test.

Lane markings are allowed. However, testing may only be conducted in an area where typical road markings depicting a driving lane may not be parallel to the test path within 3,0 m either side. Lines or markings may cross the test path but may not be present in the area where AEB activation and/or braking after FCW is expected.

7.4 Weather conditions

Conduct tests in dry conditions with ambient temperature above 0 °C and below 45 °C.

The surface temperature of the test track shall be between +10 °C and +50 °C.

No precipitation shall be falling and the horizontal visibility at ground level shall be greater than 1 km.

Wind speeds shall be below 5 m/s to minimise EVT and VUT disturbance.

Natural ambient illumination shall be homogenous in the test area and more than 1 000 lx for daylight testing with no strong shadows cast across the test area other than those caused by the VUT or EVT. Ensure testing is not performed while driving towards or away from the sun when there is direct sunlight.

Measure and record the following parameters preferably at the commencement of every single test or at least every 30 min:

- 1) ambient temperature in °C;
- 2) track temperature in °C;
- 3) wind speed and direction m/s;
- 4) ambient illumination in lx.

Weather conditions are based on ISO 21994. For some proving grounds where the lower limit of ambient temperature of 0 °C is difficult to achieve, a lower value can be adopted. However, in that case, the lower limit values shall be reported.

7.5 Surroundings

Conduct testing such that there are no other vehicles, obstructions, other objects or persons protruding above the test surface that may give rise to abnormal sensor measurements within a lateral distance of 3,0 m to either side of the test path and within a longitudinal distance of 30 m beyond the position at which the test finishes. Test areas where the VUT needs to pass under overhead signs, bridges, gantries or other significant structures are not permitted.

The general view ahead and to either side of the test area shall comprise of a wholly plain man made or natural environment (e.g. further test surface, plain coloured fencing or hoardings, natural vegetation or sky) and shall not comprise any highly reflective surfaces or contain any vehicle-like silhouettes that may give rise to abnormal sensor measurements.

7.6 VUT

7.6.1 General vehicle condition

The VUT condition shall be in accordance with the vehicle manufacturer's specifications, particularly with respect to the suspension geometries, power train (e.g. differentials and locks) configuration, and tyre fitment.

7.6.2 AEB system settings

If different settings are available, a setting shall be selected and finally reported. This setting shall not be changed until the entire test procedure is completed. The test procedure can be repeated for different settings if needed.

The AEB test protocol defined by EuroNCAP provides the following instruction for the AEB setting selection.

Set any driver configurable elements of the AEB and/or FCW system (e.g. the timing of the collision warning or the braking application if present) to the middle setting or midpoint and then next latest setting similar to the examples shown in [Table 2](#).

Table 2 — AEB and/or FCW system setting for testing

Available settings	Selected setting
Setting 1 ^a , Setting 2 ^b	Setting 2
Setting 1 ^a , Setting 2, Setting 3 ^b	Setting 2
Setting 1 ^a , Setting 2, Setting 3, Setting 4 ^b	Setting 3
^a Early brake triggering.	
^b Late brake triggering.	

The aim of EuroNCAP is to compare the performance of different vehicles with the same way of setting selection.

The purpose of this document is to measure the performance of AEB on one given vehicle. Then if several settings are available, the performance can be evaluated in any given setting.

7.6.3 Deployable pedestrian protection systems

When the vehicle is equipped with a deployable pedestrian protection system, this system shall be deactivated before the AEB tests commence.

7.6.4 Tyres

Generally, all measurements shall be conducted with original fitment tyres. If several types of tyres are available, the type of tyres shall be reported.

For a general tyre condition, new tyres shall be fitted on the test vehicle according to the manufacturer's specifications. If not specified otherwise by the tyre manufacturer, they shall be run-in according to the tyre conditioning procedure specified in 8.1.2. After running-in, maintain the run-in tyres in the same position on the vehicle for the duration of the testing.

Tyres shall have a tread depth of at least 90 % of the original value across the whole breadth of the tread and around the whole circumference of the tyre.

Tyres shall be manufactured not more than one year before the test. The date of manufacturing shall be noted in the presentation of test conditions (see Annex B).

Tyres shall be inflated to the pressure specified by the vehicle manufacturer for the test vehicle configuration. The tolerance for setting the cold inflation pressure is ± 5 kPa for pressures up to 250 kPa and ± 2 % for pressure above 250 kPa.

