Deliverable 4.1

Car to PTW AEB Test Protocol

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Executive Summary

The main objective of Work Package 4 is to provide a test procedure that could be implemented in the future Euro NCAP active safety assessments for the protection of vulnerable road users, in this case in the form of powered two-wheeler (PTW) users. For this purpose, a selection of systems and scenarios has been done in Work Package 5 by considering the main scenarios identified in Work Package 1 and the technical state of the art.

This report focus in the scenarios that could be address by Autonomous Emergency Braking systems and expose the procedures for Car to Motorbike scenarios: Rear stationary, Rear Braking, Front Turn Across Path and Front Straight Cross Path.

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1 Introduction

1.1 MUSE project

Despite representing a small part of the road users (e.g. 2% of the traffic in France) the percentage of motorcyclists in the total deaths is the highest of the VRUs (World road deaths in 2010: 23% PTWs, 22% pedestrian and 5% Cyclist). A motorcyclist is between 9 to 30 times more likely to be killed in a traffic crash than a driver (OECD 2015).

In recent years, we have observed a decrease in the number of deaths on the roads. However, this reduction is not equal for all the different road users. If we take a look at the evolution of the mortality depending of the type of road user we see that, while in the case of cars it has been reduced by 50%, in the case of the motorcyclist this reduction it has been only of the 30%. (European Comission, Directorate General for Transport 2016)

Concerned by this problematic, the French Government decide in 2015 to perform a study in collaboration with UTAC to evaluate the accidentology of the motorcyclists and the possibility of avoiding them or mitigating the consequences using the new ADAS systems. Knowing the importance of Euro NCAP in motivating the OEMs to invest in safety, in May 2016 the Interior Minister Mr. Bernard Cazeneuve and the Transport Minister Mrs. Ségolène Royal write a letter to Euro NCAP claiming for a safety rating involving PTWs. At the beginning of 2017 Euro NCAP includes the scenarios with motorcycles in their Roadmap 2020/2025 and the possibility of start to assess the presence of security systems in motorcycles.

However, how will it be possible to evaluate the systems without the necessary tools to do so? At the beginning of the project it did not exists the testing equipment who will allow us to evaluate the systems, not even a protocol in which the main scenarios and their characteristics are defined.

Furthermore, which will be the best systems to avoid the accidents? Will it generate new accidents? What about ADAS systems in the motorcycle? Is it feasible to perform real test to assess the systems?

The aim of this project was to answer these issues and to provide the OEMs and TIERs1 the tools that will enable them to develop and evaluate their systems. A first task consisted in studying the main accident scenarios and possible systems that could help to avoid them or, at least, reduce their consequences. Simultaneously, tools enabling to improve these systems and to evaluate their performances were developed.

1.2 Objectives of this report

The objective of this report is to provide a test procedure to assess the efficiency of AEB systems for the scenarios identified in Work Package 5 as the ones with more potential to be addressed a short term. For the descriptions and methodology the existent protocols of Euro NCAP AEB C2C Test Protocol v3.0.1 (Euro NCAP 2019) and *AEB VRU Test Protocol v3.0.* (Euro NCAP 2019) Have been used. The final goal of this protocol is to serve as basis for the discussions of the future Euro NCAP protocols and regulatory test assessments.

2 Definitions

Throughout this protocol the following terms are used:

Peak Braking Coefficient (PBC) – the measure of tyre to road surface friction based on the maximum deceleration of a rolling tyre, measured using the American Society for Testing and Materials (ASTM) E1136-10 (2010) standard reference test tyre, in accordance with ASTM Method E 1337-90 (reapproved 1996), at a speed of 64.4km/h, without water delivery.

Autonomous Emergency Braking (AEB) – braking that is applied automatically by the vehicle in response to the detection of a likely collision to reduce the vehicle speed and potentially avoid the collision.

Forward Collision Warning (FCW) – an audio-visual warning that is provided automatically by the vehicle in response to the detection of a likely collision to alert the driver.

Dynamic Brake Support (DBS) – a system that further amplifies the driver braking demand in response to the detection of a likely collision to achieve a greater deceleration than would otherwise be achieved for the braking demand in normal driving conditions.

Autonomous Emergency Steering (AES) – steering that is applied automatically by the vehicle in response to the detection of a likely collision to steer the vehicle around the vehicle in front to avoid the collision.

Emergency Steering Support (ESS) – a system that supports the driver steering input in response to the detection of a likely collision to alter the vehicle path and potentially avoid a collision.

Car-to-Motorbike Rear Stationary (CMRs) – a collision in which a vehicle travels forwards towards a stationary motorbike and the frontal structure of the vehicle strikes the rear structure of the motorbike.

Car-to-Motorbike Rear Braking (CMRb) – a collision in which a vehicle travels forwards towards a motorbike that is travelling at constant speed and then decelerates, and the frontal structure of the vehicle strikes the rear structure of the of the motorbike.

Car-to-Motorbike Front Turn-Across-Path (CMFtap) – a collision in which a vehicle turns across the path of an oncoming motorbike travelling at constant speed, and the frontal structure of the vehicle strikes the front structure of the motorbike.

Car-to-Motorbike Front Straight-Cross-Path Left (CMFscp-L) – a collision in which a vehicle travels straight across the path of a motorbike travelling in perpendicular direction, coming from his left at constant speed, and the frontal structure of the vehicle strikes the front structure of the motorbike.

Vehicle under test (VUT) – means the vehicle tested according to this protocol with a pre-crash collision mitigation or avoidance system on board.

Vehicle width – the widest point of the vehicle ignoring the rear-view mirrors, side marker lamps, tyre pressure indicators, direction indicator lamps, position lamps, flexible mud-guards and the deflected part of the tyre side-walls immediately above the point of contact with the ground.

Global Motorbike Target (GMT) – means the motorbike target used in this protocol as defined in the deliverable D2.1 of the MUSE project (Fritz and Wimmer 2019).

Time To Collision (TTC) – means the remaining time before the VUT strikes the GMT, assuming that the VUT and GMT would continue to travel with the speed they are travelling.

T_{AEB} – means the time where the AEB system activates. 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 m/s^2.

T_{FCW} – means the time where the audible warning of the FCW starts. The starting point is determined by audible recognition.

Vimpact – means the speed at which the VUT hits the GMT.

