EEVC Research in the Field of Developing a European Interior Headform Test Procedure

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ABSTRACT

The European Enhanced Vehicle-safety Committee (EEVC) Working Group 13 for Side Impact Protection has been developing an Interior Headform Test Procedure to complement the full scale Side Impact Test Procedure for Europe and for the proposed IHRA test procedures. In real world accidents interior head contacts with severe head injuries still occur, which are not always observed in standard side impact tests with dummies. Thus a means is needed to encourage further progress in head protection. At the 2003 ESV-Conference EEVC Working Group 13 reported the results on Interior Headform Testing. Further research has been performed since and the test procedure has been improved. This paper gives an overview of its latest status. The paper presents new aspects which are included in the latest test procedure and the research work leading to these enhancements. One topic of improvement is the definition of the Free Motion Headform (FMH) impactor alignment procedure to provide guidelines to minimise excessive headform chin contact and to minimise potential variability. Research activities have also been carried out on the definition of reasonable approach head angles to avoid unrealistic test conditions. Further considerations have been given to the evaluation of head airbags, their potential benefits and a means of ensuring protection for occupants regardless of seating position and sitting height.
The paper presents the research activities that have been made since the last ESV Conference in 2003 and the final proposal of the EEVC Headform Test Procedure.

INTRODUCTION

Beside the frontal crash the side crash is the most common crash causing severe injuries. The side impact is loading various body parts. The intruding car structure hits the occupant and can cause severe injuries. In side impact tests in laboratories direct contacts mainly occur with the torso of the dummy. Accident analyses have shown that in real world crashes also head contacts occur with the interior structure of cars. These are only very rarely observed in side impact tests according to European Regulation ECE-R95.

One reason is that real world accidents occur in various impact configurations, which cannot be represented in only one test. To overcome this deficiency in Type Approval evaluations, EEVC WG13 was tasked by the EEVC Steering Committee to develop an Interior Headform Test Procedure for Europe. There already exists a test procedure for head contacts in the interior of cars in the USA (FMVSS 201). The European proposal includes latest research results, in order to obtain a modern test procedure.

It was planned to proceed in four phases to develop this Interior Headform Test Procedure, starting with the selection of the headform impactor. At this time the FMH (Free Motion Headform) was also used in FMVSS 201. No significant advantages were identified in selecting either of the three impactors available. The US FMH, was selected as it was already in use in FMVSS 201. This was presented at ESV 1996. Current research suggests that the use of a symmetrical headform may have a number of advantages in simplifying the procedure and improving test reproducibility. WG13 is not currently in a position to make such a decission and the test procedure still uses the FMVSS 201 headform.

Following the second phase of the research it was decided to specify a non guided / free flight headform impactor. This was presented at the 16th ESV Conference.

After the decision of the impactor type and test method correlation between EuroSID and FMH responses were analysed, resulting in a formula to calculate HIC FMH to HIC EuroSID. Additionally an accident analysis study for side impact crashes was made to identify potential head impact areas. This was presented as result of phase three at the ESV 2001.

A first draft test procedure was developed and its feasibility, reproducibility and repeatability was checked. Several tests in different European and World cars were performed by TRL, TNO, Volvo and BASt. This was published at ESV 2003.

The experience obtained in these tests lead to several further investigations to optimise the test procedure. In the following paragraphs the major investigations and most important changes to the draft test protocol version of ESV 2003 are presented.

DEFINITION OF CLEAN CONTACT AND HEAD ALIGNMENT

It was observed in many cases, that the FMH contacted the interior structure twice, firstly with the calibrated zone (see figure 1) and secondly with the nose or chin part. To avoid or minimise the risk and severity of contact with an uncalibrated area a “clean contact” had to be defined (figure 2)

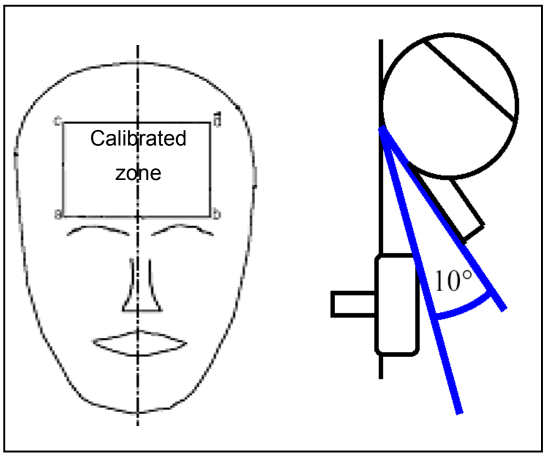
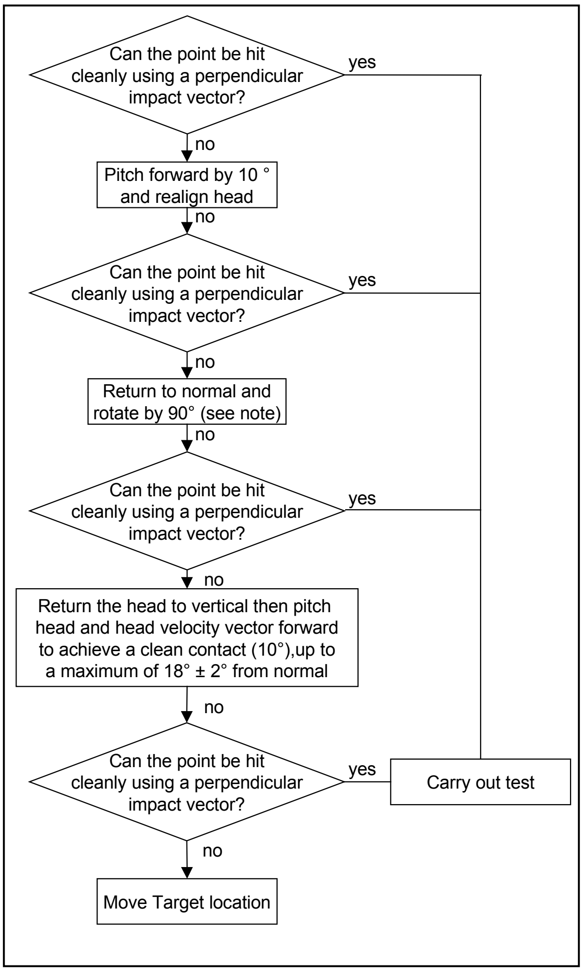


Figure 1: Calibrated zone of FMH

The former draft test procedure proposed to turn the head by up to ± 90°. With the possibility to turn the head to any angle between 0° and 90° the definition could be interpreted in several different ways.

As a result the following flow chart was developed to minimise problems of misinterpretation.
This flowchart was checked by TNO and BASt by aligning FMHs in several cars. Most of the head alignments in same cars at same targets where identical.
Another possibility is to reduce the flow chart in figure 2 by excluding the 90° rotation steps. At this point of time WG13 is not in a position to recommend one as being better than the other.



note: Clarification note on headfrom rotation
FMH axial rotation about the impact vector facing towards the target point.

Target area	Left hand side of the vehicle	Right hand side of the vehicle
A post target points	90° clockwise	90° anticlockwise
Roof rail target points	90° clockwise	90° anticlockwise
B post target points	90° anticlockwise	90° clockwise

Figure 2: Flow chart to obtain “clean contact”

The two proposed possibilities to obtain “clean contact” are more detailed shown in ANNEX A.

Even with this proposed methodology it is possible that secondary impact could still occur. One possibility to minimise further secondary impacts would be to eliminate the flow chart avoiding different interpretations, by the use of a symmetrical impactor as currently used for pedestrian testing in Europe. This has not been investigated further and can not yet be recommended by WG13

NON FRONT SEATING POSITION

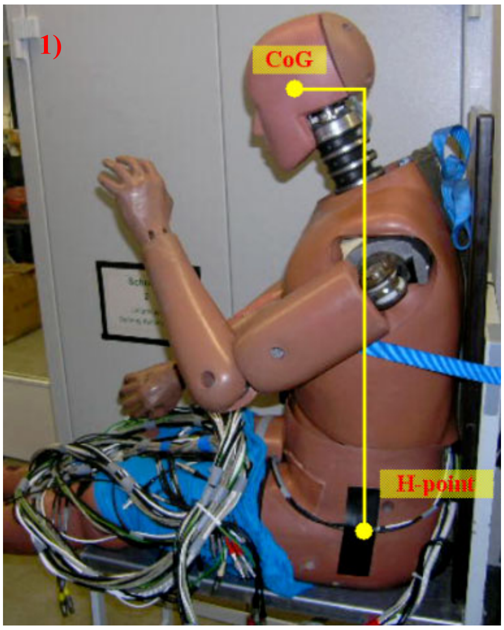
The initial WG13 research focused on frontal seating positions. To contribute a proposal for IHRA (International Harmonisation Research Activities) SIWG (Side Impact Working Group) the test procedure was extended to cover "non front seating positions".

The testing zone for the front seating position was limited to a zone constructed from the CoGs (Centre of Gravity) of a large male in the most rearward and a small female in the most forward seating position.

The procedure to define a limitation zone for the rear seating positions was changed due to different types of seats since rear seats are not usually adjustable at the seat back. Therefore the position of the CoG of different sized occupants could be more easily defined.

Figure 3 explains the procedure:

1) The dimensions from the H-point to the CoG for 5th female and 95th male are known.
2) The torso angle can be determined by the H-point-manikin.
3) The position of the CoGs can now be defined in the car.
4) The four limitation planes are constructed in the car (marked green in figure 3).



