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TNO 2016 R10927

CATS Deliverable 5.2: CATS test protocol

Date	2 September 2016
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Number of pages	25 (incl. appendices)
Number of appendices	2
Project name	CATS (www.TNO.nl/CATS)
Project number	060.07093

Contents

1 Introduction

The overall number of fatalities in road traffic accidents in Europe is decreasing, however unfortunately the number of fatalities among cyclists does not follow this trend with the same rate. In order to address this from 2018, AEB systems dedicated to avoid or mitigate car-to-cyclist collisions will be considered in the safety assessment by Euro NCAP. To develop protocols and appropriate equipment to test such systems, TNO has initiated the CATS “Cyclist-AEB Testing System” consortium, in which around 20 partners, mostly OEM’s and TIER1s, have joined forces. Accidentology was used to determine the three most common car-to-cyclist accident scenarios in the EU. Accident data and data from observation studies were used to determine the parameter ranges in the test matrix that has been proposed for the selected test scenarios. A bicyclist target has been specified to represent a real bicyclist on a bike, taking into account all different types of sensors used in AEB systems. 4activeSystem GmbH (Austria) has developed and manufactured a bicyclist target and propulsion system that meets the set of requirements to represent the defined scenarios. Together with car manufacturers and suppliers, the proposed test matrix has been verified (D5.1).

This report describes the specifications of the CATS test protocol, which uses a similar approach and structure as the Euro NCAP AEB VRU protocol [1].

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.

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.

Car-to-VRU Nearside Bicyclist Unobstructed (CVNBU) – a collision in which a vehicle travels forwards towards a bicyclist crossing its path cycling from the nearside and the frontal structure of the vehicle strikes the bicyclist when no braking action is applied.

Car-to-VRU Nearside Bicyclist Obstructed (CVNBO) – a collision in which a vehicle travels forwards towards a bicyclist crossing its path cycling from the nearside behind an obstruction and the frontal structure of the vehicle strikes the bicyclist when no braking action is applied.

Car-to-VRU Farside Bicyclist (CVFB) – a collision in which a vehicle travels forwards towards a bicyclist crossing its path cycling from the farside and the frontal structure of the vehicle strikes the bicyclist when no braking action is applied.

Car-to-VRU Longitudinal Bicyclist (CVLB) – a collision in which a vehicle travels forwards towards a bicyclist cycling in the same direction in front of the vehicle.

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

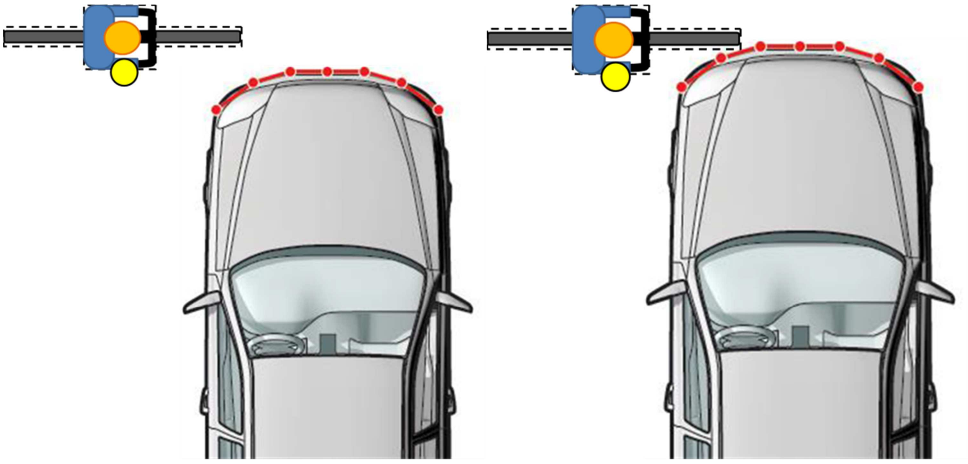
CATS Bicyclist and bike Target (BT) – means the bicyclist and bike target used in this protocol as specified in ANNEX A.

Time To Collision (TTC) – means the remaining time before the VUT strikes the BT, assuming that the VUT and BT would continue to travel with the speed it is 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.

V_{impact} – means the speed at which the profiled line around the front end of the VUT coincides with the square boxes around the BT as shown in the figure below.



3 Reference system

3.1 Convention

3.1.1 For both VUT and BT use the convention specified in ISO 8855:1991 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 1.

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 (LHD) and right hand drive (RHD) vehicles tested.

