INTERNATIONAL HARMONISED RESEARCH ACTIVITIES SIDE IMPACT WORKING GROUP STATUS REPORT

Craig Newland
Chairman
On behalf of IHRA Side Impact Working Group

Paper Number 05-0460

ABSTRACT

This paper reports on the status of work of the International Harmonised Research Activities (IHRA) Side Impact Working Group (SIWG) as at its 23rd meeting prior to the 19th ESV conference in Washington in June 2005. This includes decisions made and the reasons for them and represents a final report on this phase of the IHRA work.

INTRODUCTION

At the 2003 ESV conference, the International Harmonised Research Activities (IHRA) Side Impact Working Group (SIWG) reported a suite of draft test procedures designed to enhance safety in real world side crashes.

The draft test procedures proposed in 2003 represent a complementary suite of procedures designed to provide a range of test conditions encompassing a range of occupant sizes, seating positions and impact conditions to minimise the incentive for sub-optimisation of vehicle designs to specific test conditions. Hence, a mobile deformable barrier (MDB) to vehicle test with fifth percentile female dummies has been proposed to address vehicle to vehicle side impact crashes and a vehicle to pole test with a fiftieth percentile male dummy has been proposed to address vehicle to narrow object crashes. In addition, an interior surface headform impact test has been proposed to reduce head injury risk that may arise under different impact configurations than those specified by the MDB and pole impact test procedures. To ensure that no detrimental effects are generated by design changes to meet the testing requirements, a set of out of position test procedures are also proposed.

The IHRA SIWG undertook to coordinate an evaluation program by members of these test procedures over the period 2003-2005, with the aim of reporting recommended test procedures to enhance real world safety in side crashes at ESV 2005. The IHRA SIWG provides a crucial framework for targeting studies and research efforts. Currently, no other global framework exists under which this collaborative research effort may be conducted.

BACKGROUND

A steering committee was set up at the 15th Enhanced Safety of Vehicles (ESV) conference in Melbourne in 1996 to work towards a harmonised vehicle safety research agenda to avoid duplication of research. This is the International Harmonised Research Activities (IHRA) Steering Committee comprising government representatives including vehicle safety regulators from around the world. It was agreed that IHRA be responsible for overseeing research activities in six key areas.

One of the original key areas, functional equivalence, was replaced by side impact following the 16th ESV conference in Windsor, Canada in 1998. The six working groups under IHRA after the 16th ESV are shown below with each group chaired by the country in parenthesis:

- Side impact (Australia)
- Advanced frontal crash protection (Italy)
- Vehicle compatibility (United Kingdom)
- Biomechanics (USA)
- Pedestrian safety (Japan)
- Intelligent Transport Systems (Canada)

At the 17th ESV in Amsterdam, progress was again reviewed and it was decided to amalgamate the Advanced Frontal and Vehicle Compatibility Working Groups with the resulting five groups tasked for a further 4 years with a review at each ESV. The Steering Committee also agreed to a revised set of Terms of Reference for the Side Impact Working Group (SIWG).

The various IHRA working groups generally consist of about 10 members to ensure that progress is as speedy as possible. Although IHRA is essentially a government group, industry has been invited with a total of three representatives in each working group, one each from North America, Europe and Asia-Pacific regions. This maximises outcomes by engaging vehicle manufacturers in the research process so that countermeasures can be designed into vehicles as soon as possible.

SIWG MEMBERSHIP

The current members of the IHRA Side Impact Working Group are:

Craig Newland	Department of Transport and Regional Services, Australia (Chair)
Mark Terrell / Duncan Lockie	Department of Transport and Regional Services, Australia. (Secretaries)
Dainius Dalmotas	Transport Canada
Suzanne Tylko	Transport Canada
Adrian Roberts	EC/EEVC
Michiel van Ratingen	EC/EEVC
Joseph Kanianthra	National Highway Traffic Safety Administration, USA
Hideki Yonezawa	National Traffic Safety and Environment Laboratory, JMLIT
Minoru Sakurai	JARI
Atsushi Hitotsumatsu	OICA Asia-Pacific/JAMA
Michael Leigh / Stuart Southgate	OICA North America/AAM
Christoph Mueller	OICA Europe/ACEA
Keith Seyer	OICA Asia Pacific/FCAI