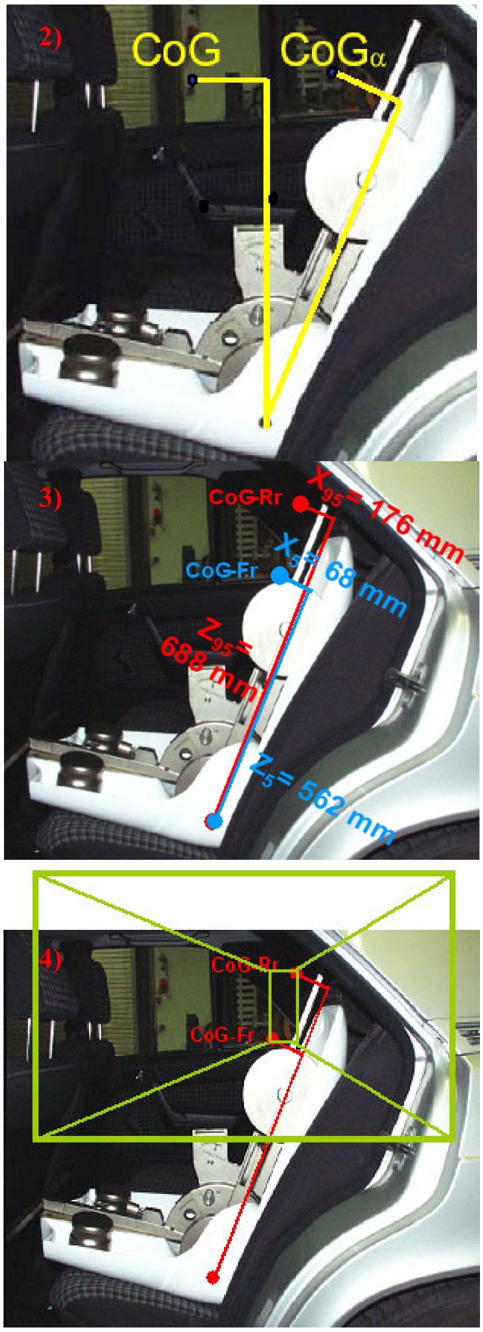


Figure 3: Construction of testing limitation zone for rear seating position

The planes are constructed through the CoGs at the same angles as for the front seating position (see figure 4)

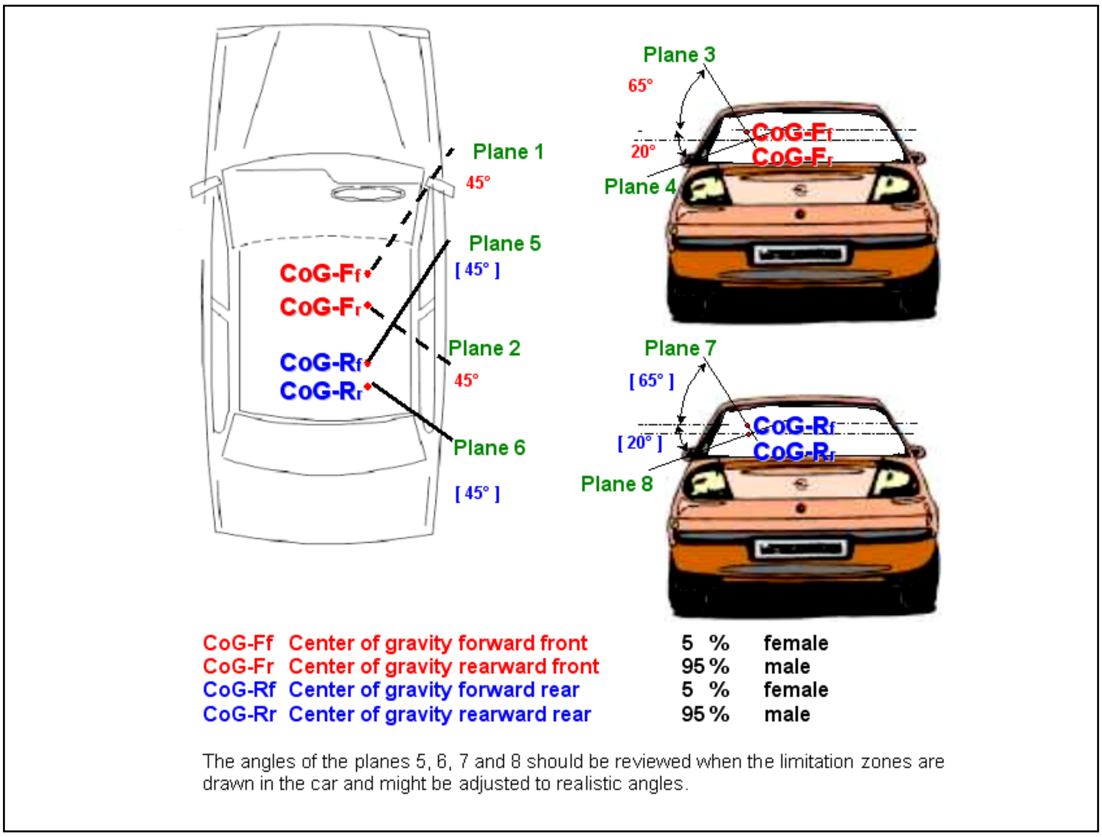


Figure 4: Planes for limitation zone

The interior testing zone is limited by the yellow line. The areas outside this line are excluded from testing.


Figure 5: Limitation zone in the car

These zones and the methodology to create them will need to be validated in broader based programmes, e.g. the European APROSYS project.

ADDITIONAL TARGET LIMITATION POSITIONS

In addition to the mentioned limitation zones further limitations are necessary since several of the surfaces and possible targets in the limitation window cannot be reached because of the shape of the vehicles interior. It is proposed that any surface within 165 mm of a glazed surface should be excluded form evaluation. This is diagrammatically shown by the application of a sphere of 165 mm diameter in figure 6.

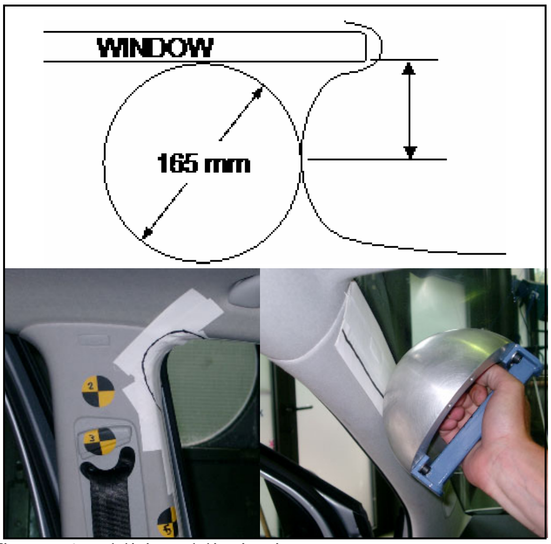


figure 6: additional limitation zone

BENEFIT OF HEAD AIRBAGS

a) Tests outside the car / basic tests

The former test procedure presented at ESV 2003 already included a part dealing with reduction of test velocity due to airbag installation covering the mounting area around the stowed head airbag. The test velocity being 5.3 m/s instead of 6.7 m/s.

WG13 believe that active head protection systems can offer many benefits and should be encouraged as they can give additional head protection. It therefore seems reasonable to enlarge the exception zone to all areas that are adequately protected by head airbag systems, only requiring lower velocity testing to the covered areas. An investigation into methods of evaluating airbags and encourage appropriate performance has been carried out by BASt, within WG13. More details of the BASt study are presented in Appendix 1.

First of all it was analysed whether these tests should be performed on a permanently inflated airbag or a fired airbag. Tests have shown that the variability in performance is marginal if the static pressure is the same as in the fired airbag at the moment of head contact. The adequate airbag pressure (about 0,5 bar) of the different airbags was provided by the airbag manufactures.

Basic tests were made on different designs of head airbags to analyse the different airbag characteristics. All tested airbags and all tested points are shown in figure 7.

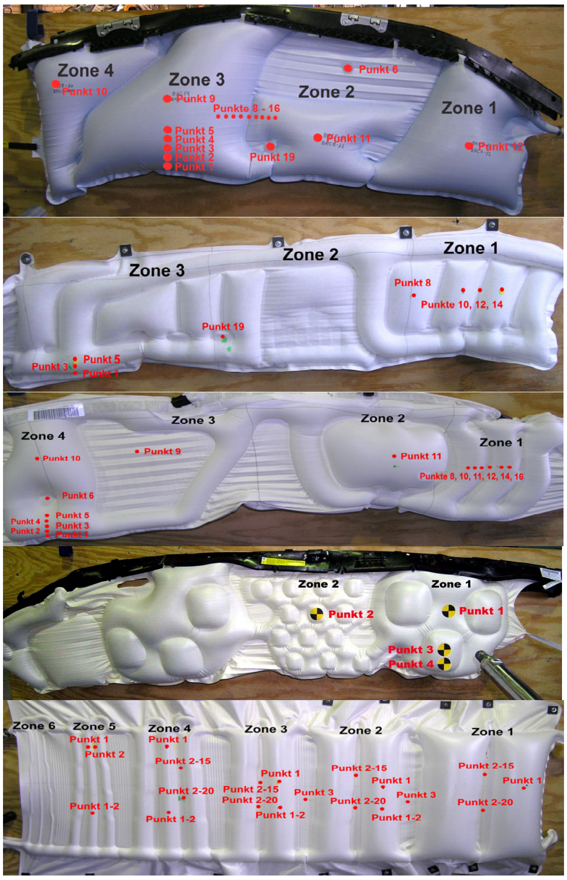


Figure 7: Tested airbags and target points

To eliminate the influence of the vehicle structure behind the bag the airbags were mounted on a homogeneous plate. Therefore a rigid wooden plate was fixed on a rigid steel wall (figure 8). In the research testing in some cases additional foam was attached to the plate, to reduce the HIC to an appropriate level.

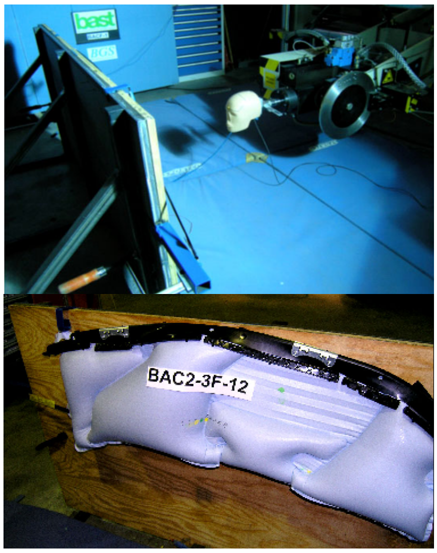


Figure 8: Test set-up – rigid wall

First of all the influence of the impact direction on the airbag was investigated. Figure 9 shows that the influence of the impact direction is marginal, within the range of angles tested, as long as the impactor does not strike through the airbag.