3.1.4 Nearside is defined as area besides vehicle closest to the kerb in the designated direction of traffic and farside is the area besides the vehicle closest to the centre of the road. See Figure 1 for left hand drive (LHD) car.

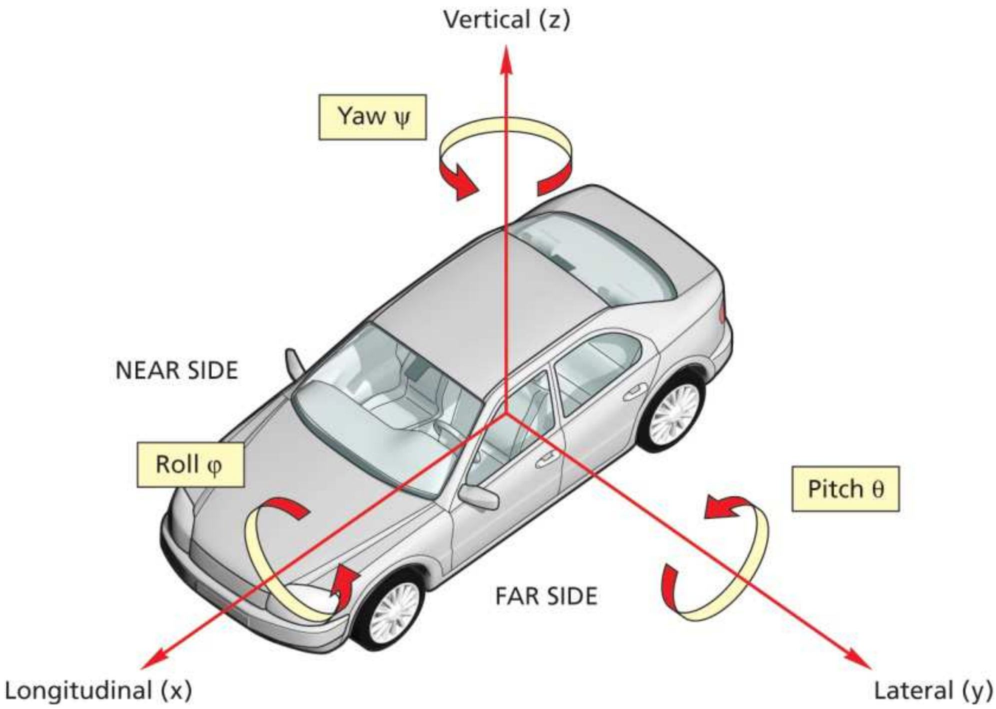


Figure 1 Coordinate system and notation (LHD & RHD) and nearside – farside for LHD vehicle.

3.2 Lateral Offset

The lateral offset is determined as the lateral distance between the centre of the front of the VUT when measured in parallel to the intended straight lined path as shown in the figure below.