Vrel_impact – means the relative speed at which the VUT hits the GMT by subtracting the velocity of the GMT from Vimpact at the time of collision.

3 Reference system

3.1 Convention

3.1.1 For both VUT and GMT use the convention specified in ISO in which the x-axis points towards the front of the vehicle, the y-axis towards the left and the z-axis upwards (right hand system), with the origin at the most forward point on the centreline of the VUT for dynamic data measurements as shown in Figure 3-1.

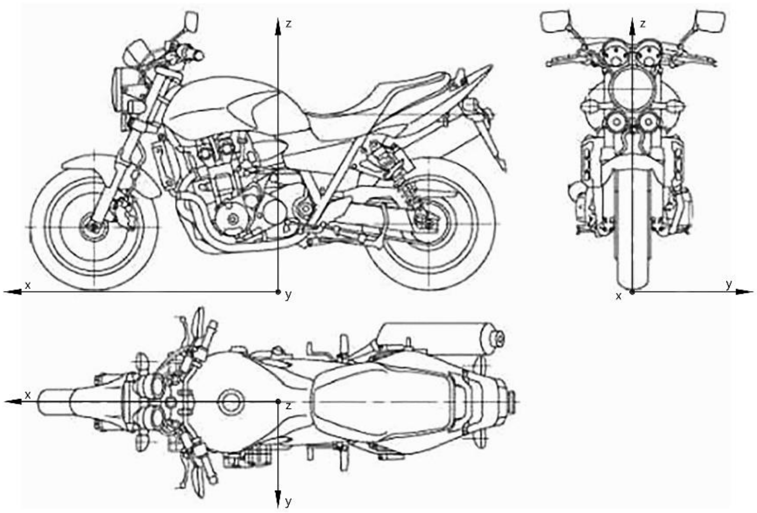


Figure 1 Coordinate system of Motorbike

3.1.2 Viewed from the origin, roll, pitch and yaw rotate clockwise around the x, y and z axes respectively. Longitudinal refers to the component of the measurement along the x-axis, lateral the component along the y-axis and vertical the component along the z-axis.

3.1.3 This reference system should be used for both left- and right-hand drive vehicles tested.

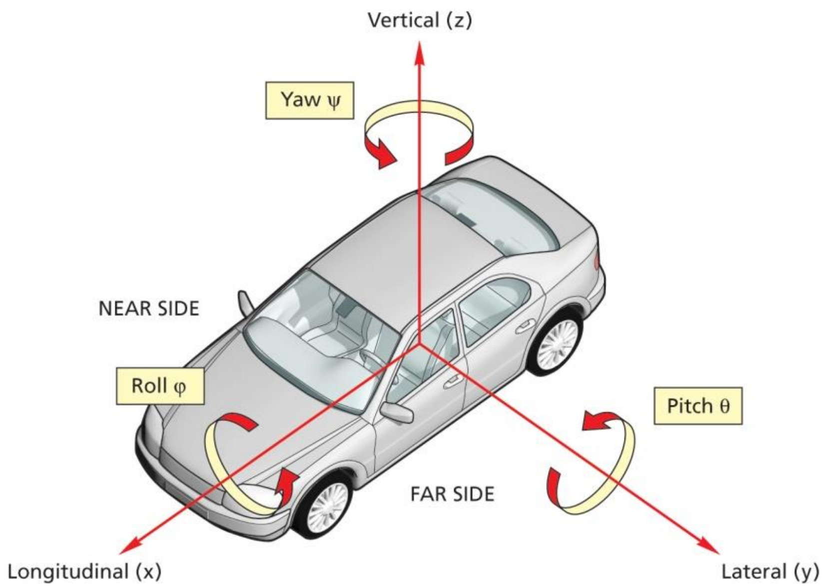


Figure 2 Coordinate system and notation

3.2 Lateral path error

3.2.1 The lateral path error is determined as the lateral distance between the centres of the front bumper of the VUT, or the GMT, and the desired trajectory as defined in the test.

Lateral Deviation from path = Y_{VUT} error

Lateral Deviation from path = Y_{GMT} error

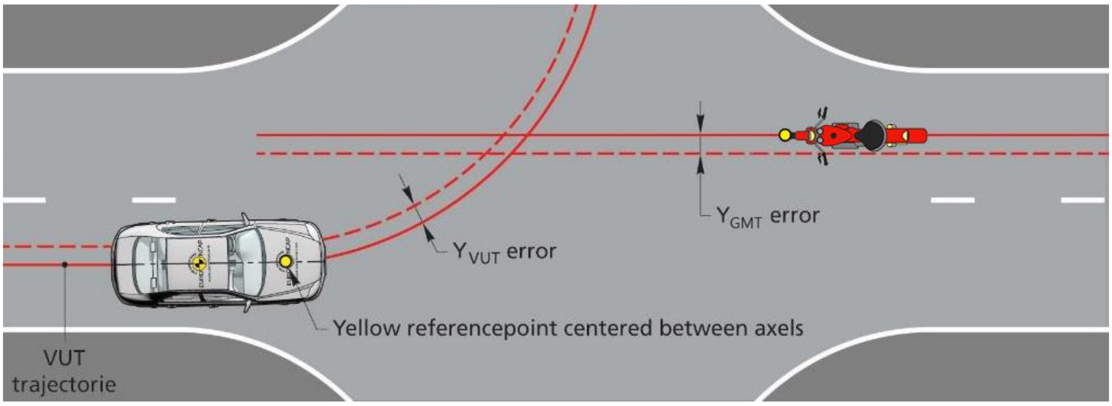


Figure 3 Lateral Path Error

3.3 Profiles for impact speed and hitpoint determination

3.3.1 A virtual profiled line is defined around the front end of the VUT. This line is defined by straight line segments connecting seven points that are equally distributed over the vehicle width minus 50mm on each side. The theoretical x,y coordinates are provided by the OEMs and verified by the test laboratory. These points will be used to define the Hitpoint for CMR,CMFtap and CMFscp-L scenarios.

