DEVELOPMENT AND EVALUATION OF THE SIDE IMPACT TEST PROCEDURE PROPOSED BY IHRA

Ton Versmissen, Margriet van Schijndel
TNO Integrated Safety
The Netherlands
Mervyn Edwards
TRL
United Kingdom
Tobias Langner
BASt
Germany
On behalf of APROSYS SP1.1 consortium
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ABSTRACT

At the 2005 ESV conference, the International Harmonisation of Research Activities (IHRA) side impact working group proposed a 4 part draft test procedure, to form the basis of harmonisation of regulation world-wide and to help advances in car occupant protection. This paper presents the work performed by a European Commission 6th framework project, called APROSYS, on further development and evaluation of the proposed procedure from a European perspective.
The 4 parts of the proposed procedure are:

- A Mobile Deformable Barrier test.
- An oblique Pole side impact test
- Interior headform tests
- Side Out of Position (OOP) tests

Full scale test and modelling work to develop the Advanced European Mobile Deformable Barrier (AE-MDB) further is described, resulting in a recommendation to revise the barrier face to include a bumper beam element.
An evaluation of oblique and perpendicular pole tests was made from tests and numerical simulations using ES-2 and WorldSID 50th percentile dummies. It was concluded that an oblique pole test is feasible but that a perpendicular test would be preferable for Europe.
The interior headform test protocol was evaluated to assess its repeatability and reproducibility and to solve issues such as the head impact angle and limitation zones. Recommendations for updates to the test protocol are made.
Out-of-position (OOP) tests applicable for the European situation were performed, which included additional tests with Child Restraint Systems (CRS) which use is mandatory in Europe. It was concluded that the proposed IHRA OOP tests do cover the worst case situations, but the current test protocol is not ready for regulatory use.

INTRODUCTION

In Europe, the order of 10,000 car occupants die in side impact crashes annually. At the 2005 ESV conference, the International Harmonisation of Research Activities (IHRA) side impact working group proposed a 4 part draft test procedure, to form the basis of harmonisation of regulation world-wide and to help advances in car occupant protection [11].
The European 6th Framework Programme Integrated Project (IP) on Advanced Protection Systems (APROSYS) focuses on developments in the field of passive and adaptive vehicle safety. The aim of Sub-Project 1 (SP1), titled 'Car Accidents', is to reduce the number of car occupant fatalities and serious injuries in Europe through the development of test and evaluation procedures that once implemented in regulation and / or consumer testing will improve car crashworthiness in side and frontal impacts.
Four tasks in SP1.1 evaluate the draft side impact test procedure proposed by IHRA. The tasks and associated type of tests investigated are:

1. Advanced protection in multi-vehicle lateral crashes – Mobile Deformable Barrier test
2. Protection in single vehicle crashes involving narrow objects – Oblique Pole test
3. Interior head protection in lateral impact - Interior headform test proposed by EEVC WG13
4. Occupant injury risk from deploying (side) airbags – Out of Position (OOP) tests

This paper details the research performed in these tasks, during the first 36 month period of the programme.

AE-MDB DEVELOPMENTS

Objectives

This section details the research of task 'Advanced protection in multi-vehicle lateral crashes'.
To represent better the world-wide car fleet IHRA proposed two tests with different Mobile Deformable Barriers (MDB):

- An MDB to represent Light Trucks and Vans (LTVs) type vehicles in the USA developed by the Insurance Institute for Highway Safety (IIHS) referred to as the IIHS-MDB [2].
- An MDB to represent the European passenger car fleet referred to as the Advanced European MDB (AE-MDB) developed by the European Enhanced Vehicle safety Committee (EEVC) side impact working group (WG13) [3].

Based on the strategy that APROSYS should focus on European problems the objectives of this task were:

- Complete the development of the AE-MDB.
- Perform an initial evaluation of the test procedure with the AE-MDB from the European perspective.

Background Information

History - The development of the new EU-barrier was started by EEVC WG13 in 2001 in support of European Governmental contributions to IHRA. The new barrier was called Advanced European Mobile Deformable barrier (AE-MDB) to differentiate it from the Regulation 95 barrier. The first test results using the AE-MDB were presented at the ESV 2003 [4]
The AE-MDB V2 specification, as defined by EEVC WG13, was presented at the 2005 ESV conference [4].
However, various members of WG13 identified major concerns with AE-MDB V2. The main concern was that in tests with this barrier face the resulting vehicle deformation (low b-pillar deformation / high door intrusions) did not compare well with that seen in baseline car to car tests. To resolve this concern, further barrier development was required which was performed in APROSYS.

AE-MDB geometry - The plan view of the new AE-MDB face design was derived taking into account two main considerations and objectives:

- The AE-MDB should reproduce, in a purely perpendicular impact with a stationary target vehicle, the loading pattern to front and rear occupants seen in a moving-car-to-moving-car side impact configuration.
- The AE-MDB face should not allow simultaneous loading of the A and C pillars, which could prevent realistic loading of the passenger compartment.

Based on this, and analysis of the dimensions of modern vehicles, the AE-MDB face (see Figure 1) was designed. It has a front face which is 1100mm wide and an overall width of 1700mm and a centre section of 500mm wide (corresponding to the width of the standard load cell wall) with edges chamfered at 45°.

Figure 1. AE-MDB dimensions.

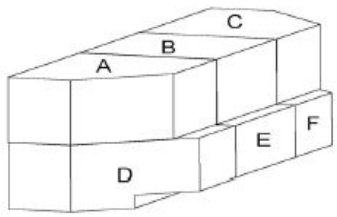
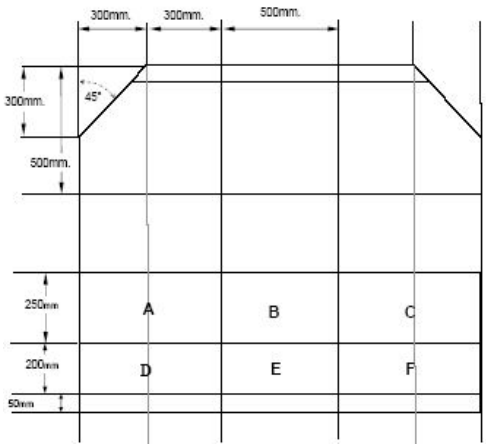


Figure 1 Isometric view of AE-MDB



AE-MDB V3 specifications – As mentioned previously, the resulting vehicle deformation in tests with the AE-MDB V2 did not compare well with that seen in baseline car to car tests. The reason for this was found to be that the AE-MDB V2 barrier block to block stiffness distribution did not adequately represent the frontal stiffness distribution of a car. The block stiffnesses for AE-MDB V2 were determined by WG13 from car crash tests into a rigid Load Cell Wall (LCW). The following remarks were made about the rigid LCW results of WG13:

- Concern was raised that the rigid LCW test may not show the effect of stiff lateral connections, such as bumper crossbeams, because they may not be strained in this test. This could result in the

specification of a barrier face with an unrepresentative weak middle block (E).