Lateral offset = Y_{VUT} error

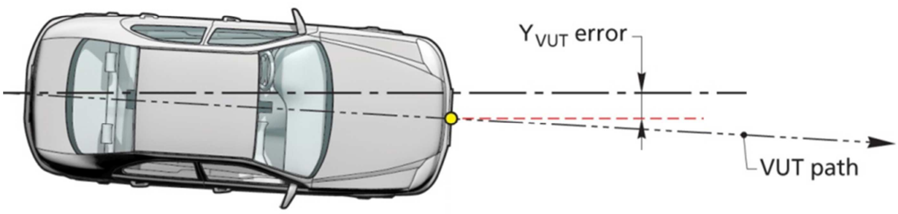


Figure 2 Lateral offset

3.3 Profiles for impact speed 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.

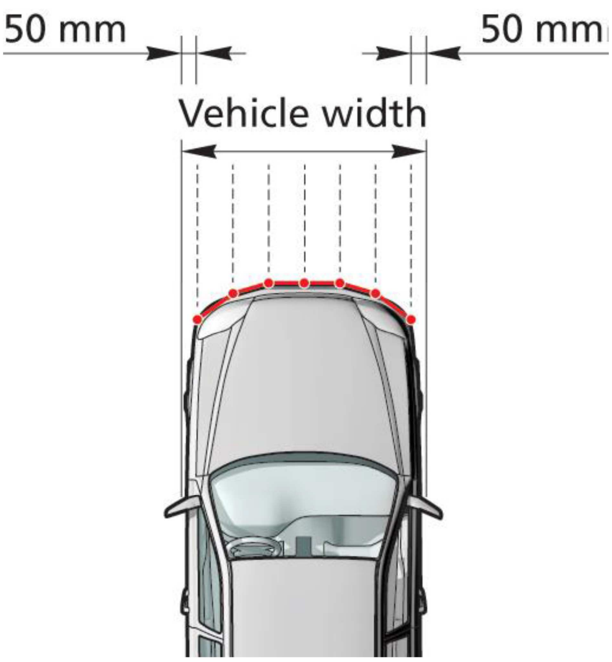


Figure 3 Virtual profiled line around vehicle front end

3.3.2 Around the BT a virtual box made of squares is defined which is used to determine the impact speed. The dimensions of these virtual boxes are shown in Figure 4 below. For crossing scenarios the reference point of the BT is the centre of the bottom bracket (crank shaft) (dashed line in Figure 4) and for the longitudinal scenario the most rearward point on the rear wheel is used.

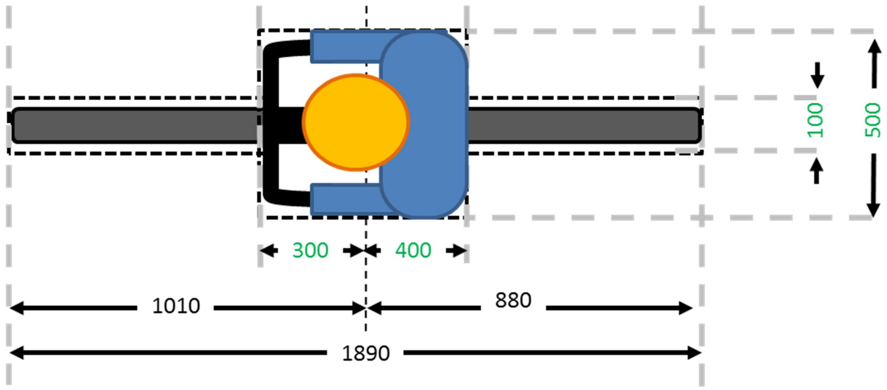


Figure 4 Virtual boxes dimensions around BT

3.4 Collision point definition

To specify the collision point the vehicle width is used as a reference, with 50% being the centreline and 0% and 100% being the outer corners of the vehicle.
For crossing scenarios this is relative to the cyclist direction, where centreline of vehicle contacting the BT reference point is 50%. At 0% the BT reference point is contacted by the vehicle corner together with the BT's front wheel. At 100% the BT reference point is contacted by the other vehicle corner together with the BT's rear wheel.
For longitudinal scenarios the 50% collision point is where the middle line of the vehicle contacts the BT rear wheel. At 0% the BT is contacted by the vehicle corner closest to the side of the road. At 100% the BT is contacted by the vehicle corner closest to the centre of the road.

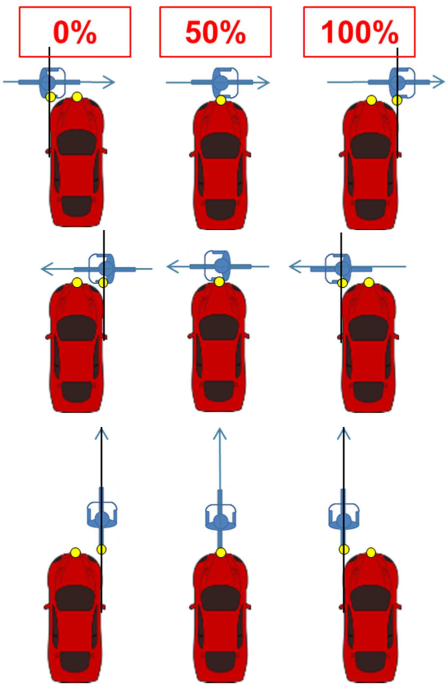


Figure 5 Collision point definition for LHD car

4 Measuring equipment

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

4.1 Measurements and variables

4.1.1 Time — T
- T_0 equals TTC = 4s — T_0
- T_{AEB}, time where AEB activates — T_{AEB}
- T_{FCW}, time where FCW activates — T_{FCW}
- T_{impact}, time where VUT impacts BT — T_{impact}

