Bicyclist target
ACEA specifications
Version 1.0

November 2018
## DOCUMENT HISTORY

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BICYCLIST TARGET

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1 INTRODUCTION

1.1 GENERAL INFORMATION

The overall number of fatalities in road traffic accidents in Europe is decreasing. Unfortunately, however, the number of fatalities among cyclists does not follow this trend with the same rate. Autonomous Emergency Braking (AEB) systems, dedicated to avoid or mitigate car-to-cyclist collisions, are being introduced. To develop protocols and appropriate equipment to test such systems, TNO has initiated the Cyclist-AEB Testing System (CATS) consortium, in which around 20 industry partners, including several automobile manufacturers and TIER1s, have joined forces. Based on the CATS/4a Bicyclist Target Specifications¹ (V1.1 from 21.12.2016) the following specification defines a bicyclist target representing a real bicyclist on a bike, taking into account all different types of sensors used in AEB systems.

1.2 DEFINITIONS

- Bicyclist and bike target = BT
- Vehicle under test = VUT
- Vulnerable road user = VRU

¹ CATS D3.4 Bicyclist Target Specifications
2 BICYCLIST AND BIKE TARGET

Figure 1: Bicyclist and bike target

The bicyclist and bike target (BT) described in this paper, represent an average human adult bicyclist on an average standard adult utility bike (Figure 1) in relation to the vulnerable road users (VRU) detection sensors used in vehicles. The requirements relate, unless not specified otherwise, to the BT including a platform. The BT is designed to work with the following types of automotive sensors technologies: radar, video, laser and near-IR-based system similar to the definition by ACEA in the Articulated Pedestrian Target Specifications\(^2\). The BT must be a full 3D-dimensional representation of a real bicyclist and bike, must have rotating wheels (synchronised to speed), pedalling legs are not mandatory.

\(^2\) Articulated pedestrian target ACEA specifications, version 1.0
2.1 BICYCLIST AND BIKE TARGET DIMENSIONS AND POSTURE

The dimensions of the bike target are based on an average Dutch utility bike for an average male according to data from TU Delft with additional dimensions taken from a standard Dutch utility bike (Gazelle Paris Pure, male size 57) to complete the dimension specifications.

Alternative European bikes have been also taken into account. The bike target is based on a standard utility bike and has a double triangle frame shape. Typical dimensions include dimensions indicated in Figure 2. The centre of the bottom bracket (crank shaft) of the bike target (red circle in Figure 2) will be used as reference o-point in X-direction and the floor level as reference o-point in Z-direction.

Figure 2: Bike target dimensions and dummy posture
Table 1: Bike target dimensions