7.6.5 Braking system

The braking system shall be in a technically perfect condition (see also ISO 21994:2007, C.2.9). Any newly installed wheel brakes (brake discs, brake drums, brake pads) shall be burnished in accordance with vehicle manufacturer's specifications. Alternatively, the burnishing procedure for brakes as specified in ISO 21994:2007, C.2.5.2 may be applied. Hydraulic systems shall be fully bled in accordance with the manufacturer's instructions.

7.6.6 Other influencing system

Any system necessary to the braking build up or performance, (e.g. ABS, ESC) shall be operative.

Considering that systems can influence the performances (i.e. ACC), it is recommended to carry out the tests in the default configuration (i.e. available at ignition) and to avoid interferences between different systems.

7.6.7 Loading conditions of the vehicle

The fuel tank shall be full and, in the course of the measurement sequence, the indicated fuel level should not drop below "half-full".

Check the oil level and top it up to its maximum level if necessary. Similarly, top up the levels of all other fluids to their maximum levels if necessary.

Measure the front and rear axle masses and determine the total mass of the vehicle. Record this mass in the test report.

Calculate the required ballast mass, by subtracting the mass of the test driver and test equipment so that the test mass is the "unladen kerb mass" as specified by vehicle manufacturer plus 200 kg.

The weight distribution in a ready-for-measurement condition shall be adjusted according to the axle load distribution specified by the vehicle manufacturer for a ready-to-drive (kerb) condition.

If the vehicle is to be tested in any other load condition (for example, GVM) then the additional payload shall be evenly distributed such that cross-axle variations do not exceed 50 kg. If weight is disturbed different, it shall be reported in the test report (see [Annex B](#)).

8 Test procedure

8.1 Test preparation

8.1.1 Brake conditioning

Condition the vehicle's brakes in the following manner.

- Perform ten stops from a speed of 56 km/h with an average deceleration of approximately $(5 - 6) \text{ m/s}^2$.
- Immediately following the series of 56 km/h stops, perform three additional stops from a speed of 72 km/h, each time applying sufficient force to the pedal to operate the vehicle's antilock braking system (ABS) for most of each stop.
- Immediately following the series of 72 km/h stops, drive the vehicle at a speed of approximately 72 km/h for five minutes to cool the brakes.
- Initiation of the first test shall begin within two hours after completion of the brake conditioning.

8.1.2 Tyre conditioning

Condition the vehicle's tyres in the following manner to remove the mould sheen.

- Drive around a circle of 30 m in diameter at a speed sufficient to generate a lateral acceleration of approximately 5 m/s^2 to 6 m/s^2 for three clockwise laps followed by three anticlockwise laps.
- Immediately following the circular driving, drive four passes at 56 km/h, performing ten cycles of a sinusoidal steering input in each pass at a frequency of 1 Hz and with an amplitude sufficient to generate a peak lateral acceleration of approximately 5 m/s^2 to 6 m/s^2 .
- Make the steering wheel amplitude of the final cycle of the final pass double that of the previous inputs.

In case of instability in the sinusoidal driving, reduce the amplitude of the steering input to an appropriately safe level and continue the four passes.

8.2 Test scenarios

The performance of the test vehicle AEB system is assessed in the CCRs, CCRm and CCRb scenarios as shown in Figures 2-4. For testing purposes, assume a straight-line path equivalent to the centreline of the lane in which the collision occurred, hereby known as the test path. Control the tested vehicle with driver inputs or using alternative control systems that can modulate the vehicle controls as necessary to perform the tests.



Figure 2 — CCRs scenario



Figure 3 — CCRm scenario

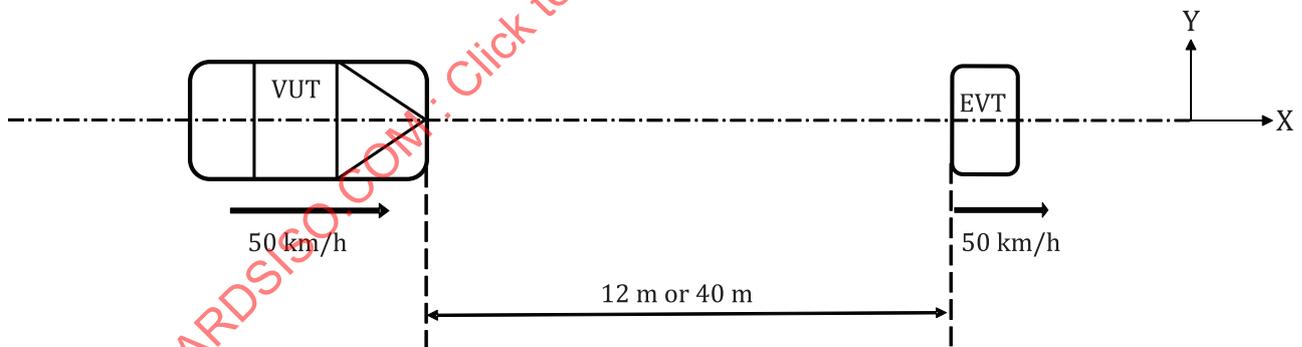


Figure 4 — CCRb scenario

The CCRs and CCRm tests will be performed with 5 km/h or 10 km/h incremental steps (see 8.4.4) within the speed ranges shown in Table 3.