4.1.2 Position of the VUT during the entire test — X_{VUT}, Y_{VUT}

4.1.3 Position of the BT during the entire test
- for crossing scenarios — Y_{BT}
- for longitudinal scenario — X_{BT}

4.1.4 Speed of the VUT during the entire test — V_{VUT}
- V_{impact}, speed when VUT impacts BT — V_{impact}

4.1.5 Speed of the BT during the entire test — V_{BT}

4.1.6 Yaw velocity of the VUT during the entire test — Ψ_{VUT}

4.1.7 Longitudinal acceleration of the VUT during the entire test — A_{VUT}

4.1.8 Steering wheel velocity of the VUT during the entire test — Ω_{VUT}

4.2 Measuring equipment

Equip the VUT and BT with data measurement and acquisition equipment to sample and record data with an accuracy of at least:
- VUT speed to 0.1km/h;
- BT speed to 0.01km/h;
- VUT lateral and longitudinal position to 0.03m;
- BT position in the direction of movement to 0.03m;
- VUT yaw rate to 0.1°/s;
- VUT longitudinal acceleration to 0.1m/s^2;
- VUT steering wheel velocity to 1.0 °/s.

4.3 Data filtering

Filter the measured data as follows:

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

4.3.2 Acceleration with a 12-pole phaseless Butterworth filter with a cut off frequency of 10Hz.

4.3.3 Yaw rate with a 12-pole phaseless Butterworth filter with a cut off frequency of 10Hz.

5 CATS test target

5.1 Specification

5.1.1 Conduct the tests in this protocol using the CATS Bicyclist and bike Target (BT) dressed in a black shirt and blue trousers, as shown in Figure 6 below. The BT replicates the visual, radar, LIDAR attributes of a typical bicyclist and bike, and is impactable at differential speeds up to 60km/h without causing significant damage to the VUT or BT.

Figure 6 CATS Bicyclist and bike Target (BT)

5.1.2 To ensure repeatable results the propulsion system and BT must meet the requirements as detailed in ANNEX A.

5.1.3 The BT 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 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 3.0m 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.

6.2 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 BT 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 BT. 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 22.0m on the side the BT starts and 4.0m on the opposite side of the VUT test path, for longitudinal tests 4.0m on both sides of the VUT test path, 1.0m around of the BT and within a longitudinal distance of 30m ahead of the VUT when the test ends.

6.3.2 Test areas where the VUT needs to pass under overhead signs, bridges, gantries or other significant structures are not permitted.

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 7.

		Setting 1	**Setting 2**		
Early		Setting 1	**Setting 2**	Setting 3	Late
	Setting 1	Setting 2	**Setting 3**	Setting 4	

Figure 7 AEB and/or FCW system setting for testing

6.4.2 Deployable Pedestrian/VRU Protection Systems
When the vehicle is equipped with a deployable pedestrian/VRU protection system, this system shall be deactivated before the testing commences.

6.4.3 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. Use inflation pressures corresponding to least loading normal condition.
Run-in tyres according to the tyre conditioning procedure specified in 7.1.3. After running-in maintain the run-in tyres in the same position on the vehicle for the duration of the testing.

6.4.4 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.

6.4.5 Unladen kerb mass

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

6.4.5.2 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.

6.4.5.3 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.

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

6.4.5.5 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.

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

6.4.6 Vehicle Preparation

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

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

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

6.4.6.4 Compare these loads with the 'unladen kerb mass'.

6.4.6.5 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.

6.4.6.6 Repeat paragraphs 6.4.6.3 and 6.4.6.4 until the front and rear axle loads and the total vehicle mass are within the limits set in paragraph 6.4.6.5. 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.

6.4.6.7 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

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:

- 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.
- Initiation of the first test shall begin within two hours after completion of the brake conditioning

7.1.3 Tyres

7.1.3.1 Condition the vehicle’s tyres in the following manner to remove the mould sheen:

- 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 VUT AEB/FCW system is assessed in the crossing nearside scenarios without obstruction; CVNBU, and with obstruction; CVNBO, the crossing farside scenario; CVFB and longitudinal scenario; CVLB. The justification and verification of scenarios and parameters can be found in Reference [2], Reference [3] and Reference [4]. These scenarios are respectively shown in Figure 8, Figure 9, Figure 10 and Figure 11.

7.2.2 For the longitudinal tests evaluating FCW (CVLB – FCW) considers collision avoidance by driver based on evasive steering, instead of braking. For CVLB – FCW the VUT can deviate from the test path from TTC = 1.5s on to avoid impact by evasive steering.

7.2.3 For testing purposes, assume a straight line path equivalent to the centreline of the lane in which the collision would occur, 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.