<table>
<thead>
<tr>
<th>Segment</th>
<th>X</th>
<th>Z</th>
<th>Unit</th>
<th>Tolerance</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Centre of bottom bracket of bike</td>
<td>0</td>
<td>280</td>
<td>mm</td>
<td>± 10</td>
<td>mm</td>
</tr>
<tr>
<td>1 Centre axis front wheel</td>
<td>670</td>
<td>340</td>
<td>mm</td>
<td>± 10</td>
<td>mm</td>
</tr>
<tr>
<td>2 Centre axis rear wheel</td>
<td>-540</td>
<td>340</td>
<td>mm</td>
<td>± 10</td>
<td>mm</td>
</tr>
<tr>
<td>3 Front top frame</td>
<td>430</td>
<td>855</td>
<td>mm</td>
<td>± 10</td>
<td>mm</td>
</tr>
<tr>
<td>4 Rear top frame</td>
<td>-215</td>
<td>860</td>
<td>mm</td>
<td>± 10</td>
<td>mm</td>
</tr>
<tr>
<td>5 Handle bars</td>
<td>310</td>
<td>1180</td>
<td>mm</td>
<td>± 10</td>
<td>mm</td>
</tr>
<tr>
<td>6 Saddle</td>
<td>-235</td>
<td>935</td>
<td>mm</td>
<td>± 10</td>
<td>mm</td>
</tr>
<tr>
<td>7 Lower edge left foot(^3)</td>
<td>105</td>
<td>495</td>
<td>mm</td>
<td>± 20</td>
<td>mm</td>
</tr>
<tr>
<td>8 Lower edge right foot</td>
<td>80</td>
<td>200</td>
<td>mm</td>
<td>± 20</td>
<td>mm</td>
</tr>
<tr>
<td>9 Knee point, left(^4)</td>
<td>150</td>
<td>860</td>
<td>mm</td>
<td>± 20</td>
<td>mm</td>
</tr>
<tr>
<td>10 Knee point, right</td>
<td>85</td>
<td>700</td>
<td>mm</td>
<td>± 20</td>
<td>mm</td>
</tr>
<tr>
<td>Total height</td>
<td>1865</td>
<td></td>
<td>mm</td>
<td>± 20</td>
<td>mm</td>
</tr>
<tr>
<td>Total length</td>
<td>1890</td>
<td></td>
<td>mm</td>
<td>± 20</td>
<td>mm</td>
</tr>
<tr>
<td>A Torso angle</td>
<td>10 (optional 30)</td>
<td></td>
<td>°</td>
<td>± 2</td>
<td>°</td>
</tr>
</tbody>
</table>

In order to ensure a realistic scenario, special requirements concerning radar reflection must be fulfilled. Thus, the diameter of the frame, seat stay and chain stay must be as follows:

- Frame: 25 mm – 35 mm
- Seat stay: 15 mm – 25 mm
- Chain stay: 15 mm – 25 mm

The material of frame, stays, spokes, steering and rim consists of a black coloured metallic outer surface to ensure that their reflection represent the one of a real bicycle.

Dimensions of the bicyclist target are based on an adult pedestrian target, described by ACEA\(^5\), representing average (50\(^{th}\) %-ile) male. The shape of the bicyclist target has to comply in its contours with the 50% RAMSIS Bodybuilder based on the RAMSIS version 3.8.30 to a permitted tolerance of ± 2 cm. The stature body height of the adult BT is, according to EN ISO 7250-1: 2016-05, 1800 mm.

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\(^3\) Lowest point of shoe – centre line tibia  
\(^4\) Knee point: rotation point of knee  
\(^5\) Articulated pedestrian target ACEA specifications, version 1.0
Figure 3: Bicyclist target dimensions in standing posture

Table 2: Bicyclist target dimensions in standing posture

<table>
<thead>
<tr>
<th>Segment</th>
<th>Dimension / angle</th>
<th>Unit</th>
<th>Tolerance</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body height (incl shoes)</td>
<td>1800</td>
<td>mm</td>
<td>± 20</td>
<td>mm</td>
</tr>
<tr>
<td>H-Point height</td>
<td>920</td>
<td>mm</td>
<td>± 20</td>
<td>mm</td>
</tr>
<tr>
<td>Shoulder width</td>
<td>500</td>
<td>mm</td>
<td>± 20</td>
<td>mm</td>
</tr>
<tr>
<td>Shoulder height</td>
<td>1500</td>
<td>mm</td>
<td>± 20</td>
<td>mm</td>
</tr>
<tr>
<td>Head width</td>
<td>170</td>
<td>mm</td>
<td>± 10</td>
<td>mm</td>
</tr>
<tr>
<td>Head height</td>
<td>260</td>
<td>mm</td>
<td>± 10</td>
<td>mm</td>
</tr>
<tr>
<td>Torso depth</td>
<td>240</td>
<td>mm</td>
<td>± 10</td>
<td>mm</td>
</tr>
</tbody>
</table>
The posture of the bicyclist target represents a natural driving position, facing forward, both hands on the steering wheel, with right foot down and left foot up (see Figure 4). The same dummy posture is used for all driving directions. The posture definition includes: lower edge of left and right foot, knee point left and right (see Figure 4 and Table 2).