Past members:

Robert Hultman	OICA North America/AAM
Haruo Ohmae	JARI
Takahiko Uchimura	OICA Asia-Pacific/JAMA
Rainer Justen	OICA Europe/ACEA
Richard Lowne	EC/EEVC
Akihisa Maruyama	OICA Asia-Pacific/JAMA
Keith Seyer	DOTARS (Chair)
Mark Terrell	Department of Transport and Regional Services, Australia (Secretary)

TERMS OF REFERENCE

At its 12th meeting, the SIWG finalised the revised Terms of Reference which states the objectives of the group, the outcomes of its first 2-year term, the activities to be undertaken in the future and a timeframe for these. These are summarised below.

Objective

Co-ordinate research worldwide to support the development of future side impact test procedure(s) to maximise harmonisation with the objective of enhancing safety in real world side crashes.

Scope

In its first 2-year term, the Side Impact Working Group (SIWG) concluded that new test procedures to address the side impact problem should include:

- A mobile deformable barrier to vehicle test
- A vehicle to pole test
- Sub-systems head impact test
- Out of position airbag evaluation

In its next term, the SIWG will also coordinate research to examine the feasibility of improving side impact protection for occupants on the non-struck side and develop a test procedure to evaluate such protection.

Activities

The SIWG is working towards achieving these goals by:

1. Reviewing any new real world crash data to prioritise injury mechanisms and identify associated crash conditions taking into account likely future trends.
2. Taking into account the need to protect both front seat and rear seat(s) adult and child occupants.
3. Interaction with the IHRA Biomechanics Working Group to monitor the development of harmonised injury criteria.
4. Interaction with the IHRA vehicle compatibility working group to ensure solutions in one area do not degrade safety in another.
5. Monitoring and, as appropriate, providing input to the development of WorldSID and any other side impact dummy.
6. Determining the greatest degree of harmonisation feasible and the design and vehicle safety performance implications of adopting different levels of test severity or the worst case condition.
7. Coordinating the evaluation of proposed test procedures subject to availability of test dummies and injury criteria.

Timeframe

While the progress of the group will be reviewed every 2 years, it is expected that:

- The target date for draft final proposal of test procedure(s) is 2003 ESV
- The target date for final proposal of test procedure(s) is 2005 ESV with validation in the intervening 2 years.

The test procedure(s) would include the best available dummies as recommended by the IHRA Biomechanics Working Group (BWG) (for example, the harmonised test dummy being developed by the ISO WorldSID Task Group (www.worldsid.org)). The BWG will also advise on availability of any other suitable test dummies and the injury criteria to be used.

Members noted that there are differences in fleet compositions around the world but were hopeful that research could be focused on these differences to determine whether they had a quantifiable effect on the injury risk in side impacts.

SUMMARY OF RESEARCH

Methodology

To determine the side impact trauma problem that needed to be addressed, the group began by examining real world crashes in the 3 major geographical regions, North America, Europe and Asia-Pacific, to identify the:

- types of side impact crashes occurring
- injuries being sustained by body region
- causes of these injuries, where possible
- characteristics of the drivers and passengers most at risk (gender, size, seating position, etc)

For vehicle to vehicle crashes, members were asked to report on any research that examined the effects on injury risk of mass, stiffness and geometry of striking vehicles together with any other parameters that were considered important for side impact protection.

There has been close cooperation and communication between the SIWG and other IHRA WGs on advanced frontal, vehicle compatibility and biomechanics, and with the WorldSID Task Group.

