



**EUROPEAN NEW CAR ASSESSMENT PROGRAMME  
(Euro NCAP)**

**PEDESTRIAN  
TESTING PROTOCOL**

Version 6.0  
February 2012

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## **Preface**

- Where text is contained within square brackets this denotes that the procedure being discussed is currently being trialled in Euro NCAP. Its incorporation in the Test Protocol will be reviewed at a later date.
- During the test preparation, vehicle manufacturers are encouraged to liaise with the laboratory and to check that they are satisfied with the way cars are set up for testing. Where a manufacturer feels that a particular item should be altered, they should ask the laboratory staff to make any necessary changes. Manufacturers are forbidden from making changes to any parameter that will influence the test, such as dummy positioning, vehicle setting, laboratory environment etc.
- It is the responsibility of the test laboratory to ensure that any requested changes satisfy the requirements of Euro NCAP. Where a disagreement exists between the laboratory and manufacturer, the Euro NCAP secretariat should be informed immediately to pass final judgment. Where the laboratory staff suspect that a manufacturer has interfered with any of the set up, the manufacturer's representative should be warned that they are not allowed to do so themselves. They should also be informed that if another incident occurs, they will be asked to leave the test site.
- Where there is a recurrence of the problem, the manufacturer's representative will be told to leave the test site and the Secretary General should be immediately informed. Any such incident may be reported by the Secretary General to the manufacturer and the person concerned may not be allowed to attend further Euro NCAP tests.

**The following information will be required from the vehicle manufacturer before any pedestrian test preparation begins.**

- Manufacturer grid marking coordinates relative to an identifiable location on the vehicle.
- Predicted colour or HIC data clearly identifying defaulted points.
- Justification for all blue points.
- Number of Manufacturer funded verification tests max (10).
- Number of Manufacturer funded blue point tests (8 max).
- Active hood description and supporting data (where applicable).
- Details of the vehicle's normal ride attitude, e.g. wheel arch height.

**The following information will be required from the vehicle manufacturer before any testing begins.**

- A maximum of three manufacturer nominated upper legform to bonnet leading edge tests.
- A maximum of three manufacturer nominated legform to bumper tests.

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# 1 VEHICLE PREPARATION

## 1.1 Unladen Kerb Weight

- 1.1.1 The capacity of the fuel tank will be specified in the manufacturer's booklet. This volume will be referred to throughout as the 'fuel tank capacity'.
- 1.1.2 Syphon most of the fuel from the tank and then run the car until it has run out of fuel.
- 1.1.3 Refill the fuel tank with fuel (or an equivalent mass of water or other ballast) to its fuel tank capacity.
- 1.1.4 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.
- 1.1.5 Ensure that the vehicle has its spare wheel on board along with any tools supplied with the vehicle. Nothing else should be in the vehicle.
- 1.1.6 Ensure that all tyres are inflated according to the manufacturer's instructions for half load.
- 1.1.7 Remove the front vehicle license plate and its holder/brackets if these are removable from the bumper.
- 1.1.8 Measure the front and rear axle weights and determine the total weight of the vehicle. The total weight is the 'unladen kerb weight' of the vehicle. Record this weight in the test details.

## 1.2 Additional Weights

- 1.2.1 Put the fore-aft adjustment of both front seats in their mid-positions. If there is no notch at the mid-position, use the first notch immediately rearward.
- 1.2.2 Place a 75kg mass on the driver's seat and a 75kg mass on the front passenger's seat.
- 1.2.3 Ensure that the front wheels are in the straight ahead position.
- 1.2.4 If the suspension is adjustable in any way, ensure that the vehicle is at the correct attitude for travelling at 40km/h. See Section 1.4.

## 1.3 Suspension Settling

- 1.3.1 Roll the vehicle forwards by a distance of at least 1 metre
- 1.3.2 Roll the vehicle backwards by a distance of at least 1 metre
- 1.3.3 Repeat steps 1.3.1 and 1.3.2 for three complete cycles. Note: This procedure may be inappropriate for cars which have to be set up as described in Section 1.2.4.
- 1.3.4 Measure and record the ride heights of the vehicle at the point on the wheel arch in the same transverse plane as the wheel centres. Do this for all four wheels.

## 1.4 Normal Ride Attitude

- 1.4.1 After following the above procedures the vehicle is in its Normal Ride Attitude when the vehicle attitude is in running order positioned on the ground, with the tyres inflated to the recommended pressures, the front wheels in the straight-ahead position, with maximum capacity of all fluids necessary for operation of the vehicle, with all standard equipment as provided by the vehicle manufacturer, with a 75kg mass placed on the driver's seat and with a 75kg mass placed on the front passenger's seat, and with the suspension set for a driving speed of 40km/h in normal running conditions specified by the manufacturer (especially for vehicles with an active suspension or a device for automatic levelling).
- 1.4.2 The manufacturer shall specify the Normal Ride Attitude with reference to the vertical (Z) position of any marks, holes, surfaces and identification signs on the vehicle body, above the ground. These marks shall be selected such as to be able to easily check the vehicle front and rear ride heights and vehicle attitude. If the reference marks are found

to be within  $\pm 25\text{mm}$  of the design position in the vertical (Z) axis, then the design position shall be considered to be the normal ride height. If this condition is met, either the vehicle shall be adjusted to the design position, or all further measurements shall be adjusted, and tests performed, to simulate the vehicle being at the design position.

1.4.3 All ride heights measured are the Normal Ride Attitude ride heights.



## **2 ASSESSMENT OF VEHICLES WITH ACTIVE BONNETS**

### **2.1 Prerequisites to Assessment**

- 2.1.1 Prior to the testing and assessment of a vehicle equipped with an active bonnet, the vehicle manufacturer must liaise with the Euro NCAP secretariat and test laboratory. This should begin several weeks before the scheduled test date.
- 2.1.2 In order for active systems to be assessed in the deployed position or for the system to be deployed during the tests, it will be necessary for the vehicle manufacturer to provide the Euro NCAP Secretariat with the relevant detailed information highlighted in the following sections.
- 2.1.3 The vehicle manufacturer is responsible for providing all necessary information, detailed in this protocol, to the Euro NCAP Secretariat regarding detection of pedestrians and the deployment of the system. Based on the evidence provided, the Secretariat will decide whether or not the vehicle qualifies for assessment in either the deployed or undeployed position or if dynamic tests are required.
- 2.1.4 General information is also required regarding the functionality of the system along with specific details of the sensing, trigger and deployment systems.
- 2.1.5 The vehicle manufacturer must ensure that the test laboratory is given adequate information regarding the replacement of consumable components, system trigger requirements, details of any health hazards and sufficient spare parts to ensure that testing can be performed on schedule.
- 2.1.6 Where there is no information, a lack of sufficient information or the system does not meet the Euro NCAP requirements; the vehicle will be assessed without triggering of the active pedestrian protection elements.
- 2.1.7 The moveable bonnet top is defined as all structures connected to the bonnet that move with the whole assembly when activated in a pedestrian impact. The rear edge of the bonnet is the most rearward point of the moveable bonnet top when it is closed

### **2.2 Detection of Pedestrians**

- 2.2.1 The vehicle manufacturer must demonstrate the sensor system's ability to detect a range of pedestrian statures that result in head contacts with the bonnet. The statures should be selected from a 6 year old child, 5th percentile female, 50th percentile male or 95th percentile male. A combination of physical testing and numerical simulations will be required to demonstrate the suitability of the sensing system for the range of pedestrian sizes.
- 2.2.2 The numerical simulations will be required to identify the 'hardest to detect' pedestrian and support the choice of test tool. The simulations will concern the pedestrian statures that result in head contact with the bonnet, as studied and proven in Section 2.3.
- 2.2.3 Physical testing will be used to further assess the capability of the sensing system(s). As a surrogate for a pedestrian that is larger/heavier than a 50th percentile male, the legform detailed in Section 9 for legform to bumper tests shall be used. This is to ensure that the system deploys when impacting larger or 'upper limit' pedestrians.
  - 2.2.3.1 Justification of test tool selection
    - 2.2.3.1.1 A minimum of two numerical simulations per appropriate stature (maximum 8 in total) will be required to identify the 'hardest to detect' pedestrian and support the choice of test tool. Pedestrian models should be selected from the different statures specified in Section 2.2.1.
    - 2.2.3.1.2 Acceptable models and codes are detailed in Appendix I.
    - 2.2.3.1.3 Where other numerical models are to be introduced, then the manufacturer must

provide supporting evidence showing suitable biofidelity and kinematics of the chosen models.

2.2.3.1.4 The pedestrian stance to be used in the model will be facing in a direction perpendicular to the vehicle centreline with the legs apart walking towards the vehicle centreline with the rearward leg being impacted by the bumper first. The same simulation shall be used even if the curvature of the bumper results in the front leg being impacted first.

*Note: Accident analyses performed using the GIDAS database have shown that over 80% of pedestrian impacts are in crossing the road situations. This was used as the basis for modelling only the pedestrian in the lateral stance.*

2.2.3.1.5 The models used in the simulations will have the following H-point height above ground:

- 95<sup>th</sup> male: 1040mm
- 50<sup>th</sup> male: 900mm
- 5<sup>th</sup> female: 820mm
- 6YO: 610mm

2.2.3.1.6 The frictional value to be applied between the foot and the ground shall be between 0.3±0.1.

2.2.3.1.7 The simulations shall be conducted at the system's lower deployment threshold (LT) impact speed specified by the vehicle manufacturer.

2.2.3.1.8 The simulations will be conducted at two separate locations on the bumper. For each of the appropriate statures simulations will be performed on the vehicle centreline and at the outboard end of the bumper test zone defined in 3.3.6. An additional simulation may be required where the bumper test zone is relatively narrow when compared to the width of the moveable bonnet top.

2.2.3.1.9 Outputs from the simulations shall clearly highlight what the critical pedestrian size is for that particular sensing system. Once the hardest to detect pedestrian is established the appropriate test tool that reflects the characteristics of that pedestrian can be identified for use in the physical tests. The minimum output parameters from the numerical simulations will be:

- Bumper force
- Effective mass
- Energy
- Bumper intrusion

2.2.3.1.10 Effective mass will be calculated as follows. This calculation assumes that peak force on the vehicle occurs when the leg velocity reaches 0m/s:

$$M_e = \frac{\int_{t_1}^{t_2} F dt}{\Delta v}$$

$M_e = \text{Effective mass (kg)}$   
 $F = \text{Force (N)}$   
 $\Delta v = \text{Change in Velocity (m/s)}$   
 $dt = \text{Time increment (s)}$   
 $t_1 = \text{Time of first contact (s)}$   
 $t_2 = \text{Time of peak force (s)}$

2.2.3.1.11 In the event that a system triggers before the peak force is imparted onto the bumper cross member, the following calculation should be used:

$$M_e = \frac{\int_{t_1}^{t_2} F dt}{\int_{t_1}^{t_2} a dt}$$

$M_e$  = Effective mass (kg)  
 $F$  = Force (N)  
 $a$  = Leg acceleration (m/s<sup>2</sup>)  
 $dt$  = Time increment (s)  
 $t_1$  = Time of first contact (s)  
 $t_2$  = Time of system trigger (s)

2.2.3.1.12 For the calculation of effective mass, only movement in the X direction are considered. The most significant structures that load the leg should be considered, such as the bumper cross member and any upper or lower cross beams. Less significant structures, such as grills and valances may be ignored. Viscous effects should be ignored.

2.2.3.1.13 Of the outputs specified in Section 2.2.3.1.9, the most appropriate parameter or parameters for the specific type of sensing system will be used to show an appropriate level of correlation between the chosen test tool and the numerical simulations. The vehicle manufacturer may choose the impact location and vehicle components for inclusion onto the calculation of the output parameters.

2.2.3.2 Physical testing

2.2.3.2.1 To ensure that the pedestrian impact sensor(s) are effective across the full bumper width, a minimum of three tests shall be performed at locations within the bumper test zone.

2.2.3.2.2 Test matrix:

Test	Impactor	Impact point	Speed	Output
1	HTD	<ul style="list-style-type: none"> <li>Directly on localised sensor e.g. accelerometer. If the sensing system uses a combination of contact strip switches and localised accelerometers, the positions of the accelerometers should be used to define the impact locations.</li> <li>For non-localised sensor systems, such as contact switches, test the vehicle centreline.</li> </ul>	LT	<ul style="list-style-type: none"> <li>High speed film</li> <li>Actuator trigger time</li> <li>Initiation of deployment</li> </ul>
2	HTD	Bumper test zone end, left or right hand side.	LT	
3	HTD	Farthest from sensor(s) if not tested already.	LT	
4	Euro NCAP detailed in Section 9.1 to account for larger pedestrians	Directly on localised sensor e.g. accelerometer. For non-localised sensor systems test directly in line with the front longitudinal member to produce the highest acceleration levels on the impactor. This test may be performed using a representative surrogate with equivalent mass and stiffness to prevent damage to instrumentation.	40km/h	

HTD = Hardest to detect

LT = Lower deployment Threshold

2.2.3.2.3 At least test #3 shall be witnessed or performed by Euro NCAP to verify deployment of the system at the lower threshold. Alternatively, it may be performed by the manufacturer and witnessed at their facility.

2.2.3.2.4 The outputs from all physical tests shall include, but is not limited to:

- Good quality high speed film showing an overview of the test.
- Documentation of the correct test location, e.g. using paint marks and post test

photographs.

- Documentation of test speed (vehicle or impactor as applicable), e.g. using known road markings or speed measurement systems etc.
- Actuator trigger time (current clamp/ECU).
- Evidence of bonnet deployment initiation, i.e. film showing the first movement of the bonnet top or frangible break wires/contacts/squibs.

## **2.3 Timing of Bonnet Deployment**

### **2.3.1 Time independent & fully deployed devices**

2.3.1.1 Where the manufacturer has demonstrated, by numerical simulations or alternative means (vehicle speed of 45km/h), that a system is fully deployed and remains in the intended position prior to the head impact time of the smallest appropriate stature pedestrian, as defined in Section 2.2.1, then all headform tests shall be performed with the bonnet in the fully deployed position. There will be no need to trigger any active elements during the sub system pedestrian tests.

2.3.1.2 Where the bonnet is shown to be fully deployed before the head impact time (HIT) of all adult headform locations, then the dynamic adult headform tests may be replaced with static tests. All small adult/child headform tests will then be performed dynamically.

2.3.1.3 The simulations shall be performed using the same CAE model/code and the same pedestrian stance detailed in Section 2.2.3.1.4 positioning the pedestrian on the vehicle centreline.

2.3.1.4 Further details on performing static tests are provided in Section 8.5.

### **2.3.2 Time dependent & partially deployed devices**

2.3.2.1 For systems that do not remain in a permanently deployed position then dynamic pedestrian testing will be required for all bonnet top test locations.

2.3.2.2 For systems that do not fully deploy before the HIT of all statures, then dynamic pedestrian testing will be required for all bonnet top locations.

2.3.2.3 The vehicle manufacturer must determine the wrap around distance for each test location and establish the relevant head impact time for that stature of pedestrian.

2.3.2.4 Further details on performing dynamic tests are provided in Section 8.5.

## **2.4 Protection at Speeds below the Deployment Threshold**

### **2.4.1 Exemption zones**

2.4.1.1 Euro NCAP maintains that bonnets which offer protection without a deployable device, offer protection at lower speeds and some protection at higher speeds. Therefore, Euro NCAP requires that vehicles equipped with deployable pedestrian protection systems also provide protection at impact speeds below the system deployment threshold.

2.4.1.2 The vehicle manufacturer must provide evidence showing that, at the lower deployment threshold speed, no part of the bonnet top testing produces HIC values above 1350. For no less than 2/3rds of the marked area, HIC values must not exceed 1000. The evidence provided shall be according to Chapter V Sections 3.2.2 and 3.2.4 of the European Regulation (EC) No 631/2009. References to HPC 2000 should however be replaced by HPC 1350.

2.4.1.3 Up to three physical tests may be performed to verify the CAE data at just below the deployment threshold speed.

2.4.1.4 The area of the bonnet top considered will be 50mm inside the side reference lines and extend rearward from the 1000mm WAD up to 50mm forward of the rear of the moveable bonnet top. Child/small adult headforms will apply between 1000mm & 1700mm WAD inclusive and adult headforms will apply to bonnet top areas between

1700mm & 2100mm WAD.

- 2.4.1.5 Where any test location or area does not meet the relevant HIC requirements, all pedestrian tests will be performed with the bonnet in the undeployed position.

## **2.5 Protection at Higher Impact Speeds**

### **2.5.1 Upper deployment threshold**

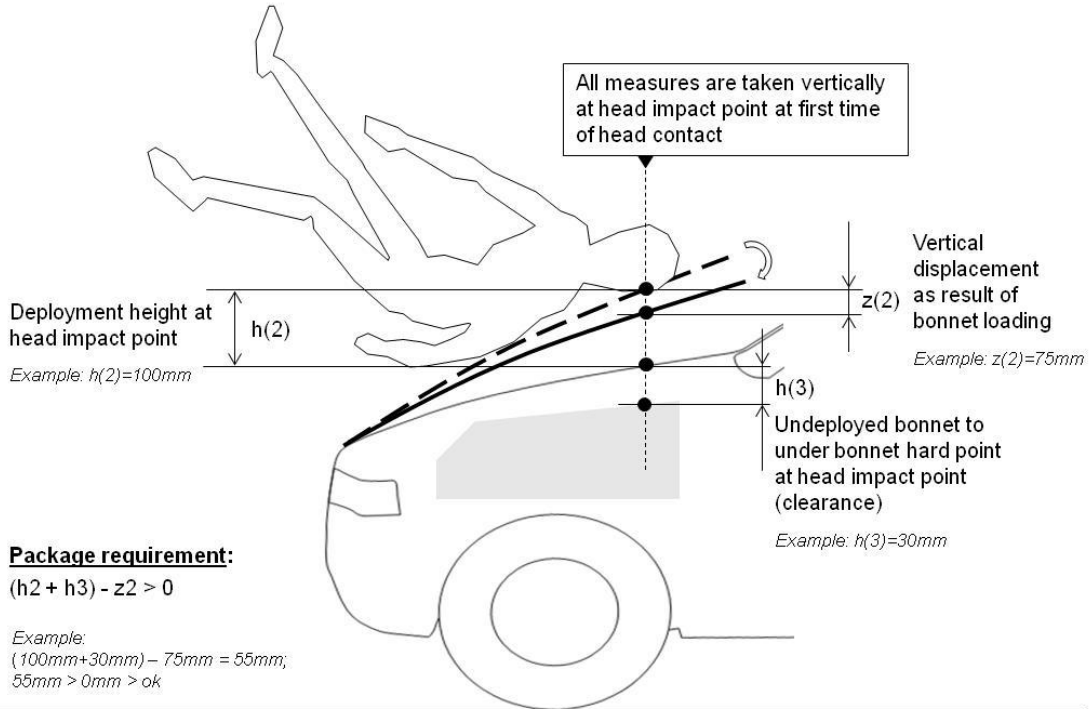
- 2.5.1.1 All deployable systems must initiate deployment at speeds of at least 50km/h. It is not necessary for a system to be fully deployed and reach the intended position before head impact at 50km/h, but the vehicle manufacturer must show that deployment has initiated.
- 2.5.1.2 A physical test using the impactor chosen in Section 2.2.3.1 is required at 50km/h to show that deployment has initiated. The outputs from the test are as those described in Section 2.2.3.2.4.
- 2.5.1.3 The test shall be performed at either the vehicle centreline or, if localised sensors used, as far away from the sensor as a possible while remaining within the bumper test zone.