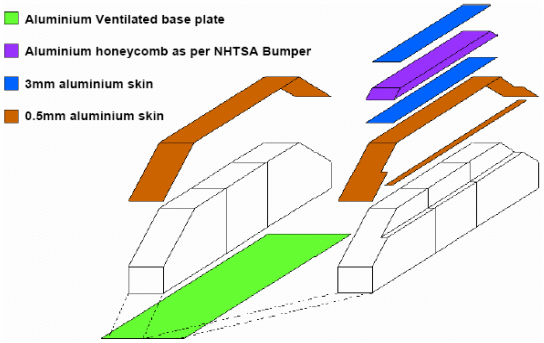
- Offset deformable tests and compatibility appear to direct vehicle design toward stronger lateral connections between energy absorbing structures.

In light of the available test and simulation results the members of EEVC WG13 discussed a series of modifications to the barrier face. It was decided by APROSYS to evaluate the following two barrier versions, both of which have a bumper beam element in contrast to the V2 face which does not.

Version 3.1 A barrier with block stiffness identical to the V2 barrier but with a bumper beam element to spread the load in lateral direction. The original depth of the lower row of blocks was reduced by 60 mm and replaced by the bumper beam element. The depth reduction was realised by removing the soft front of the blocks to obtain a stable connection of the beam element.

Version 3.9 A barrier with a reduced stiffness of the lower blocks. The two outer blocks have a design stiffness of 55% of the original V2 outer blocks and the middle block a design stiffness of 60% of the V2 outer blocks. The bumper element was identical to the V3.1 element.
Figure 2 shows the bumper element design, used on V3.1 and V3.9, which was based on the FMVSS-214 specifications.

Figure 2. AE-MDB bumper beam specifications



Test and simulation activities

Full-Scale Test Program

An extensive test program (see Table 1) with LCW barrier calibration tests, AE-MDB V3.1 and V3.9 to car tests and car to car tests was used to evaluate the AE-MDB V3 barriers. The main aim of the test program was to determine which barrier version best represented the baseline car to car tests. The Fiesta and Golf barrier tests were performed to provide a comparison between the two versions of barrier and the baseline tests. For all car to car and AE-MDB tests within the program the ES-2 dummy was positioned on the struck side in both the driver and rear seat passenger seating positions. The configuration of the AE-MDB test is presented in Figure 3 and the car to car in Figure 4.

Figure 3. AE-MDB test set-up, trolley mass 1500 kg.

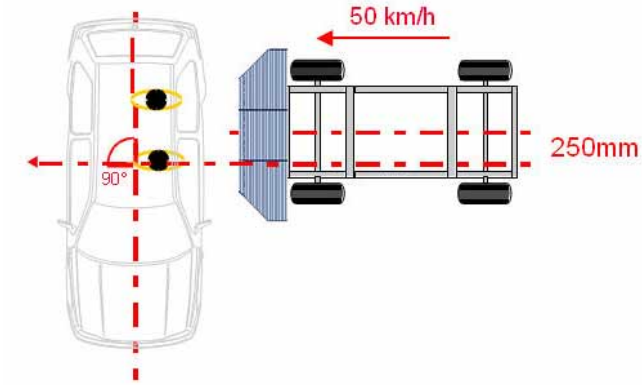


Figure 4. Car to car test set-up.

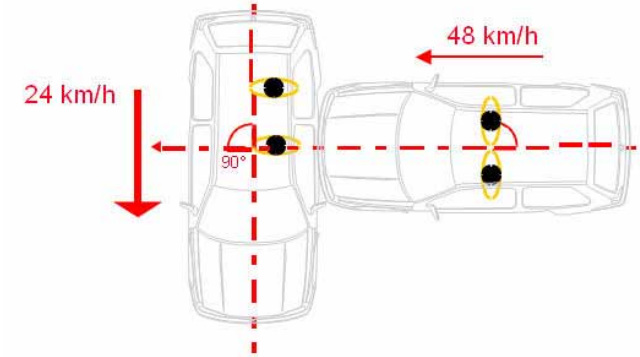


Table 1.
AE-MDB evaluation test matrix
"Green" APROSYS / "Blue" additional tests

Target Cars	Bullet cars/barriers			
	V3.1	V3.9	Baseline tests	
			Golf	Freelander
LCW calibration				
Ford Fiesta				
VW Golf				
Toyota Prius	*	*		
Volvo S80				
Robustness – sill				
Robustness - pole				

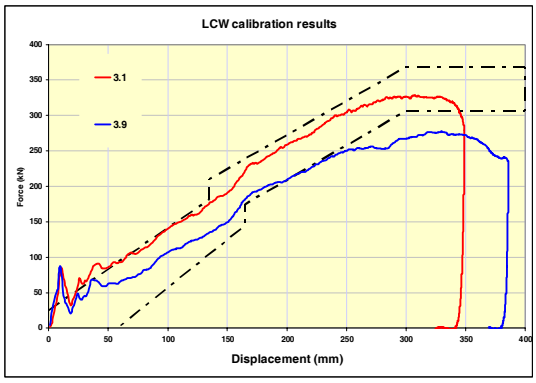
* performed without firing ANY airbag

For a barrier to be accepted into future regulation the design must be robust and repeatable. At the 1998 ESV, WG13 presented a series of test methods to assess the performance and integrity of side impact barrier faces[6]. Two of the tests proposed by WG13

were performed with both versions of the barrier. The rigid sill loading test and the offset pole test were chosen as they are considered to be the most discriminating of the tests.

LCW test results - The aim of these tests was to compare the force deflection characteristics of the V3 barriers with the V2 design corridors. The results (see Figure 5) show that both barriers are within the AE-MDB V2 design corridors for the first 200 mm of barrier deformation. For deformations larger than 200 mm the force of V3.9 is below the V2 design corridor. However, it should be noted that in all AE-MDB V3.9 tests the average maximum crush of the barrier was less than 200mm and the maximum dummy injury values were reached prior to maximum barrier deformation.

Figure 5. LCW test results AE-MDB 3.1 and 3.9 Total barrier force



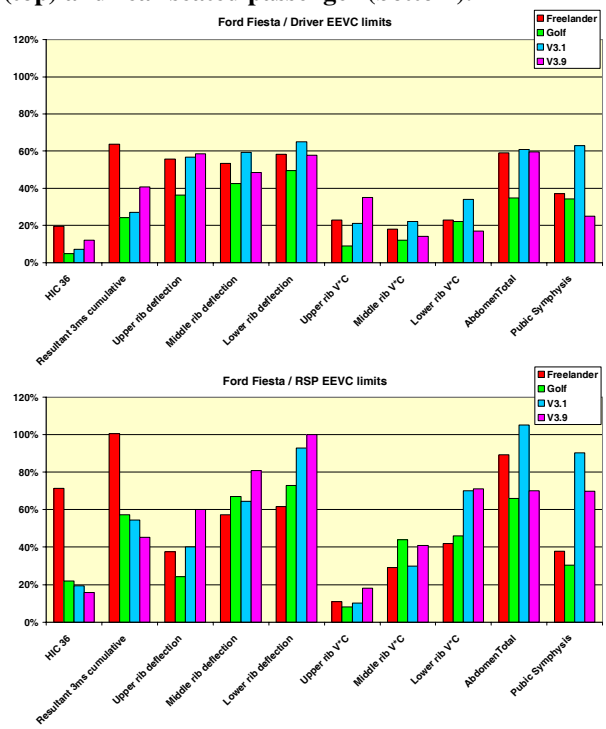
Car to car and AE-MDB test results - The dummy responses of AE-MDB and car to car tests for each dummy are shown in Figure 6 to Figure 9. The results have been expressed as a percentage of the EEVC critical limits where possible. The limits used are described in Table 2.