HIC	294 (max)	280	286	276 (min)
Angle	0°	15°	30°	45°

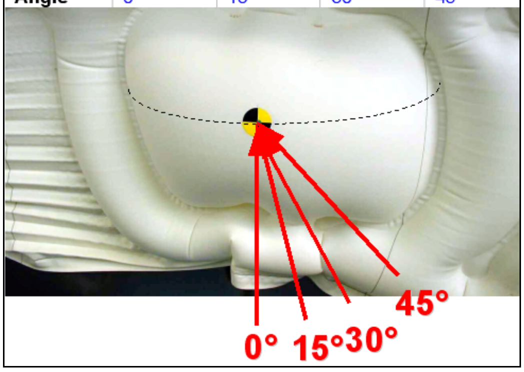


Figure 9: Different impact angles on airbag

To simplify the test procedure into an airbag, it was decided to test perpendicular to the surface below the airbag. The results on the inflated airbags are significant lower than in the tests without inflated airbags on the homogenous plate.
The following figure 10 shows an example of a test on the plate compared to tests on different cushions. The red values are tested with the head at 0° and the yellow values at 10° pitch (see clean contact definition) of the head and velocity vector.

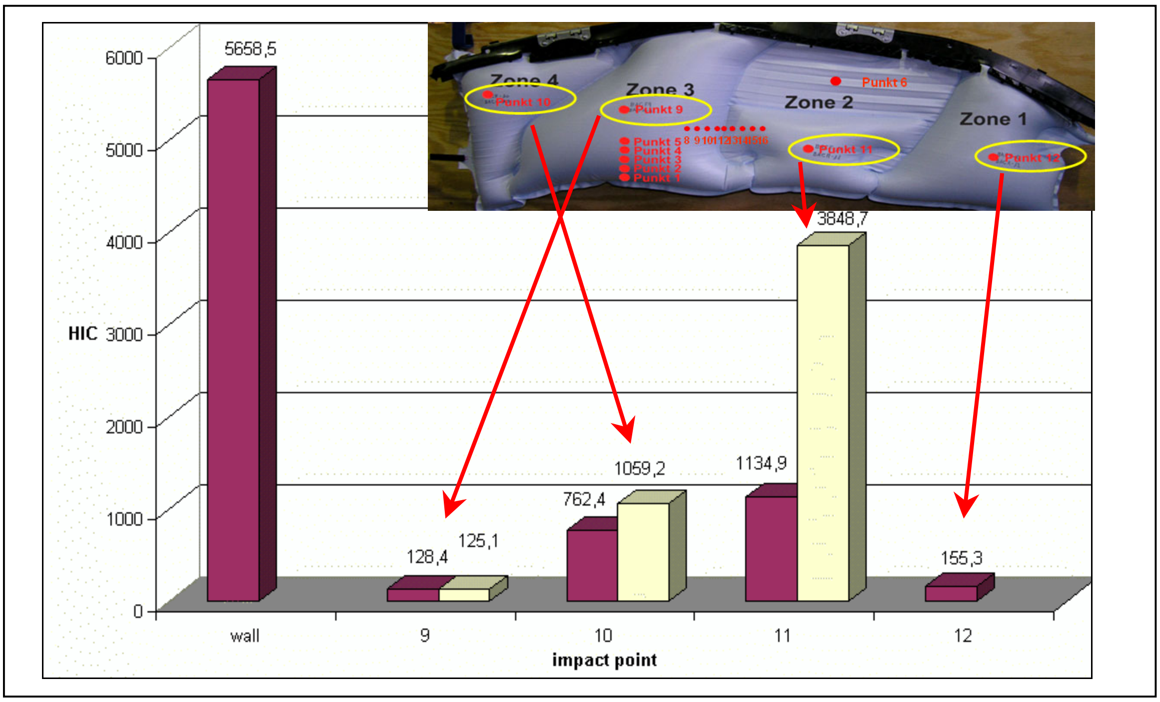


Figure 10: Protection level of different cushions

The critical areas of the airbag where evaluated as indicated in figure 11

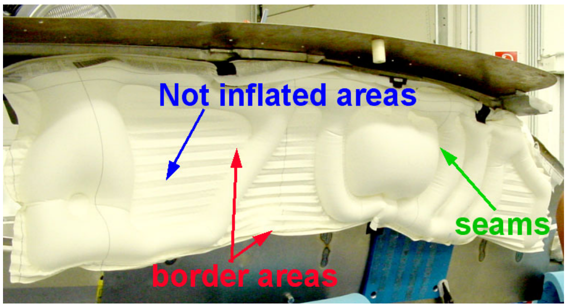


Figure 11: Critical airbag areas

The airbag procedure has been incorporated in the draft EEVC procedure.

- The car would first have to pass a pole test to ensure head airbag triggering.
- The manufacturer has to provide a drawing of areas where the airbag would give the correct level of protection, for example green for adequate protection and red for inadequate protection (see figure 12 and 13)

Figure 12: Marked protection level on airbag

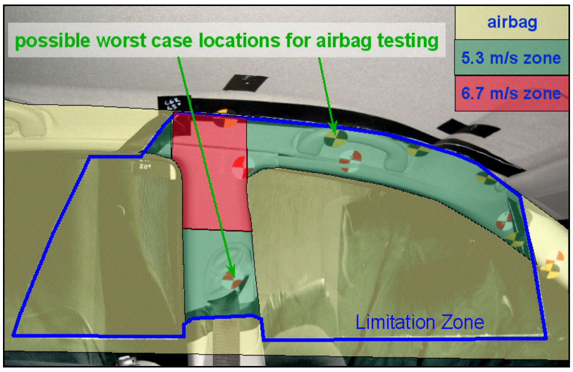


Figure 13: Marked protection level of an airbag on the interior surface

- According to the marked zones the interior structure will be tested at 6.7 m/s in red areas and 5.3 m/s in green areas, without inflated airbag.
- To check whether the determination of the airbag areas in green and red zones is adequate, a minimum of two worst case tests would have to be performed in the green zones on an inflated airbag at 6.7 m/s, in the car. The manufacturer would have to provide information on deployment test pressures and prove compliance.
- The HIC has to be below 1000 in all these tests.

The complete head airbag test proceeding is summarised in the following figure.

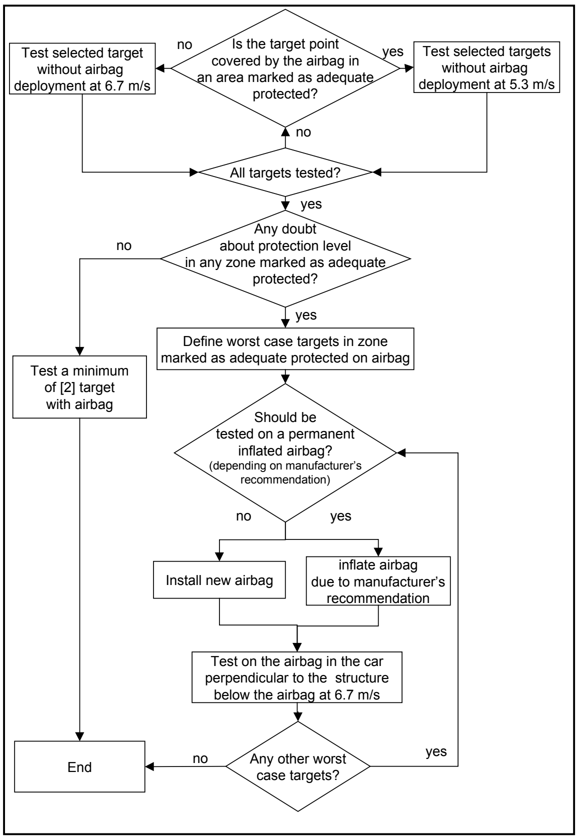


Figure 14: Flow chart for testing with head airbag tests systems

The airbag test procedure is already included in the latest version of the EEVC WG 13 test procedure for interior headform testing.

HEAD IMPACT ANGLE

TNO have carried out a modelling study to investigate reasonable impact directions in side impacts. The testing protocol requires testing of target points perpendicular to the surface structure as worst case direction. It is noted that in some cases this might lead to testing alignments which are very unrealistic compared to real world accidents. Limitation angles had been given in the test procedure, but no closer investigation had been made before the study of TNO to determine impact angles.

Various accident scenarios have been taken into account. More details of this study are given in APPENDIX 2.

Transferred to a general co-ordinate system of a car, this study proposes the following angles:

- **50° < horizontal angle < 115°**
- **-12° < vertical angle < 18°**

The EEVC headform test procedure currently indicates the angles as defined in figure 15, but it does mention the results of the TNO study. It is not yet decided which angles should be recommended in a final European test procedure. The EEVC WG13 test procedure is suggesting that the impact limitation angles should be limited to those shown in Figure 15. In a broader based practical analyse of the test procedure these angles should be examined and verified. This will be done in the European APROSYS project and other evaluation programs.

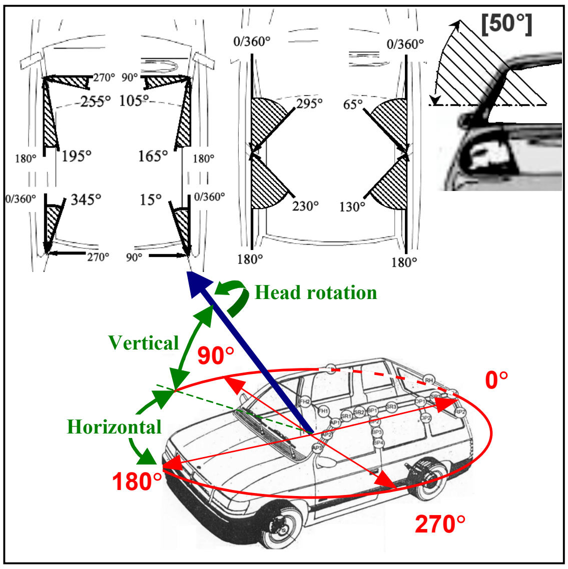


Figure 15: Additional limitation angles co-ordinate system

CONCLUSIONS

It is the aim of EEVC WG 13 to create a robust test procedure that would lead to reduction in injury in real life accidents to all statures of occupant, sitting in realistic seating positions. On one hand the procedure has to test nearly all injury causing possibilities but on the other hand it has to eliminate unrealistic or extreme unlikely tests, without imposing an unmanageable burden on test authorities and vehicle manufacturers.

Repeatability must be ensured in any test procedure that could be used in an approval process. It is also advisable to have a procedure that does not encourage 'single point' optimisation. This means that worst case target point selection should be encouraged and will be the task of the test house, with sound supporting guidance. In addition head alignment should be the same in all test laboratories.