All tests will be performed with 5 km/h incremental steps within the speed range for:

- crossing with obstruction scenario (CVNBO): 10-40 km/h
- crossing without obstruction scenarios (CVNBU and CVFB): 20-60 km/h
- longitudinal scenario (CVLB): 30-80 km/h

7.2.4 A verification test will be performed to evaluate AEB performance in the longitudinal scenario (CVLB) with a 25% collision point with VUT speed of 45 km/h to ensure AEB performance at collision points below 50%.

Table 1 CATS test matrix

Vehicle speed	**CVNBU**	**CVNBO**	**CVFB**	**CVLB**
10 km/h		10 km/h – 50 %		
15 km/h		10 km/h – 50 %		
20 km/h	15 km/h – 50 %	10 km/h – 50 %	20 km/h – 25 %	
25 km/h	15 km/h – 50 %	10 km/h – 50 %	20 km/h – 25 %	
30 km/h	15 km/h – 50 %	10 km/h – 50 %	20 km/h – 25 %	15 km/h – 50 %
35 km/h	15 km/h – 50 %	10 km/h – 50 %	20 km/h – 25 %	15 km/h – 50 %
40 km/h	15 km/h – 50 %	10 km/h – 50 %	20 km/h – 25 %	15 km/h – 50 %
45 km/h	15 km/h – 50 %		20 km/h – 25 %	15 km/h – 50 %
50 km/h	15 km/h – 50 %		20 km/h – 25 %	15 km/h – 50 %
55 km/h	15 km/h – 50 %		20 km/h – 25 %	15 km/h – 50 %
60 km/h	15 km/h – 50 %		20 km/h – 25 %	15 km/h – 50 %
65 km/h				20 km/h – 25 % | FCW
70 km/h				20 km/h – 25 % | FCW
75 km/h				20 km/h – 25 % | FCW
80 km/h				20 km/h – 25 % | FCW