Table 2.
EEVC critical limits ES-2 dummy

Dummy results		EEVC limit
HIC 36		1000
Resultant 3ms cumulative	g	88
Rib deflection	mm	42
Rib V*C	m/s	1
Abdomen Total	kN	2.5
Pubic Symphysis	kN	6

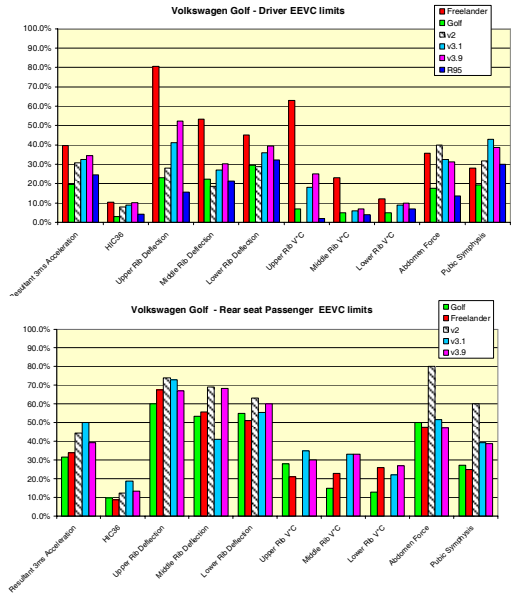
The responses from the Fiesta tests are shown in Figure 6. Examining the driver results shows that the EEVC limits were not exceeded in any test. Results of the Freelander tests were generally similar to those of both barrier impacts; in most cases the Golf test provided the lowest response. Comparison of the barrier test results indicates a difference of no more than 17% for all of the dummy body regions apart from the pubic symphysis force, where there was a difference of 38%.

Figure 6. Ford Fiesta dummy results – driver (top) and rear seated passenger (bottom).



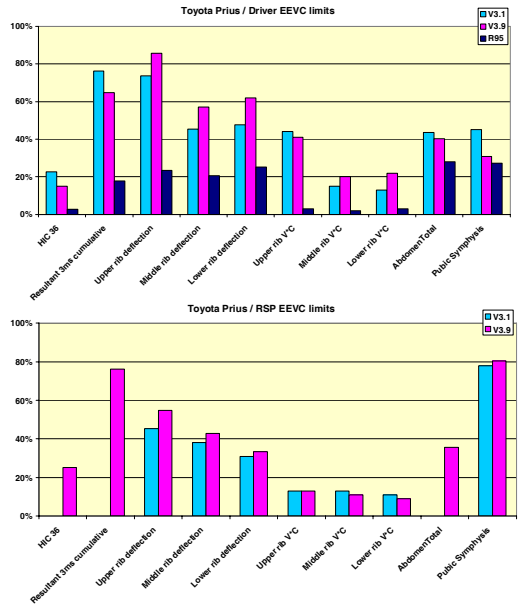
The responses from the Golf tests are shown in Figure 7. None of the driver results exceeded the EEVC limit. Additional results from an AE-MDB V2 test and a EuroNCAP test using the ECE Regulation 95 (R95) barrier have been included. The largest difference between the V3.1 and V3.9 results was only 11%. Both graphs show that the driver and passenger dummy results for the V3.1 and V3.9 are generally more in line with the baseline tests than the results from the V2. For the rear seated passenger, all

Figure 7. VW Golf V dummy results



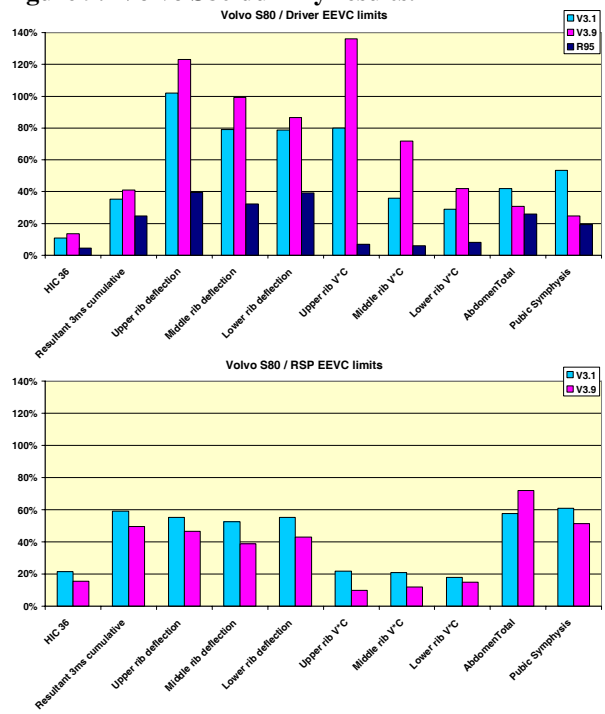
results show very similar trends.
Figure 8 shows the Prius results. No baseline test is available for Prius, therefore R95 results are presented in Figure 8 only as reference. Indeed the homologation results were obtained with side and curtain shield airbags, whereas no airbag was fired in AE-MDB tests. None of the results exceeded the EEVC limits.

Figure 8. Toyota Prius dummy results



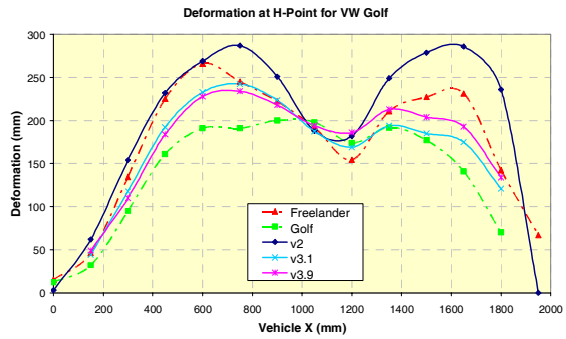
The responses from the S80 tests are shown in Figure 9. No baseline test data was available so only the V3.1, V3.9 and R95 barriers can be compared.

Figure 9. Volvo S80 dummy results.



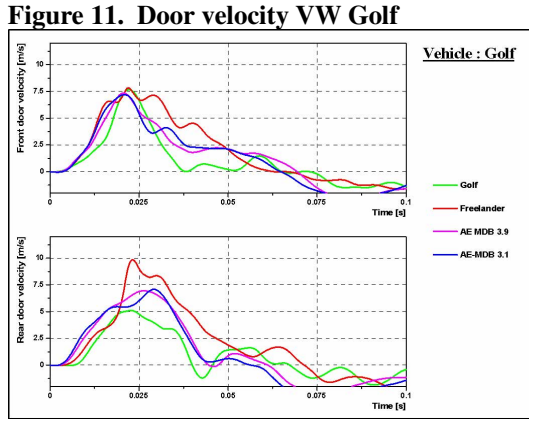
For the driver, three of the EEVC limits were exceeded.
The V3.9 barrier was generally more severe that the V3.1 with the largest difference being 56% of the limit. For the rear seat passenger there were no significant differences between the barriers. Before and after each test the profile of each target vehicle was measured to highlight the post test deformation profile left by each bullet. The deformation profiles of the Golf are typical of the vehicles tested. Further information can be found in the APROSYS deliverable [3]. The horizontal profiles for the Golf were taken at three levels, the door line, H-point height and rocker flange height. At the H-point height, see Figure 10, a similar trend as described for the Fiesta, can be seen.