The EEVC WG13 protocol has changed since the last ESV paper in 2003, due the WG13 members research investigations to improve the repeatability of the procedure. A better definition of head alignment has been included to eliminate unrealistic testing conditions.

The test procedure has been extended to evaluate head airbag systems and give credit to manufactures who fit such systems, by reducing the severity of the test to areas of the vehicle that are covered by an appropriate head airbag. Such areas being tested at a lower velocity due to reduced injury risk when undeployed.

The draft test procedure is now at a high stage of maturity.

The procedure will need to be revised further following more extensive evaluations as it includes some alternative testing strategies.

WG13 is of the opinion that it is now at a stage whereby it can be evaluated by the boarder research community.

RECOMMENDATIONS

Further improvements in repeatability and more realistic kinematics may be possible with the use of a symmetrical headform. Head alignment steps as presented in figure 2 would be reduced to a minimum and contacts with uncalibrated zones eliminated. Unrealistic dynamic head rotation would be minimised since the CoG of the test device would be aligned with the target point. Harmonisation in headform impactors in Europe could be achieved if the same impactor were to be adopted, as for pedestrian testing. No tests have been performed in cars with such a test device. Further investigations need to be performed if a symmetrical headform would be preferred to ensure that other unforeseen problems were not introduced. It is noted that a new headform would mean two different test devices for Europe and the United State.

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EEVC WG13 members are:
A K Roberts TRL (Chairman); J Ellway United Kingdom TRL (Secretary); R W Lowne TRL (former Chairman, retired); S Southgate Ford; L Martinez Spain INSIA; G Antonetti Italy Fiat; J-P Lepretre France UTAC; J Faure Renault; D Pouget Renault (retired end of 2004); M van Ratingen TNO The Netherlands; T Versmissen TNO; T Langner Germany BASt; C Müller DaimlerChrysler

APPENDIX 1 Airbag Testing (BASt studies)

Investigations of border areas

An important aspect was the protection level at the border areas of an airbag. All the airbags of figure 7 were tested. Figure A1.1 shows a border marked by the dotted line.

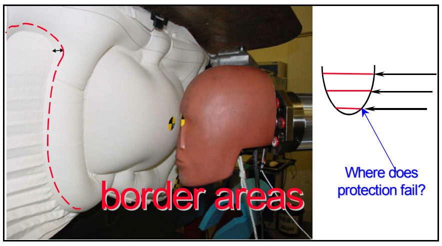


Figure A1.1: Border areas at airbags

An example for border area testing is given in figure A1.2. The result was that at the outer parts of the airbag protection is still provided. It was tested with two different head alignments: 0° (blue) to the horizontal plane and 10° (red) referring to the clean contact definition.

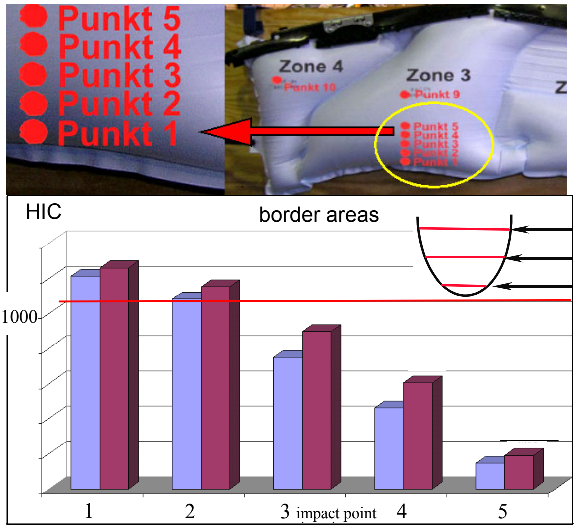


Figure A1.2: Protection level of border areas

Compared to the HIC of about 6000 in figure 10 the HIC values of less then 1300 at the lowest point 1 is quite moderate.

Investigations of seams

Head airbags are made of several airbag cushions to create an adequate shape. Therefore airbags have seams with an airbag thickness of 0 mm (see figure A1.3)

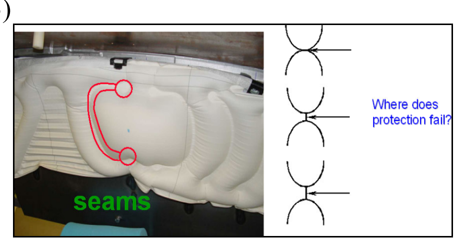


Figure A1.3: Seams at airbags

The questions were: What is the influence of these seams? Is this an area without protection? Several tests have been performed on all airbags of figure 7. Testing was done step by step from one cushion to another cushion by crossing the seam. An example is shown in figure A1.4 testing from a big cushion to a small cushion.
It is surprising that the value of point 12 at the seam with a thickness of 0 mm is still low. The location of the seams cannot be identified by the diagram. The HIC value is rising almost linear.

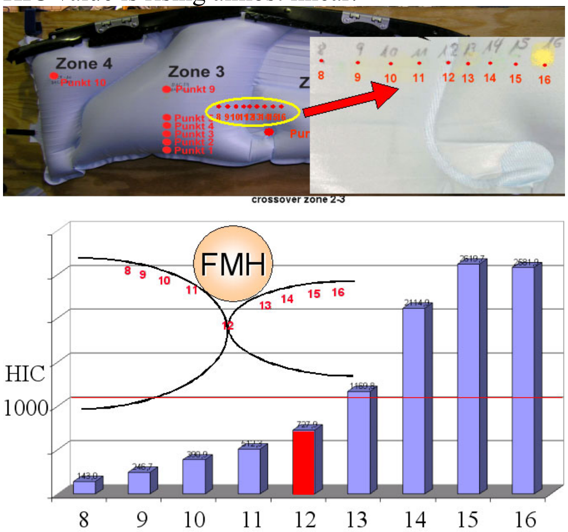


Figure A1.4: Protection level at seams

The explanation for this is: When shooting at the seam, the kinetic energy of the FMH is absorbed by the two bordering cushions (see figure A1.5)

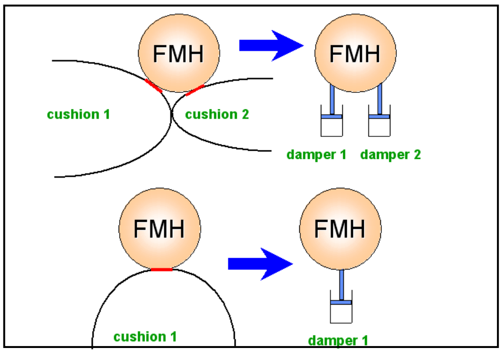


Figure A1.5: Damping effect of cushions

Nevertheless it is possible to avoid 0 mm thickness at airbag cushions. A new weaving technique with multi layer is used in some modern cars (see figure A1.6).

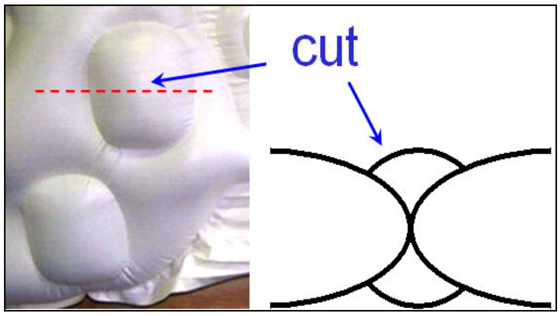


Figure A1.6: Multi layer weaving technique airbag

Special airbag

Further investigations were made of the above mentioned characteristics: cushion thickness and seams. A special woven airbag as shown in figure A1.7 was produced. Here the geometric characteristics could be tested completely isolated in the most comparable way. As shown in figure A1.7 the thickness of the cushion rises from left with Ø 10 mm to right with Ø 150 mm and the seam width from top to bottom from 5 mm to 20 mm.

Influence of airbag thickness at special airbag

First it was investigated whether there is a critical airbag thickness by testing the marked points on the airbag in figure A1.8.

Tests from zone 1 to zone 5 were performed. Point 1 is always the point at the top. Point 1-2 is always at the lower part of each cushion. The thickness is always the same for point 1 and 1-2 on the same cushion. Only the seam width between the cushions is 5 mm for point 1 and 20 mm for point 1-2.