**Figure 4: Posture of bicyclist target**

There must be a possibility to check and correct the body posture and angle of legs and arms in an easy and practical way corresponding to the defined tolerances, eg with the help of a tool with a reference shape.
2.2 VISIBLE AND INFRARED PROPERTIES

Similar to the adult pedestrian target specified by ACEA\(^6\), the BT shall be look like clothed with long-sleeved t-shirt and trousers in different colours: t-shirt in black, jeans in blue and shoes in black. The clothing has to be made from tear-proofed and water-resistant material. Skin surface parts have to be finished with a non-reflective flesh-coloured texture.

The IR reflectivity from 850 to 910 nm wavelength of clothes and the skin must be within the following range of 40% to 60%. The IR reflectivity from 850 to 910 nm wavelength of the head hairs must be within the following range of 20% to 60%. At the selection of the clothes it has to be ensured, that the IR reflectivity measured with the 45° probe must not differ for more than 20% from the reflectivity measured with the 90° probe.

The visual and infrared properties based on measurement method described in appendix A1 are defined in Figure 5, Table 3 and Table 4.

**Figure 5: Infrared properties of BT**

\(^{6}\) Articulated pedestrian target ACEA specifications, version 1.0
Table 3: Infrared properties of BT

<table>
<thead>
<tr>
<th>Segment</th>
<th>Reflectivity 90°</th>
<th>Reflectivity 45°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Black Top, Shoes</td>
<td>40% - 60%</td>
<td>40% - 60%</td>
</tr>
<tr>
<td>2 Hair</td>
<td>20% - 60%</td>
<td>20% - 60%</td>
</tr>
<tr>
<td>3 Skin, Face, Hands</td>
<td>40% - 60%</td>
<td>40% - 60%</td>
</tr>
<tr>
<td>4 Trousers</td>
<td>40% - 60%</td>
<td>40% - 60%</td>
</tr>
<tr>
<td>5 Rubber Tire (outside)</td>
<td>3% - 9%</td>
<td>3% - 9%</td>
</tr>
<tr>
<td>6 Frame</td>
<td>2% - 20%</td>
<td>2% - 20%</td>
</tr>
</tbody>
</table>

Table 4: Colour properties of BT, sRGB (0-255, Observer = 2°, Illuminant = D65)

<table>
<thead>
<tr>
<th>Segment</th>
<th>Colour</th>
<th>Red</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Black Top, Shoes</td>
<td>min</td>
<td>35</td>
<td>36</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>45</td>
<td>46</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>max</td>
<td>55</td>
<td>56</td>
<td>57</td>
</tr>
<tr>
<td>2 Hair</td>
<td>min</td>
<td>35</td>
<td>36</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>45</td>
<td>46</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>max</td>
<td>55</td>
<td>56</td>
<td>57</td>
</tr>
<tr>
<td>3 Skin, Face, Hands</td>
<td>min</td>
<td>102</td>
<td>95</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>182</td>
<td>165</td>
<td>142</td>
</tr>
<tr>
<td></td>
<td>max</td>
<td>72</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>4 Trousers</td>
<td>min</td>
<td>0</td>
<td>90</td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>0</td>
<td>110</td>
<td>153</td>
</tr>
<tr>
<td></td>
<td>max</td>
<td>20</td>
<td>130</td>
<td>173</td>
</tr>
<tr>
<td>5 Rubber Tire (outside)</td>
<td>min</td>
<td>35</td>
<td>36</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>45</td>
<td>46</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>max</td>
<td>55</td>
<td>56</td>
<td>57</td>
</tr>
<tr>
<td>6 Frame</td>
<td>min</td>
<td>35</td>
<td>36</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>45</td>
<td>46</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>max</td>
<td>55</td>
<td>56</td>
<td>57</td>
</tr>
</tbody>
</table>

The colour of stiffening ropes must be light grey and low optical reflective.