Figure 10. Deformation at H-point level - VW Golf



For each impact the velocity of the driver and passenger door intrusion was measured from the inner door skin. The transducers were placed as close as possible to the dummies to gain the best indication of the loading received. The plots for the Golf are provided in Figure 10. All other results are available in the APROSYS deliverable [3]. For the driver the Golf, V3.1 and V3.9 had similar peaks values which were almost 4m/s below that of the Freelander. For the rear door the difference was much less, but the velocities were higher than those of the front door.

Figure 11. Door velocity VW Golf



There was very little difference in the associated door velocities of all tests using the two barriers, all of the data recorded in the program suggests both barriers induce similar door velocities.

Robustness test results – Both barriers V3.1 and V3.9 showed stability problems in the sill robustness tests, failing in bending and shear as shown in Figure 12.

Figure 12. Barrier failure in sill robustness test

Investigations are ongoing to improve the barriers on this subject. Also the severity of the sill test is under discussion as the vertical forces are likely to be significantly higher than in a full scale test where the barrier would override the vehicle sill. No barrier robustness problems were observed during the full scale tests.

The performances of V3.9 and v3.1 were very similar in the offset pole test. In both tests the side of the barrier came detached from the ventilation frame but no major stability problems were seen.

Simulation Program

Based on the slightly better results of the V3.9 barrier it was decided that further development of the AE-MDB design should be continued based on the V3.9 barrier. The main issues of the modelling program were:

Barrier stiffness The V3.9 barrier was no designed to meet the EEVC WG13 defined global force corridors but I was a requirement of the partners during the project. The LCW test showed that the current barrier is below this corridor after a displacement of about 200 mm.

Bumper beam element In the rigid sill robustness test the bumper beam element detaches from the main body of the barrier and rotates in the first 6 ms of the impact, indicating a possible stability problem. The current bumper beam specification is based on the FMVSS-214 barrier beam element geometry and stiffness. As a result of this it is 200 mm high.

Modelling runs were performed to investigate the following changes to the V3.9 barrier:

- Stiffness
  - Modifying the stiffness of the barrier blocks so that it met the WG13 defined global force deflection corridors.
- Bumper beam element stability
  - Splitting it into two sections along its length
  - Reducing its height from 200 mm to 100 mm

The results of the simulations showed:

Changing the barrier stiffness profile to enable it to comply with the EEVC WG13 global stiffness corridors made no / little difference to the performance of the ES-2 dummy or car. This was because the barrier did not deform as far back as the point where the stiffness changes were made when impacting the car, thus the stiffness changes were effectively not seen.

For the bumper beam refinements, the simulations showed a small reduction in the dummy pelvic injury criterion and a small difference in the car deformation at the lower levels.

Conclusions

- Both V3 barriers give more comparable dummy injury values and final deformation measures to the baseline Golf and Freelander tests than the V2 barrier does. Note both V3 barriers have a bumper beam element whereas the V2 does not.
- The dummy injury values for both V3 barriers are higher than for the regulation R95 barrier
- The differences in the cars' performances for the V3.1 and V3.9 barrier tests were slight for the dummy injury values, door velocities and deformations. However, the driver dummy pubic symphysis values for the V3.9 barrier compared better to the baseline test values than the V3.1 barrier.
- In the sill robustness tests both V3.1 and V3.9 barrier failed in shear / bending showing barrier stability problems. In the pole robustness tests no stability problems were seen with V3.1 or V3.9.
- Refining the AE-MDB V3.9 stiffness profile to enable it to comply with the EEVC WG13 global stiffness corridors made no / little difference to the performance of the ES-2 dummy or car. This was because the barrier did not deform as far back as the point where the stiffness changes were made when impacting the car, thus the stiffness changes were effectively not seen. For the bumper beam refinements, the simulations show a small reduction in the dummy pelvic injury criterion and a small difference in the car deformation at the lower levels.

CAR TO POLE

Objectives

The evaluation of the IHRA car to pole test protocol was carried out using full scale tests and numerical simulations. The main objectives of the full scale test program were:

- To carry out an assessment of practicality and repeatability of the car to pole test proposed by IHRA, which is based on NPRM-214 [7]
- To check the feasibility of using the ES-2 dummy or the WorldSID dummy in the proposed test procedure.
- To investigate the effect of impact location variation.

Main objective of the simulation study was:

- To investigate the influence of test parameters such as impact angle, velocity, pole impact position and diameter on the injury levels for several body regions.

Work Programme

Within APROSYS four car to pole full scale tests were carried out. To broaden the protocol assessment, results from four other tests performed outside APROSYS were also used. The complete test matrix is presented in Table 3.

Table 3.
Car to pole (above) and car to car test matrix including input test parameters

Subaru Legacy	Test S1	Test S2	Test S3	Test S4
• angle/speed	75° / 32 km/h	90° / 32 km/h	*75° / 32 km/h*	*90° / 29 km/h*
• impact location	NPRM-214	Euro NCAP	*NPRM-214*	*Euro NCAP*
• dummy	WorldSID 50%	WorldSID 50%	*ES-2*	*ES-2*
• project	APROSYS	APROSYS	-	-
Toyota Avensis	**Test T1**	**Test T2**	**Test T3**	**Test T4**
• angle/speed	75° / 32 km/h	75° / 32 km/h	75° / 32 km/h	*90° / 29 km/h*
• impact location	NPRM-214	NPRM 214	Euro NCAP	*Euro NCAP*
• dummy	ES-2	ES-2	ES-2	*ES-2*
• project	APROSYS	APROSYS/DOTARS	APROSYS	*Euro NCAP*

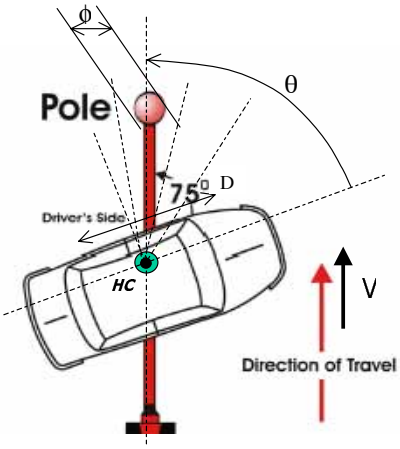
Subaru Legacy	Test S1	Test S2	Test S3	Test S4
• Test ID	045106JI	O3QQ	PB31RZP	EA82RZP
• Laboratory	IDIADA	TRL	Subaru	Subaru
• Dummy	WorldSID	WorldSID	ES-2	ES-2
• Test mass	1725 kg	1730 kg	1789 kg	1681 kg
• Test angle	75°	90°	75	90°
• Test velocity	31.8 km/h	31.7 km/h	31.5 km/h	29.0 km/h
• Impact accuracy	4 mm fore	8 mm aft	2 mm/*	6 mm/*
Toyota Avensis	**Test T1**	**Test T2**	**Test T3**	**Test T4**
• Test ID	F044703	F051701	14497	04NQ
• Laboratory	TNO	TNO	Fiat	TRL
• Dummy	ES-2	ES-2	ES-2	ES-2
• Test mass	1500 kg	1505 kg	1501 kg	1506 kg
• Test angle	75°	75°	75°	90°
• Test velocity	32.4 km/h	31.9 km/h	32.5 km/h	29 km/h
• Impact accuracy	4 mm fore	7 mm fore	7 mm fore	14 mm aft

The influence of test parameters such as impact angle, velocity, pole impact position and pole diameter on the injury levels for head and other body regions was investigated. APROSYS performed simulations using a Generic Car FE Model of a mid-sized vehicle developed by another APROSYS sub-project. This model was equipped with thorax and curtain airbags. In addition to the APROSYS work similar simulations were carried out by Subaru, using a FE model of the Legacy.
The specifications for the APROSYS numerical study are presented in Table 4 and Figure 13.