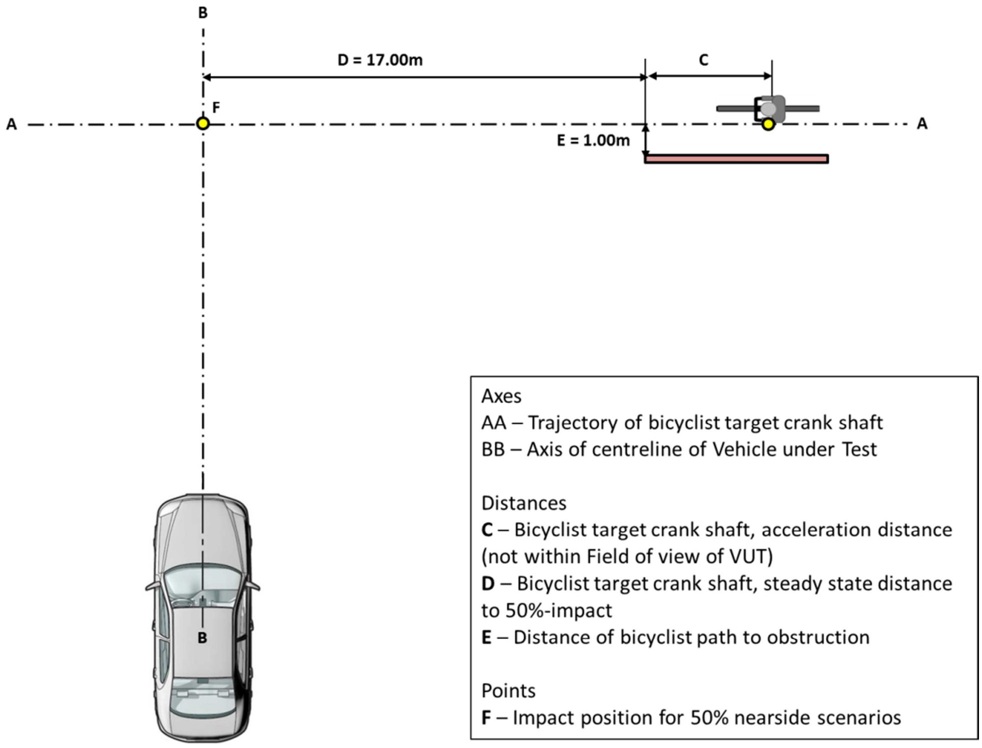


Figure 8 CVNBU, Bicyclist from Nearside Unobstructed

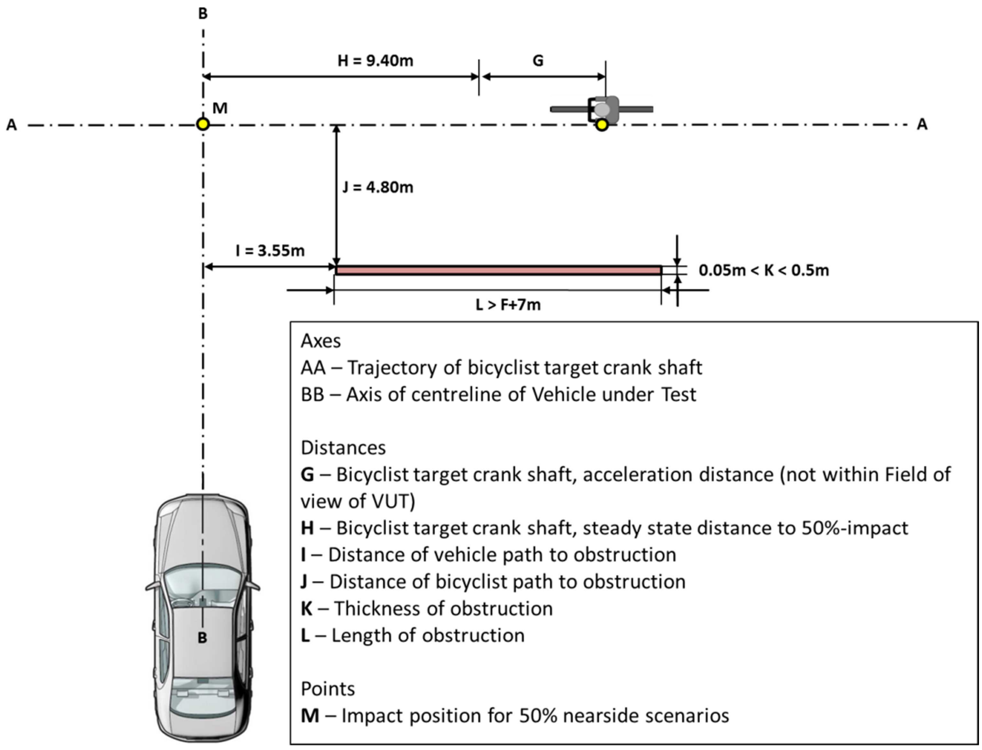


Figure 9 CVNBO, Bicyclist from Nearside Obstructed

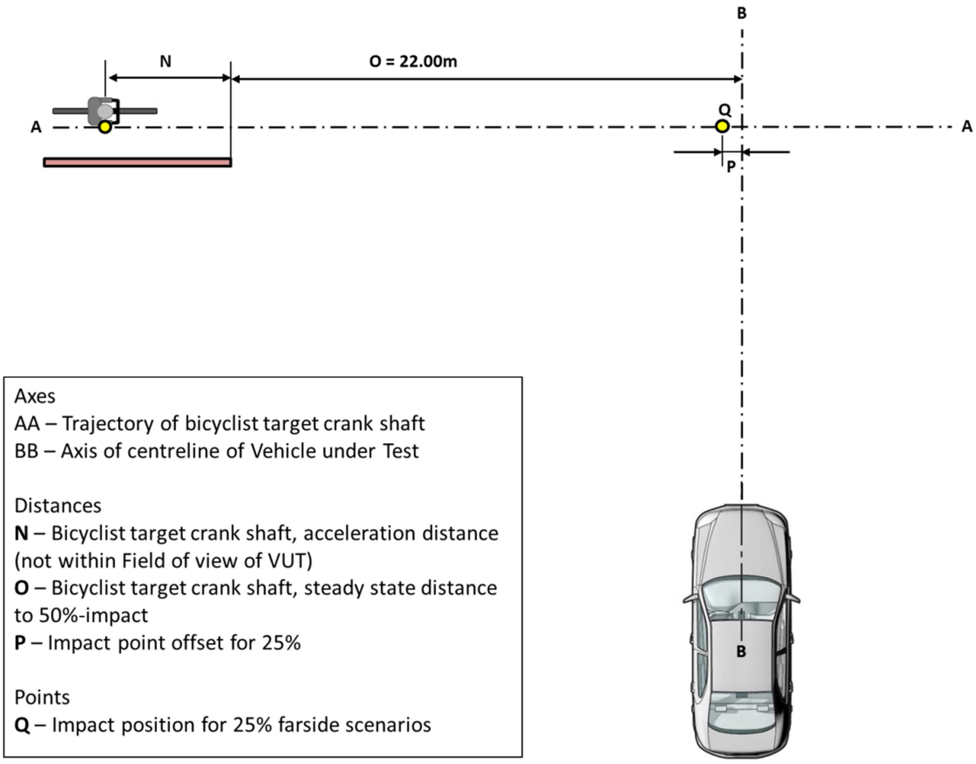


Figure 10 CVFB scenario, Bicyclist running from Farside

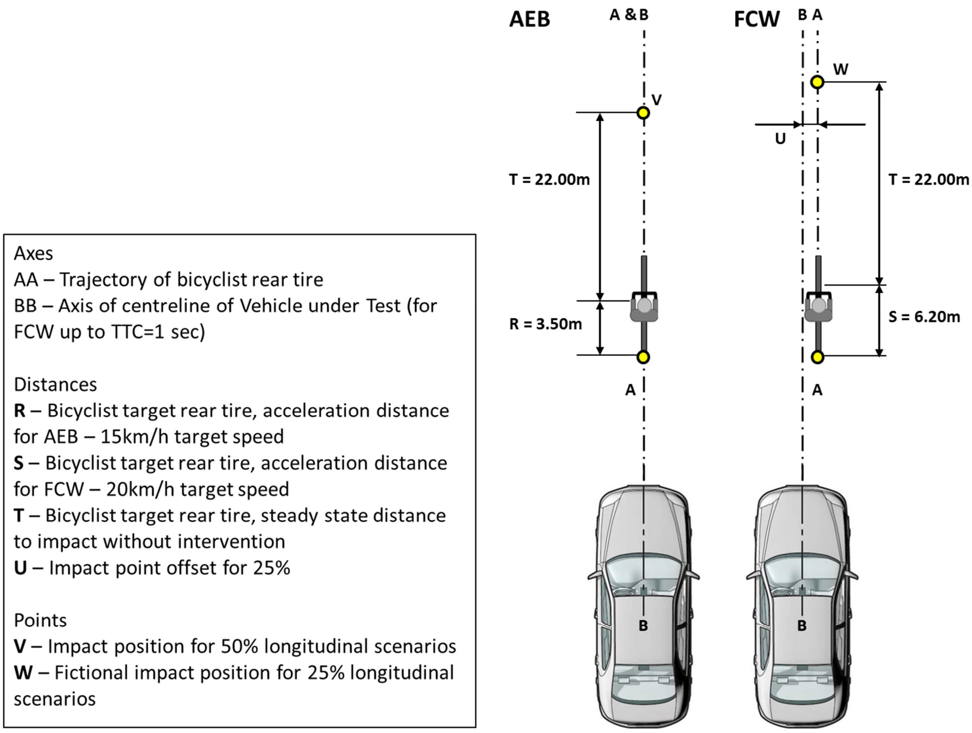


Figure 11 CVLB AEB and FCW, Bicyclist in Longitudinal scenario

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. 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.

7.3.3 Perform the first test a minimum of 90s and a maximum of 10 minutes after completing the tyre conditioning, 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 BT 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 (for CVLB-AEB T_0-1s) and T_{AEB}/T_{FCW}:

- Speed of VUT (GPS-speed) — Test speed + 0.5 km/h
- Lateral deviation from VUT test path — 0 ± 0.05 m
- Lateral deviation (relative to VUT test path) from BT test path
  - crossing scenarios — 0 ± 0.05 m
  - longitudinal scenario — 0 ± 0.15 m
- Yaw velocity — 0 ± 1.0 °/s
- Steering wheel velocity — 0 ± 15.0 °/s