Table 3 — Speed ranges for test scenarios

Scenarios	AEB speed range	FCW speed range
CCRs	10 km/h to 50 km/h	30 km/h to 80 km/h
CCRm	30 km/h to 80 km/h	30 km/h to 80 km/h

The CCRb tests will be performed at a fixed speed of 50 km/h for both VUT and EVT with all combinations of 2 m/s² and 6 m/s² deceleration and 12 m and 40 m headway.

The desired deceleration of the EVT shall be reached within 1,0 s and shall not vary by more than $\pm 0,25 \text{ m/s}^2$ of the desired level at any point in time until the EVT has come to a full stop.

8.3 Test conduct

Before every test run, drive the VUT around a circle with a maximum diameter of 30 m at a speed less than 10 km/h for one clockwise lap followed by one anticlockwise lap, and then manoeuvre the VUT on the test path. If requested by the OEM an initialisation run may be included before every test run. Bring the VUT to a halt and push the brake pedal through the full extent of travel and release.

For vehicles with an automatic transmission select Drive (D) position. For vehicles with a manual transmission select the highest gear where the RPM will be at least 1 500 at the test speed. If fitted, a speed-limiting device or cruise control may be used to maintain the VUT speed, unless the vehicle manufacturer shows that there are interferences of these devices with the AEB system in the VUT. Apply only minor steering inputs as necessary to maintain the VUT tracking along the test path.

Perform the first test a minimum of 90 s and a maximum of 10 min after completing the tyre conditioning, and subsequent tests shall be performed in the same time window. If the time between consecutive tests exceeds 10 min, repeat the tyre conditioning procedures and recommence testing.

Between tests, manoeuvre the VUT at a maximum speed of 50 km/h and avoid riding the brake pedal and harsh acceleration, braking or turning unless strictly necessary to maintain a safe testing environment.

NOTE The performance of "perception" sensors, (i.e. the sensors that define a target is one that needs a braking activation) is an important part of AEB performance. Additionally, it is important that perception sensors cannot have the target continuously in their field from one test run to the other. Therefore, the VUT is driven around a circle before every test run.

8.4 Test execution

8.4.1 Speed

Accelerate the VUT and EVT (if applicable) to the respective test speeds.

8.4.2 Validity criteria

The test shall start at T_0 (4 s TTC) and is valid when all boundary conditions are met between T_0 and T_{AEB} :

- speed of VUT (GPS-speed) test speed $\pm 1,0 \text{ km/h}$;
- speed of EVT (GPS-speed) test speed $\pm 1,0 \text{ km/h}$;
- lateral deviation from the intended straight-lined path ($0 \pm 0,1$) m;
- relative distance between VUT and EVT (CCRb) (12 or 40) m $\pm 0,5 \text{ m}$;
- yaw velocity ($0 \pm 1,0$) $^\circ/\text{s}$;
- steering wheel velocity ($0 \pm 15,0$) $^\circ/\text{s}$;
- if automatic accelerator control is used to maintain the test speed, the throttle shall be released when the automatic speed reduction has reached 5 km/h. If manual speed control or the vehicle's cruise control unit is used, this is not necessary as long as the throttle stays in the original position during automatic brake.

8.4.3 End of test conditions

The end of a test is considered when one of the following occurs when:

- $V_{EVT} = 0$ km/h;
- $V_{VUT} < V_{EVT}$;
- contact between VUT and EVT is achieved. In this case the speed of VUT when contact occurs shall be reported.

8.4.4 Determination of speed incremental steps

For AEB systems tests, when there is complete avoidance, the subsequent test speed for the next test is incremented by 10 km/h. When there is contact, first perform a test at a test speed of 5 km/h less than the test speed where contact occurred. After this test, continue to perform the remainder of the tests with speed increments of 5 km/h by repeating 8.4.1 to 8.4.3. Stop testing when the speed reduction seen in the test is less than 5 km/h (or other desired condition).

9 DBS tests (optional)

The same test scenarios can be applied to test a DBS system.