Table 4.
Specifications APROSYS / SUBARU numerical study

Parameter	
Vehicle model	▪ 'Generic' model of a 4-doors passenger car ▪ Subaru Legacy
Impact angles θ [°]	90 (FMVSS-201) / 82.5 / 75 (NPRM-214)
Test velocities V [km/h]	29 (FMVSS-201) / 32 (NPRM-214) / 36
Impact point	-100, 0 and 100 mm shifted from specified, along vehicle for-aft axis
Pole diameters Φ [mm]	254 (NPRM-214) / 350 (ISO)
Dummy	ES-2 model

Figure 13. NPRM 214 test set up, including parameters numerical studies

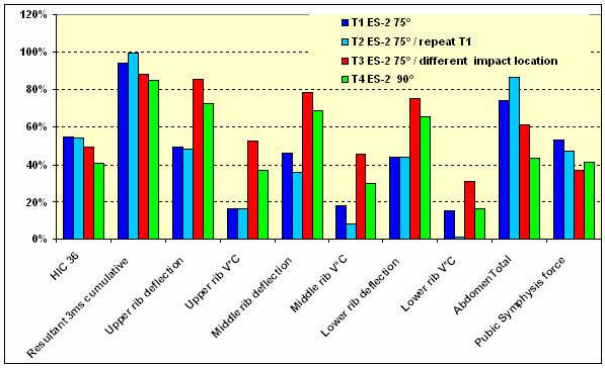


Results

The main dummy results of the full scale tests with the Toyota Avensis are shown in Figure 14. Unfortunately, the high speed video recordings of the four Legacy tests show such large differences in airbag timing and airbag behaviour that they could not be used to compare the test methods.
The dummy injury values are expressed relative to the ECE R95 limits for the ES2 dummy, see Table 2. The following observations were made:

- The repeatability of the test with the ES-2 dummy was good (compare T1 with T2). The changes in dummy injury criteria values did not exceed 15% of the performance limit.

Figure 14. Toyota Avensis main dummy results.



- Changing the impact location in the oblique test from NPRM to EuroNCAP (effectively moving the impact point on the car rearwards) results in a large increase in the rib injury criteria and a slight decrease in the other body region injury criteria (compare T1/T2 with T3).
- The proposed test configuration (NPRM-214) results in significantly lower injury criteria values for the ribs but higher values for other body regions, especially the abdomen, compared to the EuroNCAP configuration (compare T1/T2 with T4). The observation that these injury value changes are similar to those seen for the change in impact location indicates that the major influencing factor on test severity, when changing the impact angle, is likely to be the change in impact location.

Further detail can be found in the APROSYS deliverable AP-SP11-0086 [8].

Discussion and Conclusions

- Two similar oblique tests (IHRA specifications) with the Toyota Avensis showed good repeatability.
- The Toyota Avensis tests and Subaru simulation work showed that the dummy injury values found in the proposed oblique test are approximately the same as those found in a perpendicular test with the initial impact point moved 100 mm forward.
- An oblique test needs a modification of the currently used test equipment and is more complex to perform. Also the currently available dummies, ES-2 and WorldSID, are nowadays more accurate in a perpendicular loading situation. Design changes for the WorldSID dummy are ongoing to improve the behaviour for oblique loading conditions.
- Since other programs to evaluate the pole test procedure proposed by IHRA are still ongoing, worldwide harmonisation must be a leading priority in future decisions about its specification.

INTERIOR HEADFORM TESTS

Introduction

Accident analyses have shown that in real world crashes serious head contacts occur with the interior structure of cars. These are only very rarely observed in ECE R95 type side impact tests. One reason for this is that real world accidents occur in various impact configurations, which cannot be represented in only one test set-up. 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. The ongoing development of the EEVC WG13 interior headform test procedure has been reported at previous ESV conferences [12]. A test procedure for head contacts in the interior of cars already exits in the USA (FMVSS 201).

Objectives

The overall aim of APROSYS task "Improved Interior Head Protection in Lateral Impacts" was to evaluate the latest test protocol version 103r. This draft protocol is available on the EEVC home page: www.eevc.org. The main objectives of this work were:

- to evaluate the repeatability and reproducibility of the WG13 test procedure.
- to evaluate the WG13 target limitation zone procedure for rear seat occupants.

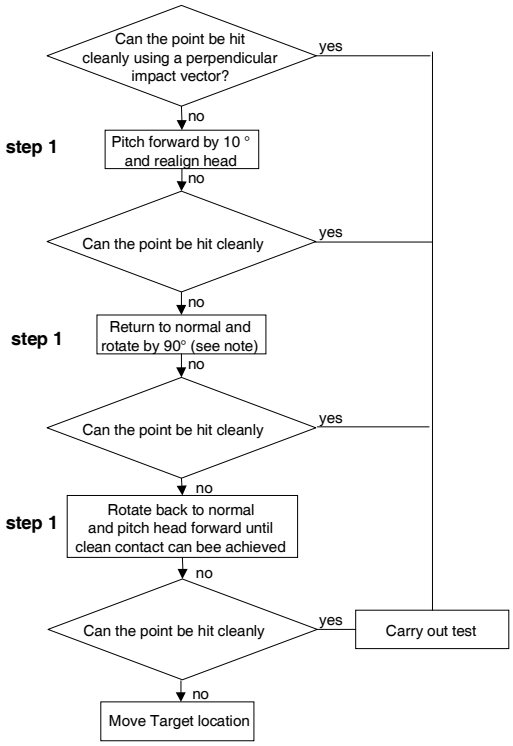
Repeatability / Reproducibility

One of the major factors to affect reproducibility is head alignment, i.e. the effects of different head alignments at same targets when tested within different laboratories. The head alignment procedure is described in the flow chart in Figure 15.
The results of the work programme to investigate the affect of head alignment on reproducibility for two cars are described below. The test houses involved were IDIADA, TRL, Fiat and BASt.

Fiat Stilo

Fiat selected the worst case targets and provided IDIADA with the 3D measurement data to mark the car. The test institutes performed the head alignment completely independently from each other for exactly the same targets by following the flowchart for the FMH alignment. The results of head alignments from Fiat and IDIADA were compared to identify if the testing protocol and flowchart were clearly defined.

Figure 15. Head alignment flow-chart



Direction of 90° roll in step 2:

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

Finally, IDIADA and Fiat tested the car according to their own head alignment to get information on the differences of HIC results on identical targets with their own head alignments.
The following aspects were of interest:

- if same head alignments were chosen by two different test houses following the test procedure.
- the deviation of HIC values obtained by different test houses, testing identical targets using their own head alignments.