## **2.6 Bonnet Deflection due to Body Loading**

- 2.6.1 Given that deployable bonnets may have reduced support from their peripheral structures compared to passive systems, Euro NCAP requires that head protection is not compromised by bonnet collapse.
  - 2.6.1.1 This is done by measuring and comparing the Z displacement at the position of head contact for both a deployed and undeployed bonnet at the time of first head contact. At the position of head impact the difference between deployed and undeployed bonnet can be no more than 75% of the generated deployment height at that point, see Figure 1.
  - 2.6.1.2 The evaluation shall be calculated with the use of CAE without the ‘package’ being present. The package meaning engine and ancillaries. All body in white structures and bonnet supports must be present. However, all components that load the legs and pelvis must be included.
  - 2.6.1.3 At the point of head impact it is essential that the bonnet deflection in the deployed state does not exceed the total available clearance between deployed bonnet and under bonnet hard point, i.e.  $(h_2 + h_3) - z_2 > 0$ .
  - 2.6.1.4 This would be established using numerical simulations at 40km/h with the appropriate sized pedestrian that loads the least supported part of the bonnet top for that particular size of vehicle. For example, on a small vehicle with a short bonnet it may be that the 50th percentile male contacts the vehicle rearward of the bonnet top. Therefore, a smaller pedestrian stature will be required.
  - 2.6.1.5 The stance described in Section 2.2.3.1.4 shall be used positioning the pedestrian’s head on the vehicle centreline.

*Note: Impacts at the centreline were chosen to simplify to the modelling needed and to avoid the possibility of glancing blows. It is also assumed there will be the least support to the bonnet at the centreline.*

**Simulation:** 40km/h, centreline, walking posture, 50<sup>th</sup>% (if no bonnet contact 5<sup>th</sup>%)



**Figure 1: Bonnet Deflection due to Body Contact**

## 3 VEHICLE MARKING

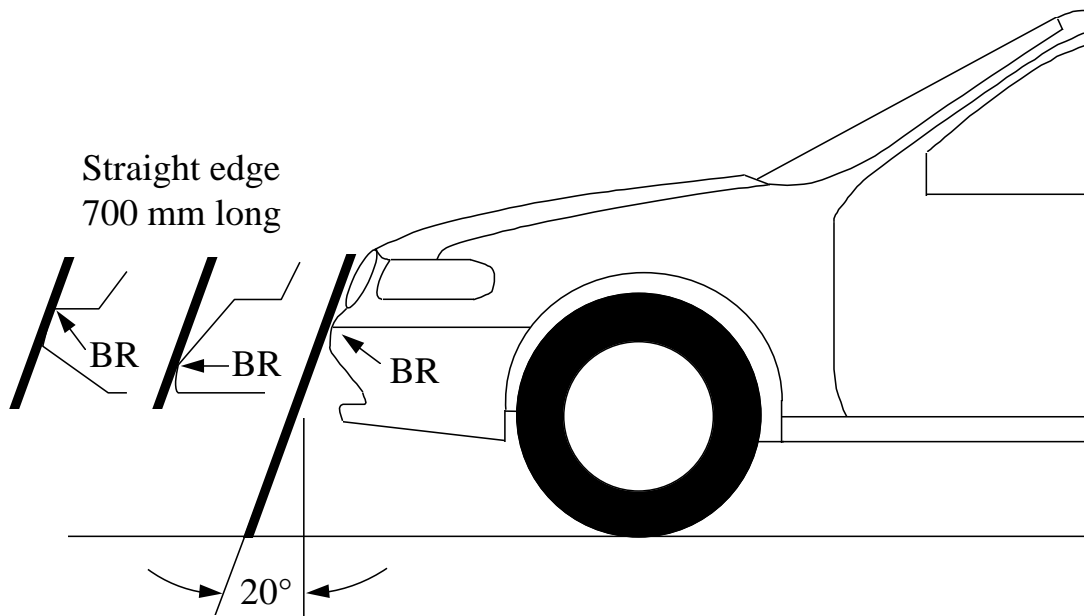
### 3.1 General

- 3.1.1 The vehicle shall be marked with a grid as described in the following sections. The marking procedures divide the front and bonnet of the car into zones which are then assessed using appropriate impactors.
- 3.1.2 Where no predicted data is to be provided by the vehicle manufacturer, the headform impact zone shall be marked with sixths and quarters as described in the Euro NCAP Pedestrian Testing Protocol version 5.3.1, November 2011.
- 3.1.3 All markings and measurements should be made with the vehicle in its Normal Ride Attitude.
- 3.1.4 The vehicle manufacturer must provide Euro NCAP with coordinates of all grid points derived from either CAE data or physical mark out.
- 3.1.5 A comparison of the grid origin C0,0 and two other points on 2100WAD, will be made between the laboratory mark out and the data provided by the vehicle manufacturer. For manufacturer data to be accepted, grid points must be within 10mm of each other.
- 3.1.6 Where the grid points of Euro NCAP and vehicle manufacturer are within 10mm of each other the laboratory mark-out shall be used.
- 3.1.7 Where the two grids differ by more than 10mm the vehicle manufacturer shall be informed and both markings will be examined in greater detail to establish the cause of any differences. The Secretariat will then take a decision as to how to proceed with vehicle marking.
- 3.1.8 The vehicle manufacturer must provide data for all grid locations. Testing will be carried out by Euro NCAP to a number of locations to verify the accuracy of data provided by the vehicle manufacturer.
- 3.1.9 For vehicles fitted with active bonnets, the headform impactor marking will be applied to the vehicle with the bonnet in the undeployed state. This will be the case regardless of whether or not the bonnet is locking or non-locking.
- 3.1.10 For vehicles fitted with active bonnets, the bonnet leading edge line will be marked on the vehicle with the bonnet in the un-deployed state. If bonnet deployment occurs prior to the pedestrian contact with the bonnet leading edge (BLE), creating an increased hazard such as higher BLE height and/or bumper lead, the Euro NCAP secretariat will give consideration to marking out the BLE in the deployed state.  
*Note: Marking in the undeployed state was chosen to avoid the possibility of discontinuities in the test areas leading to anomalies or inconsistencies in the test results.*
- 3.1.11 Where the vehicle manufacturer provides data showing that a deployable bonnet system offers protection to the upper leg, the upper legform to BLE tests will be carried out by conducting dynamic tests. The BLE will be marked on the vehicle in the deployed position.

### 3.2 Bumper Reference Lines

For vehicles with an identifiable bumper structure the upper Bumper Reference Line is defined as the geometric trace of the upper most points of contact between a straight edge and the bumper, when the straight edge, held parallel to the vertical longitudinal plane of the car and inclined rearwards by 20 degrees, is traversed across the front of the car whilst maintaining contact with the upper edge of the bumper. For a vehicle with no identifiable bumper structure it is defined as the geometric trace of the upper most points of contact between a straight edge 700 mm long and the bumper, when the straight edge, held parallel to the vertical longitudinal plane

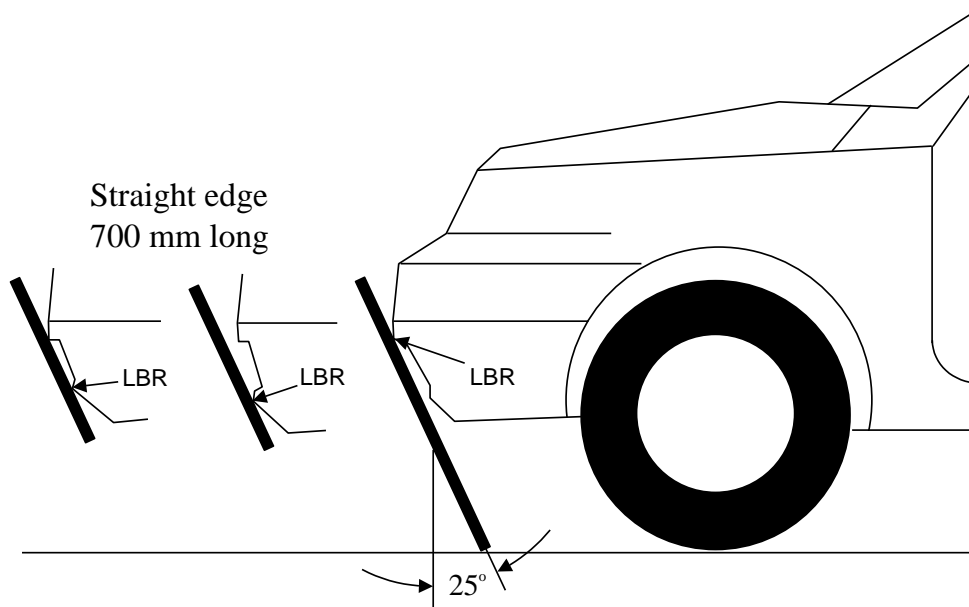
of the car and inclined forwards by 20 degrees, is traversed across the front of the car, whilst maintaining contact with the ground and the surface of the bumper. See Figure 2.



**Figure 2: Determination of upper bumper reference line**

- 3.2.1 With a 700mm straight edge fixed at 20° to the vertical and in a plane parallel to the vertical longitudinal plane of the car, position the straight edge at one end of, and in contact with, the bumper and the ground. The straight edge may be shortened to avoid contact with structures above the bumper, the straight edge may also be lengthened to reach the bumper, this is at the test laboratories discretion.
- 3.2.2 Mark the uppermost point of contact of the straight edge and bumper.
- 3.2.3 Pull the straight edge away from the bumper, move it towards the other end of the bumper by not more than 100mm and then into contact with the bumper.
- 3.2.4 Mark the uppermost point of contact of the straight edge and bumper.
- 3.2.5 Repeat Sections 3.2.3 to 3.2.4 along the whole of the length of the bumper.
- 3.2.6 Using a flexible rule, join the marks on the bumper to form a line. This line may not be continuous but may 'jump' around the licence plate area etc. This line is the Upper Bumper Reference Line (UBRL).
- 3.2.7 The Lower Bumper Reference Line (LBRL) also needs to be marked on the vehicle. This line identifies the lower limit to significant points of pedestrian contact with the bumper. It is defined as the geometric trace of the lower most points of contact between a straight edge 700mm long and the bumper, when the straight edge, held parallel to the vertical longitudinal plane of the car and inclined forwards by 25°. It is traversed across the front of the car, while maintaining contact with the ground and with the surface of the bumper; see Figure 3 below.
- 3.2.8 Proceed as per Sections 3.2.2 to 3.2.6, this line is the Lower Bumper Reference Line.

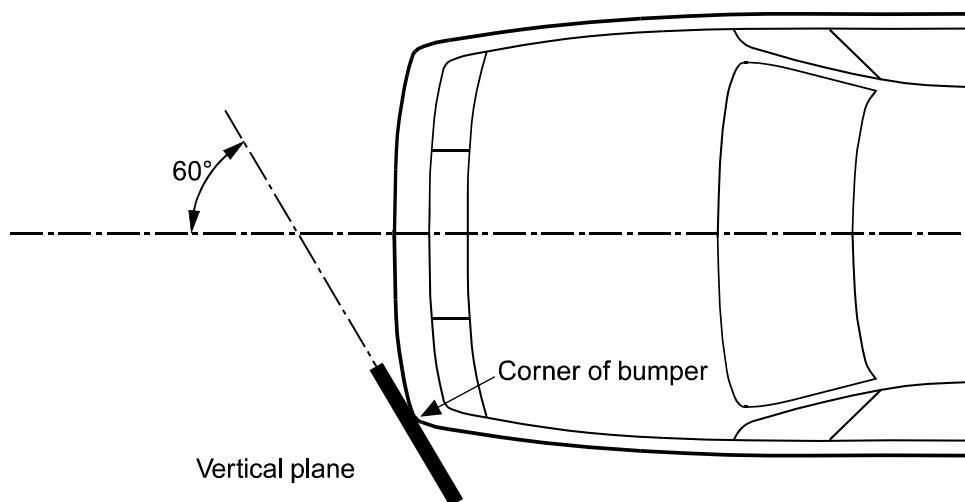




**Figure 3: Determination of the Lower Bumper Reference Line**

### 3.3 Bumper Corners and Bumper Test Zone

The Corner of Bumper is the point of contact of the vehicle with a vertical plane which makes an angle of  $60^\circ$  with the vertical longitudinal plane of the car and is tangential to the outer surface of the bumper, see Figure 4. Where multiple or continuous contacts occur the most outboard contact shall form the bumper corner.



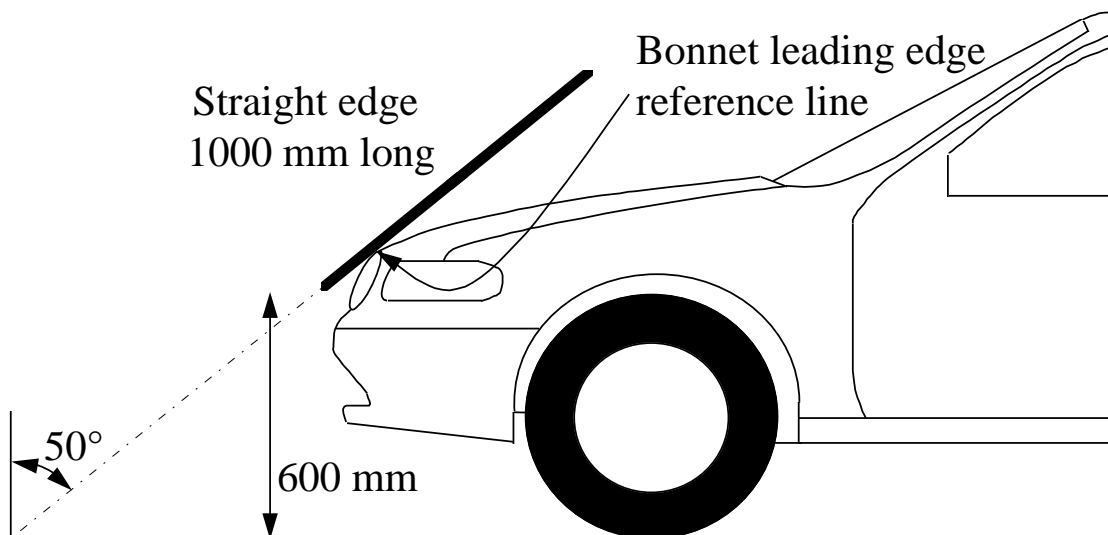
**Figure 4: Determination of bumper corner**

- 3.3.1 Fix a 700mm straight edge at  $60^\circ$  to the longitudinal direction of the car. With this edge horizontal move it into contact with the most forward part of the bumper.
- 3.3.2 Mark the point of contact between the straight edge and the bumper. This is the Bumper Corner.
- 3.3.3 If the bumper is angled at essentially  $60^\circ$ , so that the straight edge makes a continuous contact or multiple contacts rather than a point contact, the outermost point of contact shall be the Bumper Corner.
- 3.3.4 Repeat for the other side of the vehicle.

- 3.3.5 Remove the plastic bumper cover and any associated components.
- 3.3.6 Identify the outermost ends of the bumper beam/lower rails/cross beam structures. This area is termed the bumper test zone.
- 3.3.7 Record the distance from the vehicle centreline to the end of the test zone.
- 3.3.8 Replace the bumper components and mark both edges of the bumper test zone on the external bumper face.

### 3.4 Bonnet Leading Edge Reference Line

The Bonnet Leading Edge Reference Line is defined as the geometric trace of the points of contact between a straight edge 1000mm long and the front surface of the bonnet, when the straight edge, held parallel to the vertical longitudinal plane of the car and inclined rearwards by 50° and with the lower end 600mm above the ground, is traversed across and in contact with the bonnet leading edge, see Figure 5. For vehicles having the bonnet top surface inclined at essentially 50°, so that the straight edge makes a continuous contact or multiple contacts rather than a point contact, determine the reference line with the straight edge inclined rearwards at an angle of 40°. For vehicles of such shape that the bottom end of the straight edge makes first contact then that contact is taken to be the bonnet leading edge reference line, at that lateral position. For vehicles of such shape that the top end of the straight edge makes first contact then the geometric trace of 1000mm wrap around distance will be used as the Bonnet Leading Edge reference line at that lateral position. The top edge of the bumper shall also be regarded as the bonnet leading edge, if it is contacted by the straight edge during this procedure.



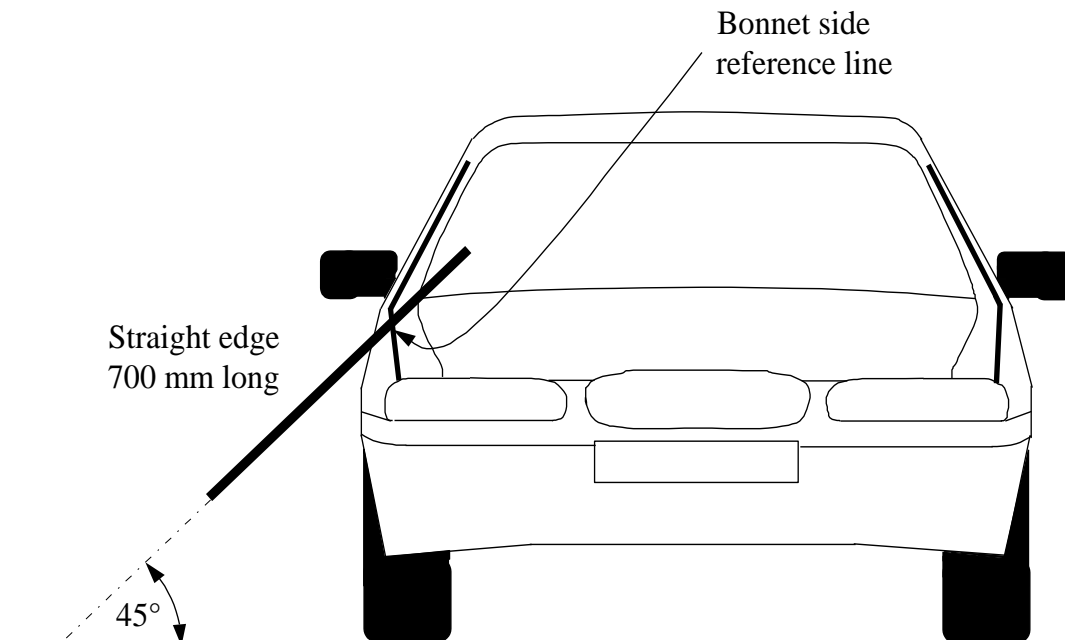
**Figure 5: Determination of the Bonnet Leading Edge Reference Line**

- 3.4.1 The bonnet leading edge is defined as the front upper outer structure including the bonnet and wings, the upper side members of the headlight surround and any other attachments. The reference line identifying the position of the leading edge is defined by its height above ground and by the horizontal distance separating it from the bumper (Bumper Lead), as determined in accordance with Sections 3.4, 11.3 and 11.4.
- 3.4.2 Fix a straight edge that is 1000mm long at 50° to the vertical and with its lower end at a height of 600mm. If the top surface of the bonnet is inclined at essentially 50° so that the straight edge makes a continuous contact or multiple contacts rather than a point contact, determine the reference line with the straight edge inclined rearwards at an angle of 40°. With this edge in a plane parallel to the vertical longitudinal plane of the

- car, position the straight edge at one end of, and in contact with, the bonnet.
- 3.4.3 Mark the point of contact of the straight edge and bonnet.
- 3.4.4 If the bottom end of the straight edge makes first contact then mark this point of contact.
- 3.4.5 If the top end of the straight edge makes first contact behind the 1000mm Wrap Around Line, then use the geometric trace of the 1000mm Wrap Around Line at that lateral position.
- 3.4.6 Pull the straight edge away from the bonnet, move it towards the other end of the bonnet by not more than 100mm and then into contact with the bonnet.
- 3.4.7 Mark the point of contact of the straight edge and bonnet.
- 3.4.8 Repeat Sections 3.4.4 to 3.4.7 across the whole width of the bonnet. Using a flexible rule, join the marks on the bonnet to form a line. This line may not be continuous but may 'jump' around the grill and badge area etc. This line is the Bonnet Leading Edge Reference Line.

### 3.5 Bonnet Side Reference Line

The Bonnet Side Reference Line is defined as the geometric trace of the highest points of contact between a straight edge 700mm long and the side of a bonnet, as defined in Section 3.4.1 and A-Pillar, when the straight edge, held parallel to the lateral vertical plane of the car and inclined inwards by 45° is traversed down the side of the bonnet top and A-Pillar, while remaining in contact with the surface of the body shell, any contact with door mirrors is ignored. See Figure 6. Where multiple or continuous contacts occur the most outboard contact shall form the bonnet side reference line.