- Speed of BT during steady state
  - CVNBO — 10 ± 0.2 km/h
  - CVNBU — 15 ± 0.2 km/h
  - CVFB — 20 ± 0.2 km/h
  - CVLB - AEB — 15 ± 0.2 km/h
  - CVLB - FCW — 20 ± 0.2 km/h
- BT Steady state
  - CVNBU — 17m from vehicle centreline
  - CVNBO — 9.4m from vehicle centreline
  - CVFB — 22m from vehicle centreline
  - CVLB – AEB & FCW — 22m from vehicle front impact point

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

- Contact between VUT and BT
- V_{VUT} speed:
  - crossing scenarios CVNBU, CVNBO and CVFB — $V_{VUT} = 0$km/h
  - longitudinal scenario CVLB (stable speed for 0.1 s) — $V_{VUT} < V_{BT} + 5$km/h
- BT has left the VUT path or the VUT has left the BT path

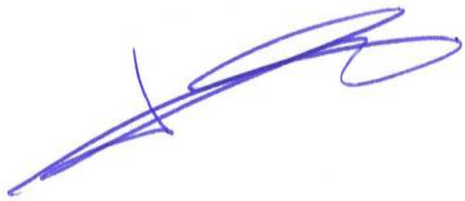
7.4.4 For manual or automatic accelerator control, it needs to be assured that during automatic brake the accelerator pedal does not result in an override of the system. The accelerator pedal needs to be released when the initial test speed is reduced by 5 km/h. There shall be no operation of other driving controls during the test, e.g. clutch or brake pedal.