In such a test, a specified brake application is applied at a given time. If the vehicle is equipped with a forward collision warning system (FCW) a common definition for the time of application is a delay after the FCW is issued.

For DBS system tests, when there is complete avoidance, the subsequent test speed for the next test is incremented by 10 km/h. When there is contact, first perform a test at a test speed of 5 km/h less than the test speed where contact occurred. After this test, continue to perform the remainder of the tests with speed increments of 5 km/h by repeating 8.4.1 to 8.4.3. Only perform tests at the test speeds where there was no avoidance in the AEB function tests, where applicable. Stop testing when the speed reduction seen in the test is less than 5 km/h.

The DBS system tests should be performed using a braking robot reacting to the warning (FCW) with the specified delay time (default delay time 1,2 s) to account for driver reaction time.

In case a brake profile is applied, it is recommended to follow the description in Annex A. However, alternative brake profiles may be used. A report shall be drafted independent of the applied brake profile and shall contain details on it.

10 Performance metrics

10.1 Maximum speed of VUT at which collision is avoided: V_{VUT}

V_{VUT} is the maximum speed of VUT at which collision is avoided for each AEBS test scenarios (CCRs, CCRm and CCRb), when the VUT speed is increased according to 8.2.

10.2 Mean longitudinal acceleration of the VUT: $(A_{VUT})_{mean}$

$(A_{VUT})_{mean}$ is the average value of longitudinal acceleration of VUT from T_{AEB} to complete stopping when VUT avoids collision a last time for each AEBS test scenarios (CCRs, CCRm and CCRb), when the VUT speed is increased according to 8.2.

10.3 Maximum longitudinal acceleration of the VUT with DBS: $(A_{VUT})_{max}$

$(A_{VUT})_{max}$ is the maximum value of longitudinal acceleration of VUT from T_{AEB} to complete stopping when VUT avoids collision a last time for each AEBS test scenarios (CCRs, CCRm and CCRb), when the VUT speed is increased according to [8.2](#).

10.4 Average increase rate of longitudinal acceleration of VUT with DBS: $(A_{VUT})_{increase\ rate}$

$(A_{VUT})_{increase\ rate}$ is the average value of increase rate of longitudinal acceleration of VUT from T_{AEB} to complete stopping when VUT avoids collision a last time for each AEBS test scenarios (CCRs, CCRm and CCRb), when the VUT speed is increased according to [8.2](#).

10.5 Impact speed of VUT at which collision first occurs: V_{impact}

V_{impact} is the speed at which the VUT impacts EVT when the first collision occurs for each AEBS test scenarios (CCRs, CCRm and CCRb), when the VUT speed is increased according to [8.2](#).

10.6 Activation time of AEBS: T_{AEB}

T_{AEB} is the time at which the AEB system autonomous brakes and collision is avoided for the last time. It is the activation time of AEBS when VUT avoids collision a last time for each AEBS test scenarios (CCRs, CCRm and CCRb), when the VUT speed is increased according to [8.2](#).

10.7 Activation time of FCW: T_{FCW}

T_{FCW} is the time at which the forward collision warning is provided and collision is avoided for the last time. It is the activation time of FCW when VUT avoids collision a last time for each AEBS test scenarios (CCRs, CCRm and CCRb), when the VUT speed is increased according to [8.2](#).

10.8 Maximum yaw rate of the VUT: ψ_{VUT}

ψ_{VUT} is the maximum yaw rate in the time interval T_0 and T_{AEB}/T_{FCW} at which collision is avoided for the last time. It is the maximum value of yaw rate of VUT when VUT avoids collision a last time for each AEBS test scenarios (CCRs, CCRm and CCRb), when the VUT speed is increased according to [8.2](#).

10.9 Lateral offset of the VUT: Y_{VUT}

Y_{VUT} is the maximum lateral offset between VUT and EVT in the time interval T_0 and T_{AEB}/T_{FCW} at which collision is avoided for the last time. It is the maximum value of lateral offset of VUT when VUT avoids collision a last time for each AEBS test scenarios (CCRs, CCRm and CCRb), when the VUT speed is increased according to [8.2](#).

10.10 Maximum steering wheel velocity of VUT: Ω_{VUT}

Ω_{VUT} is the steering wheel velocity in the time interval T_0 and T_{AEB}/T_{FCW} at which collision is avoided for the last time. It is the maximum value of steering wheel velocity of VUT when VUT avoids collision a last time for each AEBS test scenarios (CCRs, CCRm and CCRb), when the VUT speed is increased according to [8.2](#).