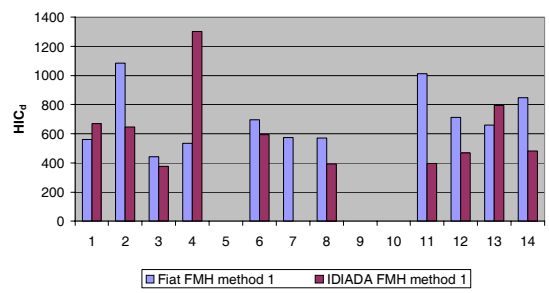
In an optimal situation the results should have been identical. The head alignment results are shown in the following table.

Table 5. Comparison of head alignment at IDIADA and Fiat.

Target	Horizontal angle [°]		diff.	Vertical angle [°]		diff.	last step in flowchart	
	IDIADA	Fiat	[°]	IDIADA	Fiat	[°]	IDIADA	Fiat
1	281	270	11	16	0	16	1	1
2	268	270	-2	10	9	1	1	1
3	259	270	-11	-10	0	-10	2	1
4	252	270	-18	-20	7	-27	4	3
5								
6	283	270	13	-11	-11	0	1	3
7	264	270	-6	-7	-40	33	4	1
8	270	270	0	-45	-39	-6	2	1
9								
10								
11	291	270	21	48	32	16	1	1
12	283	325	-42	-1	0	-1	3	4
13	283	270	13	-10	-12	2	4	4
14	286	270	16	-14	-4	-10	1	1
	average deviation		14	average deviation		11		

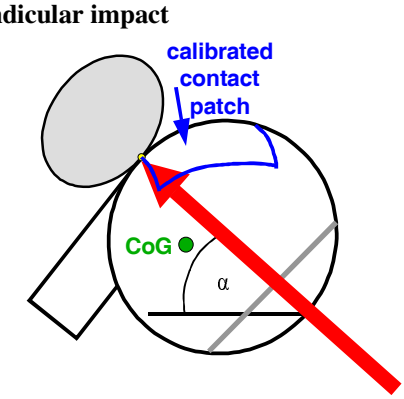
It was of interest how much influence this deviation of impact angles had on the HIC results. Figure 16 shows the obvious differences in HIC.

Figure 16. Comparison of FMH tests at Fiat and IDIADA according to method 1



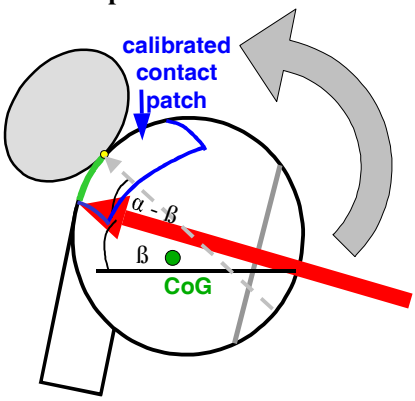
It was found by analysing pictures and videos that different contacts in the contact patch were chosen at both test houses. This might influence the test results significantly. To minimise rotation of FMH, it always should be the aim to keep the lever between contact point and FMH's centre of gravity as small as possible. Therefore it is suggested to select the most downward point on the contact patch, which can contact the target as first contact point. If head alignment is perpendicular to the surface of the target, it must always be the same target point in the lowest part of the contact patch as shown in Figure 17.

Figure 17. Contact point in contact patch for perpendicular impact



Perpendicular to the surface of the interior does not always result in realistic impact directions. Therefore impact angles are limited for horizontal and vertical alignment. For some targets, angle limitation leads to non perpendicular impacts. Nevertheless, the contact point should be as much downwards as possible and has to be the first contact point during the impact.
A vertical limitation to an angle ß would result in an upwards movement of the contact point in the contact patch as shown in Figure 18.

Figure 18. Contact point in contact patch for non perpendicular impact



To achieve reproducible results, it is recommended that the procedure is revised to include a definition of the contact point in the contact patch as above.

<u>VW Golf</u>

It was of interest, if identical head alignments would be chosen by two different test houses which are well trained in the use of the procedure, TRL and BASt. BASt selected worst case targets and provided TRL with the 3D measurement data to mark the car. Both test institutes performed the head alignment completely independently from each other for exactly the same targets by following the flowchart as in Figure 15.
The results of the head alignments from TRL and BASt, shown in

Table 6, were compared. The variation in angle definition and choice of the alignment step in the flow chart are quite similar between the two test houses for identical targets. An average deviation of 3° for horizontal and 4° for vertical angles is very low. The low variation in head alignment is probably the result of a high training level. TRL and BASt have been involved in the development of the test procedure and therefore might have a similar understanding / interpretation.

Table 6. Head alignment results

Target	Horizontal angle [°]		diff.	Vertical angle [°]		diff.	last step in flowchart	
	BASt	TRL	[°]	BASt	TRL	[°]	BASt	TRL
AP2	77	80	-3	35	29	6	0	0
AP1	88	85	3	46	45	1	0	0
SR1	87	89	-2	50	58	-8	1	0
SR2	89	90	-1	53	59	-6	0	0
BP1	85	85	0	25	25	0	3	3
BP2	90	90	0	0	15	-15	0	0
BP3	-	-		-	-		-	-
BP4	101	100	1	15	15	0	2	2
BP5	96	90	6	36	39	-3	3	2
BP6	39	30	9	12	10	2	2	1
SR3	87	89	-2	48	50	-2	1	1
CP2	119	111	8	20	23	-3	2	2
	average deviation		3	average deviation		4		

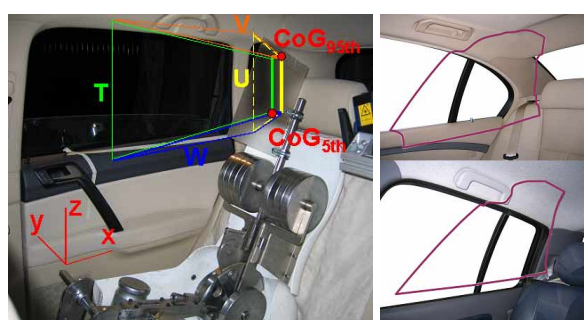
To achieve reproducible results it will be necessary to improve the head alignment definition, in particular the contact point in the contact patch.

Limitation Zones for Rear Seat Occupants

To be in line with the AE-MDB test procedure the WG 13 interior headform test procedure was extended for rear seat positions. Technical University Graz (TUG) compared the defined head contact zone defined by the WG13 procedure with head contact points from accident data.

TUG and BASt chose 10 cars and defined the contact zones according to the WG13 protocol. A funnel created by four planes, (see figure below) projects an area in which targets can be selected for interior headform testing. The planes start from the head's centre of gravity of a large male and a small female. These planes are V 60° upwards, W 20° downwards, T and U 45° sidewards.

Figure 19. Example of limitation zone according to WG13 test procedure



It was found that the currently proposed limitation zone for rear seating positions does not include important areas identified in real world accidents. TUG gave recommendations to optimise these limitation zones to be closer to real world data: Plane

V must be more upwards to include roll over. Plane T must be more forward to include the grab handle and the B-pillar. Plane W must be more downwards to include the upper door panel, especially for non struck side head contacts. Plane U is sufficient, but targets behind the rear headrests must be excluded.