The front, rear and all four pedal reflectors (left – right and front - rear) should be marked BS6102/2 (or equivalent) and coloured respectively white (front), red (rear) and amber (pedals). The front and
rear reflector should be located on the bike target between 350 mm and 900 mm from the ground level, with the white front reflector positioned between most forward point of bike target and point 3 in Figure 2 facing forward. The red rear reflector is positioned between most rearward point of the bike target and point 4 in Figure 2 facing rearward. The amber coloured pedal reflectors should be on the front and rear side of both left and right pedal. The wheel reflectors will be white reflective strips on both sides of the rims or tyres.

To provide robust behaviour of the outer cover, the textile should have the following characteristics:

- Area weight: < 300 g/m²
- Water resistance (AATCC 127): > 600 mm
- Strength (ASTM D5034): > 350 lbs
- Light fastness (AATCC 169): > 6000 h
- Wear resistance ASTM (D3884): > 500 cycles

**Figure 6: Components of BT**
Figure 7: Description of the different components of the BT

- Changeable handle bar for Dutch and European bike
- Adjustable torso-angle
- White reflector in the front mounted on the frame
- Red reflector in the back mounted on the luggage rack
- Plastic mud guard
- Room between spokes should be transparent and not give reflections for radar or visual systems independent of the viewing angle
- Rubber tire with reflecting ring
- Orange reflector on the rear and front side of the pedals
- Rim with radar-reflective material
- RCS: a black colored metallic surface ensures that the reflection of the BT corresponds to the one of a real bicycle
- Rotating wheels due to contact to the ground
2.3 RADAR PROPERTIES

The radar reflectivity characteristics of the bicyclist and bike target should be equivalent to a human being cycling of the same size.

2.3.1 RADAR CROSS SECTION (RCS)

The radar cross section of a bicyclist depends on the observation angle and typically varies significantly. Theoretically there is no RCS variation with the distance. However due to the field of view of the radar sensor and the implemented free space loss compensation the measured RCS significantly varies over distance and in near distances the bicyclist is not scanned over its complete height. Therefore, in this document RCS is referred to as the measured RCS by radar sensor with its specific parameter set and it does not correspond to the physical RCS. The RCS is also influenced by geometrical effects (ie multi path with constructive and destructive interferences).

Therefore, it must be taken into account that the RCS will be reviewed not only constantly, but by a description of the RCS by closing on the BT (see example of the RCS distribution at 76GHz of real bicyclist in appendix A3). It must be ensured that the RCS value is homogeneously distributed over the whole body of the BT. This allows achieving the effect of decreasing RCS at a shorter distance by only partial coverage. A more precise definition must be made individually for each frequency and sensor variant.

Additionally, a homogenous and realistic distribution of the RCS over the whole dummy area shall be ensured. At a viewing angle of 90° the RCS per wheel shall be about 1 to 10 dBsm, for the frame about 1 to 16 dBsm and for the bicyclist target about -5 to 5 dBsm (measurement setup see appendix A2, far field condition).

The radar cross section of the bicyclist target, achieved with a 77 GHz Sensor Bosch MRR-SGU (see appendix A3), should stay within a defined range, depicted in Figure 8.
Figure 8: Bicyclist and bike target RCS-boundaries (77 GHz Sensor Bosch MRR-SGU)

If other sensors are used or the mounting position of the sensor is different, slightly other RCS values may be obtained. In that case an additional verification/adaption of the boundaries may be necessary for validation of the BT.
2.3.2 DOPPLER EFFECT OF ARTICULATION

State-of-the-art radar sensor technology is able to measure and detect the relative velocities of rotating wheels on the bike. This characteristic of moving wheels will be referenced as micro-Doppler in the specifications (an example of the distribution of relative velocities of a transversal moving bicyclist, measured by radar (77 GHz Sensor, 1 GHz bandwidth), is provided in A4.