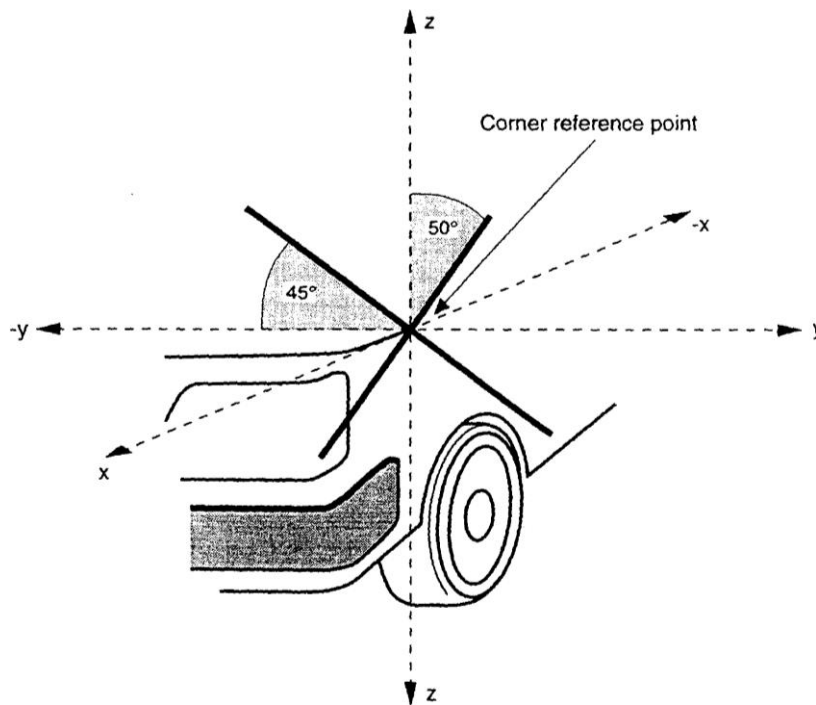
**Figure 6: Determination of the bonnet side reference lines**

- 3.5.1 Fix a straight edge that is 700mm long at 45° to the vertical. With this edge in a plane parallel to the lateral vertical plane of the car, position the straight edge at one end of the front wing, and in contact with, the bonnet.
- 3.5.2 Proceed as per sections 3.2.2 to 3.2.6, but moving the edge along the length of the wing, A-Pillar and Cant Rail if required (depending on the anticipated position of the 2100 Wrap Around Distance).

3.5.3 Repeat for the other side of the vehicle.

### 3.6 Corner Reference Point

The Corner Reference Point is defined as the intersection of the Bonnet Leading Edge Reference Line (Section 3.4) and the Bonnet Side Reference Line (Section 3.5), see Figure 7. Where multiple or continuous contacts occur the most outboard contact shall form the corner reference point.

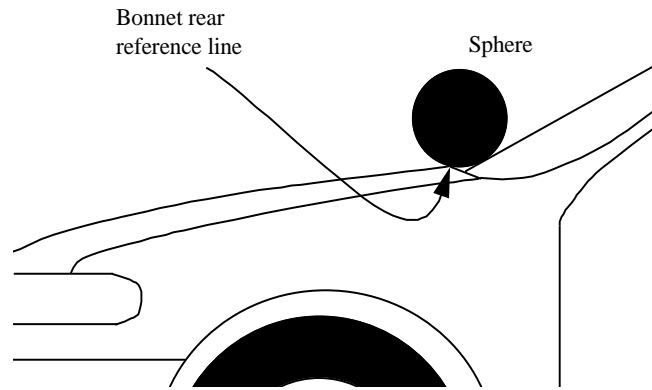


**Figure 7: Determination of the corner reference point**

### 3.7 Bonnet Rear Reference Line

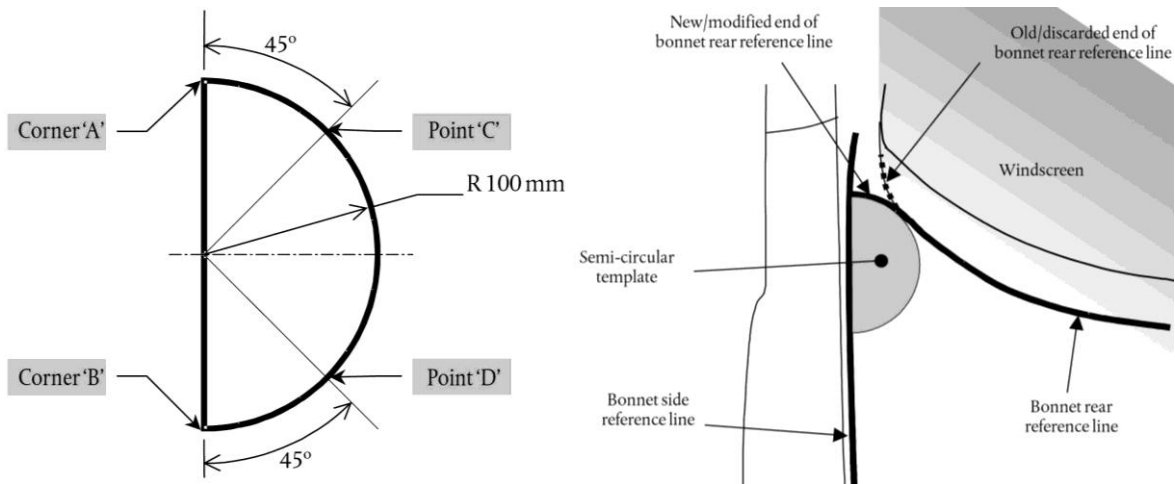
The Bonnet rear reference line is defined as the geometric trace of the most rearward point of contact between a 165mm sphere and the frontal upper surface, when the sphere is traversed across the frontal upper surface, while maintaining contact with the windscreen.

- 3.7.1 Remove the wiper blades and arms.
- 3.7.2 Place a 165mm sphere at the vehicle centreline on the frontal upper surface so that the rearmost point of contact of the sphere is with the glass.
- 3.7.3 Mark the most forward point of contact between the sphere and the vehicle's frontal upper surface. Repeat this at suitable increments moving outboard until the sphere contacts the side reference line on both sides of the vehicle. See Figure 8.



**Figure 8: Determination of the bonnet rear reference line**

- 3.7.4 If the bonnet rear reference line is located at a wrap around distance of more than 2100mm, the bonnet rear reference line is defined by the geometric trace of the 2100mm wrap around distance.
- 3.7.5 Where the bonnet rear reference line and side reference line do not intersect, the bonnet rear reference line is extended and/or modified using a semi-circular template, of radius 100mm. The template shall be made of a thin flexible sheet material that easily bends to a single curvature in any direction. The template shall, if possible, resist double or complex curvature where this could result in wrinkling. The recommended material is a foam backed thin plastic sheet to allow the template to ‘grip’ the surface of the vehicle.
- 3.7.6 The template shall be marked up with four points ‘A’ through ‘D’, as shown in Figure 9, while the template is on a flat surface. The template shall be placed on the vehicle with Corners ‘A’ and ‘B’ coincident with the side reference line. Ensuring these two corners remain coincident with the side reference line, the template shall be slid progressively rearwards until the arc of the template makes first contact with the bonnet rear reference line. Throughout the process, the template shall be curved to follow, as closely as possible, the outer contour of the vehicle’s bonnet top, without wrinkling or folding of the template. If the contact between the template and bonnet rear reference line is tangential and the point of tangency lies outside the arc scribed by points ‘C’ and ‘D’, then the bonnet rear reference line is extended and/or modified to follow the circumferential arc of the template to meet the side reference line, as shown in Figure 9.
- 3.7.7 If the template does not make simultaneous contact with the side reference line at points ‘A’ and ‘B’ and tangentially with the bonnet rear reference line, or the point at which the bonnet rear reference line and template touch lies within the arc scribed by points ‘C’ and ‘D’, then additional templates shall be used where the radii are increased progressively in increments of 20mm, until all the above criteria are met.
- 3.7.8 Once defined, the modified bonnet rear reference line is assumed in all subsequent paragraphs and the original ends of the line are no longer used.
- 3.7.9 Replace the wiper arms and blades.

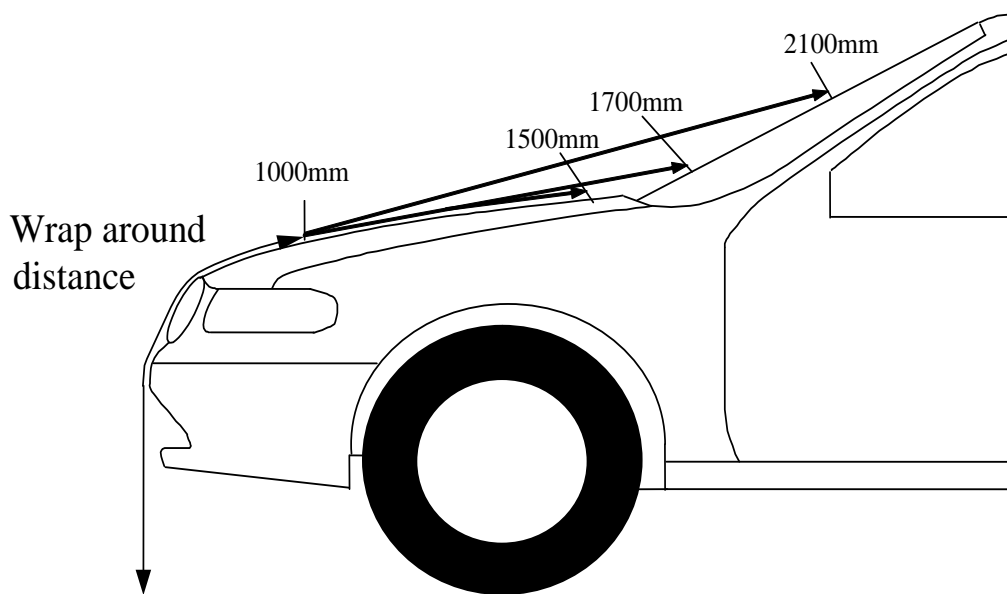


**Figure 9: Bonnet rear reference line template and extension**

### 3.8 Marking Wrap Around Distances

The headform test area is defined as the outer structure that includes the upper surface of all outer structures. It includes, but is not limited to, the bonnet, wings, windscreen scuttle, wiper arms/spindles, windscreen frame, A-pillars and roof. It is bounded by the geometric trace of the 1000mm wrap around line in the front, the Bonnet Side Reference Lines and the 2100mm wrap around line.

- 3.8.1 Begin at the vehicle centreline.
- 3.8.2 Place the end of a flexible tape measure or graduated wire on the floor vertically below the front face of the bumper.
- 3.8.3 Wrap the tape or wire over the bumper, bonnet windscreen and roof ensuring that it is maintained in a vertical longitudinal (X, Z) plane and that its end is still in contact with the ground. The tape should be held taut throughout the operation, vertically below the front face of the bumper, see Figure 10.

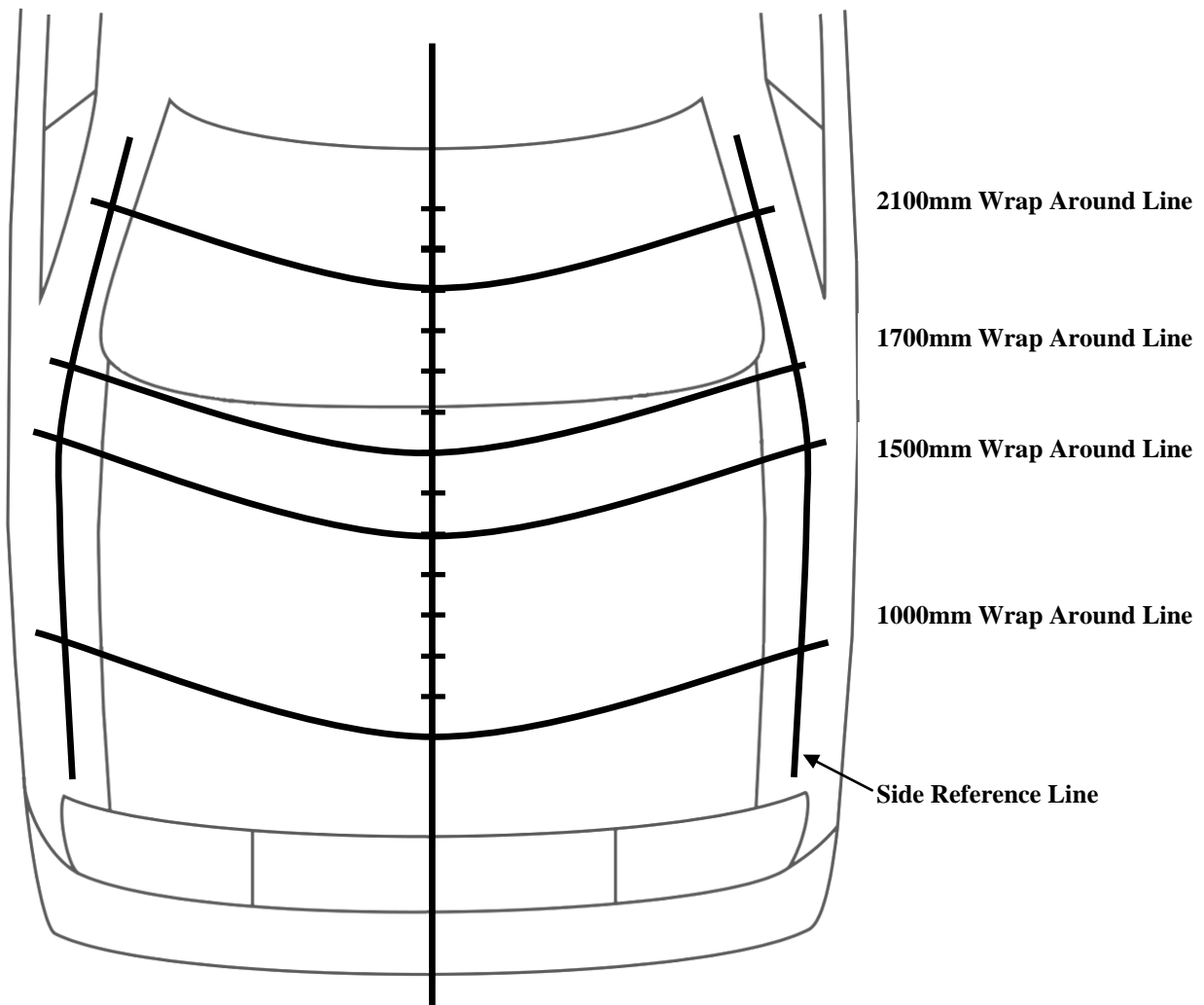


**Figure 10: Marking wrap around lines**

- 3.8.4 Mark on the bonnet top, windscreen, A-pillars and/or roof the Wrap Around Lines of

1000mm, 1500mm, 1700mm and 2100mm. These are the geometric traces described on the outer surface of the vehicle by the end of flexible tape or wire 1000, 1500, 1700 or 2100mm long, when it is held in a vertical fore/aft plane of the car and traversed across the front of the bonnet and bumper.

- 3.8.5 Where any of the WAD's lie below the outer contour of the vehicle, for example in the gap behind the bonnet, using the tape or wire approximate the outer contour of the vehicle horizontally rearward from the last point of contact and project the WAD vertically down onto the underlying structure.
- 3.8.6 Reposition the end of the tape on the ground no further than 100mm laterally outboard starting at the vehicle centreline up to the Corner of Bumper. The tape should be stretched over the A-pillars where necessary.
- 3.8.7 Repeat steps 3.8.5 to 3.8.8 until the width of the vehicle has been marked up to the Side Reference Lines.
- 3.8.8 Join the points marked on the bonnet to form lines at wrap around distances of 1000mm, 1500mm, 1700mm and 2100mm. Points located between 1000 and 1500mm WAD will be assessed using the child/small adult headform. Points between 1700 and 2100 mm WAD will be assessed with the adult headform, see Figure 11.
- 3.8.9 Where the bonnet rear reference line is between 1500mm-1700mm WAD, points forward of and directly on the bonnet rear reference line will be assessed using the child/small adult impactor. Points rearward of the bonnet rear reference line between 1500mm-1700mm WAD will use the adult impactor.

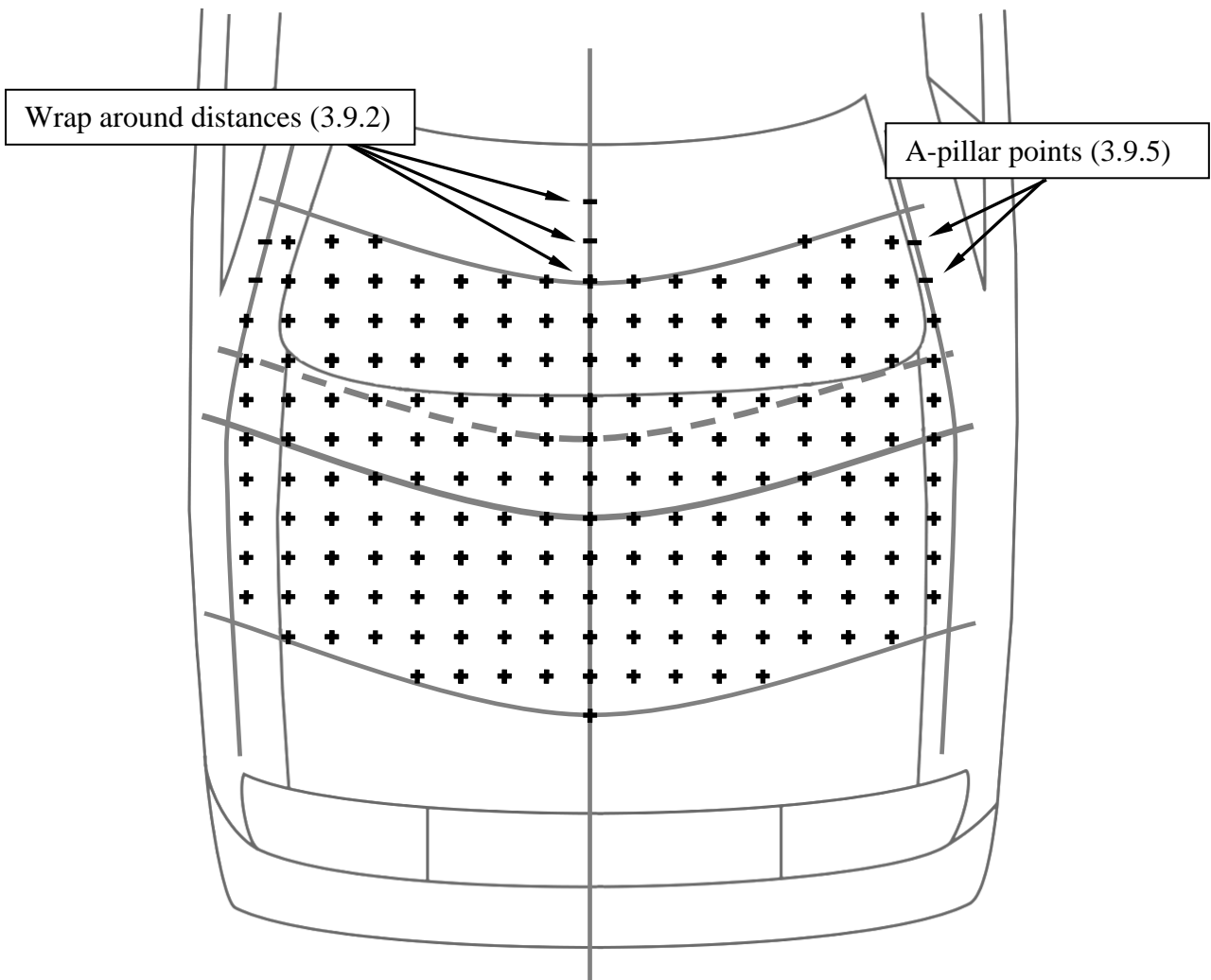


**Figure 11: Headform test area**

### 3.9 Marking Headform Impact Area Grid Points

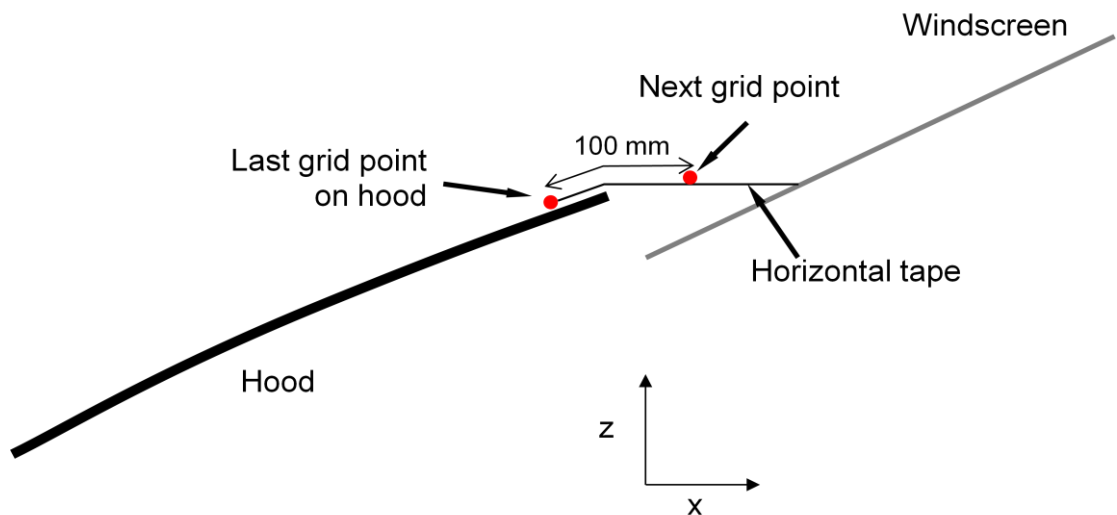
- 3.9.1 Mark the longitudinal centreline of the vehicle on the bonnet top, windscreen and roof.
- 3.9.2 Mark Wrap Around Distances (not lines) on the centreline only at 100mm intervals. Start from Wrap Around Distance 1000mm and end at Wrap Around Distance 2100mm. For vehicles with a V-shaped front end it may also be necessary to mark additional Wrap Around Distances of 2200mm, 2300mm, etc. See Figure 12.
- 3.9.3 Starting at one of the wrap around distance marks at the centreline, mark grid points every 100mm in both lateral directions up to the side reference lines. The 100mm distances are measured horizontally in a lateral vertical plane through the respective centreline mark and projected vertically onto the vehicle surface.
- 3.9.4 Repeat step 3.9.3 for every wrap around distance on the vehicle centreline until the entire headform impact area is marked with grid points. Depending on the shape of the vehicle, (e.g. V-shaped vehicle front end) it may be necessary to also use the wrap around distance points at 2200mm, 2300mm, etc. See Figure 12.
- 3.9.5 For A-pillars only, mark an additional grid point at the intersection of the lateral vertical plane and the side reference line for each wrap around distance.