Real World Crash Studies

As part of the IHRA Biomechanics Working Group (BWG) task to define the real world side impact safety problem, Transport Canada analysed the real world crash data submitted by the various regions. This study, to be reported by the IHRA BWG, indicated that:

- Collectively, side impacts involving vehicle to vehicle crashes and vehicle to narrow object crashes constitute about 90% of the side impact trauma. However, the frequency of involvement of specific vehicle types and narrow objects varied from region to region.
- Most of the trauma in side impacts occurs to struck side occupants.
- Up to 40% of the trauma to occupants of the struck car in side crashes occurs to non-struck side occupants depending on the geographical region.
- The head and chest were consistently the most frequently injured body regions.
- The frequencies of abdominal, pelvic and lower extremity injuries were also significant, but varied with geographical region.
- The main contact points causing injury to struck side occupants were door structure, exterior object and B-pillar.
- Depending on the region, the proportions of male and female severely or fatally injured occupants in vehicle-to-vehicle crashes were either similar or slightly predominated by females (up to 60%).
- Young males predominated in vehicle to narrow object crashes.
- Elderly occupant casualties were over-represented in vehicle to vehicle crashes.
- Rear occupants account for less than 15% of road trauma in side impacts.

The above research, combined with the need to ensure enhanced side impact protection for all adult occupants, would indicate the importance of using a small adult female test device in the front driver position in an MDB to vehicle test and using a mid sized adult male test device in a vehicle to pole test. Regulators may wish to specify requirements for other dummy sizes, if crash statistics indicate such a need for a particular region.

Parametric Studies on Effect of Mass, Stiffness and Geometry on Dummy Response

Research conducted within IHRA found differences in the makeup of the vehicle fleets in each of the global regions.

Since a mobile deformable barrier (MDB) represents a striking vehicle, it was noted that it may be difficult to propose a single MDB representative of striking vehicles from all global vehicle fleets. Jurisdictions in which the striking vehicles are predominantly passenger cars felt that it may not be appropriate for them to consider an MDB representing an SUV.

A number of parametric studies have been conducted to examine the effect on injury risk of the mass, stiffness and geometry of the striking vehicle in side impacts. The data presented to the SIWG included results from:

- A computer simulation by the UK Transport Research Laboratory
- A cooperative project of full-scale tests by the Australian Department of Transport and Regional Services and Transport Canada.
- A full-scale test series by the US Insurance Institute for Highway Safety (IIHS).
- Full scale tests by Transport Canada.
- A computer simulation by the NHTSA.
- Full-scale tests and FEM simulations of front-end structures of impacting vehicles for the comparison with current European MDB face by JAMA.
- Full scale tests by JMLIT.

Based mainly on single parameter variations, these data supported the following conclusions on the factors that increased dummy response:

- Raising ground clearance of the striking vehicle/trolley had the greatest effect (mainly due to a reduction in engagement of the side sill of the struck vehicle).
- Increasing the mass and stiffness of the striking vehicle/trolley has a lesser effect.
- A perpendicular impact of the striking vehicle/trolley maximises the loadings to the driver when compared to crabbing the vehicle/trolley.
- Non-homogeneous barriers generate more “punch-through” than homogeneous ones.

It was also noted that:

- In high frontal profile striking vehicles such as 4WDs/Light Trucks and Vans (LTVs) there is typically less engagement of the sill and floorpan of the struck vehicle and these striking vehicles are more likely to load the head (from contact with the high hood/bonnet) and chest (from the higher intrusion profile).
- Typically, injuries occur (40-50 msec after impact) before momentum transfer to the struck vehicle occurs (around 70 msec).
- The stiffness ratio between the front and side structure of vehicles is so high that, for the same geometry, variation in front structure stiffness has little effect on dummy response.

Some of these studies also included increasing impact speed which was found to have an effect similar to increasing ground clearance. For example one of the studies showed that increasing the speed from 50 to 60 km/h had the same or similar effect on dummy responses as increasing the ground clearance from 300 mm to 400 mm.

Compound variations of mass, stiffness, geometric and velocity parameters were not investigated.

Non-Struck Side Test Research

Members agreed that there should be a test to evaluate injuries to non-struck side occupants because real world crash data attributed up to 40% of road trauma to this group depending on the geographic region. In the US, FMVSS201 addresses this problem to some extent.