Annex A (informative)

Brake application procedure

A.1 General

The braking input characterisation test determines the brake pedal displacement and force necessary to achieve a vehicle deceleration typical of that produced by a typical real-world driver in emergency situations.

A.2 Definitions

TBRAKE - The first data point where the brake pedal displacement exceeds 5 mm.

T-6 m/s² - The point in time is defined as the first data point where filtered, zeroed and corrected longitudinal acceleration data is less than -6 m/s².

T-2 m/s², T-4 m/s² - analogue to T-6 m/s².

A.3 Measurements

Measurements and filters to be applied as described in [Clause 6](#).

A.4 Brake characterization procedure

Perform the brake and tyre conditioning tests as described in [8.1.1](#) and [8.1.2](#). The brake input characterisation tests should be undertaken within 10 min after conditioning the brakes and tyres.

A.4.1 Brake displacement gradient starting value

Push the brake pedal through the full extent of travel and release.

Accelerate the VUT to a speed more than 85 km/h. Vehicles with an automatic transmission will be driven in D. For vehicles with a manual transmission select the highest gear where the RPM will be at least 1 500 at the 85 km/h.

Release the accelerator and allow the vehicle to coast. At a speed of $(80 \pm 1,0)$ km/h initiate a ramp braking input with a pedal application rate of (20 ± 5) mm/s and apply the brake until a longitudinal acceleration of -7 m/s² is achieved. For manual transmission vehicles, press the clutch as soon as the RPM drops below 1 500. The test ends when a longitudinal acceleration of -7 m/s² is achieved.

Measure the pedal displacement defined as the distance travelled by the centre of the brake-pedal plate in the direction of its movement starting from free pedal position.

Using linear regression and the least squares method, calculate the pedal travel value corresponding to a longitudinal acceleration of -4 m/s² (=D4, unit is length).

This brake pedal displacement is referred as D4 in [A.4.2](#) and [A.5](#).

A.4.2 Final brake characterisation tests

Push the brake pedal through the full extent of travel and release.

Accelerate the VUT to a speed more than 85 km/h. Vehicles with an automatic transmission will be driven in D. For vehicles with a manual transmission select the highest gear where the RPM will be at least 1 500 at the 85 km/h.

Release the accelerator and allow the vehicle to coast. At a speed of $(80 \pm 1,0)$ km/h initiate a ramp braking input with a pedal application rate of $(D4_{\text{slow}}/200 \text{ ms})$, unit is speed) with a tolerance of $\pm 5 \text{ mm/s}$ and apply the brake until a longitudinal acceleration of -7 m/s^2 is achieved. For manual transmission vehicles, press the clutch as soon as the RPM drops below 1 500. The test ends when a longitudinal acceleration of -7 m/s^2 is achieved. Measure pedal displacement and applied force normal to the direction of travel. Three valid pedal force characteristic tests are required. A minimum time of 90 s and a maximum time of 10 min is allowed between consecutive tests. If the maximum time of 10 min is exceeded, the tyre and brake conditioning procedures should be repeated before restarting the brake pedal force characterisation tests. Using linear regression and the least squares method, calculate the pedal force value corresponding to a longitudinal acceleration of -4 m/s^2 ($=F4$, unit is N).

This brake pedal force is referred as F4 in [A.5](#).

A.5 Brake application profile

Detect T_{FCW} during the experiment in real-time.

Release the accelerator at $T_{\text{FCW}} + 1 \text{ s}$.

Perform displacement control for the brake pedal, starting at $T_{\text{FCW}} + 1,2 \text{ s}$ with a gradient of $D4/0,2\text{s}$ (meaning the gradient to reach pedal position D4 as defined in [A.3](#) within 200 ms).

Monitor brake force during displacement control and use second-order filtering with a cut-off frequency of 100 Hz (online). Alternatively use moving averages over 10 ms (corresponding to cut-off frequency of 100 Hz).

Switch to force control with a desired value of F4 when whatever of the following conditions come first:

- i) the value D4 as defined in [A.3](#) is exceeded for the first time;
- ii) the force F4 as defined in [A.3](#) is exceeded for the first time.

The point in time where position control is switched to force control is noted as T_{switch} .

Maintain the force within boundaries of $F4 \pm 25 \%$. A stable force level should be achieved within a period of 200 ms maximum after the start of force control.

Additional disturbances of the force over $F4 \pm 25 \%$ due to further AEB interventions are allowed, as long as they have a duration of less than 200 ms.

The average value of the force between $T_{\text{FCW}} + 1,4 \text{ s}$ and the end of the test should be in the range of $F4 \pm 10 \text{ N}$.