7.4.5 The subsequent test speeds for the VUT have 5km/h increments.

7.4.6 For practical use it is advised to start the crossing scenarios test series at the VUT speed which has best expected performance and reduce VUT speed until no performance is observed and increase VUT speed until no performance is observed.

8 Signature

Helmond, September 2nd 2016 TNO



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10 Acknowledgements

The CATS project gratefully acknowledges the contributions from:

A CATS target and propulsion system specification

The bicyclist and bike target used in this protocol (CATS Bicyclist and bike Target (BT)) is described in detail in Reference [5]. The justification of the defined specifications can be found in Reference [6]. The specifications of the propulsion system can be found in Reference [7].

B Obstruction specifications

The obstruction represents a permanent full view blocking obstruction from the ground up (brick building or wall) between vehicle and bicyclist running parallel with the bicyclist path.

B.1 Obstruction dimensions

The obstruction should have flat uniform surfaces from the ground up visible from the VUT.

- Height of the obstruction ≥ 2.00m
- Width of the obstruction ≥ 0.05 and ≤ 0.50m
- Length of the obstruction ≥ 8.50m

B.2 Visible properties

The obstruction sides visible from the VUT should have a uniform light colour.

B.3 Radar properties

The radar cross section (RCS) properties of the obstructions long side, visible from the VUT, should be similar to brick wall with similar RCS observed from VUT test path in CVNBO as depicted in Figure 12.

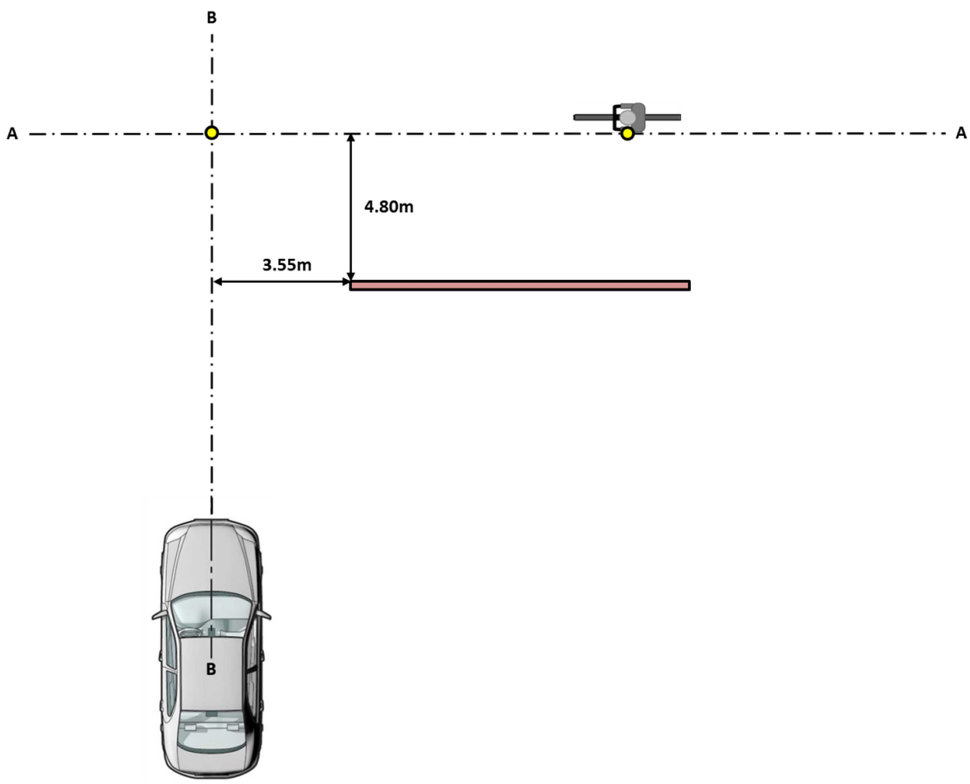

Figure 12 Obstruction measurement set-up