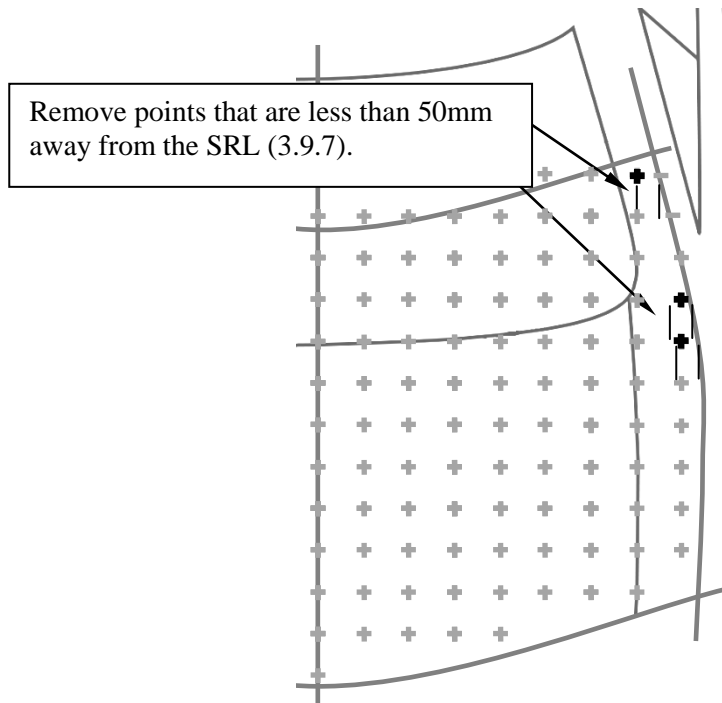
**Figure 12: Grid points**

3.9.6 Where any of the grid points lie underneath the outer contour of the vehicle, for example in the gap behind the bonnet, approximate the outer contour of the vehicle horizontally rearward from the last point of contact by using an adhesive tape. Mark the grid point on the tape to replace the underlying grid point. See Figure 13.



**Figure 13: Grid points beneath outer contour (example at vehicle centreline)**

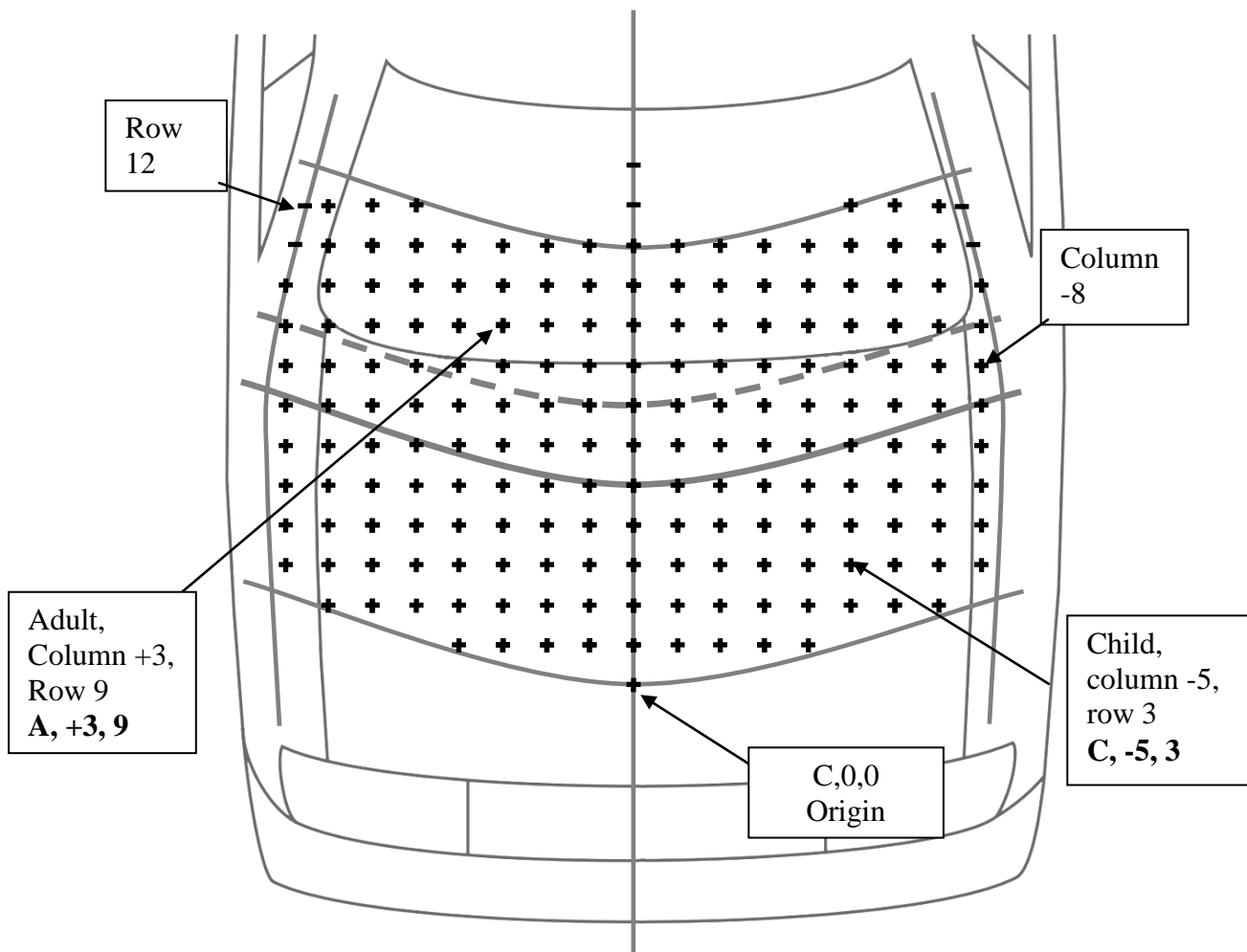
- 3.9.7 Remove those grid points that have a distance, measured in the lateral Y axis, of less than 50mm to the side reference lines, excluding those points which are on A-pillar side reference line. See Figure 14.
- 3.9.8 The remaining grid points are used for the assessment of the vehicle. For impact testing, these grid points are the aiming points.



**Figure 14: Deleting grid points**

### 3.10 Identification of the Headform Grid Points

- 3.10.1 All child/small adult headform grid points will contain the prefix 'C'. All adult headform points will contain the prefix 'A'.
- 3.10.2 The grid point will be identified by means of a row and column system. The origin will be at the grid point on the vehicle centreline and the 1000mm WAD. This point is C0,0.
- 3.10.3 The column on the centreline will be column 0, the adjacent column on the right of the vehicle, as shown below, will be column +1, with the other columns increasing by 1 toward the SRL, i.e. +2, +3, ....+8. The column on the left of the vehicle will be column -1 with the other columns decreasing by 1 toward the SRL, i.e. -2, -3, ....-8.
- 3.10.4 The rows at the origin will be row 0, the subsequent rows will be marked in increasing increments of 1 up to the rearmost row.
- 3.10.5 Every point will be identified firstly by the relevant headform impactor (A or C), then by the column, then by the row. See Figure 15.



**Figure 15 Labelling of the headform grid points**

### 3.11 Dividing the Bonnet Leading Edge Reference Line into Sixths

- 3.11.1 Using a flexible tape, measure the distance between the two corner reference points, along the outer contour of the bonnet (measure directly between the corner reference points and not along the Bonnet Leading Edge Reference Line).
- 3.11.2 Divide the measured distance by six and project forward, parallel to the centreline of the vehicle, each point onto the bonnet leading edge. See Figure 16.

#### NOTES:

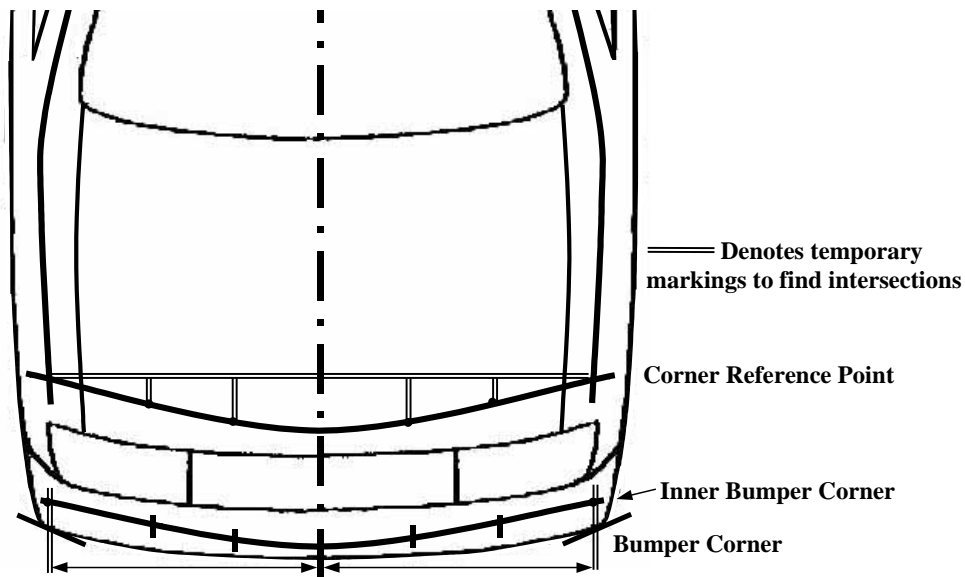
The division of the bonnet leading edge reference line has resulted in three areas (thirds) across the front of the vehicle, each consisting of two halves.

### 3.12 Dividing the Bumper Reference Lines into Sixths

- 3.12.1 Place a flexible measuring tape along the horizontal contour of the Upper Bumper Reference Line, ignoring any small discontinuities in the bumper profile, for example licence plate depressions. Using the Bumper Corners as the extreme measuring points, measure and divide the distance by six. See Figure 16. If the Bumper Corner is not coincidental with the Upper Bumper Reference Line, then mark a point (Inner Bumper Corner) on the Upper and Lower Bumper Reference Lines at the same lateral distance as the Bumper Corner.
- 3.12.2 Repeat the above process for the Lower Bumper Reference Line if necessary.

**NOTES:**

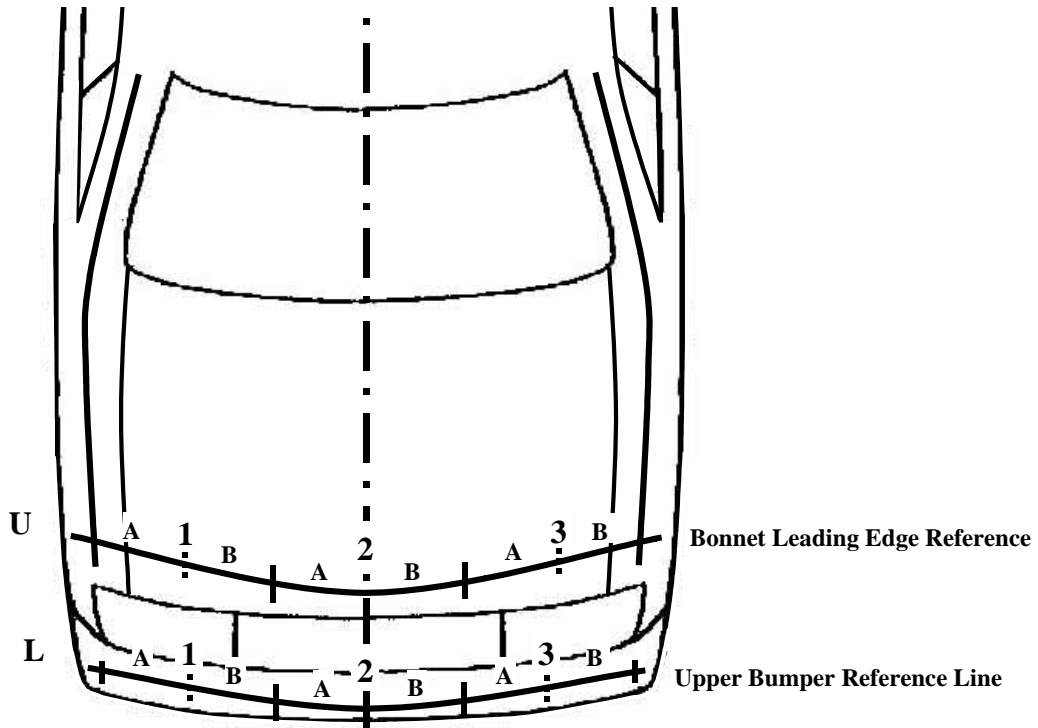
The division of the Upper Bumper Reference Line results in three test zones across the front of the vehicle, each consisting of two halves.



**Figure 16: Division of the bonnet leading edge and upper bumper reference lines**

**3.13 Labelling the Bonnet Leading Edge and Bumper Test Zones**

- 3.13.1 Beginning with the Bonnet Leading Edge Reference Line, move from the right hand side of the vehicle to the left hand side of the vehicle the first third (two sixths) is labelled U1. The remaining thirds are then labelled U2 and U3.
- 3.13.2 Each third has been divided into two, beginning with the first sixth within U1, label from the right hand side of the vehicle to the left hand side of the vehicle alphabetically i.e. A and B. Repeat this for the remaining two thirds.
- 3.13.3 Repeat steps 3.13.1 and 3.13.2, for the Bumper Reference Lines, replacing U with L. See Figure 17.



**Figure 17: Labelling the bonnet leading edge and bumper test zones**

## 4 GRID DATA

### 4.1 Manufacturer Supplied Data

- 4.1.1 The vehicle manufacturer is required to provide the Euro NCAP Secretariat with HIC<sub>15</sub> or colour data detailing the protection offered by the vehicle at all grid locations.
- 4.1.2 All data must be supplied by the manufacturer before any vehicle marking or testing begins, preferably with delivery of the test vehicle(s).
- 4.1.3 For the headform area, data shall be provided for each grid point according to the following performance criteria:
- |                                 |          |
|---------------------------------|----------|
| HIC <sub>15</sub> < 650         | = Green  |
| 650 ≤ HIC <sub>15</sub> < 1000  | = Yellow |
| 1000 ≤ HIC <sub>15</sub> < 1350 | = Orange |
| 1350 ≤ HIC <sub>15</sub> < 1700 | = Brown  |
| 1700 ≤ HIC <sub>15</sub>        | = Red    |
- 4.1.4 Some grid points may have a default red or green rating awarded to them. These shall be clearly identified as defaulted in the predicted data. The only areas that may be defaulted are as follows:
- A-pillars = Default red (unless data is provided to suggest otherwise)
  - Windscreen glazing = Default green (as defined in Section 4.1.5 & 4.1.6)
- 4.1.5 Grid points that are within 165mm of the A-pillars, roof and any underlying structures behind the windscreen, including rubber and any trim parts, may not be defaulted green.
- 4.1.6 Grid points that are within 165mm of the windscreen base, when measured from the lowest part of the glazing, cannot be defaulted green. The windscreen base is identified as the exposed glazed area at the bottom of the windscreen that may be painted black or supported directly from behind by the facia or any trim parts.
- 4.1.7 These distances are to be measured following the outer contour of the vehicle.
- 4.1.8 Where the vehicle manufacturer can provide evidence that shows an A-pillar is not red, those grid points will be considered in the same way as other points.
- 4.1.9 Defaulted locations are not included in the random selection of verification tests, see Section 5, and the correction factor calculation.
- 4.1.10 Before testing begins defaulted locations will be confirmed. Any areas that were not defaulted (red/green) which should have been will be verified and confirmed by Euro NCAP.

### 4.2 Unpredictable Grid Locations

- 4.2.1 Where certain structures are such that the protection offered by particular grid points is unpredictable, those grid points may be coloured blue in the predicted data.
- 4.2.2 Those areas of the vehicle that may contain blue grid points are limited to the following structures:
- Plastic scuttle
  - Windscreen wiper arms and windscreen base
  - Headlamp glazing
  - Break-away structures
- 4.2.3 Where blue points are identified, the vehicle manufacturer must provide justification showing the unpredictable performance of the location(s).
- 4.2.4 Blue points, either singly or grouped together in pairs, will form a blue zone.

- 4.2.5 Where there are two grid points in a zone they must be adjacent (longitudinally, laterally and diagonally) to each other. A maximum of eight zones may be blue over the entire headform impact area.
- 4.2.6 The laboratory will choose one blue point to assess each zone. Symmetry may be applied.
- 4.2.7 The test results of blue points will be applied to the grid point(s) in each zone. The colour of each tested blue point will be changed from blue to the colour corresponding to the HIC<sub>15</sub> measured.
- 4.2.8 Blue point tests will not be used in the random selection of verification tests, see Section 5, and the correction factor calculation.

### **4.3 Absence of Manufacturer Data**

- 4.3.1 Where predicted data is NOT provided by the vehicle manufacturer, the vehicle sponsor may choose for ALL grid points to be tested by the Euro NCAP laboratory.
- 4.3.2 Alternatively, test points will be selected on a worst case performance basis.
  - 4.3.2.1 The bonnet marking and point selection will follow that outlined in the Euro NCAP Pedestrian Testing Protocol version 5.3.1, November 2011.
  - 4.3.2.2 The latest impactors will be used which are specified in Section 12.
  - 4.3.2.3 The latest performance criteria will be applied; details of the criteria are contained in the assessment protocol.