The SIWG received information regarding preliminary research and a work plan for a collaborative program between General-Motors Holden’s, Monash University, George Washington University, Virginia Tech, DOTARS and Autoliv. This work showed that current dummies are unlikely to provide correct kinematics but that WorldSID’s design showed promise. This work is reported elsewhere in this ESV. However, there is much more to be done in this area and should be given a higher priority in the SIWG’s considerations in the future.

CONCLUSIONS

After reviewing further research data, members confirmed that the IHRA Side Impact test procedure should comprise:

1. A mobile deformable barrier to vehicle test to simulate the vehicle to vehicle crash condition.
2. A vehicle to pole test to simulate the vehicle to narrow object crash condition.
3. Sub-systems interior surface head impact test to address the risk of head injury under crash conditions other than the specific MDB and pole tests.
4. Out-of-position side airbag evaluation test(s).

Draft test procedures were proposed in the status report from the IHRA Side Impact Working Group at ESV 2003. During 2003-2005, a number of organisations have commenced validation of these draft test procedures.

Since a recommendation for suitable test device(s) and injury criteria has not been made by the IHRA Biomechanics Working Group, the validation work has been undertaken using a range of existing side impact dummies and injury criteria. It is anticipated that further verification testing may be required when test dummies and criteria are recommended.

The following sections will discuss the progress and status of work conducted by the IHRA SIWG on each of these tests.

MOBILE DEFORMABLE BARRIER (MDB) TEST

Defining the parameters of the Mobile Deformable Barrier (MDB) test has proven to be the most challenging task for the group. While the group was hopeful of recommending only one MDB test, it became clear that this would be difficult because of the fleet differences between regions around the world.

In North America, LTVs currently account for approximately 50% of all new light vehicle sales (cars, light trucks and vans). In other regions there has been an increase in the popularity of "soft-roaders"/small 4WDs, although not to the same extent as North America. While smaller and lighter than traditional 4WDs, their high geometry front structures present similar problems to vehicles they strike.

Therefore, the group agreed to consider two MDB test procedures to be taken into the validation phase which may result in further refinements:

1. An MDB test using a barrier based on a passenger car/small 4WD-type bullet vehicle. This will initially be the Advanced European (AE)-MDB test procedure currently being developed by the EEVC.

2. An MDB test using a barrier based on a LTV type vehicle. This will initially be the Insurance Institute for Highway Safety (IIHS) MDB test procedure currently being used by the IIHS.

The group noted that:

- A single "worst case" test would be the ideal for harmonisation. However, this could only be achieved if the proposed more severe test could be guaranteed to provide at least the same degree of protection for all significant body regions as generated by the less severe test.
- By taking at least 2 draft test procedures (eg the new draft AE-MDB and the IIHS MDB) into the validation phase, there would be some latitude to develop and select appropriate tests for the different fleet mixes and to examine whether the worse case test option is feasible.
- The accident data indicated that, at a minimum, a small female dummy should be used in the MDB tests and a mid-sized dummy should be used in the pole test.

A number of side impact parametric studies were reported to the group, including both physical testing and computer simulation, evaluating the influence of MDB characteristics on injury risk and vehicle structural behaviour. These concluded that the ground clearance of the front of the MDB (and consequent reduction in engagement of the side sill of the struck vehicle) had a major effect on injury risk, whilst MDB mass and stiffness has only a minor effect. This formed the basis for the proposed MDB mass of 1500kg - probably lighter than a typical striking vehicle in some jurisdictions, but heavier than a typical striking vehicle from other jurisdictions, but with the effect of mass not such an important factor. Further, the perpendicular impact mode provided more severe load conditions for the driver, while the force – deflection response of etched (progressive) honeycomb barriers was different in the crabbed mode to perpendicular mode. For these reasons, perpendicular impact is the preferred impact mode as reported in the previous IHRA SIWG status report. Since this report, NHTSA has expressed some concerns regarding this position.

Accident studies from Asia-Pacific, North America and Europe have shown that 50 km/h would be an appropriate perpendicular impact speed for the MDB.