Conclusions

The Interior Headform tests in the different laboratories showed that the results of the tests following the draft EEVC WG13 protocol are very sensitive to the head alignment (impact vector deviation and the contact point position in the contact patch). A procedure to position the contact point in the contact patch to minimize head rotation and help reproducibility has been defined. Concerning the head contact limitation zone for rear seat occupants, a small change in the definition procedure is recommended to give a more realistic testing zone. Progress with respect to protocol clarification, point selection and testing the rear seat occupant zone has been made. However, further work on the head alignment procedure and angle limitations is still needed to ensure a reproducible and robust test.

SIDE OUT OF POSITION TESTS

Objective

The main objective of APROSYS task "Evaluation of occupant injury risk for deploying side airbags" was to evaluate the need and appropriateness of the IHRA proposed Side Out of Position (S-OOP) test procedure for application in Europe [9]. This test was proposed to minimise the potential negative effects of side airbag systems.

The test procedures include tests for seat-mounted airbags, door/quarter panel-mounted and roof-rail mounted airbags using 3-year old, 6-year old Hybrid-III and small female SID-IIs dummies. The test procedure has been accepted as part of IHRA harmonized test procedures in order to encourage car manufacturers and suppliers to take measures that minimise the potential negative side effects of side airbags.

Two activities were undertaken, firstly a review of the protocol for application in Europe and secondly a test programme to investigate issues such as repeatability and reproducibility.

Review of IHRA Protocol for Europe

A review of the procedure was performed to answer the following questions:

- Are the proposed dummies representative for the European situation?
- Are the proposed injury levels representative for the European situation?
- Which test configurations, dummy type / dummy positions, should be tested?
- Are there any technical and/or practical problems to carry out the proposed tests?

The review of the IHRA proposal showed clear differences between the US and EU situation, particularly related to assumptions of belt use and child restraint use.
It was proposed to limit the number of different scenarios to be tested in a potential EU side OOP proposal to the ones considered relevant for the EU. In the IHRA proposal, combinations of airbags can be fired. When both side and curtain airbags are fired, the dummy could be moving out of the way of the other deploying airbag as a result of the other airbag, thereby potentially lowering the total dummy loading. Therefore it was decided that in the current research, the airbag modules should only be tested on their own, e.g. combinations of airbags would not be tested.

European Regulations. In Europe, the usage of seat belts is mandatory, as well as the use of child restraint systems (CRS) for the transport of children in cars. These regulations have an effect on the OOP risk in Europe. Hence it was decided that in the current research only belted dummies would be tested and additional tests with CRS would be added to the program.

Accident Statistics. From the over 40.000 car occupants cumulatively documented till June 2004 in the available databases no deaths or serious injuries have been recorded worldwide from side airbags. In Europe only eight side airbag induced injuries were found, all but one being rated as minor injuries (≤AIS1).Therefore it was concluded that currently, these kind of injuries are very rare.

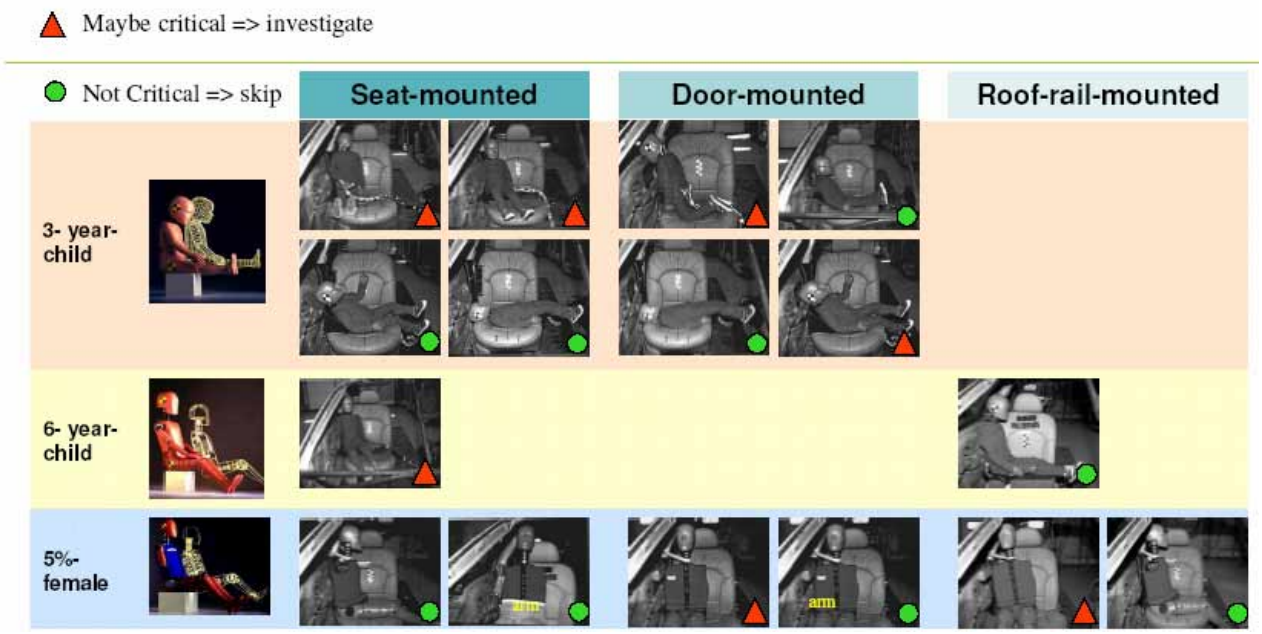
Test Programme

Based on the IHRA protocol and the review results of the partners a test program was defined that covers the following:

- Side OOP tests following the IHRA-TWG proposal, for those scenarios relevant for Europe.
- Side OOP tests including CRS systems, additional to the IHRA-TWG proposal.

Attention was paid towards repeatability and reproducibility, particularly focussed on the dummy positioning procedures.
Although door mounted airbags have tended to be replaced by seat mounted airbags, door mounted Therefore seat mounted side airbags, door mounted

Figure 20. Investigation of Side OOP scenarios.



airbags might become more important again because of the increasing number of MPV/SUV type of cars. side airbags, head thorax bags and curtain airbags were included in the study. Because of the poor availability of vehicles equipped with door mounted airbags, the part of the work on door mounted airbags was covered by a short literature survey.
The selected positions, dummies and airbags tested are summarized in Figure 20**Error! Reference source not found.**. All critical scenarios, marked with ▲, were tested in the program, except the scenarios with door mounted airbags. The rearward positions of the dummy are not a realistic seating position in Europe but were chosen as a potential test to measure the airbag aggressiveness.

The complete IHRA protocol test matrix is presented in
Table 7.

Table 7.
Test matrix IHRA protocol.

			Laboratory			
Dum	**Airbag**	**Test**	**A**	**B**	**C**	**D**
3yo	Thorax	Forward	2	2		
3yo	Thorax	Rearward	2		2	2
3yo	Head/thorax	Forward			1	
3yo	Head/thorax	Rearward			1	1
6yo	Thorax	Forward	2			
6yo	Head/thorax	Forward			1	
SID	Curtain	Forward	2		2	2

In total three different vehicles models were used because it was not the purpose of this study to assess individual airbags or vehicles. One model was chosen as typical example of cars having a seat integrated

thorax bag in combinations with a curtain airbag system. Two models were chosen as typical examples of cars equipped with head-thorax bags.