## 5 VERIFICATION TESTS

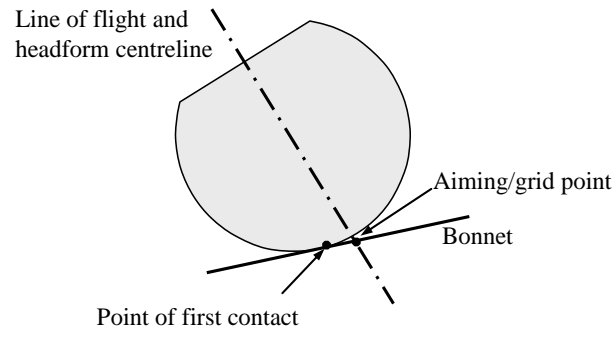
### 5.1 Verification Tests

- 5.1.1 The vehicle sponsor will fund 10 verification tests in the headform area.
- 5.1.2 The vehicle manufacturer has the option of sponsoring up to 10 additional headform verification tests. These are in addition to any blue points and those funded by the sponsor. Where this is the case, the vehicle manufacturer must inform Euro NCAP of the number of tests when predicted data is provided.
- 5.1.3 The location of all verification tests will be selected at the same time and at random by the Euro NCAP Secretariat regardless of the test sponsor.
- 5.1.4 Only those grid points on defaulted grid positions or those coloured blue will be excluded from the randomly selected points. All other grid points are eligible for selection.
- 5.1.5 There is no restriction as to the location of the randomly selected tests. Tests to adjacent impact locations are acceptable provided that permanent vehicle damage would not influence other test results.
- 5.1.6 Where damage from already tested grid points affects other verification tests, the Secretariat will be informed and will take a decision on how to proceed.
- 5.1.7 The results of all verification tests will be used in the calculation of a correction factor.

### 5.2 Headform Tests

- 5.2.1 The selected grid point shall be treated as the aiming point for the headform impactor.
- 5.2.2 The centreline of the headform impactor shall be directly in the line of flight toward the aiming point. See Figure 18.
- 5.2.3 The effect of gravity shall be considered when positioning the propulsion system for test. Under the influence of gravity the headform will deviate from the trajectory it has initially when leaving the propulsion system.
- 5.2.4 Gravity must be taken into account in order to establish the correct trajectory for the headform. The determination of where to position the firing mechanism will require the following information:
  - Headform diameter
  - Distance that the headform must travel after leaving the propulsion system
  - Required angle of impact to horizontal
  - Angle of the bonnet top at the point of impact
  - Required impact velocity
- 5.2.5 Using the above information calculate the distance from the aiming point to ensure that the required correct trajectory is established. The angle to which the propulsion system should be set and the velocity that the propulsion system must give to achieve the required velocity at impact and the required angle of incidence at impact must also be calculated.





**Figure 18: Aiming point**

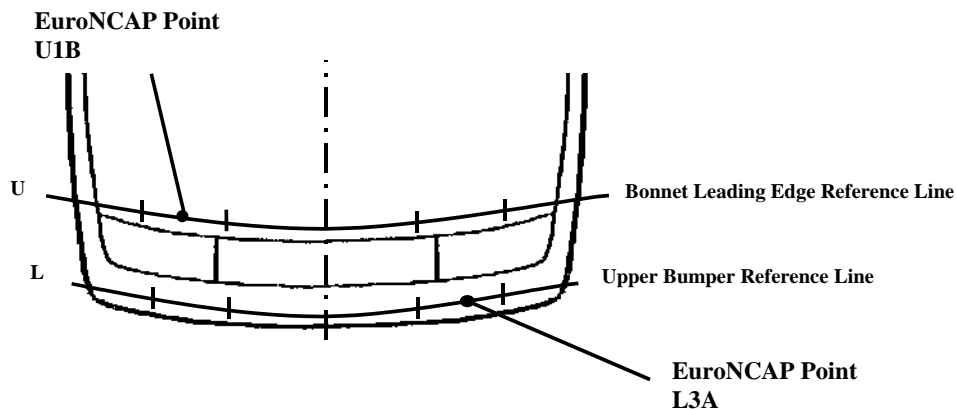
## **6 DETERMINATION OF LEG IMPACT POINTS**

### **6.1 Legform to Bumper Tests**

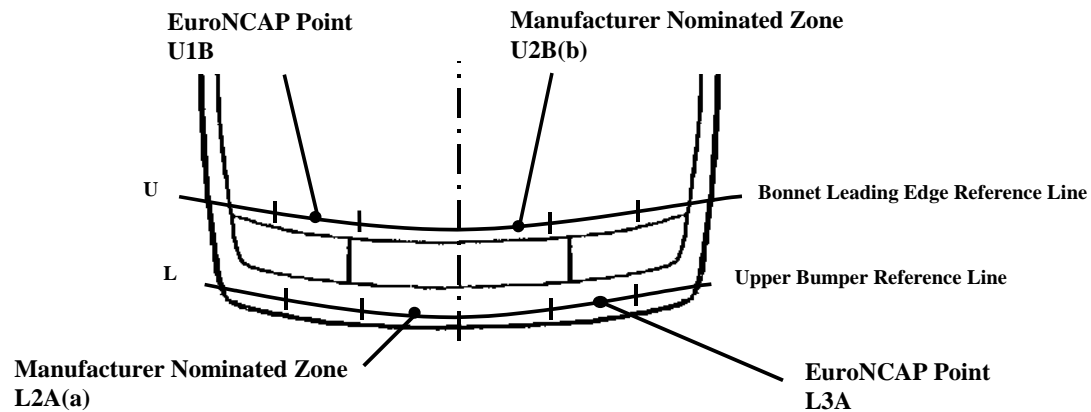
- 6.1.1 The legform to bumper tests will be conducted if the lower bumper reference line at the impact point is less than 425mm above the ground when the test vehicle is at its Normal Ride Attitude. For vehicles where part or all of the Lower Bumper Reference Line is above 425mm, select the bumper impact points as in Section 6.1.2 and afterwards refer to Section 6.2.
- 6.1.2 The impact points shall be chosen in accordance with the following:
  - 6.1.2.1 In order to establish the location of any injurious structures, the test laboratory shall remove the bumper cover and any associated components when selecting test locations.
  - 6.1.2.2 There shall be three Euro NCAP chosen impact points on the bumper.
  - 6.1.2.3 The three Euro NCAP impact points should be chosen for areas which are judged to be the most likely cause of injury.
  - 6.1.2.4 The impact points shall normally be between the Bumper Corners.
  - 6.1.2.5 However, where there are structures outboard of the bumper corners, which are deemed to be more injurious than locations in the adjacent third, Euro NCAP will perform a test to those structures for use in the final vehicle assessment. These tests will be limited to locations between the two outermost ends of the bumper beam/lower rails/cross beam structures.
  - 6.1.2.6 Points selected outside of the bumper corner will be applied to the outermost areas L1A and/or L3B in the vehicle rating. The remaining areas, L1B & L3A will remain free for nomination.
  - 6.1.2.7 Where the manufacturer nominates L1A and/or L3B, test locations outside the bumper corner will also be considered and chosen, if they are deemed to be more injurious than locations in the adjacent sixth. These tests will be limited to locations between the two outermost ends of the bumper beam.
  - 6.1.2.8 No impact point may be closer than 132mm to any other bumper impact point. This distance is to be set with a flexible tape held tautly along the outer surface of the vehicle.
  - 6.1.2.9 Where the spacing requirement prevents a test from being performed in a sixth, that sixth will be awarded the score from the most appropriate adjacent or symmetrical sixth.

Where a manufacturer considers that the single Euro NCAP impact point, in a particular third, would not adequately reflect the performance of that area, the vehicle manufacturer may fund and nominate an additional test in the adjacent half next to the Euro NCAP impact point. The manufacturer must choose their nominated test zones (for all impactors) before any testing begins, once the manufacturer has nominated the desired test zones, Euro NCAP will then choose the impact point which is judged to be the most likely cause of injury within each of the nominated test zones. One Euro NCAP legform test is performed in either of the first two sixths, one in either of the middle two sixths and one in either of the final two sixths. The manufacturer nominated test zones (up to a maximum of three) can be in one or more of the remaining sixths. Where any of the impact points are centred on an internal border of a third, the manufacturer can choose which of the adjacent test zones it is deemed to be in. The test in the other zone would then have to comply with the spacing requirements between impact points.

- 6.1.2.10 If symmetrically identical impact points are present, both points may be chosen. However, the score for the second point may be taken to be the same as that of the first, without being tested, unless the car manufacturer provides evidence to suggest that the rating would be different or, for the manufacturer's nominated test zones, Euro NCAP expect different results. Agreement between the test house and manufacturer on all symmetrical impact points should be reached before testing begins, disputes will be referred to the Euro NCAP secretariat.
- 6.1.3 Often the most injurious locations will be at similar points on all cars and some suggestions are made below. However, the following should be used as a *guide only*. Euro NCAP may decide to test other areas, if they appear particularly aggressive. The following examples are given for illustrative purposes only and need not be chosen for testing:
- Towing eye. This is normally mounted on the bumper beam to the right or left front lower rails. If the eye is removable, carry out the test without it, and fit the applicable cover over the hole.
  - Areas outside the bumper corners may contain more injurious structures than those inside. For example there may be a lack of foam padding over the bumper beam or little support to the lower part of the legform.
  - Localised stiff structures such as crumple-cans, cooling components or front spoiler mounted lights.
  - Radiator/intercooler edges or fixation mounts
- 6.1.4 Place a mark on the bumper to represent the point of impact of the centre of the legform.
- 6.1.5 The test point is labelled using the name of the zone in which it falls. See Figure 19.
- 6.1.6 If the manufacturer wishes to nominate additional tests the point will be labelled in the same way as 6.1.5, but it will contain an additional label, in lower case characters, to signify the zone which was nominated. See Figure 20.



**Figure 19: Impact point labelling in the Bonnet Leading Edge and Bumper Reference Line test zones**



**Figure 20: Additional impact point labelling in the Bonnet Leading Edge and Bumper test zones**

## 6.2 Upper Legform to Bumper Tests

- 6.2.1 These tests are conducted, instead of the legform to bumper tests, if the Lower Bumper Reference Line at the position(s) defined in Section 6.1, is greater than 500mm vertically above the ground at the vehicle's normal ride attitude.
- 6.2.2 Where the Lower Bumper Reference Line at the position(s) defined in Section 6.1, is between 425mm and 500mm vertically above the ground at the vehicle's normal ride attitude, the vehicle manufacturer may choose to use either the Legform to bumper test or the Upper Legform to bumper test.
- 6.2.3 The upper legform to bumper tests must be carried out at the same lateral position as the points selected in Section 6.1, with the intersection of the longitudinal and lateral planes, at the centre of the impactor, aimed mid way between the Upper Bumper Reference Line and the Lower Bumper Reference Line.

## 6.3 Upper Legform to Bonnet Leading Edge Tests

- 6.3.1 A test is not required if the calculated impact energy would be less than 200J. The impact locations shall be chosen using a method similar to Section 3.1 but with the following changes:
- 6.3.1.1 The impact points shall be marked on the Bonnet Leading Edge Reference Line.
- 6.3.1.2 The selected impact points must be at least 75mm from the Corner Reference Points and at least 150mm apart. These distances are to be set with a flexible tape held tautly along the outer surface of the vehicle.
- 6.3.1.3 Where the spacing requirements in 6.1.2.8 prevent a test from being performed in a sixth, that sixth will be awarded the score from the most appropriate adjacent or symmetrical sixth.

Where a manufacturer considers that the single Euro NCAP impact point, in particular third, would not adequately reflect the performance of that area, the vehicle manufacturer may fund and nominate an additional test in the adjacent half next to the Euro NCAP impact point. The manufacturer must choose their nominated test zones (for all impactors) before any testing begins, once the manufacturer has nominated the desired test zones, Euro NCAP will then choose the impact point which is judged to be the most likely cause of injury within each of the nominated test zones. One Euro NCAP upper legform test is performed in either of the first two sixths, one in either of the middle two sixths and one in either of the final two sixths. The

manufacturer nominated test zones (up to a maximum of three) can be in one or more of the remaining sixths. Where any of the impact points are centred on an internal border of a third, the manufacturer can choose which of the adjacent test zones it is deemed to be in. The test in the other zone would then have to comply with the spacing requirements between impact points.

- 6.3.1.4 If symmetrically identical impact points are present, both points may be chosen. However, the score for the second point may be taken to be the same as that of the first, without being tested, unless the car manufacturer provides evidence to suggest that the rating would be different or, for the manufacturer's nominated zone(s), Euro NCAP expect different results. Agreement between the test house and manufacturer on all symmetrical impact points should be reached before testing begins, disputes will be referred to the Euro NCAP secretariat.
- 6.3.2 Test three points at those locations which are considered to be the most injurious within a test zone. Often, the most injurious locations will be at similar points on all cars and some suggestions are made below. However, the following should be used as a *guide only*, other locations should be chosen if they appear more aggressive:
- Radiator mounts
  - Bonnet support structures (rubber bump stops)
  - Headlight fixation points
  - Areas of high energy, where BLE height and bumper lead is high. This may be influenced by bonnet styling
  - Bonnet catch
- 6.3.3 After the impact points have been marked, additional marks shall be made on the Upper Bumper Reference Line which are in the same vertical longitudinal plane as the marks on the Bonnet Leading Edge Reference Line. The marks made on the bumper will be used to determine the Bonnet Leading Edge Height and the Bumper Lead at the impact points.
- 6.3.4 The impact point is labelled using the name of the test zone in which it falls. If the manufacturer wishes to nominate additional tests the impact point will be labelled in the same way.

## **7 RECORDING THE IMPACT POINT LOCATIONS**

### **7.1 General**

- 7.1.1 A three dimensional measuring system with an accuracy of  $\pm 0.5\text{mm}$  shall be used to record the grid origin and the points chosen for test. For the Bumper and Bonnet Leading Edge record the position of the impact point placed on the Upper Bumper Reference Line and the Bonnet Leading Edge Reference Line respectively, at the chosen lateral test positions. For the bonnet top, A-pillar, windscreen and roof record the position of markers placed on the selected impact points.
- 7.1.2 Care should be taken at all times not to move the vehicle while the impact points are being recorded or transferred.

### **7.2 Measuring Impact Points**

- 7.2.1 Ensure that the vehicle is at its test weight and fully test prepared as defined in Section 1.
- 7.2.2 Measure the ride heights at all four wheels using the marks defined in Section 1.3.4. Record the ride heights in the test details.
- 7.2.3 During digitising, care should be taken not to move the vehicle by, for example, leaning on it.
- 7.2.4 The co-ordinates of all impact locations should be digitised with the 3D arm. For each of the bonnet leading edge locations, record both the co-ordinates of the location and that point on the Upper Bumper Reference Line in the same longitudinal vertical plane as it.
- 7.2.5 A hard copy of the impact points' co-ordinates should be obtained for reference.
- 7.2.6 After digitisation, the bonnet top and bumper featuring all the impact points shall be removed and replacements fitted. See Section 8.3 for fitting procedures.
- 7.2.7 The original bonnet and bumper shall be kept for reference and will be replaced on the vehicle once testing is complete.

### **7.3 Transferring Impact Points to Replacement Vehicle Parts**

- 7.3.1 Replacement parts will need to be fitted to the vehicle for the series of tests. It is not practical to have to mark out each of the parts completely for a single test. Therefore, the original marked-out bonnet will be retained as a reference and individual impact locations transferred to replacement components.
- 7.3.2 With the new component(s) fitted, measure the ride heights at all four wheels.
- 7.3.3 These ride heights must be altered until they match the original recorded ride heights (Section 1.3). If the ride heights are too high then they can be reduced by adding weights. If the ride heights are too low then they can be increased by removing weight from the vehicle and/or inserting blocks under the body of the vehicle. The additional weights and/or blocks shall be removed before testing.
- 7.3.4 Set up the 3D measuring system.
- 7.3.5 Using the co-ordinates recorded in Section 7.2 for the original impact points, locate and mark the desired impact point on the new component.

## 8 PERFORMING OF PEDESTRIAN IMPACT TESTS

### 8.1 General

- 8.1.1 Safety to personnel shall be a priority at all times
- 8.1.2 Ensure that all equipment used is in full working order, has been checked for safety and is in calibration where appropriate

### 8.2 Propulsion System

- 8.2.1 An air, spring or hydraulic gun will be used to propel the various body form impactors.
- 8.2.2 For the legform and the headform tests the impactors are required to be in free flight at the time of impact.

### 8.3 Fitting Replacement Parts to Vehicles

- 8.3.1 Careful note shall be taken before any testing is performed as to how any parts liable to need replacement are fitted to the vehicle structure.
- 8.3.2 Fitting of parts shall not increase or decrease the strength of the structure of the vehicle.
- 8.3.3 If significant repair work is required, this will be done at a manufacturer-approved dealer.

### 8.4 Photographic Record

- 8.4.1 A photographic record shall be kept of each test.
- 8.4.2 Before any testing has been conducted but after the vehicle is fully test prepared including all markings, the vehicle shall be photographed according to the following schedule. Note that these shall be the only pre-test photographs taken.

#### 8.4.3 List of still photographs

<u>Amount of vehicle visible</u>	<u>View Point</u>
Full vehicle	Left side
Full vehicle	Right side
Front third vehicle	Left side
Front third vehicle	Right side
Full vehicle	Front
Left half vehicle	Front
Right half vehicle	Front
Front third of vehicle	Top
Front third, right half of vehicle	Top
Front third, left half of vehicle	Top
Legform test points	Front
Upper legform test points	Front
Child head zone test points	Top
Adult head zone test points	Top

- 8.4.4 Post-test photographs are detailed for each test type in the individual test procedures.

### 8.5 Testing Deployable Bonnets

- 8.5.1 Head test zones
  - 8.5.1.1 The test sites will be chosen with the bonnet in the deployed state, unless the system is to be tested in the undeployed state.
  - 8.5.1.2 Where bonnets are fully deployed and remain in the intended position before the smallest appropriate stature pedestrian head impact time (HIT), all testing will be carried out statically with the bonnet in the deployed state.
  - 8.5.1.3 Where bonnets are NOT fully deployed prior to the smallest appropriate stature

pedestrian, all testing will be performed dynamically. This also applies to systems that do not remain in a permanently deployed position.

#### 8.5.2 Static pedestrian tests

8.5.2.1 Static pedestrian tests will be performed in the normal way and according to the usual tolerances.

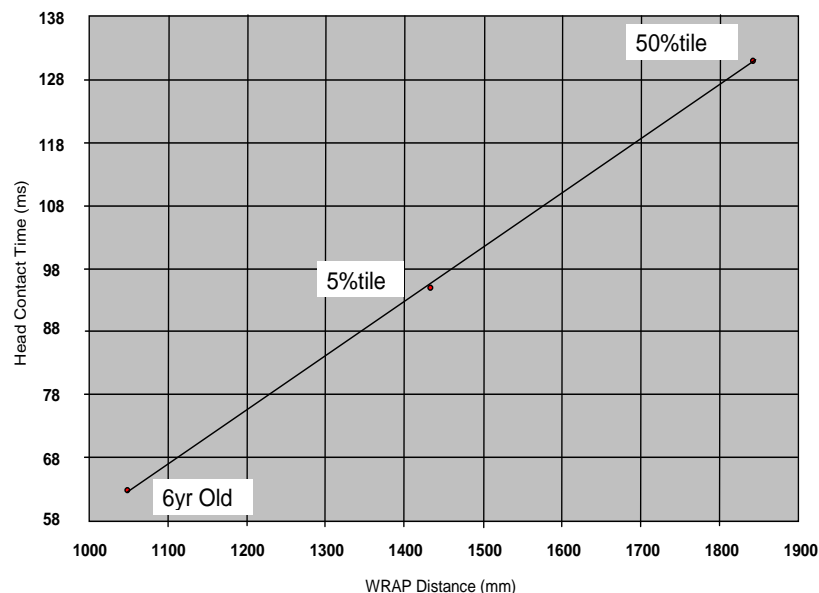
#### 8.5.3 Dynamic pedestrian tests

8.5.3.1 Where dynamic tests are required, only a lateral impact tolerance of +/-10mm will be required. The headform shall be aimed at the nominated injurious structure, such as the engine top, the subsequent impact location on the bonnet top will then be determined by the timing of the bonnet deployment relative to the propulsion of the headform.