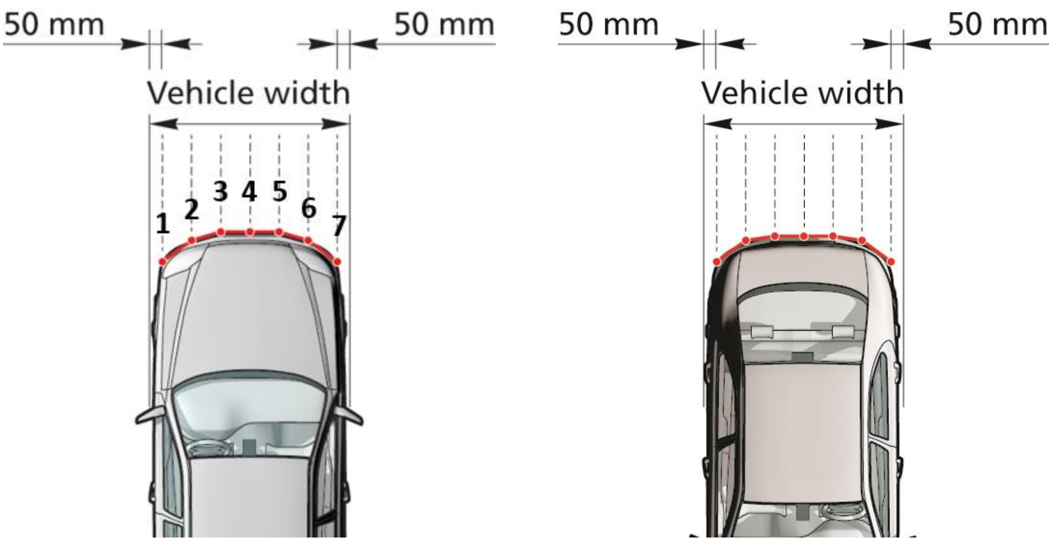


Figure 4 Virtual profiled line around vehicle front (left) end and rear end (right)

		Equivalence Hitpoit/Offset
		Offset
Hitpoint	**1**	2.6%
	2	18.4%
	3	34.2%
	4	50%
	5	65.8%
	6	81.6%
	7	97.4%

3.3.2 Around the GMT a virtual box is defined which is used to determine the impact speed. The dimensions of this virtual box are shown in Figure 3-5 below. For CMFtap and CMFscp scenarios, the most forward point of the front wheel is used. For CMR scenarios, the most backward point of the back wheel is used as reference.

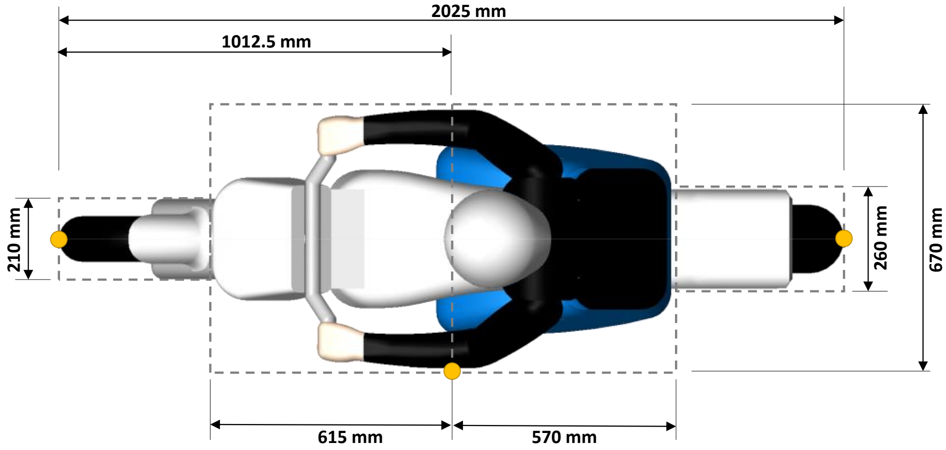


Figure 5 Virtual box dimensions around GMT

4 Measuring equipment

4.1 Measurements and variables

4.1.1 Sample and record all dynamic data at a frequency of at least 100Hz. Synchronise using the DGPS time stamp the GMT data with that of the VUT.

4.1.2	Time	**T**
	• CMRs, CMRm, CMFtap and CMFscp-L: T_0 equals TTC = 4s (CMRb: T_0 when GMT starts decelerating)	$\mathbf{T}_0$
	• T_{AEB}, time where AEB activates	$\mathbf{T}_{AEB}$
	• T_{FCW}, time where FCW activates	$\mathbf{T}_{FCW}$
	• T_{impact}, time where VUT impacts GMT	$\mathbf{T}_{impact}$
	• T_{steer}, time where VUT enters in curve segment	$\mathbf{T}_{steer}$
4.1.3	Position of the VUT during the entire test	$\mathbf{X}_{VUT}$, $\mathbf{Y}_{VUT}$
4.1.4	Position of the GMT during the entire test	$\mathbf{X}_{GMT}$, $\mathbf{Y}_{GMT}$
4.1.5	Speed of the VUT during the entire test	$\mathbf{V}_{VUT}$
	• V_{impact}, speed when VUT impacts GMT	$\mathbf{V}_{impact}$
	• $V_{rel,impact}$, relative speed when VUT impacts GMT	$\mathbf{V}_{rel,impact}$
4.1.6	Speed of the GMT during the entire test	$\mathbf{V}_{GMT}$
4.1.7	Yaw velocity of the VUT during the entire test	$\dot{\Psi}_{VUT}$
4.1.8	Yaw velocity of the GMT during the entire test	$\dot{\Psi}_{GMT}$
4.1.9	Acceleration of the VUT during the entire test	$\mathbf{A}_{VUT}$
4.1.10	Acceleration of the GMT during the entire test	$\mathbf{A}_{GMT}$
4.1.11	Steering wheel velocity of the VUT during the entire test	$\mathbf{\Omega}_{VUT}$

4.2 Measuring equipment

4.2.1 Equip the VUT and GMT with data measurement and acquisition equipment to sample and record data with an accuracy of at least:

- VUT and GMT speed to 0.1km/h;
- VUT and GMT lateral and longitudinal position to 0.03m;
- VUT heading angle to 0.1°;
- VUT and GMT yaw rate to 0.1°/s;
- VUT and GMT longitudinal acceleration to 0.1m/s^2;
- VUT steering wheel velocity to 1.0 °/s.