Since the circumferential speed of a rolling wheel without slip is the same as the wheel centre speed, the maximum positive velocities have to be two times the bicyclist speed, the minimum velocities have to be zero. Main reflection points contributing to the micro-Doppler must be located on the wheel’s outer rims. The RCS per wheel shall be about 1 to 10 dBsm at 90° viewing angle (measurement setup see appendix A2, far field condition).

Both wheels shall rotate to achieve the typical H-shape with one rotation centre at the back and one at the front wheel. The micro-Doppler spread shall be homogenously distributed referencing to the two rotation centres within zero speed and the double bicycle speed.

2.4 ARTICULATION

Only wheels articulation is requested by the dummy, since rotating wheels are always available at crossing bicyclist. Pedalling legs are not a necessarily characteristic of human while biking.

The wheels should be in constant contact with the ground and rotate at the corresponding speed forward.

2.5 MOUNTING AND GUIDANCE SYSTEM

- All visible parts of the BT mounting and guidance system must be coloured in grey. In case of a uniform background the colour shade of the background can be used.
- It must be ensured that the BT mounting is not influencing radar return.
- Any supporting ropes or tubes for fixing the dummies position must not interfere with the VRU emergency braking system.

2.6 BICYCLIST AND BIKE TARGET WEIGHT AND COLLISION STABILITY

After a collision the correctness of the BT posture and dimension has to be checked before starting a new test. The most relevant BT parameters are defined in Table 2 and are requested during the testing phase (wind, acceleration). Additionally, to the values mentioned in the table, a lateral
(relative to moving direction of BT) oscillation has to be prevented: sideward tolerances ± 5°.

- The BT must not have any hard impact points to prevent damage of the VUT.
- Max relative collision velocity of 60 km/h (crossing) / 45 km/h (longitudinal).
- Max BT weight: 11 kg.
- The bicyclist shall be coated with a closed textile outer cover.

After a series of test repetitions and previous collisions the target must not show relevant changes in its shape and the functionality of the articulations.
3 APPENDIX

A1 MEASUREMENT OF THE IR REFLECTIVITY

The measurement of the IR reflectivity must be carried out using a measuring device according to the following specifications.

**IR reflectivity measurement device**

Spectrometer for wavelength range 800 nm – 900 nm eg: Jaz – mobiles Miniaturspektrometer von Fa. Ocean Optics, wavelength range 350 nm – 1000 nm, in combination with Reflexionssonde QR600-7-VIS125BX

**Figure 9: Jaz spectrometer**

**Calibration**

Before the start of the measurement, the device must be calibrated with a reflection standard, material spectralon, reflectance 99%. The calibration has to be verified by reflectance standards with reflectivity of 50%, 20%.

Example of reflection standards:
Labsphere Reflexionsstandards SRS-99-020, SRS-50-020, SRS-20-020,
...

**Figure 10: Reflexion standards; 99% - 75% - 50% - 20% - 2%**
**Measurement setup**

The measurement of the target must be conducted with a special attachment which ensures a defined distance between probe and target as defined in the following figure.

**Figure 11: Measurement probe 90°, measurement probe 45°**

Entire test setup with Jaz-Spectrometer, reflectance probe, 90° measuring attachment and reflection standards:

**Figure 12: Complete Measurement Setup**

The measurement shall be performed at three different points of the measuring object and shall be recorded.

The resulting IR reflectivity value corresponds to the average of the three reflectivity measurements.
A2 MEASUREMENT OF RADAR REFLECTIVITY

The measurement of the radar reflectivity must be carried out by using a measurement setup according to the following specification.

Recommended measurement setup

A reference measurement with a corner reflector (calibrated $\rightarrow 10$ dBsm) before and after measurements is recommended.