8.5.3.2 The vehicle manufacturer will be required to provide Euro NCAP with data from numerical simulations performed with the bonnet in the undeployed position. Simulations are to be conducted with a vehicle speed of 40km/h with all pedestrian statures that result in head contact to bonnet. Pedestrian models should be selected from the following statures, a 6 year old, 5th percentile female, 50th percentile male and 95th percentile male. The pedestrian position and stance to be used in the model is defined in Section 2.6.1.5.

8.5.3.3 From the simulations both head contact time and the wrap around distance that the head contacts the bonnet should be recorded.

8.5.3.4 A graph shall be plotted with a best fit straight line as shown in Figure 21. When a test point is selected, as the wrap distance will be known, the equivalent head contact time can be obtained from the graph that will be used in the dynamic test set up.



**Figure 21: WAD vs HCT**

8.5.3.5 The vehicle manufacturer must provide the test laboratory with all the necessary details of how to trigger the system, monitor trigger signals and replace spare parts.

#### 8.5.4 Upper leg test zones

8.5.4.1 The test sites will be chosen with the bonnet in its un-deployed state. If bonnet deployment occurs prior to pedestrian contact with the Bonnet Leading Edge, creating an increased hazard such as higher BLE height and/or bumper lead, the Euro NCAP secretariat will give consideration to marking out the BLE in the deployed state.



- 8.5.4.2 Unless there is concern about additional hazards being created by the bonnet deploying prior or during pedestrian contact with the Bonnet Leading Edge, all upper legform to bonnet leading edge testing will be carried out with the bonnet in the un-deployed state.
- 8.5.4.3 Where the vehicle manufacturer provides data showing that a deployable bonnet system offers protection to the upper leg, the upper legform to bonnet leading edge tests will be carried out by conducting dynamic tests.

## 9 LEGFORM TESTS

### 9.1 Description of Legform and its Instrumentation

9.1.1 The legform impactor used shall conform to that specified in Regulation (EC) No 78/2009 of the European Parliament and of the Council (14<sup>th</sup> January 2009) and annexed in R (EC) 631/2009 (22<sup>nd</sup> July 2009).

9.1.2 Instrumentation:

Location	Measurement	CFC (Hz)	CAC	No of channels
Bottom of Femur	Angle (gives shear displacement)	180	*10mm/ 21.3°	1
Top of Tibia	Knee Bend Angle	180	50°	1
Tibia, non-impacted side	Acceleration	180	500g	1

*\*This does not require that the impactor itself be able to physically bend and shear to this angle.*

### 9.2 Certification

9.2.1 The certification procedures are detailed in Regulation (EC) 631/2009 (22<sup>nd</sup> July 2009).

9.2.2 The legform shall be re-certified after a maximum of 20 impacts and the foam replaced.

9.2.3 The legform shall be re-certified at least once every 12 months regardless of the number of impacts it has undergone.

9.2.4 If the legform exceeds any of its CACs then it shall be re-certified

9.2.5 The legform shall be certified before the test programme.

### 9.3 Test Procedure - Pre Test

9.3.1 Ensure that the vehicle is fully test prepared as described in Section 1.

9.3.2 Ensure that the legform, the vehicle, the propulsion system and the data acquisition equipment has soaked in a temperature in the range of 16°C to 24°C for at least 2 hours prior to testing.

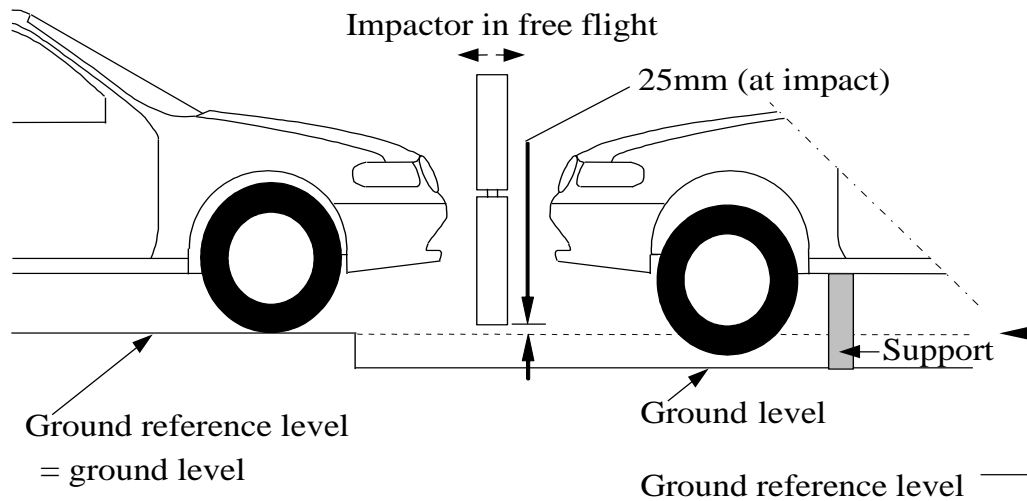
9.3.3 Fit a new piece of foam<sup>1</sup> to the legform and fit the neoprene skin over the foam.

9.3.4 Align the vehicle so that the propulsion system can aim at the impact position and the propulsion system can fire the legform in a direction that is parallel to the vehicle centre line.

9.3.5 Roll the vehicle forwards to give the desired free flight distance.

9.3.6 At the time of first contact the bottom of the legform shall be 25mm above Ground Reference Level  $\pm 10$ mm. Insert blocks under the wheels of the vehicle such that vehicle height is raised as required by the gravity correction method used to ensure the above tolerance; and the tolerance for direction of impact are both satisfied. Alternatively, ensure that the vehicle is positioned above a trench in the floor. See Figure 22.

<sup>1</sup> The foam shall be 25mm thick Confor<sup>TM</sup> foam type CF-45



**Figure 22: Legform to Bumper tests**

- 9.3.7 If required, ensure the vehicle is at the same ride heights as those recorded during marking up of the vehicle, friction in the vehicle's suspension system may be a source of variance.
- 9.3.8 To ensure that the legform impacts with its bottom at the correct height above the ground a correction to take into account the action of gravity when the legform is in free flight is required. This can take the form of raising the legform a distance  $h$ , and firing it horizontally so that the action due to gravity results in the bottom of the impactor being at ground level at the point of first contact with the vehicle. This can be achieved using the method in Section 9.4. However, this method will only remain within the tolerance specified in 9.5.9 if its free flight distance is about 400mm or less. For test houses that use a free flight distance of more than 400mm then the legform shall be fired using a ballistic correction procedure as described in Section 9.5.

#### **9.4 Compensation for Gravity (horizontal firing)**

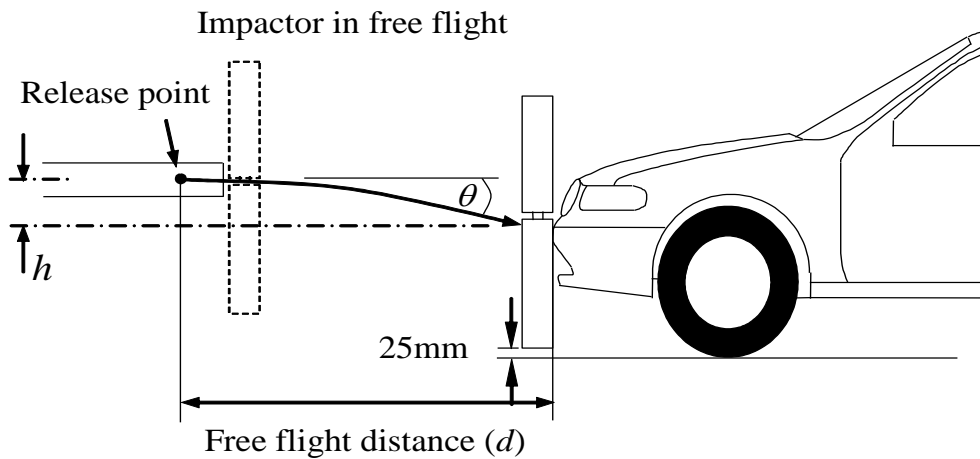
- 9.4.1 Measure the distance  $d$  (in metres) between the point of first contact and the point from where the legform will leave the propulsion system and begin free flight (release point).
- 9.4.2 The distance that the legform will fall due to gravity can be calculated from the formula:

$$\text{Fall due to Gravity } h = \frac{gd^2}{2v^2}$$

Assuming values for  $g$ , acceleration due to gravity =  $9.81\text{ms}^{-2}$  and  $v$ , exit velocity of the legform from the propulsion system (at the release point) =  $11.1\text{ms}^{-1}$  gives:

$$\text{Fall due to Gravity } h = 0.03981 d^2$$

- 9.4.3 Raise the propulsion system by this calculated amount,  $h$ . The angle  $\theta$  must remain within the tolerance specified in Section 9.5.9. See Figure 23.
- 9.4.4 Proceed to Section 9.5.8.



**Figure 23: Droop Compensation**

### 9.5 Ballistic Compensation

There are two procedures which can be used for ballistic compensation, it is at the discretion of the test house as to the most appropriate method, see Figure 24. The terms used for the calculations are:

At the release point:

$u$  = initial velocity  
 $\phi$  = firing angle

At the point of first contact:

$v$  = impactor velocity (11.1m/s)  
 $\theta$  = direction of impact ( $0^\circ$ )  
 $d$  = free flight distance  
 $h$  = height increase

9.5.1 The first case is where  $\phi$  is fixed, and  $\theta = 0^\circ$ ,  $v = 11.1\text{m/s}$ . The vehicle must be positioned in relation to the fixed propulsion system, therefore  $u$ ,  $d$ , and  $h$  are the subjects.

9.5.2 Using the following equations find  $u$ ,  $d$ , and  $h$ :

$$u = \frac{v}{\cos(\phi)}$$

$$d = \frac{v^2}{g} \tan(\phi)$$

$$h = \frac{v^2}{2g} \tan^2(\phi)$$

9.5.3 Position the vehicle to be the correct distance away from, and height above the release point. Proceed to Section 9.5.8.

9.5.4 The second case is where  $d$  is fixed, and  $\theta = 0^\circ$ ,  $v = 11.1\text{m/s}$ . The propulsion system is positioned and aimed in relation to the vehicle, therefore  $u$ ,  $h$  and  $\phi$  are the subjects.

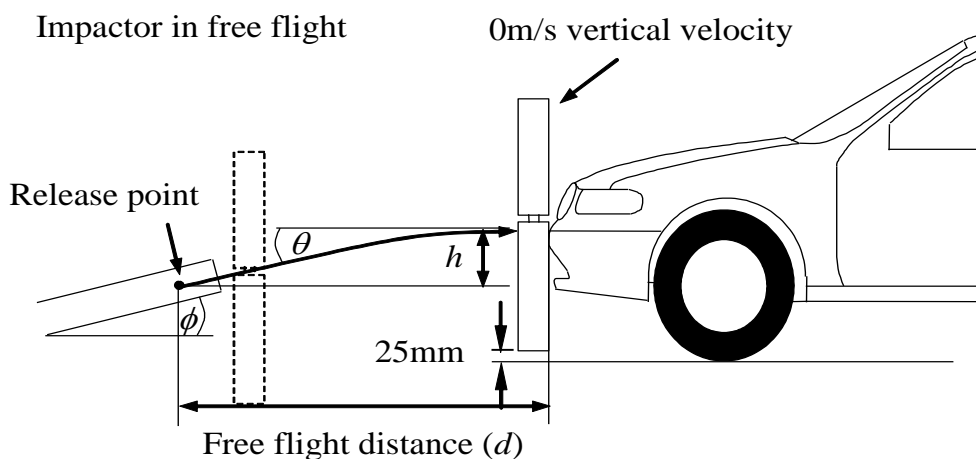
9.5.5 Using the following equations find  $u$ ,  $h$  and  $\phi$ :

$$u = v \left( 1 + \frac{g^2 d^2}{v^4} \right)^{\frac{1}{2}}$$

$$h = \frac{gd^2}{2v^2}$$

$$\phi = \tan^{-1} \left( \frac{gd}{v^2} \right)$$

- 9.5.6 Position the propulsion system to be the correct distance away from, height above and correctly aimed at the vehicle.
- 9.5.7 The angle  $\phi$  shall be set so that the impactor is at the top of the ballistic at the point of first contact.



**Figure 24: Ballistic Correction Procedure**

- 9.5.8 Set the speed control on the propulsion system to give 11.1m/s  $\pm$ 0.2m/s at the point of first contact. The velocity measuring device should be able to measure to an accuracy of at least  $\pm$ 0.02 m/s. The effect of gravity shall be taken into account when the impact velocity is obtained from measurements taken before the point of first contact.
- 9.5.9 The direction of impact at the point of first contact shall be in the horizontal plane and parallel to the longitudinal vertical plane of the vehicle. The axis of the legform shall be vertical at the time of first contact. The tolerance to these directions is  $\pm$ 2°.
- 9.5.10 At the time of first contact the impactor shall have the intended orientation about its vertical axis, for correct operation of the knee joint, with a tolerance of  $\pm$ 2°.
- 9.5.11 At the time of first contact the centre line of the legform impactor shall be within  $\pm$ 10mm of the selected impact point.
- 9.5.12 During contact between the legform impactor and the vehicle, the impactor shall not contact the ground or any object not part of the vehicle.
- 9.5.13 Fire the propulsion system.

## 9.6 Test Procedure - Post Test

- 9.6.1 Take at least two still photographs of the resultant dent, one from the side and one from the front. Each photograph shall have some means of identifying the vehicle and test location. The preferred method shall be to use unique run numbers for each test.

- 9.6.2 Additional photographs may be required for an individual test at the Project Managers discretion.
- 9.6.3 Check that no CAC has been exceeded before conducting the next test, if this has occurred then the impactor must be re-certified before the next test.
- 9.6.4 Replace any damaged part of the vehicle that will affect the results of the next test with new parts according to Section 8.3.
- 9.6.5 Repeat procedure for the next impact location.

## 10 UPPER LEGFORM TO BUMPER TESTS

### 10.1 Description of Upper Legform and its Instrumentation

10.1.1 The upper legform impactor used shall conform to that specified in Regulation (EC) 78/2009 of the European Parliament and of the Council (14th January 2009) and annexed in R (EC) 631/2009 (22nd July 2009).

10.1.2 Instrumentation:

Location	Measurement	CFC (Hz)	CAC	No of channels
Upper femur	Force	180	10kN	1
Lower femur	Force	180	10kN	1
Centre of femur	Bending moment	180	1000Nm	1
50mm above centre of femur	Bending moment	180	1000Nm	1
50mm below centre of femur	Bending moment	180	1000Nm	1

### 10.2 Certification

10.2.1 The certification procedures are detailed in Regulation (EC) 631/2009 (22nd July 2009).

10.2.2 The upper legform shall be certified before the test programme.

10.2.3 The foam sheet<sup>2</sup> from which the pieces of foam shall be taken shall be certified before the test programme.

10.2.4 The upper legform shall be re-certified after a maximum of 20 impacts.

10.2.5 The upper legform shall be re-certified at least once every 12 months regardless of the number of impacts it has undergone.

10.2.6 If the upper legform exceeds any of its CACs then it shall be re-certified.

### 10.3 Test procedure - Pre-test

10.3.1 Ensure that the vehicle is fully test prepared as described in Section 1.

10.3.2 Ensure the vehicle is at the normal ride attitude as recorded during marking up of the vehicle.

10.3.3 Ensure that the upper legform, the vehicle, the propulsion system and the data acquisition equipment has soaked in a temperature in the range of 16°C to 24°C for at least 2 hours prior to testing.

10.3.4 The total mass of the upper legform impactor including those propulsion and guidance components which are effectively part of the impactor during the impact shall be 9.5kg ±0.1kg. The upper legform impactor mass may be adjusted from this value by up to ±1kg, provided the required impact velocity is also changed using the formula:

$$V = \sqrt{\frac{1170}{M}}$$

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<sup>2</sup> The foam shall be 25mm thick Confor<sup>TM</sup> foam type CF-45

Where:  $V$  = impact velocity (m/s)  
 $M$  = mass (kg), measured to an accuracy of better than  $\pm 1\%$

- 10.3.5 The total mass of the front member and other components in front of the load transducer assemblies, together with those parts of the load transducer assemblies in front of the active elements, but excluding the foam and skin, shall be  $1.95 \pm 0.05\text{kg}$ .
- 10.3.6 Fit new pieces of foam, from the certified sheet of foam, to the upper legform.
- 10.3.7 Align the vehicle so that the propulsion system can aim at the impact position as defined in Section 6.1 and the propulsion system can propel and guide the upper legform in a direction that is parallel to the vehicle centre line  $\pm 2^\circ$ . At the time of first contact the impactor centre line shall be midway between the Upper Bumper Reference Line and the Lower Bumper Reference Line with  $\pm 10$  mm tolerance and laterally with the selected impact location with a tolerance of  $\pm 10$  mm.
- 10.3.8 The impact velocity of the upper legform impactor when striking the bumper shall be  $11.1\text{m/s} \pm 0.2\text{m/s}$ . The velocity measuring device should be able to measure to an accuracy of at least  $\pm 0.02$  m/s. The effect of gravity shall be taken into account when the impact velocity is obtained from measurements taken before the point of first contact.
- 10.3.9 Roll the vehicle forwards to give the desired distance, so that the impactor strikes the vehicle after it has been accelerated to the test speed and so that any end stops on the guidance system do not interfere with its interaction with the vehicle.
- 10.3.10 The direction of impact shall be in the horizontal plane and parallel to the longitudinal vertical plane of the vehicle. The axis of the upper legform shall be vertical at the time of first contact. The tolerance to these directions is  $\pm 2^\circ$ .
- 10.3.11 Fire the propulsion system.

#### **10.4 Test Procedure - Post Test**

- 10.4.1 Take at least two still photographs of the resultant dent, one from the side and one from the front. Each photograph shall have some means of identifying the vehicle and test location. The preferred method shall be to use unique run numbers for each test.
- 10.4.2 Additional photographs may be required for an individual test at the Project Managers discretion.
- 10.4.3 Check that no CAC has been exceeded before conducting the next test, if this has occurred then the impactor must be re-certified before the next test.
- 10.4.4 Replace any damaged part of the vehicle which would affect the results of the next test with new parts according to Section 8.3.
- 10.4.5 Repeat procedure for the next impact location.



## 11 UPPER LEGFORM TO BONNET LEADING EDGE TESTS

### 11.1 Description of Upper Legform and its Instrumentation

11.1.1 The upper legform used shall conform to that specified in Regulation (EC) 78/2009 of the European Parliament and of the Council (14th January 2009) and annexed in R (EC) 631/2009 (22nd July 2009).

11.1.2 Instrumentation:

Location	Measurement	CFC (Hz)	CAC	No of channels
Upper femur	Force	180	10kN	1
Lower femur	Force	180	10kN	1
Centre of femur	Bending moment	180	1000Nm	1
50mm above centre of femur	Bending moment	180	1000Nm	1
50mm below centre of femur	Bending moment	180	1000Nm	1

### 11.2 Certification

11.2.1 The certification procedures are detailed in Regulation (EC) 631/2009 (22nd July 2009).

11.2.2 The upper legform shall be certified before the test programme.

11.2.3 The foam sheet<sup>3</sup> from which the pieces of foam shall be taken shall be certified before the test programme.

11.2.4 The upper legform shall be re-certified after a maximum of 20 impacts.

11.2.5 The upper legform shall be re-certified at least once every 12 months regardless of the number of impacts it has undergone.

11.2.6 If the upper legform exceeds any of its CACs then it shall be re-certified

### 11.3 Bumper Lead

This is defined as the horizontal distance between the Bonnet Leading Edge Reference Line and the Upper Bumper Reference Line. The bumper lead may vary across the front of the car; therefore, the bumper lead must be measured separately at all selected bonnet leading edge impact points.

11.3.1 Position a vertical straight edge in contact with the Upper Bumper Reference Line positioned longitudinally to align with the Bonnet Leading Edge impact point.

11.3.2 Measure the horizontal longitudinal distance from the Bonnet Leading Edge Reference Line to the vertical straight edge. This is the bumper lead at that point. Alternatively a 3D measuring arm can be used to establish this distance. Record the Bumper Lead for each impact point.