4.3 Data filtering

4.3.1 Filter the measured data as follows:

4.3.1.1 Position and speed are not filtered and are used in their raw state.

4.3.1.2 Acceleration, yaw rate and VUT steering wheel velocity with a 12-pole phaseless Butterworth filter with a cut off frequency of 10Hz.

5 Global motorbike target

5.1 Specification

5.1.1 Conduct the tests in this protocol using the Global Motorbike Target (GMT) as shown in Figure 6 below. The GMT replicates the visual, radar and LIDAR attributes of a typical L3 PTW.

Figure 6 Global Motorbike Target (GMT)

5.1.2 To ensure repeatable results the combination of the propulsion system and GMT must meet the requirements as detailed in deliverables 2.1 **(Fritz and Wimmer 2019)** and 3.1 **(Núñez Miguel 2019)** of the MUSE project.

5.1.3 The GMT is designed to work with the following types of sensors:

- Radar (24 and 77 GHz)
- LIDAR
- Camera

6 Test conditions

6.1 Test track

6.1.1 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.

6.1.2 The surface must be paved and may not contain 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 3.0m to either side of the test path and with a longitudinal distance of 30m ahead of the VUT when the test ends.

6.1.3 The presence of lane markings is 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 3.0m 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.

6.1.4 Junction and Lane Markings

6.1.4.1 The CMFtap and CMFscp-L tests described in this document requires the use of a junction. The main approach lane where the VUT and GMT paths start, (horizontal lanes in Figure 7-1) will have a width of 3.5m. The side lane (vertical lanes in Figure 7-1) will have a width of 3.25 to 3.5m. The lane markings on these lanes need to conform to one of the lane markings as defined in UNECE Regulation 130:

1. Dashed line starting at the same point where the radius transitions into a straight line with a width between 0.10 and 0.15m
2. Solid line with a width between 0.10 and 0.25m
3. Junction without any central markings

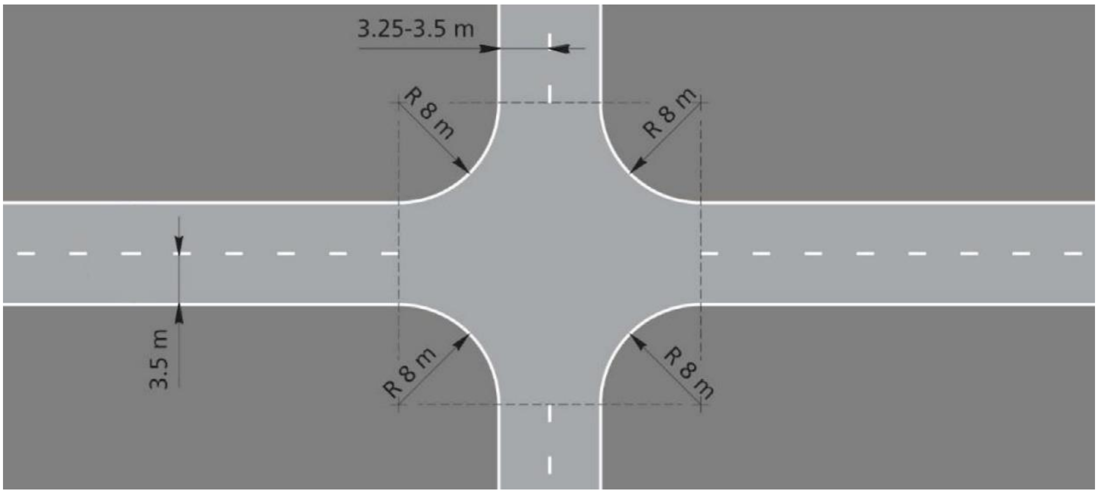


Figure 7 Layout of junction and the connecting lanes

6.2 Weather conditions

6.2.1 Conduct tests in dry conditions with ambient temperature above 5°C and below 40°C.

6.2.2 No precipitation shall be falling and horizontal visibility at ground level shall be greater than 1km. Wind speeds shall be below 10m/s to minimise GMT and VUT disturbance.

6.2.3 Natural ambient illumination must be homogenous in the test area and in excess of 2000 lux for daylight testing with no strong shadows cast across the test area other than those caused by the VUT or GMT. Ensure testing is not performed driving towards, or away from the sun when there is direct sunlight.

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

a) Ambient temperature in °C;
b) Track Temperature in °C;
c) Wind speed and direction in m/s;
d) Ambient illumination in Lux.

6.3 Surroundings

6.3.1 Conduct testing such that there are no other vehicles, highway furniture, obstructions, other objects or persons protruding above the test surface that may give rise to abnormal sensor measurements within a lateral distance of 3.0m to either side of the test path and within a longitudinal distance of 30m ahead of the VUT when the test ends (Figure 4).

6.3.2 Test areas where the VUT needs to pass under overhead signs, bridges, gantries or other significant structures are not permitted. For the entire test, 3m of free surroundings is to be ensured on both sides of the test path of the VUT.

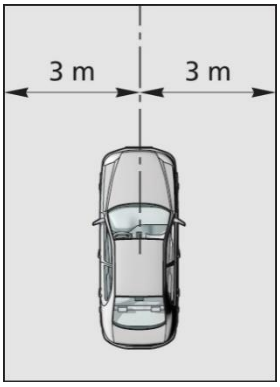


Figure 8 Free surroundings

6.3.3 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 etc.) and must not comprise any highly reflective surfaces or contain any vehicle-like silhouettes that may give rise to abnormal sensor measurements.

6.4 VUT Preparation

6.4.1 AEB and FCW system settings

6.4.1.1 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 Figure 9.