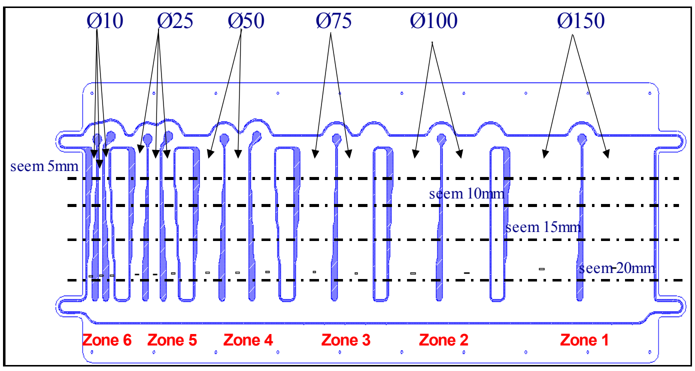


Figure A1.7: Special airbag

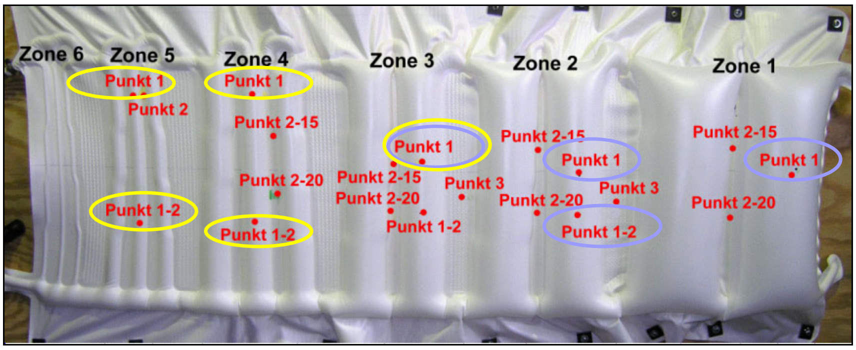


Figure A1.8: Tested points on cushions

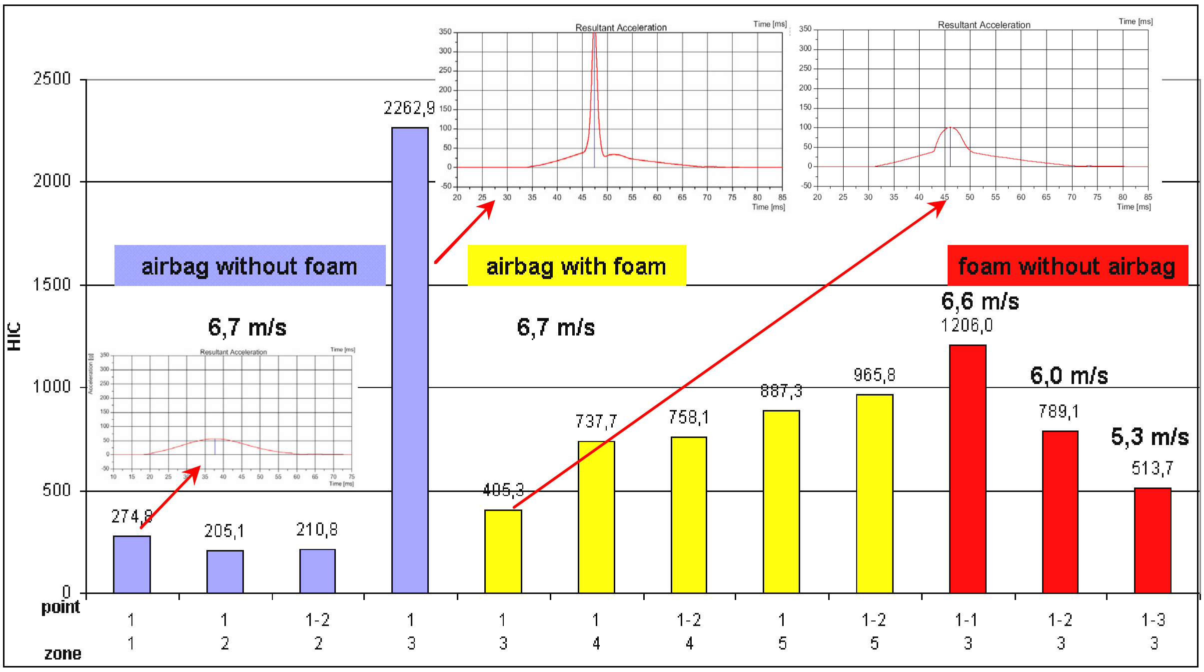


Figure A1.9: Results of cushions testing

The results in zone 1 and 2 show that the airbag thickness has no influence as long as the impactor does not strike through the cushion. The reason is that the kinetic energy was completely absorbed by the cushion. At point 1 in zone 3 the impactor starts to strike through. The critical airbag thickness is under-run. This is visible in the sudden peak in the acceleration curve in figure A1.9. To reduce HICs to an adequate level, further investigations were made with foam underneath the airbag (foam as used in pedestrian testing). Therefore the bars in figure A1.9 are coloured blue when testing without foam and yellow when testing with foam.
After retesting this point with foam underneath, the sudden peak is still visible but is moderated. Further tests from zone 3 to zone 5 show: The thinner the cushion is, the less kinetic energy is absorbed before hitting the structure underneath the airbag.

This study investigated the influence of the thickness completely isolated from any other airbag characteristics. Nevertheless it is impossible to define a certain thickness value where protection fails. There are several other important factors to be taken into account: Volume and air permeability of the cushion, pressure, number of overflow canals, shape and the kind of cushions connected to the tested cushion. Additionally low protection level may be sufficient for a soft structure underneath.

Influence of seam width at special airbag
Now the influence of seams between cushions was investigated.
It was tested from zone 1 to zone 5 at the marked points in figure A1.10, again with foam under the airbag (yellow) and without foam under the airbag (blue).
Only the size of the seams is changing in one zone from top to bottom, indicated by the prefix -15 and -20.
As assumed, the results from zone 1 and 2 are almost identical because the kinetic energy of the head is completely absorbed by the airbag. Therefore it does not make much of a difference if the seam is wide or narrow in this case. In zone 3 the FMH begins to strike through. From here onwards the width of the seams has an influence as shown by point 2-15 and 2-20 in zone 3.

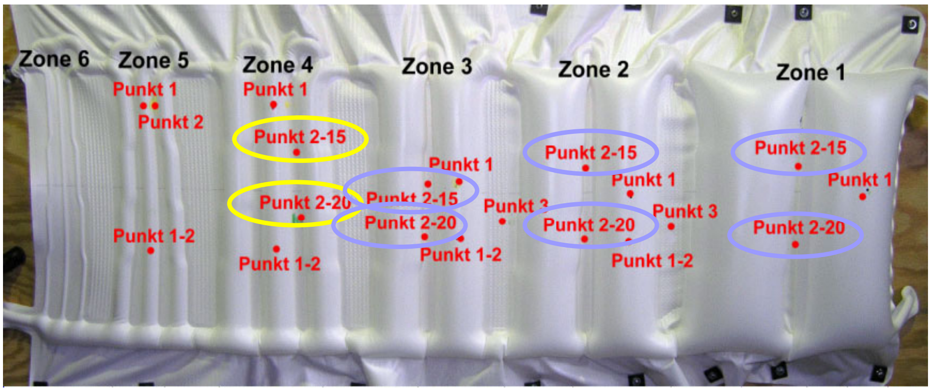


Figure A1.10: Tested points on seems

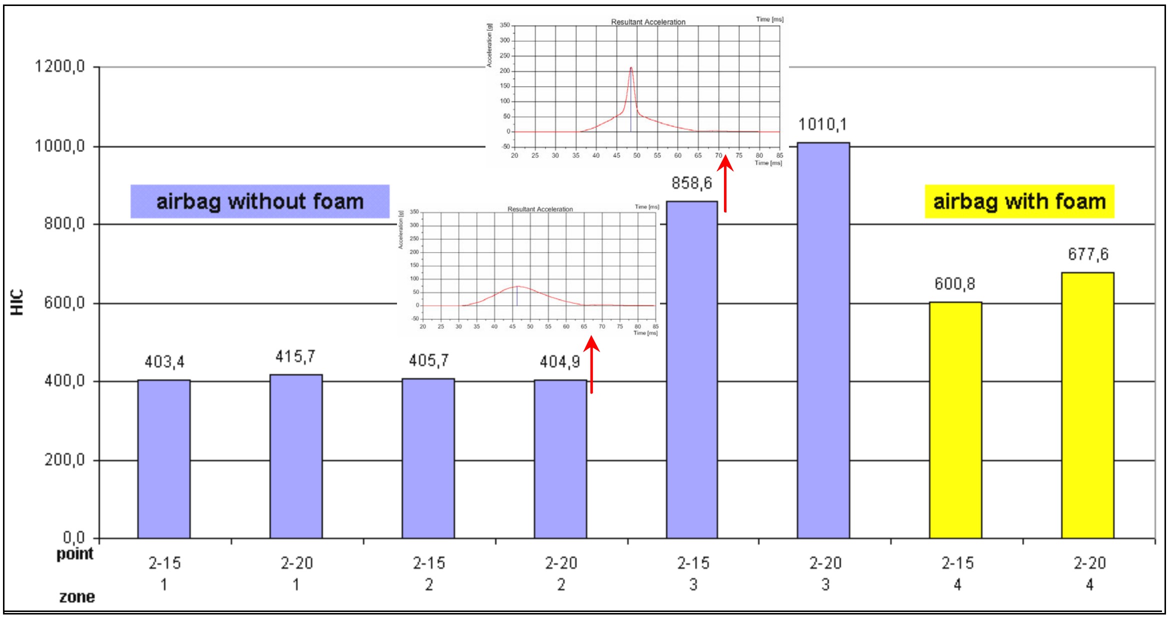


Figure A1.11: Results of seem testing

Looking at figure A1.9 and figure A1.11 it is extremely surprising that the HIC values are higher for zone 1 and zone 2 and lower at zone 3 and 4; tests at seams compared to the cushion values. This indicates that in thin areas where the impactor strikes through, seams offer a better protection than the cushion. The answer is already given in figure A1.5. When shooting at seams the impactor contacts two cushions and is therefore decelerated more effectively.
This means that more energy is absorbed at seams at the same intrusion distance than at cushions.
Result: As long as the impactor does not strike through, the higher deceleration capability of the two cushions leads to higher HICs. In this case the lower deceleration capability with one cushion leads to lower HICs. But more interesting is what happens when the impactor strikes through. The higher deceleration capability by two cushions can absorb more energy before striking on the underlying structure. With only one cushion the HIC value will now be higher because the impactor is hitting the underlying structure with a higher velocity than with two cushion protection.
This should not imply in general that seams are safer than cushions. It always depends on seam width, shape, volume, radius of the bordering cushions etc.
It is been shown that head airbags offer a very good level of protection for head contacts.

Tests inside the car

In this test phase it was analysed how to give benefit to head airbag systems in an “interior headform test procedure”.
Originally the idea was to test the car interior at 6.7 m/s with an exception zone of 5.3 m/s tests, in the area where the head airbag is stored. It is reasonable to enlarge that exception zone to all areas where the head airbag provides adequate protection. This motivates the manufacturers to improve their airbags.
To analyse the effect of airbags in cars, several points on the B-pillar in two different cars where

investigated. Three different test scenarios were analysed:

1) without inflated airbag -> 5,3 m/s
2) without inflated airbag -> 6,7 m/s
3) with inflated airbag -> 6,7 m/s

A typical result is shown in figure A1.12.