Additionally, tests with child restraint systems were carried with group 2/3 child restraint systems, since these groups were assumed to give the largest chance of interaction between a side airbag and a child and/or CRS. Different qualities of CRS were used, with and without backrest for group 2 and group 3 respectively. Tests were performed with 3-yo and 6-yo Hybrid-III dummies in forward facing positions to be able to compare with the forward facing IHRA positions. Both seat mounted thorax airbags and seat mounted head thorax bags were included. The CRS was initially mounted according its manual; the dummy was then positioned following as close as possible to the TWG protocol for forward facing positions, aiming at the largest possible interaction between dummy, CRS and airbag. The complete matrix, including repeatability tests, is presented in Table 8.

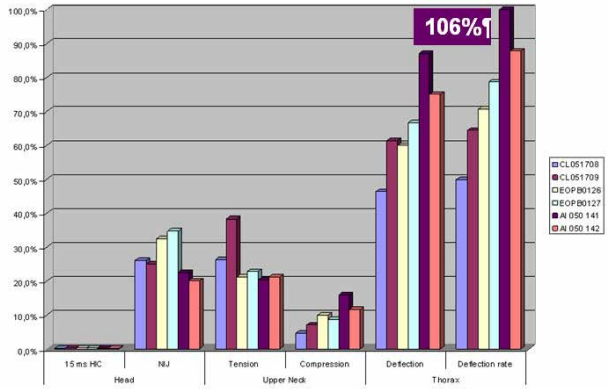
Table 8.
Test matrix with dummies in CRS.

Dum	Airbag	CRS	Laboratory A	B	D
3yo	Thorax	High end		2	
3yo	Thorax	Simple		2	
6yo	Thorax	High end	2		
6yo	Head/thorax	High end			1
6yo	Thorax	High end	1		
6yo	Thorax	Simple	2		

All dummy test results are available in the APROSYS deliverable [10].

From the test results of the seat integrated thorax bags, it is concluded that most probably the airbags have been designed following the TWG proposal. The injury reference values found were all well below the reference values, except for the thorax deflection rate in one rearward facing test, see Figure 21. (The dummy injury values are expressed as a percentage of the reference values of the IHRA protocol.). The figure presents the results of 6 identical test carried out in 3 laboratories. Please not also that this is not a realistic seating position in Europe.

Figure 21. Test results 3yo dummy in rearward facing position.



From the test results in one laboratory it was concluded that the repeatability was reasonable, whereas, by comparing results from various laboratories, the reproducibility was poor. This was mainly caused by a different interpretation of the TWG protocol. Generally, the injury risk for the 6-year-old dummy seems to be less than for the 3-year-old dummy.

Concerning the CRS tests with seat mounted airbags the following remarks can be made:

- Using a CRS with a backrest decreases the risk of interaction between dummy and airbag during airbag deployment. No serious airbag – dummy or CRS interaction was observed in these seat mounted thorax airbag tests.
- No significant differences were found between different types of CRS, although with a simple booster (without horns) it is easier to come closer to the airbag, in the potential zone of danger.
- Generally it was concluded that the TWG proposal for forward facing 3 and 6 year old dummies covers the worst case situation that could occur when seated in a CRS.
- From the TWG proposal, the rearward facing 3 year old dummy is facing the most severe loading.

The tests with the combined head/thorax airbags showed that this airbag design seems to include a risk in CRS- out-of-position conditions (sleeping child), however, this risk is likely to be covered by the TWG tests (forward facing on booster seat, not checked in this project). A general note is that CRS positioning on the rear bench should be preferred over the front passenger seat.

In the tests with the curtain bags large differences are observed, particularly between the Nij values, with one test exceeding the limits. This is related to the different airbag – dummy interaction observed. In 50% of the tests, the airbag was deployed between the dummy and the window, whereas in the other 50%, the dummy was in between the airbag and the window. Differences in the dummy positioning and seat adjustment contribute to differences in the airbag – dummy interaction. The positioning protocol of the SID-IIs for this position needs further refinement for potential use in regulatory testing.

Conclusions

The following conclusions were drawn:

- No relevant accident data was found regarding injuries induced by side airbags.
- Out of the IHRA/TWG protocol, test scenarios relevant for Europe were identified
- Different side OOP tests were performed in four different laboratories over Europe, resulting in a reasonable repeatability within laboratories but poor reproducibility between different laboratories. The current test protocol is not clear enough to be used in a European regulatory environment at this stage.

SUMMARY OF CONCLUSIONS

The 4 parts of the draft IHRA proposal have been evaluated and additional development activities have been carried out.

- The AE-MDB work showed that both V3 barriers gave more comparable dummy injury values and car

deformation measures to the baseline car to car tests than the V2 barrier. Please note that the major difference between the V3 barriers and V2 barrier is the addition of a bumper beam element. For one car, the results of V3.9 were slightly more comparable with the baseline test than V3.1. Tests with the AE-MDB V3, which has a trolley mass of 1500 kg, were found to be more severe than the current regulation ECE R95, which has a trolley mass of 950 kg. Both V3.1 and 3.9 exhibited stability problems in sill robustness tests. However, the severity of this test is under discussion as it may be unrealistically high. Further work, based on the modeling work in the project, is needed to finalize the barrier design and to solve, if needed, the stability problem.

- Car to pole full-scale tests and numerical studies showed that the severity of a car to pole test has a stronger relation to the impact location than to the impact angle. Therefore, based on practicality of the test and the better performance of the current side impact dummies with perpendicular loading, a perpendicular car to pole test with the impact location positioned ahead of the head centre of gravity would be preferable for Europe. However, an oblique test could be acceptable if other reasons, such as international harmonization, demand it.
- The Interior Headform tests in the different laboratories showed that the results of the tests following the draft EEVC WG13 protocol are very sensitive to the head alignment (impact vector deviation and the contact point position in the contact patch). A procedure to position the contact point in the contact patch to minimize head rotation and help reproducibility has been defined. Concerning the head contact limitation zone for rear seat occupants, a small change in the definition procedure is recommended to give a more realistic testing zone. Progress with respect to protocol clarification, point selection and testing the rear seat occupant zone has been made. However, further work on the head alignment procedure and angle limitations is still needed to ensure a reproducible and robust test.
- Current accident statistics show no need for a Side Out of Position regulation in Europe. If future accident studies show a need for an OOP regulation only a limited number of scenarios of the IHRA draft protocol will be needed in Europe to cover the situation with belted occupants and children in child restraint systems. Then an update of the IHRA protocol will be required to make the protocol suitable for European regulatory testing, especially with respect to the seat and dummy positioning. Special attention for the risks of OOP injuries will be needed if door mounted airbags are re-introduced in the car fleet.

The current APROSYS SP1.1 consortium members are:

- BAST, Germany
- Cellbond Composites Ltd, United Kingdom
- CRF Italy
- Fiat Italy
- IDIADA, Spain
- INSIA, Spain
- Takata Petri, Germany
- Technical University Graz, Austria
- TNO, the Netherlands
- TRL, United Kingdom
- Toyota motor Europe NV/SA, Belgium
- Volkswagen, Germany

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