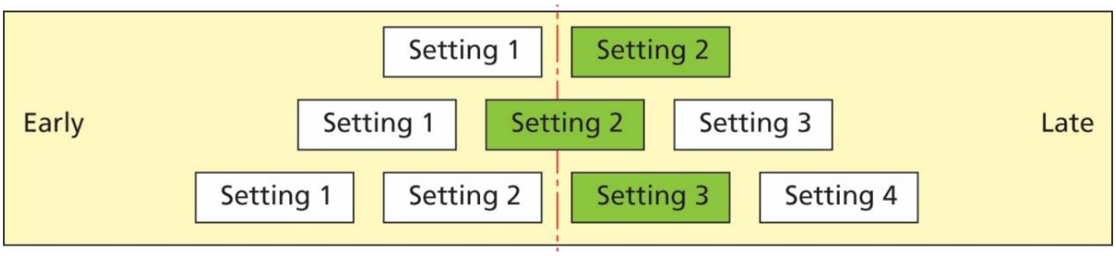


Figure 9 AEB and/or FCW system setting for testing

6.4.2 Tyres

Perform the testing with new original fitment tyres of the make, model, size, speed and load rating as specified by the vehicle manufacturer. It is permitted to change the tyres which are supplied by the manufacturer or acquired at an official dealer representing the manufacturer if those tyres are identical make, model, size, speed and load rating to the original fitment. Inflate the tyres to the vehicle manufacturer's recommended cold tyre inflation pressure(s). Use inflation pressures corresponding to least loading normal condition.

Run-in tyres according to the tyre conditioning procedure specified in 8.1.3. After running-in maintain the run-in tyres in the same position on the vehicle for the duration of the testing.

6.4.3 Wheel alignment measurement

The vehicle should be subject to a vehicle (in-line) geometry check to record the wheel alignment set by the OEM. This should be done with the vehicle in kerb weight.

6.4.4 Unladen kerb mass

6.4.4.1 Fill up the tank with fuel to at least 90% of the tank's capacity of fuel.

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

6.4.4.3 Ensure that the vehicle has its spare wheel on board, if fitted, along with any tools supplied with the vehicle. Nothing else should be in the car.

6.4.4.4 Ensure that all tyres are inflated according to the manufacturer's instructions for the appropriate loading condition.

6.4.4.5 Measure the front and rear axle masses and determine the total mass of the vehicle. The total mass is the 'unladen kerb mass' of the vehicle. Record this mass in the test details.

6.4.4.6 Calculate the required ballast mass, by subtracting the mass of the test driver and test equipment from the required 200 kg interior load.

6.4.5 Vehicle preparation

6.4.5.1 Fit the on-board test equipment and instrumentation in the vehicle. Also fit any associated cables, cabling boxes and power sources.

6.4.5.2 Place weights with a mass of the ballast mass. Any items added should be securely attached to the car.

6.4.5.3 With the driver in the vehicle, weigh the front and rear axle loads of the vehicle.

6.4.5.4 Compare these loads with the "unladen kerb mass"

6.4.5.5 The total vehicle mass shall be within ±1% of the sum of the unladen kerb mass, plus 200kg. The front/rear axle load distribution needs to be within 5% of the front/rear axle load distribution of the original unladen kerb mass plus full fuel load. If the vehicle differs from the requirements given in this paragraph, items may be removed or added to the vehicle which has no influence on its performance. Any items added to increase the vehicle mass should be securely attached to the car.

6.4.5.6 Repeat paragraphs 6.4.5.3 and 6.4.5.4 until the front and rear axle loads and the total vehicle mass are within the limits set in paragraph 6.4.5.5. Care needs to be taken when adding or removing weight in order to approximate the original vehicle inertial properties as close as possible. Record the final axle loads in the test details. Record the axle weights of the VUT in the 'as tested' condition.

6.4.5.7 Verify the x-y coordinates for the virtual front end vehicle contour given by the manufacturer. When the coordinates given are within 10mm of those measured by the test laboratory, the coordinates as provided by the manufacturer will be used. When the coordinates are not within 10mm, the coordinates as measured by the laboratory will be used.

7 Test procedure

7.1 VUT Pre-test conditioning

7.1.1 General

7.1.1.1 A new car is used as delivered to the test laboratory.

7.1.1.2 If requested by the vehicle manufacturer, drive a maximum of 100km on a mixture of urban and rural roads with other traffic and roadside furniture to 'calibrate' the sensor system. Avoid harsh acceleration and braking.

7.1.2 Brakes

7.1.2.1 Condition the vehicle's brakes in the following manner, if it has not been done before or in case the lab has not performed a 100km of driving:

- Perform twenty stops from a speed of 56km/h with an average deceleration of approximately 0.5 to 0.6g.
- Immediately following the series of 56km/h stops, perform three additional stops from a speed of 72km/h, each time applying sufficient force to the pedal to operate the vehicle's antilock braking system (ABS) for the majority of each stop.
- Immediately following the series of 72km/h stops, drive the vehicle at a speed of approximately 72km/h for five minutes to cool the brakes.

7.1.3 Tyres

7.1.3.1 Condition the vehicle's tyres in the following manner to remove the mould sheen, if this has not been done before for another test or in case the lab has not performed a 100km of driving:

- Drive around a circle of 30m in diameter at a speed sufficient to generate a lateral acceleration of approximately 0.5 to 0.6g for three clockwise laps followed by three anticlockwise laps.
- Immediately following the circular driving, drive four passes at 56km/h, performing ten cycles of a sinusoidal steering input in each pass at a frequency of 1Hz and amplitude sufficient to generate a peak lateral acceleration of approximately 0.5 to 0.6g.
- Make the steering wheel amplitude of the final cycle of the final pass double that of the previous inputs.

7.1.3.2 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.

7.1.4 AEB/FCW system check

7.1.4.1 Before any testing begins, perform a maximum of ten runs at the lowest test speed the system is supposed to work, to ensure proper functioning of the system.

7.2 Test scenarios

7.2.1 The performance of the AEB system is assessed in the CMRs, CMRb, CMFtap and CMFscp-L scenarios as shown in the sections 7.2.3, 7.2.4, 7.2.5 and 7.2.6.

7.2.2 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 VUT with driver inputs or using alternative control systems that can modulate the vehicle controls as necessary to perform the tests.

7.2.3 Car-to-Motorbike Rear stationary

The CMRs scenario will be performed with 10km/h incremental steps in speed within the ranges as shown in the table below.