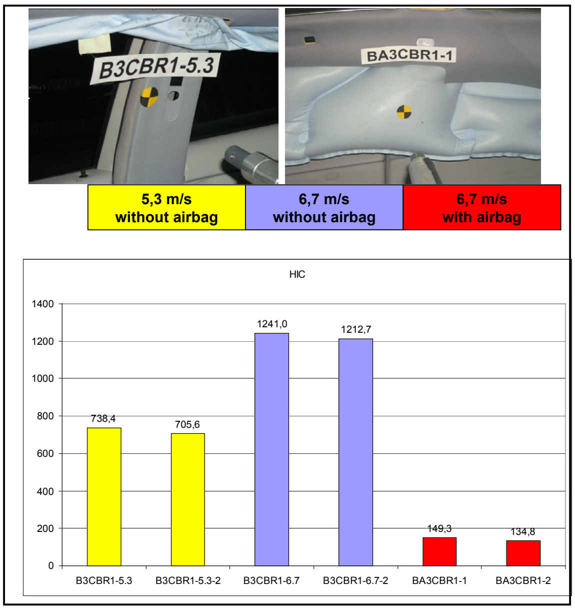


Figure A1.12: Comparison of testing at different velocities and different protections

In some cases the results with 5,3 m/s testing directly on the interior structure were higher than the results with 6.7 m/s testing on the airbag above the interior structure and vice versa, depending on the tested airbag thickness.
Nevertheless again it shows that head airbags can provide a high level of protection.
It should be mentioned that in most tests the airbags were not mounted in their designed positions, because current head airbags are often not equipped with cushions at the B-pillar. The thickest cushion is usually at the position where the pole hits the car in a pole crash according FMVSS 201. Therefore the head airbags have been mounted further backwards.
A procedure which gives benefit to head airbags providing an adequate protection, would lead to a better level of protection in the majority of cars.

APPENDIX 2 Impact Angles (TNO studies)

In the TNO study of impact angles in side impacts various accident scenarios were taken into account. The size of cars is responsible for different kinematics and therefore for different severity of accidents. As first scenario a heavy bullet vehicle (Honda Accord) against a relatively light target vehicle (Chrysler Neon) was selected. The second scenario was performed with two heavy vehicles, Honda Accord against Ford Taurus. For mass and size information see figure A2.1.

Model	Category	Test mass [kg]	Length [m]	Width [m]
Chrysler Neon	Medium size	1381	4.36	1.71
Honda Accord	Medium Family car	1636	5.06	1.90
Ford Taurus	Large	1776	5.07	1.86

Figure A2.1: Mass and size information

Additionally different seating positions and occupant sizes were taken into account as described in figure A2.2.

	Target vehicle	Occupant	Initial occupant position
1	NEON	5th percentile female HBM	Normal (fully forward)
2	NEON	95th percentile male HBM	Normal (fully rearward)
3	NEON	50th percentile male HBM	Normal (mid)
4	NEON	50th percentile male ES-2 dummy	Normal (mid)
5	NEON	5th percentile female HBM	Fully rearward *
6	NEON	50th percentile male HBM	Focus on side rail **
7	TAURUS	5th percentile female HBM	Fully rearward *
8	TAURUS	95th percentile male HBM	Normal (fully rearward)

* such that there is highest likelihood of contact with B-pillar (representing a passenger).
** such that there is highest likelihood contact with roof rail.

Figure A2.2: Different seating positions and occupant sizes

Impact angles from 30° to 120° and various impact location at 50 km/h were taken into account (see figure A2.3).

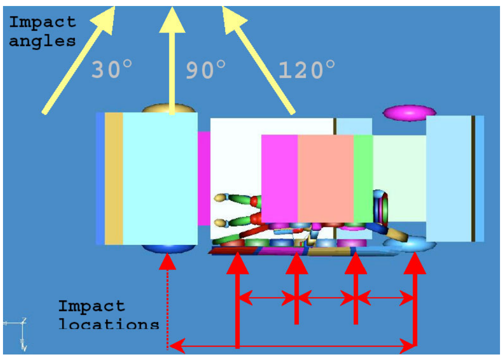


Figure A2.3: Angles and impact locations (top view)

For virtual testing the MADYMO human body occupant model was used because it is more biofidelic than dummy models.

To detect contact between the occupant's head and the interior of the vehicle, a plane was constructed in the car interior by three points. Two points were at the B-pillar and one point at the side roof rail. The plane was not deformable in the simulation but was moved inwards by the crash according to the structure deformation.

For each target car three different planes were used to represent variation in car geometry.

First the base plane was rotated 23° to the vertical and then in addition ± 6° (see figure A2.4)

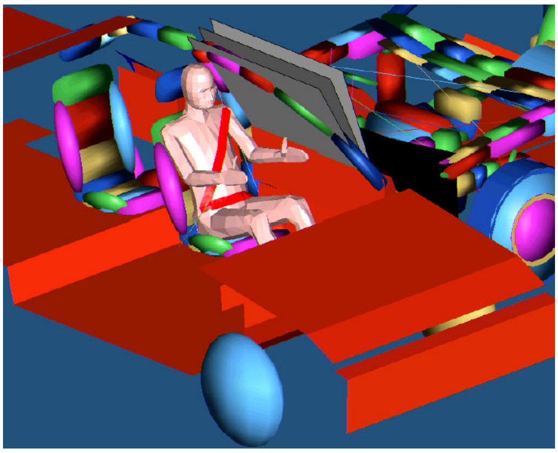


Figure A2.4: Base plane for head contacts

The impact angles are defined according to the constructed plane as shown in figure A2.5.

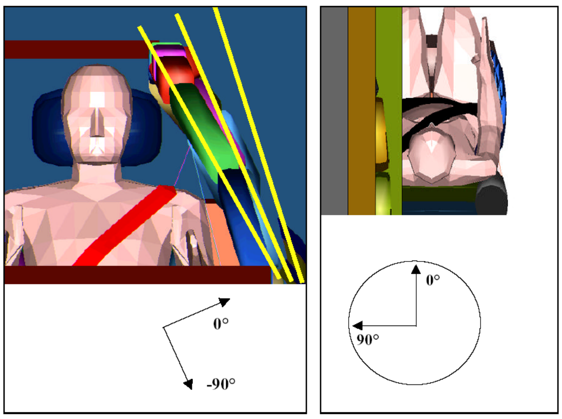


Figure A2.5: Co-ordinate system refereed to base plain

Altogether eight scenarios were simulated: seven with three different sized human models and one with a dummy model in different seating positions. Finally 432 simulations were run.

An example of the head contacts is shown in the following figure A2.6 for different occupant sizes and seating positions for the middle plane (see plane in figure A2.4 and A2.5 rotated at 23°).

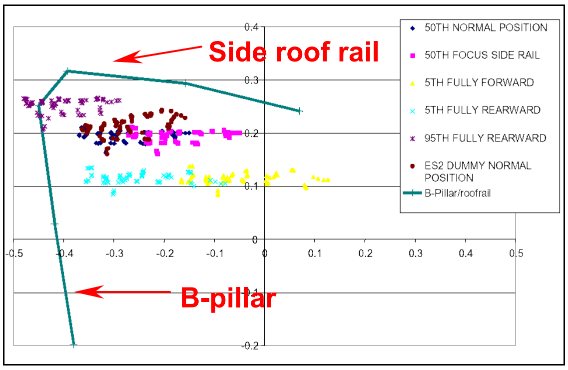


Figure A2.6: Allocation of head contacts for different human sizes

As expected the 95th percentile male has got the highest risk to contact the B-pillar region whereas the 5th female would contact the window area.

The received head impact velocities differ according to occupant size and car mass. The impact velocity is the difference between the velocity of the impact plane and head CoG. A range of 3 to 9 m/s appeared in the simulation. The average was 6.7 m/s, the same as in the interior headform test procedure.
The horizontal and vertical impact angles according to the co-ordinate system in figure A2.7 and A2.8 are also influenced by the seating position and occupant size.

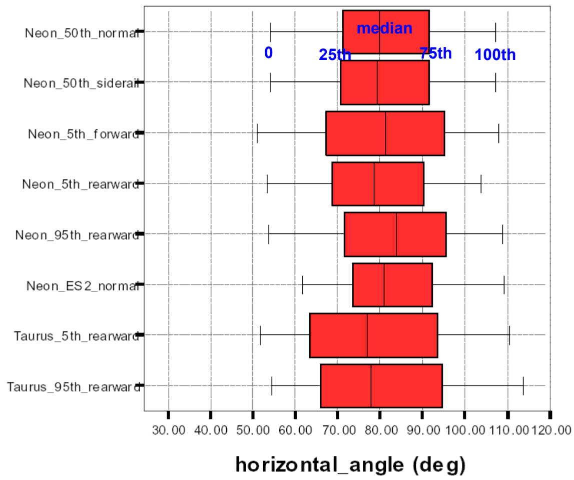


Figure A2.7: Range of horizontal angles

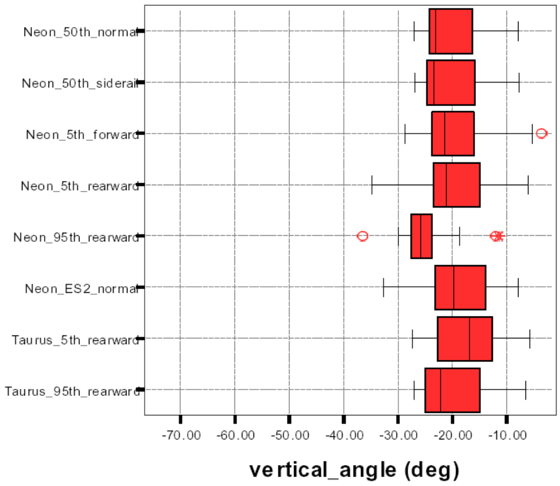


Figure A2.8: Range of vertical angles

The horizontal impact angle is between 50° and 115° and the vertical between –5° and –35° as shown in figure A2.9.

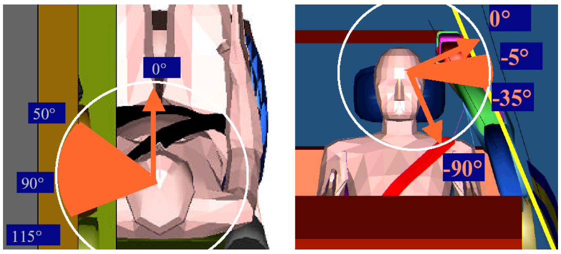


Figure A2.9: Maximum of observed angles

Transferred to a general co-ordinate system of a car, this study proposes the following angles:

- **50° . < horizontal angle < 115°**
- **-12° < vertical angle < 18°**

ANNEX A
SUMMARY OF TEST PROTOCOL

Headform – US Free Motion Headform FMH

Text and values between squared bracket are proposed and to be confirmed before the final issue of the protocol. (Example: [255] degrees)

The headform used for testing conforms to the specifications of FMVSS-201 (part 572, subpart L “Free motion headform”)

NOTE:
The headform shall be re-certified:
- after every [10] tests,
- after each test in which HICdummy > 1000
- after any test in which damage to the head-form flesh is suspected

Forehead impact zone
The forehead impact zone
of the headform is determined according to the procedure specified in sections i to vi below.

i. Position the headform so that the baseplate of the skull is horizontal. The midsagittal plane of the headform is designated as Plane S.
ii. From the centre of the threaded hole on top of the headform, draw a line 69 mm forward towards the forehead, coincident with Plane S, along the contour of the outer skin of the headform. The front end of the line is designated as Point P. From Point P, draw a line 100 mm forward toward the forehead, coincident with Plane S, along the contour of the outer skin of the headform. The front end of the line is designated as Point O.
iii. Draw a 125 mm line which is coincident with a horizontal plane along the contour of the outer skin of the forehead from left to right through Point O so that the line is bisected at Point O. The end of the line on the left side of the headform is designated as Point a and the end on the right as Point b.
iv. Draw another line 125 mm which is coincident with a vertical plane along the contour of the outer skin of the forehead through Point P so that the line is bisected at Point P. The end of the line on the left side of the headform is designated as Point c and the end on the right as Point D.
v. Draw a line from Point a to Point c along the contour of the outer skin of the headform using a flexible steel tape. Using the same method, draw a line from Point b to Point d.
vi. The forehead impact zone is the surface area on the FMH forehead bounded by lines a-O-b and c-P-d, and a-c and b-d.