### 11.4 Bonnet Leading Edge Height

This is defined simply as the vertical height above the ground of the Bonnet Leading Edge Reference Line. This line follows the contours of the bonnet and its height may vary across the front of the car, therefore, the bonnet leading edge height must be measured separately at all

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<sup>3</sup> The foam shall be 25mm thick Confor<sup>TM</sup> foam type CF-45

selected Bonnet Leading Edge impact points, which will be chosen in Section 6.

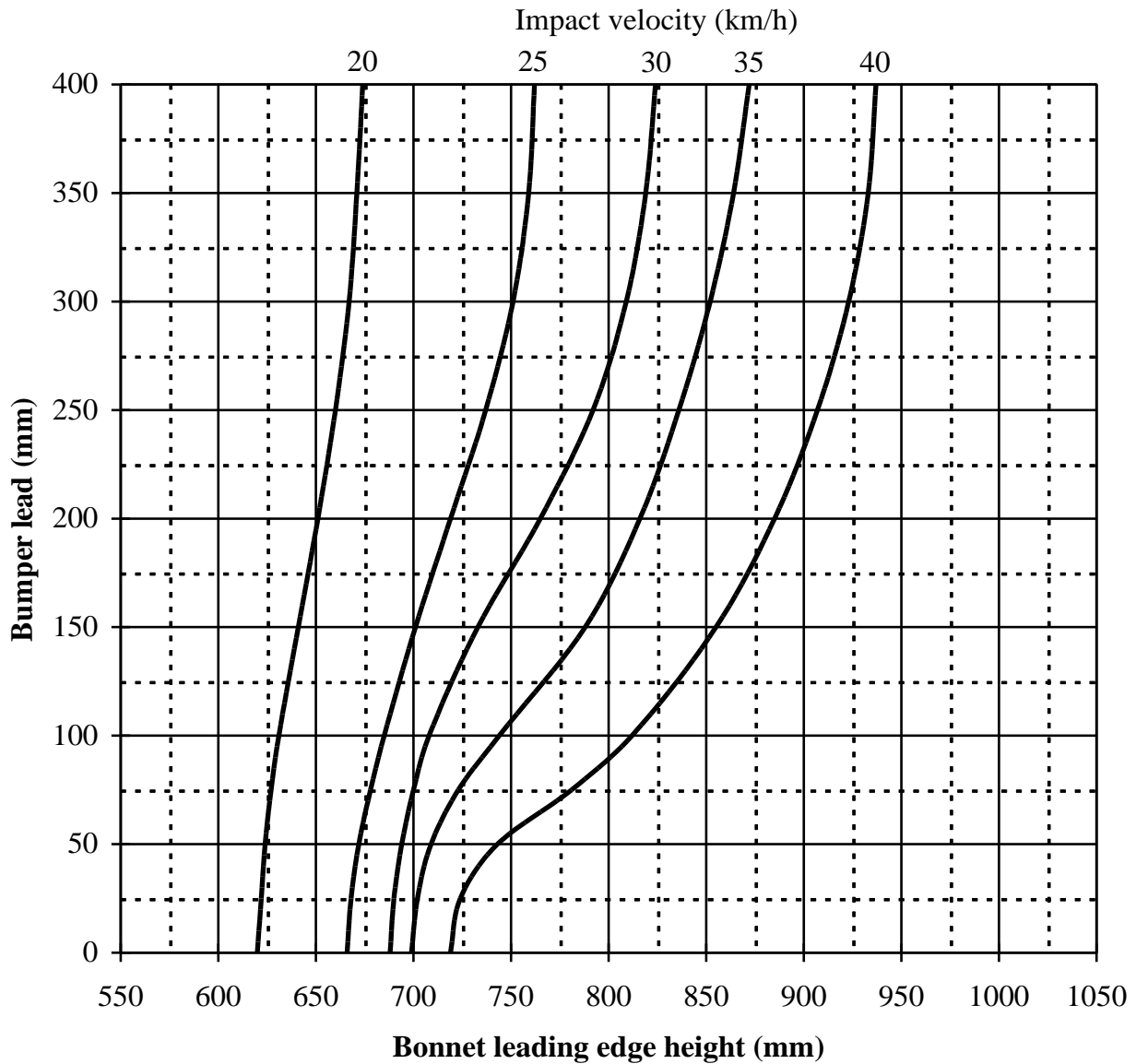
11.4.1 Position a horizontal straight edge with one end in contact with the impact point on the Bonnet Leading Edge Reference Line and measure the vertical distance to the ground. Alternatively use a 3D measuring arm to measure and record the Bonnet Leading Edge height for each impact point.

### **11.5 Determination of Impact Velocity, Impact Angle and Impact Energy**

11.5.1 The shape of the front of the car determines the velocity, angle of incidence and kinetic energy of the impactor. Full details are given in EEVC WG17 Report, 'Improved Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars', December 1998. The velocity, angle of impact and total kinetic energy of the impactor will be calculated from the bonnet leading edge height and bumper lead.

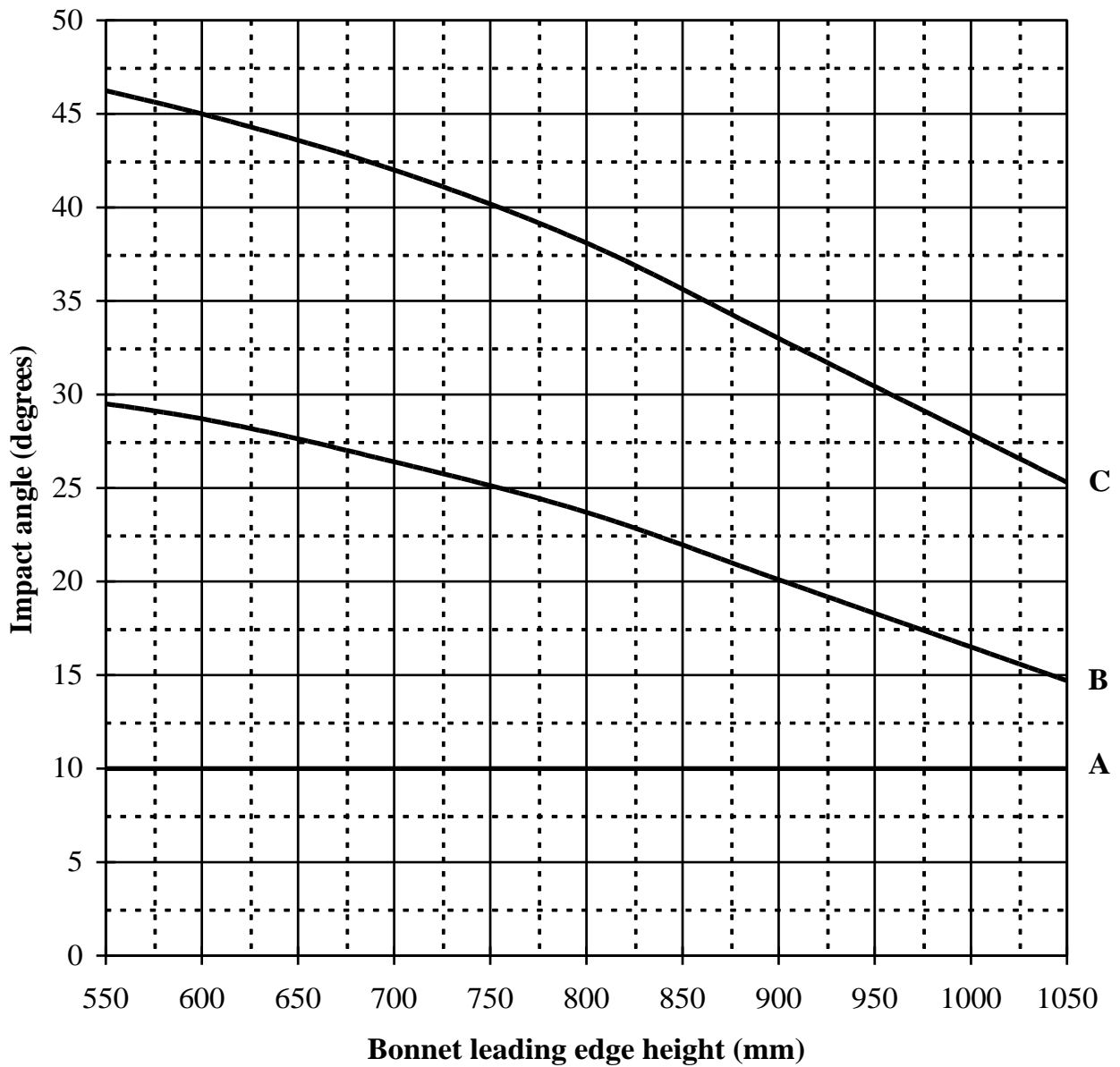
11.5.2 Determine the Bonnet Leading Edge Height and the Bumper Lead at each impact point. These can be simply calculated using the previously digitised co-ordinates of the bonnet leading edge location and its 'equivalent' point on the Upper Bumper Reference line.

11.5.3 Determine the required impact velocity, angle and the kinetic energy for the value of Bonnet Leading Edge height and Bumper Lead found in 11.5.1 using Figure 25, Figure 26 and Figure 27.



**Figure 25: Velocity of upper legform to Bonnet Leading Edge tests with respect to vehicle shape**

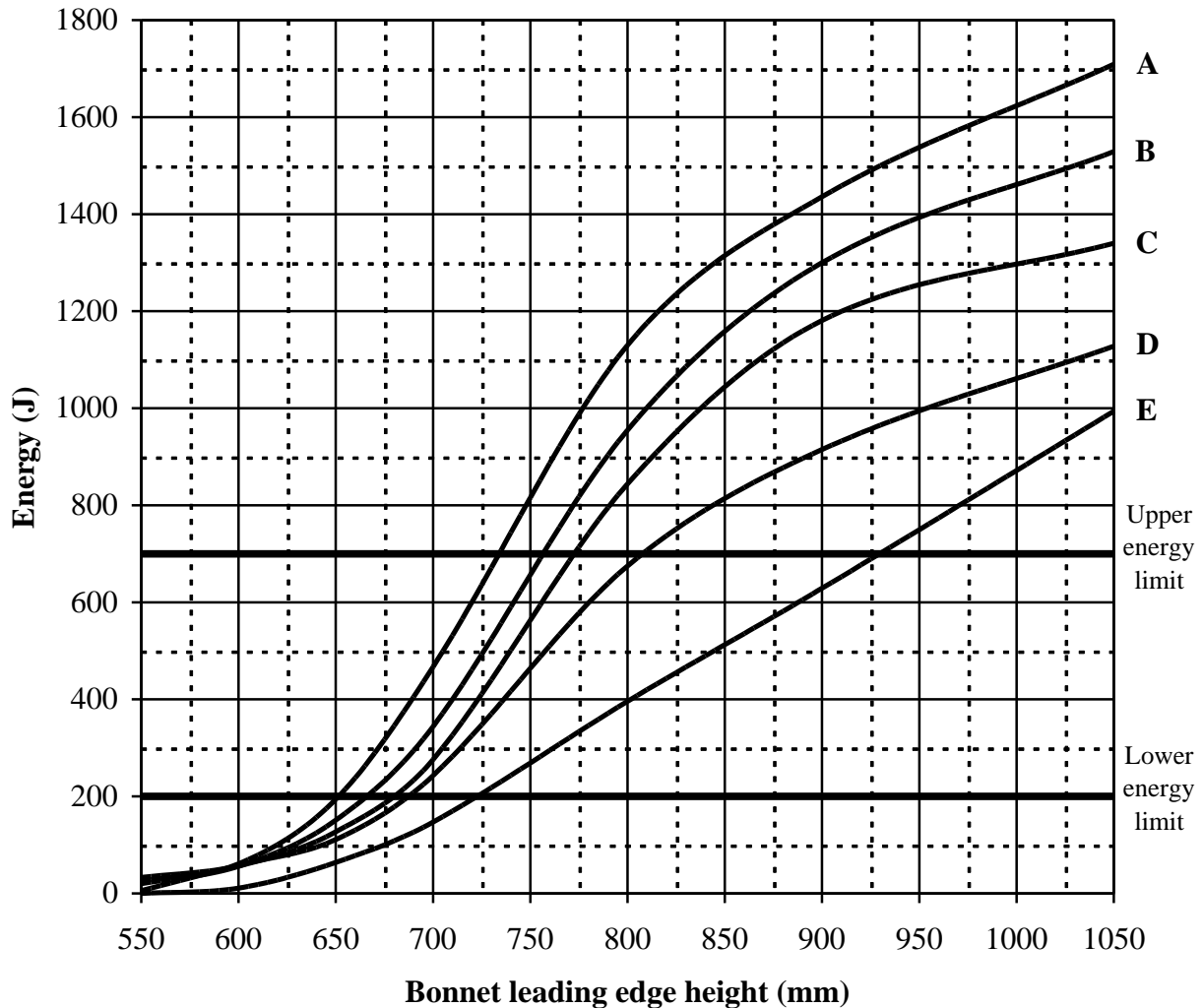
- Notes:
1. Interpolate horizontally between curves.
  2. With configurations below 20km/h - test at 20km/h.
  3. With configurations above 40km/h - test at 40km/h.
  4. With negative bumper leads - test as for zero bumper lead.
  5. With bumper leads above 400mm - test as for 400mm.



**Figure 26: Angle of upper legform to Bonnet Leading Edge tests with respect to vehicle shape**

Key: A = 0mm bumper lead  
 B = 50mm bumper lead  
 C = 150mm bumper lead

- Notes:
1. Interpolate vertically between curves.
  2. With negative bumper leads - test as for zero bumper lead.
  3. With bumper leads above 150mm - test as for 150mm.
  4. With bonnet leading edge heights above 1050mm - test as for 1050mm.



**Figure 27: Kinetic energy of upper legform to Bonnet Leading Edge tests with respect to vehicle shape**

Key: A = 50mm bumper lead  
 B = 100mm bumper lead  
 C = 150mm bumper lead  
 D = 250mm bumper lead  
 E = 350mm bumper lead

- Notes:
1. Interpolate vertically between curves.
  2. With bumper leads below 50mm - test as for 50mm.
  3. With bumper leads above 350mm - test as for 350mm.
  4. With bonnet leading edge heights above 1050 mm - test as for 1050mm.
  5. With a required kinetic energy above 700J - test at 700J.
  6. With a required kinetic energy below 200J - no test is required.

11.5.4 The total mass of the upper legform impactor includes those propulsion and guidance components which are effectively part of the impactor during the impact, including the extra weights. Calculate the value of the upper legform impactor mass from:

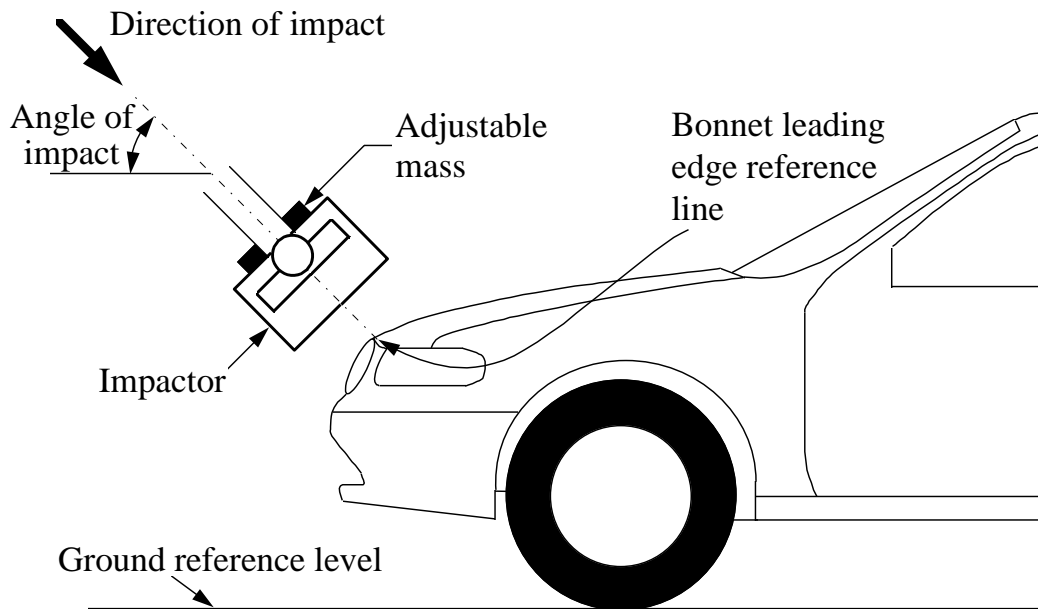
$$M = \frac{2E}{V^2}$$

The upper legform impactor mass may be adjusted from the calculated value by up to  $\pm 10\%$ , provided the required impact velocity is also changed using the above formula to maintain the same impactor kinetic energy.

The influence of gravity on the velocity of the impactor must also be accounted for.

## **11.6 Test procedure - Pre-test**

- 11.6.1 Ensure that the vehicle is fully test prepared as described in Section 1.
- 11.6.2 Ensure the vehicle is at the same ride heights as those recorded during marking up of the vehicle.
- 11.6.3 Ensure that the upper legform, the vehicle, the propulsion system and the data acquisition equipment has soaked in a temperature in the range of  $16^{\circ}\text{C}$  to  $24^{\circ}\text{C}$  for at least 2 hours prior to testing.
- 11.6.4 Fit a new piece of foam to the upper legform impactor from the certified sheet of foam.
- 11.6.5 Apply weights to the back of the upper legform impactor to bring the total mass up to that calculated in Section 11.5.4. Larger weights should first be applied and various smaller weights should then be added to achieve the correct weight. The upper legform impactor mass should be measured to an accuracy of better than  $\pm 1\%$ , and if the measured value differs from the required value then the required velocity should be adjusted to compensate, as specified in 11.5.4.
- 11.6.6 The upper legform impactor shall be aligned such that the centre line of the propulsion system and the longitudinal axis of the impacting upper legform impactor are in the fore and aft vertical plane of the section of the vehicle to be tested. The tolerances to these directions are  $\pm 2^{\circ}$ . At the time of first contact the impactor centre line shall be coincident with the bonnet leading edge reference line with a  $\pm 10\text{mm}$  tolerance, and laterally with the selected impact location with a tolerance of  $\pm 10\text{mm}$ .
- 11.6.7 Adjust the propulsion system to give the correct velocity and angle of incidence at the point of impact with the tolerance on the impact velocity being  $\pm 2\%$ . The effect of gravity shall be taken into account when the impact velocity is obtained from measurements taken before the first point of contact. The velocity measuring device should be able to measure to an accuracy of at least  $\pm 0.02\text{m/s}$ . The effect of gravity shall be taken into account when the impact velocity is obtained from measurements taken before the point of first contact. The tolerance on impact direction  $\pm 2^{\circ}$ .
- 11.6.8 Roll the vehicle forwards to give the desired distance, so that the impactor strikes the vehicle after it has been accelerated to the test speed and so that any end stops on the guidance system do not interfere with its interaction with the vehicle. See Figure 28.
- 11.6.9 Fire the propulsion system.



**Figure 28: Upper Legform to Bonnet Leading Edge Test**

### **11.7 Test Procedure - Post Test**

- 11.7.1 Take at least two still photographs of the resultant dent, one from the side and one from the front. Each photograph shall have some means of identifying the vehicle and test location. The preferred method shall be to use unique run numbers for each test.
- 11.7.2 Additional photographs may be required for an individual test at the Project Managers discretion.
- 11.7.3 Check that no CAC has been exceeded before conducting the next test, if this has occurred then the impactor must be re-certified before the next test.
- 11.7.4 Replace any damaged part of the vehicle which would affect the results of the next test with new parts according to Section 8.3.
- 11.7.5 Repeat procedure for the next impact location.

## 12 HEADFORM TESTING

### 12.1 Description of Headforms and Their Instrumentation

12.1.1 The headforms used shall conform to that specified in Regulation (EC) 78/2009 of the European Parliament and of the Council (14th January 2009) and annexed in Regulation (EC) 631/2009 (22nd July 2009).