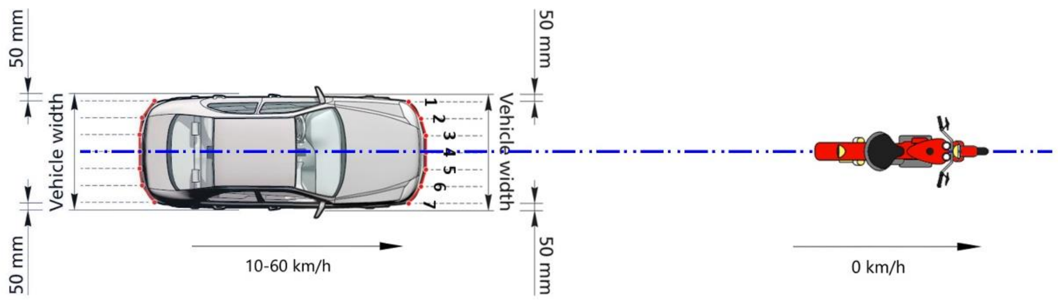


Figure 10 CCRs scenario

	AEB only
AEB CMRs	10-60 km/h

7.2.4 Car-to-Motorbike Rear braking

The CMRb tests will be performed at a fixed speed of 50km/h for both VUT and GMT with 4m/s2 deceleration and 12 and 40m headway. The hitpoint of this scenario will be the number 5 of the front bumper of the car and the rear reference point of the motorbike.

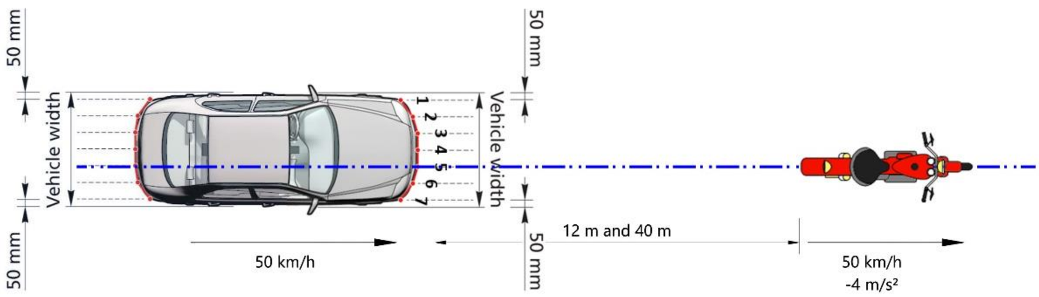


Figure 11 CCRb scenario

		AEB+FCW combined & AEB only
		4 m/s^2
AEB CMRb	12m	50 km/h
	40m	50 km/h

The desired deceleration of the GMT shall be reached within 1.0 seconds (T0 + 1.0s) which after the GMT shall remain within ± 0.5 km/h of the reference speed profile, derived from the desired deceleration, until the vehicle speed equals 1 km/h.

7.2.5 Car-to-Motorbike Front turn across path

7.2.5.1 For the CMFtap scenario, for the VUT assume an initial straight-line path followed by a turn (clothoid, fixed radius and clothoid as specified in section 7.2.5.5), followed again by a straight line, hereby known as the test path.

7.2.5.2 The GMT will follow a straight-line path in the lane adjacent to the VUT's initial position, in the opposite direction to the VUT. The straight-line path of the VUT and target will be 1.75m from the inner side of the centre dashed lane marking of the VUT lane.

7.2.5.3 The paths of the VUT and target vehicle will be synchronised so that the front edges of the vehicle (hitpoint 4) meet with the front reference point of the GMT (assuming no system reaction) of the width of the VUT.

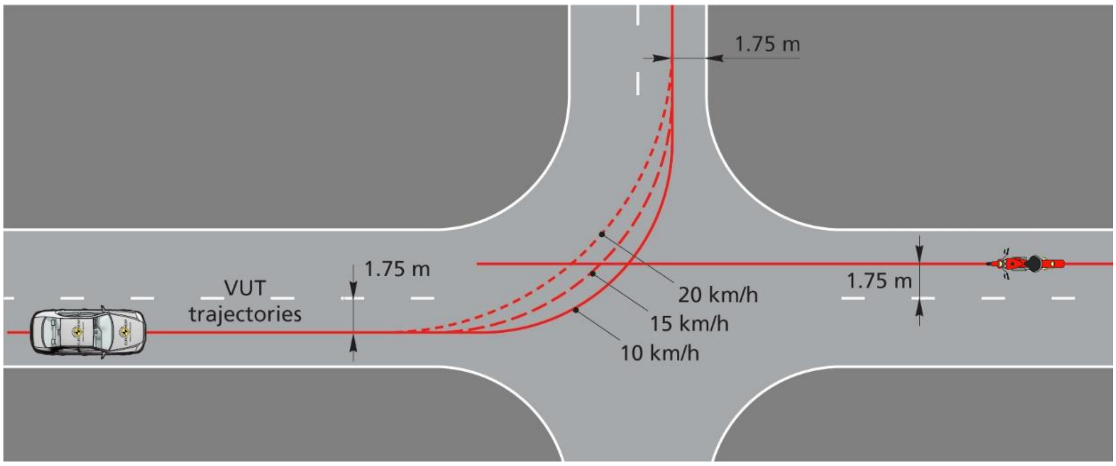


Figure 12 CMFtap scenario paths

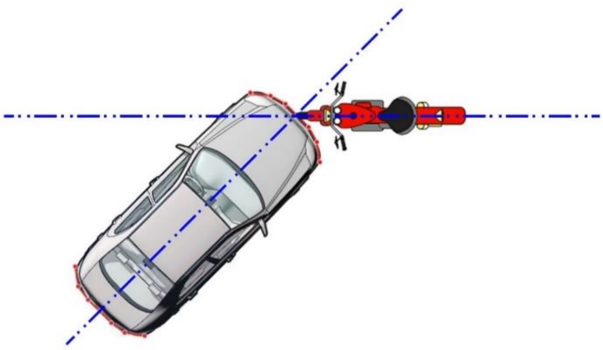
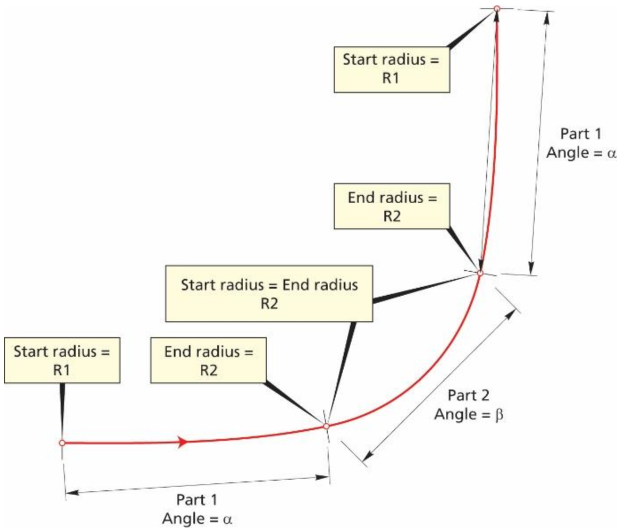


Figure 13 CMFtap impact definition

7.2.5.4 The CMFtap scenarios are all combinations of VUT speeds of 10, 15 and 20 km/h combined with GMT speeds of 30, 40 and 50 km/h.