Free flight trajectory
The FMH must be accelerated under linear control and released for free flight between 25 and 100mm from the point of first contact.

Impact Velocity
Two headform impact velocities are specified, the higher one for the evaluation of all target points not possessing and covered by active Head Protection Systems, and the lower one being used for defined areas of the of vehicle, which are covered by approved areas of an active Head Protection System.
- The standard impact speed is 6.7 m/s ± 0.2 m/s measured ≤ 100 mm from the contact point for ‘normal’ surfaces.
- For areas covered by ‘active head protection systems’, the impact speed is 5.3 m/s ± 0.2 m/s measured ≤ 100 mm from contact point

Impact location accuracy
- The impact alignment accuracy shall be within a radius of ≤ 10.0 mm of the selected target point.

Impact Environment
- The test temperature range shall be between 19 and 26°C
- The relative humidity shall be between 10 to 70%
- The environment shall be stabilised for a period ≥4 hours prior to test
- Time period between repeated tests using the same headform shall not be less than 3 hours

Test location and Head-form orientation
One FMH test should be performed to each test location. These are then restricted to those that lie within the ‘defined’ target area i.e. within an area defined by four planes, two passing through horizontal axes defined by the locations of the heads of large male and small female occupants and two passing through vertical axes also defined by the locations of the heads of large male and small female occupants.
In addition, tests are performed at certain defined structures (taken from FMVSS201u):
- Upper seat belt anchorage
- Seat belt adjustment device, if located above the anchorage point

- Grab handle (located within the defined header rail distance)
- Lighting control unit, coat hook or other such ‘fixed’ vehicle furniture.

Tests at one position must not compromise a test at an adjacent position due to ‘pre-damage’. Although testing will be performed with adjustable windows in the open position, only those contact points, which can be contacted by the headform with the windows closed, will be tested. The impact angle, defined as the angle of the impact velocity vector with respect to the plane tangential to the surface at the point of contact, shall be selected to be the “worst case” as close as possible to perpendicular to the impact surface.

Method 1

Then, for each selected target location, the headform orientation and actual impact location for each test is determined according to the following procedure. For clarity this procedure is illustrated by means of a decision making flow chart in Figure a.

- With the mid-sagittal plane vertical, should coincide with the impact velocity vector through the contact target.
- If a clean contact is not possible without contacting other noncertified parts of the FMH, then the headform and impact velocity vector should be pitched forward with respect to the normal by 10° ± 2° and realigned with the target, figure b.
- If a clean contact cannot be made with the head mid-sagittal plane, aligned vertically following this adjustment then the FMH and velocity vector should be returned to normal to the surface and the FMH be rolled by 90° ± 2° around the velocity vector, as described in the note.
- If the target location point still cannot be hit cleanly, then the headform should be rotated back to its original vertical position and the headform and impact velocity vector should be pitched forwards, with respect to normal, until a clean contact is established up to a maximum allowable pitch of 18° ± 2° to normal. A pitch of 18° reduces the lateral component of the impact vector by approximately 5%.
- If the selected point still cannot be impacted cleanly, then the target point should be moved within the limits defined in Appendix 1, Section 1.3 while still seeking a worst case contactable position.

Method 2

Then, for each selected target location, the headform orientation and actual impact location for each test is determined according to the following procedure.

- With the mid-sagittal plane vertical, the impact velocity vector shall be perpendicular to the surface through the contact target.
- If a clean contact is not possible without contacting other noncertified parts of the FMH, then the headform and impact velocity vector should be pitched downward with respect to the normal by 10° ± 2° and realigned with the target, figure b
- If the target point still cannot be hit cleanly, again the headform and impact velocity vector should be pitched downwards, with respect to normal, until a clean contact is established.
- If the selected point still cannot be impacted cleanly, then the target point should be moved within the limits still seeking a worst case contactable position.

For any method the following exceptions will apply:

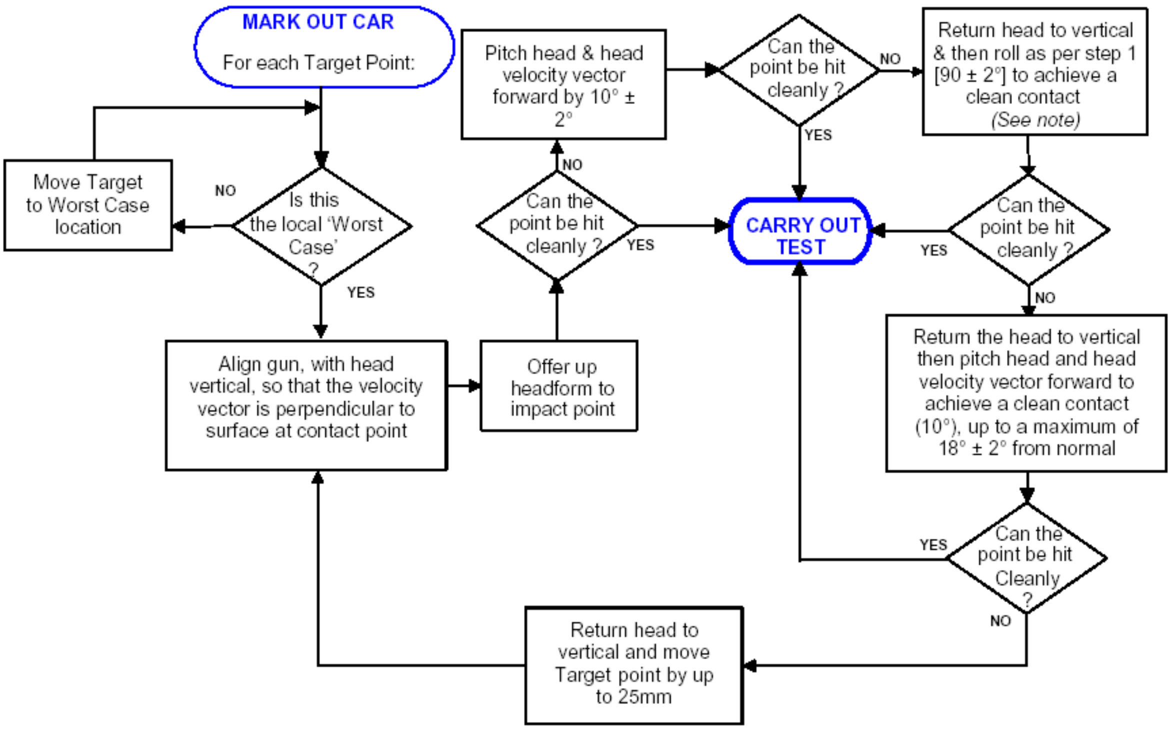
(a) Vertical approach angles will be limited to no more than [50] degrees (as is used in FMVSS 201) for all impacts. (Recent computer simulations has suggested that Vertical approach angles of [-10 to +20] degrees may be more appropriate, see TNO study above)

(b) When testing the A-pillar, the horizontal approach angle will be limited to between [195] and [255] degrees for the left hand side, and [105] to [165] degrees for the right hand side. Figure c. For impacts on the A-pillar only the longitudinal vertical plane passing through the forehead impact zone points O and P shall be perpendicular to the primary axis of the A-pillar at the impact point. Figure d.

(c) When testing side roof structures, B-pillars and other pillars (where applicable), the horizontal approach angle will be limited to between [230] and [295] degrees for the left hand side, and between [65] and [130] degrees for the right hand side. Figure e.

(d) For point BP2, the horizontal approach angle will be limited to [270] degrees for the left hand side and [90] degrees for the right hand side.

(e) When testing the rearmost pillar, the horizontal approach angle will be limited to between [270] and [345] degrees for the left hand side and [15] to [90] degrees for the right hand side. Figure c.



note: Clarification note on headfrom rotation
FMH axial rotation about the impact vector facing towards the target point.