12.1.2 The child/small adult impactor to be used is defined in Part V (Test impactors), no. 3 of the Annex of Regulation (EC) 631/2009. The adult impactor to be used is defined in Part V (Test impactors), no. 4 but excluding no. 4.1.1 of the Annex of Regulation (EC) 631/2009.

12.1.3 Instrumentation:

Location	Measurement	CFC	CAC	No of channels
Centre of gravity of headform	Fore/Aft acceleration <sup>4</sup>	1000	500g	1
Centre of gravity of headform	Vertical acceleration	1000	500g	1
Centre of gravity of headform	Lateral acceleration	1000	500g	1

### 12.2 Certification - Dynamic

12.2.1 The certification procedures are detailed in Regulation (EC) 631/2009 (22nd July 2009).

12.2.2 The headforms<sup>6</sup> shall be certified before the test programme.

12.2.3 The headforms<sup>6</sup> shall be certified after a maximum of 20 impacts.

12.2.4 The headforms<sup>6</sup> shall be certified at least once every 12 months regardless of the number of impacts they have undergone.

12.2.5 If the headforms<sup>6</sup> exceed any of their CACs then they shall be re-certified.

### 12.3 Test Procedure - Pre Test

12.3.1 Ensure that the vehicle is fully test prepared as described in Section 1.

12.3.2 Ensure the vehicle is at the same ride heights as those recorded during marking up of the vehicle.

12.3.3 Ensure that the headforms, the vehicle, the propulsion system and the data acquisition equipment have soaked in a temperature in the range of 16°C to 24°C for at least 2 hours prior to testing.

12.3.4 Fit the required headform to the propulsion system. A child/small adult headform impactor shall be used for tests to the forward section of the bonnet top, A-pillars, windscreen, roof (labelled C in Section 3.10), with the test locations lying between boundaries described by wrap around distances of 1000mm and 1500mm. An adult headform impactor shall be used for tests to the rearward section of the bonnet top (labelled A in Section 3.10), with the test locations lying between boundaries described by wrap around distances of 1700 mm and 2100 mm. Where test locations

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<sup>4</sup> Relative to the direction of motion of the headform

<sup>6</sup> Headforms consist of headskins, aluminium sphere and instrumentation



lie between 1500 mm and 1700 mm the structure being tested will determine the headform to be used, see Section 3.8.9.

- 12.3.5 The position of the 'test location' describes the location of the injurious point and will always determine which impactor shall be used; this will also be the case where the injurious point is not coincidental with the point of first contact. For example, between 1500 mm and 1700 mm an injurious point on the windscreen base will be impacted by the adult headform even if the point of first contact is with the rear edge of the bonnet.
- 12.3.6 Roll the vehicle forwards to give the desired free flight distance.
- 12.3.7 Adjust the propulsion system so that it can fire the headform at the injurious point with the correct angle of incidence and is aimed at the impact point.
- 12.3.8 The direction of impact shall be in the fore and aft vertical plane of the section of the vehicle to be tested. The tolerance for this direction is  $\pm 2^\circ$ . The direction of impact of tests to the bonnet top shall be downward and rearward, as if the vehicle were on the ground. The angle of impact for tests with the child/small adult headform impactor shall always be  $50^\circ \pm 2^\circ$  to the Ground Reference Level. For tests with the adult headform impactor the angle of impact shall always be  $65^\circ \pm 2^\circ$  to the Ground Reference Level. The effect of gravity shall be taken into account when the impact angle is obtained from measurements taken before the time of first contact.
- 12.3.9 At the time of first contact, the point of first contact of the headform impactor shall be within a  $\pm 10$ mm tolerance to the selected impact location.
- 12.3.10 Set the speed control on the propulsion system to give a velocity of  $11.1 \pm 0.2$ m/s at the point of first contact. The velocity measuring device should be able to measure to an accuracy of at least  $\pm 0.02$ m/s. The effect of gravity shall be taken into account when the impact velocity is obtained from measurements taken before the point of first contact.
- 12.3.11 Fire the propulsion system.

#### **12.4 Test Procedure - Post Test**

- 12.4.1 Take at least two still photographs of the resultant dent, one from the side and one from the front. Each photograph shall have some means of identifying the vehicle and test location. The preferred method shall be to use unique run numbers for each test.
- 12.4.2 Additional photographs may be required for an individual test at the Project Manager's discretion.
- 12.4.3 Check that no CAC has been exceeded before conducting the next test, if this has occurred then the impactor must be re-certified before the next test.
- 12.4.4 Replace any damaged part of the vehicle which would affect the results of the next test with new parts according to Section 8.3.
- 12.4.5 Repeat procedure for the next impact location.

**Where a specified requirement has not been met, Euro NCAP reserves the right to decide whether or not the test will be considered as valid.**

## 13 INJURY PARAMETERS

### 13.1 General

- 13.1.1 Any breakages or other damage of the body form impactors caused by the severity of the impact shall be recorded.
- 13.1.2 All data channels shall be filtered at their specified Channel Frequency Class.

### 13.2 Limits

- 13.2.1 The table below lists the various pedestrian impactor threshold values related to the defined human injury risk acceptance levels:

Bodyform Impactor	Assessment criterion	Threshold	Method of calculation
Legform	Knee bending angle	15°	see 13.2.2
	Knee shear displacement	6mm	see 13.2.3
	Upper tibia acceleration	150g	Maximum Value
Upper legform	Sum of Impact forces	5kN	See 13.2.4
	Bending moment	300Nm	Maximum Value
Child/Small Adult Headform	Head Injury Criterion	650	See 13.2.5
Adult Headform	Head Injury Criterion	650	See 13.2.5

#### 13.2.2 Calculation of Knee Bending Angle

13.2.2.1 Channel required: rotational transducer in the tibia.

13.2.2.2 The units of radians shall be used in the following formula:

$$\text{Instantaneous Bending Angle} = \theta(t) + \sin^{-1}(1.3678 * \sin \theta(t))$$

where  $\theta(t)$  is the angle that the transducer measures.

Note: The value of 1.3678 in the above equation is the ratio of lengths in the knee. These lengths shall be checked before testing begins

#### 13.2.3 Calculation of Knee Shear displacement

13.2.3.1 Channel required: rotational transducer in the femur

$$\text{Instantaneous Shear Displacement} = \sin \phi(t) \times 27.5$$

13.2.3.2 Units of radians and millimetres are used in the following formula:

where  $\phi(t)$  is the angle that the transducer measures

Note: The value of 27.5 in the above formula is a measured length and shall be checked before any testing begins

13.2.4 Calculation of Sum of Impact forces

13.2.4.1 Channels required: Load transducer at the top of the femur

Load transducer at the bottom of the femur

13.2.4.2 Units of kN are used in the following formula:

$$\text{Instantaneous sum of impact forces } F(t) = F_t(t) + F_b(t)$$

where  $F_t(t)$  is the instantaneous value of the top load transducer

$F_b(t)$  is the instantaneous value of the bottom load transducer

13.2.5 Calculation of the Head Injury Criterion

13.2.5.1 Channels required: Fore/aft acceleration

Vertical acceleration

Lateral acceleration

13.2.5.2 Units of g are used in both of the following formulae

$$\text{Resultant Acceleration } A_R = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

13.2.5.3 Calculate the resultant head acceleration according to:

Where  $A_x$  is the instantaneous acceleration in the Fore/Aft direction

$A_y$  is the instantaneous acceleration in the Vertical direction

$A_z$  is the instantaneous acceleration in the Lateral direction

13.2.5.4 Calculate the Head Injury Criterion (HIC) according to:

$$\text{HIC} = (t_2 - t_1) \left[ \frac{\int_{t_1}^{t_2} A_R \cdot dt}{(t_2 - t_1)} \right]^{2.5}$$

Values for HIC for which the time interval ( $t_2-t_1$ ) is greater than 15 ms are ignored for calculating the maximum value.

## GLOSSARY OF TERMS

**Dynamic pedestrian tests** - Synchronisation of the headform propulsion device and bonnet deployment to achieve correct head impact time.

**Static pedestrian tests** - Test to be carried out without the need to trigger the bonnet in due time. Bonnet is deployed and maintained in place with appropriate systems recommended by vehicle manufacturer.

**Locking devices** - systems that reach and remain in the intended position before head impact.

**Non locking devices** - systems that do not remain in a permanent deployed position or systems that do not reach the intended position before head impact.

**Initiate deployment** - Initiation of deployment means that there must be visible movement of the deployable component, such as the bonnet top. The signal sent from the ECU to the deployable components alone is NOT considered as 'initiation of deployment'.

## REFERENCES

Section 2.2.3.1.4  
Lateral impacts only.

- *Reference: Fredriksson and Rosén, Accident Analysis and Prevention Journal 2010*

## Appendix I

Pedestrian CAE model	Pedestrian Sizes	Level of Biofidelity	References	Notes
<p>Honda Human FE model (Adult)</p> <p>Geometric reconstruction derived from CT/MRI scans (bones, ligaments) - pelvis and lower limb</p> <p>Articulated rigid body for upper body (lumbar and above) - neck and lumbar divided into 7 and 5 segments</p>	<p>Baseline model represent anthropometry close to 50th percentile male; baseline model can be scaled to any sizes of adult population</p>	<p>whole body kinematics (head, T1, T8, pelvis) during an impact against a small sedan and a large SUV at 40 km/h</p>	<p>Small sedan: Kerrigan, J. R., Murphy, D. B., Drinkwater, D. C., Kam, C. Y., Bose, D., Crandall, J. R. : Kinematic Corridors for PMHS Tested in Full-Scale Pedestrian Impact Tests, 19thESV, Paper number 05-0394 (2005)</p> <p>Large SUV: Kerrigan, J. R., Kam, C. Y., Drinkwater, D. C., Murphy, D. B., Bose, D., Ivarsson, J., Crandall, J. R. : Kinematic Comparison of the POLAR-II and PMHS in Pedestrian Impact Tests with a Sport-Utility Vehicle, IRCOBI Conference (2005)</p>	<p>Source of human response data</p>
			<p>Kikuchi, Y., Takahashi, Y., Mori, F. : Full-Scale Validation of a Human FE Model for the Pelvis and Lower Limb of a Pedestrian, SAE World Congress, Paper Number 2008-01-1243 (2008)</p>	<p>Source of validation results</p>
		<p>Dynamic lateral compression of pelvis (Force-deflection at acetabulum and ilium in both acetabulum and iliac loadings)</p>	<p>Salzar, R. S., Genovese, D., Bass, C. R., Bolton, J. R., Guillemot, H., Damon, A. M., Crandall, J. R. : Load Path Distribution within the Pelvic Structure under Lateral Loading, International Crashworthiness Conference (2008)</p>	<p>Source of human response data</p>
			<p>Takahashi, Y., Suzuki, S., Ikeda, M., Gunji, Y. : Investigation on Pedestrian Pelvis Loading Mechanisms Using Finite Element Simulations, IRCOBI Conference (2010) (To be published)</p>	<p>Source of validation results</p>
		<p>Dynamic 3-point bending of lower limb long bones in lateral-medial direction at mid-shaft, distal third and proximal third</p>	<p>Kerrigan J. R., Bhalla K. S., Madeley N. J., Funk J. R., Bose D., Crandall J. R. : Experiments for Establishing Pedestrian-Impact Lower Limb Injury Criteria, SAE Paper #2003-01-0895 (2003)</p>	<p>Source of human response data</p>
			<p>Takahashi, Y., Kikuchi, Y., Mori, F., Konosu, A. : Advanced FE Lower Limb Model for Pedestrians, 18th ESV, Paper number 218 (2003)</p>	<p>Source of validation results</p>
		<p>Dynamic 3-point bending of thigh and leg (with flesh on) in lateral-medial direction at mid-shaft, proximal third (leg only) and distal third</p>	<p>Ivarsson, J., Lessley, D., Kerrigan, J., Bhalla, K., Bose, D., Crandall, J., Kent, R. : Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities, IRCOBI Conference (2004)</p>	<p>Source of human response data</p>
			<p>Kikuchi, Y., Takahashi, Y., Mori, F. : Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb, SAE World Congress, Paper number 2006-01-0683 (2006)</p>	<p>Source of validation results</p>
		<p>Dynamic knee ligament distraction to failure at different loading rates for MCL, LCL, ACL (anterior and posterior parts</p>	<p>Bose D., Sanghavi P., Kerrigan J. R., Madeley N. J., Bhalla K. S., Crandall J. R. : Material Characterization of Ligaments using Non-Contact Strain Measurement and Digitization, International Workshop on Human Subjects for Biomechanical Research, (2002)</p>	<p>Source of human response data</p>

Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
			individually) and PCL (anterior and posterior parts individually)	Takahashi, Y., Kikuchi, Y., Mori, F., Konosu, A. : Advanced FE Lower Limb Model for Pedestrians, 18th ESV, Paper number 218 (2003)	Source of validation results
				Van Dommelen, J. A. W., Ivarsson, B. J., Jolandan, M. M., Millington, S.A., Raut, M., Kerrigan, J.R., Crandall, J.R., Diduch, D.R. : Characterization of the Rate-Dependent Mechanical Properties and Failure of Human Knee Ligament, SAE Paper number 2005-01-0293 (2005)	Source of human response data
				Kikuchi, Y., Takahashi, Y., Mori, F. : Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb, SAE World Congress, Paper number 2006-01-0683 (2006)	Source of validation results
			Dynamic 4-point bending of knee joint in valgus bending	Ivarsson, J., Lessley, D., Kerrigan, J., Bhalla, K., Bose, D., Crandall, J., Kent, R. : Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities, IRCOBI Conference (2004)	Source of human response data
				Kikuchi, Y., Takahashi, Y., Mori, F. : Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb, SAE World Congress, Paper number 2006-01-0683 (2006)	Source of validation results
			General	Takahashi, Y., Kikuchi, Y., Konosu, A., Ishikawa, H., <i>Development and validation of the finite element model for the human lower limb of pedestrians</i> , Stapp Car Crash journal, Vol. 44, 2000-101-SC22 (2000)	
Honda Human FE model (Child)	Geometric reconstruction derived from MRI scans from a 6YO child (whole-body external shape, lower limb bones and ligaments) FE model for thigh and leg; Articulated Rigid Body model for pelvis and above representing freedom of motion of spine Represent child-specific anatomical structures such as cartilaginous layers at ends of long bones	Represent 6YO child anthropometry	Dynamic 3-point bending of child femur and child tibia in lateral-medial direction	Ouyang, J. et al.: <i>Biomechanical Character of Extremity Long Bones in Children and its significance</i> , Chinese Journal of Clinical Anatomy, Vol.21, No.6, p620-p623 (2003), (in Chinese)	Source of human response data
				Ito, O., Okamoto, M., Takahashi, Y., Mori, F. : <i>Validation of an FE Lower Limb Model for a Child Pedestrian by Means of Accident Reconstruction</i> , SAE paper number 2008-01-1240 (2008)	Source of validation results
			Leg fracture prediction validated against CIREN in-depth accident data by means of accident reconstruction	Ito, O., Okamoto, M., Takahashi, Y., Mori, F. : <i>Validation of an FE Lower Limb Model for a Child Pedestrian by Means of Accident Reconstruction</i> , SAE paper number 2008-01-1240 (2008)	Source of validation results

Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
THUMS		AM50, AF05, 6YO	injury parameters are accurately predicted	T. Yasuki and Y. Yamamae, Validation of Kinematics and Lower Extremity Injuries Estimated by Total Human Model for Safety in SUV to Pedestrian Impact Test, Journal of Biomechanical Science and Engineering Vol. 5 (2010) , No. 4 Special Issue on Biomechanics in Cardiovascular Systems T. Maeno et al., Development of a Finite Element Model of the Total Human Model for Safety (THUMS) and Application to Car-Pedestrian Collisions, ESV 2001	Commercially available (AM50) Toyota in-house models (AF05, 6YO)
JLR Human FE model		child, 5th 50th 95th	See references	HOWARD, M., THOMAS, A., KOCH, D. W., WATSON, J. & HARDY, R. (2000) Validation and Application of a Finite Element Pedestrian Humanoid Model for Use in Pedestrian Accident Simulations. IRCOBI. Montpellier, France, IRCOBI. Developments in the simulation of real world car to pedestrian accidents using a pedestrian humanoid finite element model R Hardy, J Watson, M Howard - International Journal of Crashworthiness, 2000. HOWARD, M. S. (2002) Pedestrian Accident Simulation and Protection. Technology Evaluation. School of Engineering. Cranfield University.	JLR in-house model
MADYMO	Details see references, MADYMO Human Models Manual, Version 7.3, TNO Automotive, Delft, The Netherlands, November 2010	3yo, 6yo, 5th F, 50th M, 95th. These models result from a scaleable mid-size male pedestrian model	Details see references, MADYMO Human Models Manual, Version 7.3, TNO Automotive, Delft, The Netherlands, November 2010	MADYMO Human Models Manual, Version 7.3, TNO Automotive, Delft, The Netherlands, November 2010.	Commercially available
IEE-WPI FE Model	Up-right pedestrian model based on WPI study with following improvements 1. introduction of upper body masses represented by rigid bodies 2. more detailed knee modelling (a. ligaments b. non-linear and strain-rate dependent material laws with appropriate failure criteria	50% male available. 5% female and 6 year old child under development	Model aims at a humanlike interaction with the vehicle bumper and therefore has: - hip- / knee-joint mechanics (ligaments) - tissue / ligament / bone sub-structure - correct anthropometric proportions Rigid-body model validation according to Madymo (c.f. J.van Hoof)	C. Silvestri - Development and validation of a knee-thigh-hip LS-DYNA model of a 50th percentile male PhD Thesis, Worcester Polytechnic Institute, April 2008  C. Silvestri, M. H. Ray - Development of a Finite Element Model of the Knee-Thigh-Hip of a 50th Percentile Male including Ligaments and Muscles, International Journal of Crashworthiness, Vol. 14, No. 2, pp: 215-229, 2009  FE-based pedestrian modelling to simulate the collision process with a car front-end	IEE in-house model

Pedestrian CAE model	Pedestrian Sizes	Level of Biofidelity	References	Notes
c. introduction of a simplified knee capsule 3. femur and tibia soft tissue material 4. femur meshed with shell elements		FE-model validation according to - J. Kajzer et al - J.R. Kerrigan et al - J.A.W. van Dommelen et al	Dr. Wener Bieck (IEE S.A.) 5. pedestrian protection conference, July 2010 (by Carhs & BGS)	
PAMCRASH	3yo, 6yo, 5th F, 50th M, 95th. These models result from a scaleable mid-size male pedestrian model	model aims to replace Madymo-Multi-Body-Model in case of whole body kinematics and Head contact times (uses the same biomechanical validation corridors as Madymo-models)	1. Teng T., 2008, "Development and validation of a pedestrian deformable finite element model", Journal of Mechanical Science and Technology 23 (2009) 2. Coley G., "Pedestrian Human Body Validation Using Detailed Real-World Accidents", Paper, Ircobi Conference 3. Ishikawa H., 1993, "Computer Simulation of Impact Response of the Human Body in Car-Pedestrian Accidents", SAE Technical Paper 933129 4. SAE Proposal J2782, 2007, "Performance Specifications for a 50th Percentile Male Pedestrian Research Dummy"	currently in development for PAMCRASH-user to reduce simulation time
JAMA Human FE Model	Coupling of the upper body from THUMSTM(Ver.1.4) and the lower body from H-modelTM based Honda Human Pedestrian Model Modifications were made to improve biofidelity and computational stability.	Baseline model represent anthropometry close to 50th percentile male; baseline model can be scaled to any sizes of adult population	whole body kinematics (head, thoracic and lumbar spines, femur, tibia and foot) during an impact against four types of vehicles (minicar, sedan, SUV and minivan), only one trajectory of which is published Injuries not yet satisfactorily reproduced  Sugimoto, T., Yamazaki, K., First Results from the JAMA Human Body Model Project, 19th ESV Conference, Paper Number 05-0291 (2005) Kamiji, K., Yamazaki, K., Development of Finite Element Model of Human to Reduce Injuries in Traffic Accidents, Journal of Society of Automotive Engineers of Japan 62(5), pp. 34-39 (2008) (in Japanese)	Overview  Source of validation results