7.2.5.5 The following parameters should be used to create the test paths where the turn signal is applied at 1.0s before Tsteer:



Test speed	Part 1 (clothoid)			Part 2 (constant radius)			Part 3 (clothoid)		
	Start Radius R1 [m]	End Radius R2 [m]	Angle α [deg]	Start Radius R2 [m]	End Radius R2 [m]	Angle β [deg]	Start Radius R2 [m]	End Radius R1 [m]	Angle α [deg]
10 km/h	1500	9.00	20.62	9.00	9.00	48.76	9.00	1500	20.62
15 km/h	1500	11.75	20.93	11.75	11.75	48.14	11.75	1500	20.93
20 km/h	1500	14.75	21.79	14.75	14.75	46.42	14.75	1500	21.79

7.2.6 Car-to-Motorbike Front straight cross path Left

7.2.6.1 For the CMFscp-L scenario, for the VUT assume an initial straight-line path hereby known as the test path. The path of the VUT will be at 1.75m from the inner side of the centre dashed lane parallel to his trajectory.

7.2.6.2 The GMT will follow a straight-line path in the perpendicular lane to the VUT's path, coming from the far side of the car. The path of the GMT will be at 1.75m from the inner side of the centre dashed lane parallel to his trajectory.

7.2.6.3 The paths of the VUT and target vehicle will be synchronised so that the hitpoint 2 of the vehicle will meet with the front reference point of the GMT (assuming no system reaction) of the width of the VUT.

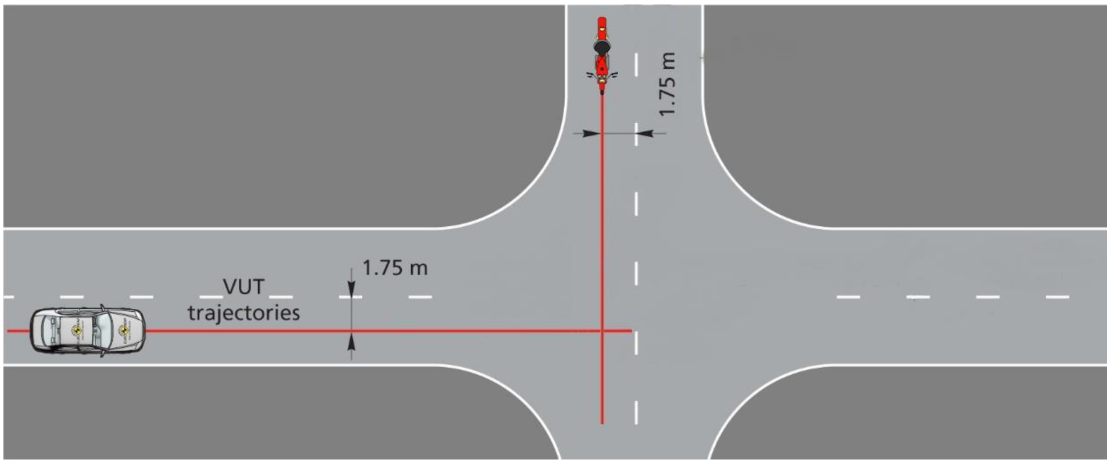


Figure 14 CMFscp-L scenario paths

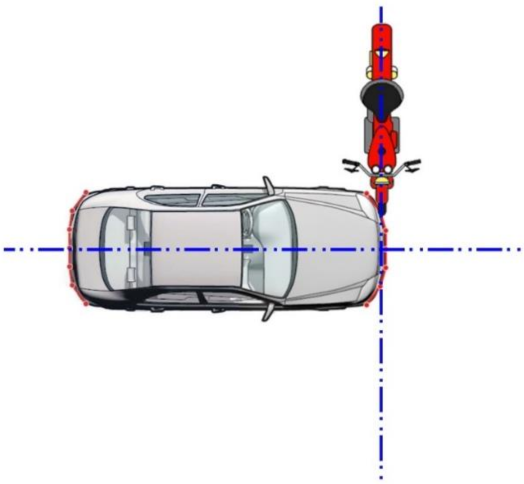


Figure 15 CCMscp-L scenario paths and impact definition

7.2.6.4 The CMFscp-L scenarios are all combinations of VUT speeds of 10, 15 and 20 km/h combined with GMT speeds of 30, 40 and 50 km/h.

7.3 Test conduct

7.3.1 Before every test run, drive the VUT around a circle of maximum diameter 30m at a speed less than 10km/h for one clockwise lap followed by one anticlockwise lap, and then manoeuvre the VUT into position on the test path. If requested by the OEM a simple 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.

7.3.2 For vehicles with an automatic transmission select D. For vehicles with a manual transmission select the highest gear where the RPM will be at least 1500 at the test speed. If fitted, a speed limiting device or cruise control may be used to maintain the VUT speed (not ACC), 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.

7.3.3 Perform the first test a minimum of 90s and a maximum of 10 minutes after completing the tyre conditioning (if applicable), and subsequent tests after the same time period. If the time between consecutive tests exceeds 10 minutes perform three brake stops from 72 km/h at approximately 0.3g.