Target area	**Left hand side of the vehicle**	**Right hand side of the vehicle**
A post target points	90° clockwise	90° anticlockwise
Roof rail target points	90° clockwise	90° anticlockwise
B post target points	90° anticlockwise	90° clockwise

Figure a: Method 1, headform alignment flow chart

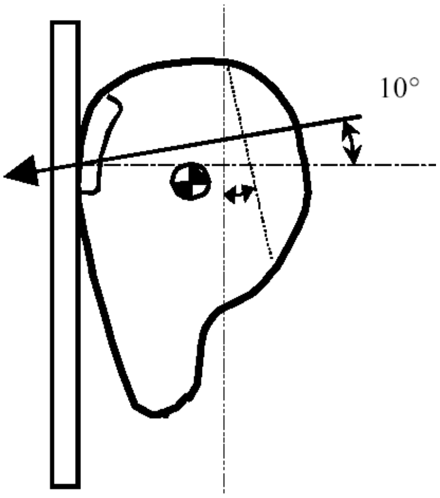


figure b: 10° pitch to the normal

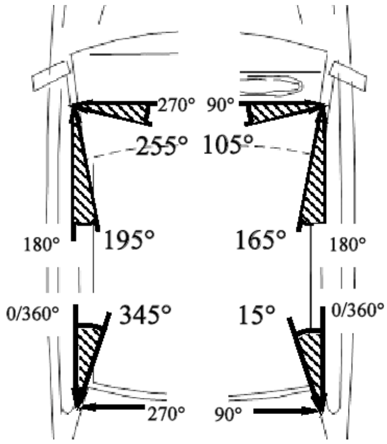


figure c: Horizontal approach angle limitation for A- and rearmost pillar

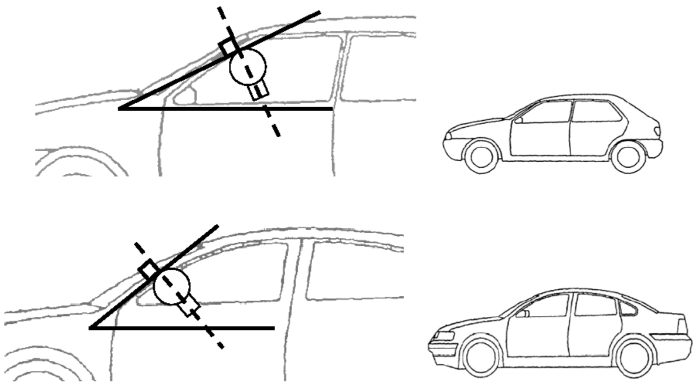


figure d: Perpendicular impact to the A-pillar

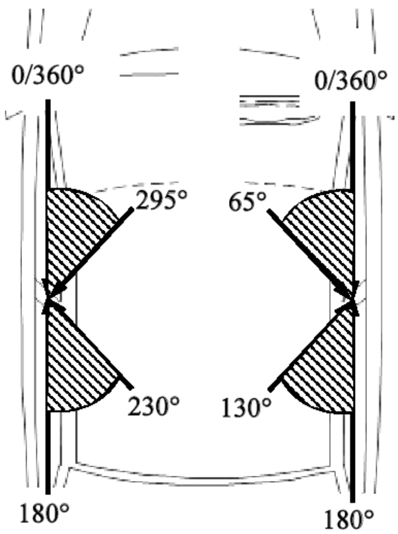


figure e: B-pillar and other pillar horizontal approach angle limitations

Note:
During the first phase of the WG13 research the US FMH was selected as the preferred impactor, thus all of the reported WG13 research has focussed on the use of this test device.

General guidance

• 'Worst Case' impacts

It is expected that 'worst case' will differ between vehicles, thus each vehicle should be assessed, by examining the drawings or physical inspection, before assuming the padding, fixing or other structure would be a worst case position. An inspection of the trims and underlying structure should be carried out to look for:

- Where the crush depth of padding is minimal.
- The location of fixings and bolts.
- The position of welds, joints or internal webs in the chassis.
- The attachment of padding or other components

The presence of such features could be used to guide a test authority regarding focal point for 'worst case' impacts.

• Closeness of repeated test

- Multiple impacts
  A vehicle being tested may be impacted multiple times, subject to the limitations given below
- Impacts within 300 mm of each other may not occur less than 30 minutes apart.
- No impact may occur within 150 mm of any other impact. The requirement within

FMVSS 201 has been increased to 200 mm between points for what is believed to be technical reasons.

The distance between impacts is the distance between the centres of the target circle for each impact, measured along the vehicle interior.

• Examination of collateral damage

If other impacts are to be carried out within a 200 mm radius of a previous impact point then any structural damage around and beneath the target point must be assessed. If damage is noted and full repair is not possible then no further adjacent impacts should be performed within the area of damage extended by 200 mm from the target point. Tests at the adjacent points would have to be performed in a different vehicle.

Note – the chin of the headform can contact parts of the vehicle structure 150 mm from the contact point.

Damage assessment

- If any trim or padding has been permanently deformed or show signs of elastic distortion, including attachment points within a 100 mm radius of the target points then the padding must be replaced for adjacent tests. The 100 mm radius could be increased if it is considered that the damage might affect the stiffness of the padding structure in any adjacent impact. All padding and trim attachment points should be examined and assessed for possible collateral stiffness.

- The extent of damage/deformation to structures underlying the padding should be assessed. If any permanent damage is detected the limit of the damage must then be quantified. No adjacent test should be carried out within 200 mm of the edge of the identified structural damage.

Vehicle preparation, including support

The vehicle should be rigidly supported off its wheels with the principle axes of the vehicle being aligned with ground reference co-ordinates. The maximum displacement of the exterior surface of the vehicle, along the axis of the impact adjacent to the point of contact, shall not exceed 10 mm. If necessary, the exterior of the vehicle may be 'additionally' supported to limit exterior movement to 10 mm.

If the side window can be opened, tests should be performed with the window fully open.

Pole impact test Procedure.*

The vehicle impacts a fixed 254 mm diameter rigid vertical pole at an impact speed of 29 ± 2 km/h. The pole is aligned with the centre of gravity of the head of the ES-2 dummy. In order to achieve this impact, the vehicle is placed on a carrier, which can translate freely in the direction perpendicular to the vehicle's longitudinal vertical plane.

* NOTE: The pole impact test procedure is based on that specified in FMVSS 201 with the ES-2 dummy. The specifications for the test procedure defined in Annex 1 have been taken from an edited version of the Euro NCAP protocol, since this also uses ES-2. Elements only used in the derivation of Euro NCAP ratings and items not appropriate for this draft procedure have been removed.

The impact angle should be 90° ± 3°.

The dummy's seating position should be adjusted, if necessary, to ensure that the head presents a target through the side glazing and is not obscured by the B-pillar.

The active system FMH tests and active system sub-structure FMH tests will only be performed where the requirements of the pole impact test are satisfied. The procedure is shown in figure f.

Performance criteria

FMH Head Injury Criterion

The Head Injury Criterion for the head-form (HICFMH) is calculated according to the following formula:

$$HIC_{fmh} = \left(\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} ad\ (t) \right)^{2.5} (t_2 - t_1)$$

where 'a' is the resultant head-form acceleration, expressed as a multiple of 'g' (the acceleration due to gravity), and t1 and t2 are any two points in time during the impact, which are separated by not more than a thirty-six millisecond time interval.

$HIC_{dummy} = 0.75446\ HIC_{FMH} + 166.4 * 1000$

Pole Test Head Injury Criterion

In the pole impact test, the Head Injury Criterion (HIC) must not be more than 1000. The HIC is the maximum value of the expression:

$$HIC_{fmh} = \left(\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} ad\ (t) \right)^{2.5} (t_2 - t_1)$$

where 'a' is the resultant head-form acceleration, expressed as a multiple of 'g' (the acceleration due to gravity), and t1 and t2 are any two points in time during the impact, which are separated by not more than a thirty-six millisecond time interval.

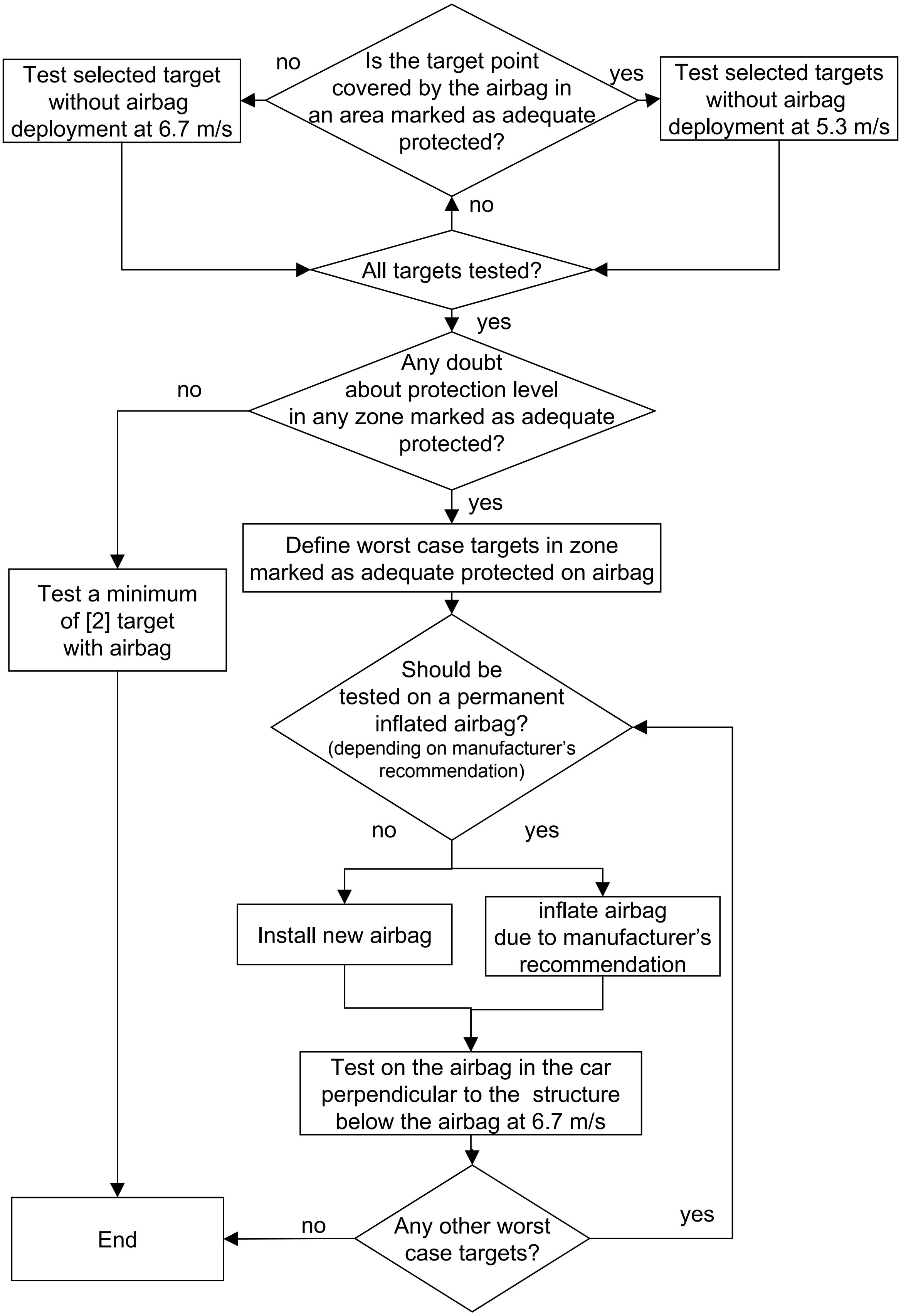


figure f: Flow chart for testing with head airbag systems