Sensor

- Vertical distance to ground as sensor application height 50 cm $\pm$ 15 cm
- Horizontal alignment $\pm 1^\circ$ to centre line
- Vertical alignment $\pm 1^\circ$ to centre line
- 77 GHz sensor:
  - Bosch MRR-SGU
  - Continental ARS300/ARS301/ARS400 series (optional)

Car

- Angular driving deviation $< 2^\circ$ (driving direction)
- Positioning accuracy longitudinal/lateral $< 5$ cm

Bicyclist and bike target

- Positioning accuracy longitudinal/lateral $< 1$ cm
- Angular orientation deviation $< 3^\circ$ (moving direction)

Test environment

- No additional objects/buildings in the observation area
- Proving ground surface completely covered with tarmac or concrete
- Ground conditions: flat, dry street
- No metallic or other strong radar-reflecting parts in-ground or surrounding area
- Reference measurement with 10 dBsm @ 40 m distance, corner reflector mounting height: 1 m
Figure 13: Test Environment
MEASUREMENT SCENARIOS

Scenario 1

- Static BT with moving vehicle
- Initial distance 40 m to 4 m
- Max approaching speed 10 km/h, no abrupt deceleration
- Measurement angles 90°, 180°, 270° (static BT facing direction relative to vehicle)
- Averaging five approaches
- Low pass filtering using a sliding average window (± 2.5 m)

Figure 14: Radar test scenario 1

Scenario 2

- Moving BT with stationary vehicle
- BT velocity: 10 km/h
- Measurement VUT-BT distance 20 m
- Measurement angles 90°, 180° and 270° (BT facing direction relative to vehicle)
- BT moving direction 90°, 180° and 270°
- Low pass filtering using a sliding average window (± 2.5 m range of radar)
- Averaging five measurements per distance and orientations

Figure 15: Radar test scenario 2
A3  MEASUREMENTS OF RCS

Figure 16, Figure 17, Figure 18, Figure 19 and Figure 20 provide examples, comparing real bicyclist versus 4a bicyclist dummy using the evaluation methodology of appendix Measurement of Radar Reflectivity for different viewing angles.

Figure 16: Example RCS of 4a bicyclist dummy target versus real bicyclist (77 GHz Sensor Bosch MRR-SGU) 0°
Figure 17: Example RCS of 4a bicyclist dummy target versus real bicyclist (77 GHz Sensor Bosch MRR-SGU) 45°
Figure 18: Example RCS of 4a bicyclist dummy target versus real bicyclist (77 GHz Sensor Bosch MRR-SGU) 90°
Figure 19: Example RCS of 4a bicyclist dummy target versus real bicyclist (77 GHz Sensor Bosch MRR-SGU) 135°
Figure 20: Example RCS of 4a bicyclist dummy target versus real Bicyclist (77 GHz Sensor Bosch MRR-SGU) 180°
A4 MEASUREMENTS OF MICRO DOPPLER

Figure 21: Micro-doppler effect example

Distance vs distribution of relative velocities for a non-pedalling transversal moving bicyclist (top), and for a non-pedalling BT (bottom) (77 GHz sensor, 1 GHz bandwidth).
ABOUT ACEA

- ACEA represents the 15 Europe-based car, van, truck and bus manufacturers: BMW Group, DAF Trucks, Daimler, Fiat Chrysler Automobiles, Ford of Europe, Honda Motor Europe, Hyundai Motor Europe, Iveco, Jaguar Land Rover, PSA Group, Renault Group, Toyota Motor Europe, Volkswagen Group, Volvo Cars, and Volvo Group.
- More information can be found on www.acea.be or @ACEA_eu.

ABOUT THE EU AUTOMOBILE INDUSTRY

- 13.3 million people – or 6.1% of the EU employed population – work in the sector.
- The 3.4 million jobs in automotive manufacturing represent over 11% of total EU manufacturing employment.
- Motor vehicles account for some €413 billion in tax contributions in the EU15.
- The sector is also a key driver of knowledge and innovation, representing Europe's largest private contributor to R&D, with €54 billion invested annually.
- The automobile industry generates a trade surplus of €90.3 billion for the EU.