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

7.4 Test execution

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

7.4.2 The test shall start at T_0 (4s TTC) and is valid when all boundary conditions are met between T_0 and T_{AEB} and/or T_{FCW}, or any other system intervention:

- Speed of VUT (GPS-speed) Test speed + 1.0 km/h
- Speed of GMT (GPS-speed) Test speed ± 1.0 km/h

- Lateral deviation from test path for VUT 0 ± 0.05 m for CMR and CMFscp-L
  0 ± 0.05 m for CMFtap straight-line

  0 ± [0.10] m for CMFtap turn

- Lateral deviation from test path for GMT 0 ± [0.15] m

- Relative distance VUT and GMT (CMRb) 12m or 40m ± 0.5m

- Yaw velocity of VUT (CMR) 0 ± 1.0 °/s
- Yaw velocity of GMT 0 ± 2.0 °/s
- Steering wheel velocity 0 ± 15.0 °/s

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

- V_{VUT} = 0km/h
- $V_{VUT} < V_{GMT}$ for CMR
- Contact between VUT and GMT

7.4.4 To avoid contact in the CMFtap scenario, the test laboratory may include an automated braking action by the robot in case the AEB system fails to intervene (sufficiently). This braking action is applied automatically when:

- The VUT reaches the latest position at which maximum braking applied to the vehicle will prevent the VUT entering the path of the motorbike and no intervention from the AEB system is detected.
- Lateral separation between the VUT and GMT reaches ≤ 0 during / after AEB intervention.

It is at the labs discretion to select and use one of the options above to ensure a safe testing environment.

7.4.5 For manual or automatic accelerator control, it needs to be assured that during automatic brake the accelerator pedal does not result in an override of the system.

7.4.6 The FCW system tests should be performed using a braking robot reacting to the warning with a delay time of 1.2 seconds as per A.4 to account for driver reaction time.

7.4.7 Braking will be applied that results in a maximum brake level of -4 m/s^2 - 0.50 m/s^2 when applied in a non-threat situation. The particular brake profile to be applied (pedal application rate applied in 200ms (max. 400mm/s) and pedal force) shall be specified by the manufacturer. When the brake profile provided by the manufacturer results in a higher brake level than allowed, the iteration steps as described in ANNEX A will be applied to scale the brake level to -4 m/s^2 - 0.50 m/s^2.

7.4.8 When no brake profile is provided, the default brake profile as described in ANNEX A will be applied.

8 Annex A: Brake application procedure

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.

8.1 Definitions

TBRAKE - The point in time where the brake pedal displacement exceeds 5mm.

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

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

8.2 Measurements

Measurements and filters to be applied as described in Chapter 4 of this protocol.

8.3 Brake characterization procedure

First perform the brake and tyre conditioning tests as described in 7.1.2 and 7.1.3. The brake input characterisation tests shall be undertaken within 10 minutes after conditioning the brakes and tyres.

8.3.1 Brake displacement characterisation tests

- Push the brake pedal through the full extent of travel and release.
- Accelerate the VUT to a speed in excess of 85km/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 1500 at the 85km/h.
- Release the accelerator and allow the vehicle to coast. At a speed of 80 ± 1.0km/h initiate a ramp braking input with a pedal application rate of 20±5mm/s and apply the brake until a longitudinal acceleration of $-7m/s^2$ is achieved. For manual transmission vehicles, press the clutch as soon as the RPM drops below 1500. The test ends when a longitudinal acceleration of $-7m/s^2$ is achieved.
- Measure the pedal displacement and applied force normal to the direction of travel of the initial stroke of the brake pedal, or as close as possible to normal as can be repeatedly achieved.

  Perform three consecutive test runs. A minimum time of 90 seconds and a maximum time of 10 minutes shall be allowed between consecutive tests. If the maximum time of 10 minutes is exceeded, perform three brake stops from 72 km/h at approximately 0.3g.
- Using second order curve fit and the least squares method between T_{-2m/s^2}, T_{-6m/s^2}, calculate the pedal travel value corresponding to a longitudinal acceleration of $-4\ m/s^2$ (=D4, unit is m). Use data of at least three valid test runs for the curve fitting.
- This brake pedal displacement is referred to as D4 in the next chapters.
- Using second order curve fit and the least squares method between T_{-2m/s^2}, T_{-6m/s^2}, calculate the pedal force value corresponding to a longitudinal acceleration of $-4\ m/s^2$ (=F4, unit is N). Use data of at least three valid test runs for the curve fitting.
- This brake pedal force is referred to as F4 in the next chapters.

8.3.2 Brake force confirmation and iteration procedure

- Accelerate the VUT to a speed of 80+1km/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 1500 at the 80km/h.
- Apply the brake force profile as specified in B.4, triggering the input manually rather than in response to the FCW. Determine the mean acceleration achieved during the window from T_{BRAKE} +1s T_{BRAKE} +3s. If a mean acceleration outside the range of -4-0.5m/s2 results, apply the following method to ratio the pedal force applied.

  F4new = F4original * (-4/mean acceleration), i.e. if F4original results in a mean acceleration of -5m/s2, F4new = F4original * -4 / -5

- Repeat the brake force profile with this newly calculated F4, determine the mean acceleration achieved and repeat the method as necessary until a mean acceleration within the range of -4-0.5m/s2 is achieved.

8.3.2.1 Three valid pedal force characteristic tests (with the acceleration level being in the range as specified) are required. A minimum time of 90 seconds and a maximum time of 10 minutes shall be allowed between consecutive tests. If the maximum time of 10 minutes is exceeded, perform three brake stops from 72 km/h at approximately 0.3g.

- Before restarting the brake pedal force characterisation tests. This brake pedal force is referred as F4 in the next chapters.

8.4 Brake application profile

- Detect TFCW during the experiment in real-time.
- Release the accelerator at T_{FCW} + 1 s.
- Perform displacement control for the brake pedal, starting at T_{FCW} + 1.2 s with a gradient of the lesser of 5 x D4 or 400mm/s (meaning the gradient to reach pedal position D4 within 200ms, but capped to a maximum application rate of 400mm/s).
- Monitor brake force during displacement control and use second-order filtering with a cut-off frequency between 20 and 100 Hz (online) as appropriate.
- Switch to force control, maintaining the force level, with a desired value of F4 when
  i. the value D4 as defined in B.3 is exceeded for the first time,
  ii. the force F4 as defined in B.3 is exceeded for the first time,
  whichever is reached first.
- The point in time where position control is switched to force control is noted as T_{switch}.
- Maintain the force within boundaries of F4 ± 25% F4. A stable force level should be achieved within a period of 200ms maximum after the start of force control. Additional disturbances of the force over ± 25% F4 due to further AEB interventions are allowed, as long as they have a duration of less than 200ms.
- The average value of the force between T_{FCW} + 1.4s and the end of the test should be in the range of F4 ± 10 N.

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