The geometric and stiffness requirements for a proposed MDB were not as easy to reconcile. Since the Insurance Institute for Highway Safety (IIHS) had already finalised a specification for its side impact assessment, the IHRA SIWG agreed to consider this test procedure as a potential candidate procedure on the basis that this barrier had been designed to represent a large SUV striking vehicle. In parallel, EEVC Working Group 13 had been developing a new MDB (known as the AE-MDB) to represent small SUVs and passenger car striking vehicles.

Advanced European (AE)-MDB Test Procedure

The AE-MDB is designed to provide an impact environment similar to that seen in car-to-car and small 4WD-to-car side impacts. The objective has been to

(i) provide a sufficiently stringent test condition for the rear seat dummy while maintaining the same level of severity for the front seat dummy

(ii) provide a perpendicular test

(iii) provide a severity of test appropriate for a predominantly car-based fleet mix.

(iv) develop test conditions that would require protection measures that would be effective in real car-to-car impacts (i.e. that could not be overcome by vehicle design changes optimised for the MDB but that would not work in many car-to-car accidents).

The car-based barrier test, to be used within the IHRA SIWG suite of test procedures is being developed by EEVC Working Group 13. A report on the status of this research is being prepared by WG13 (Roberts et al, 2005.) Since the last IHRA SIWG progress report the external shape of the AE-MDB has remained unchanged but its specification has developed to incorporate the manufacturing and build features as is specified in the revised ECE Regulation (R95/02) MDB face and the principle of 'progressive stiffness' honeycomb. EEVC has also developed the dynamic crush certification corridors to reflect the geometric characteristics of the barrier.

It is important that the advanced barrier is appropriate for use in a range of different loading conditions. At the time of the previous ESV report WG13 had been assessing the AE-MDB performance against the results of two struck vehicles being struck by two other vehicles, in moving car to moving car tests. The target cars were the Toyota Camry and the Renault Megane being struck by a Ford Mondeo, which was considered to be an 'average European family car' with reasonably good EuroNCAP scores and a Landover Freelander, a typical European SUV, also considered equivalent to a large family car. Since 2002 WG13's research has extended the baseline assessment testing to include the Alfa 147 and Toyota Corolla as target vehicles (both three door vehicles). The Freelander has continued to be one of the bullet vehicles. The other bullet vehicles have been the Toyota Corolla and the Renault Megane. Tests with the AE-MDB, to the revised build specification, have also been performed into these new target vehicles and into the rigid load cell wall as part of certification and repeatability studies.

Further information on the stiffness of modern vehicles has been obtained and has generally confirmed that the force deflections previously used are valid, for this particular loading condition, which has traditionally been used to specify the dynamic performance of European barrier faces used in the European standards.

The IHRA MDB test procedures are expected to use more advanced side impact test dummies (possibly the 5th%ile WorldSID) with enhanced injury assessment capability, as recommended by the IHRA Biomechanics group. The IHRA Biomechanics group has not yet made a recommendation for a 5th%ile side impact dummy. Since the previous IHRA SIWG report in 2003, EEVC WG13 has been evaluating the AE-MDB test procedure using the ES-2 dummy, not with the rib extension modification as this has not been approved for regulatory application in Europe or been recommended by EEVC WG12, the EEVC Dummies group.

The latest full scale tests with the AE-MDB are suggesting that the MDB loading into the struck cars may not be as representative as was hoped when compared to the vehicle to vehicle tests. One suggestion for this is due to the fact the AE-MDB is not interacting with some of the more rigid structures of the struck vehicles, e.g. the stiff B posts. It has also been noted that some front structures of modern cars now incorporate lateral stiffening structures, cross beams, which can form a link across the two outer longitudinals. Research is currently taking place by WG13 and within the EC APROSYS project to investigate changes to the AE-MDB to include such attributes. EEVC WG13 is therefore not in a position to recommend that the AE-MDB barrier, described in the former report is sufficiently well developed for it to be considered for wide spread evaluation within the IHRA suite of test procedures.

It is hoped that a design revision will be agreed upon in the next year. At this point in time the IHRA suite of procedures can not be completed with the AE-MDB test procedure. This has resulted in an inability to compare the two candidate MDB test procedures at this time and hence the IHRA SIWG is not in a position to recommend an MDB test at present.

Japanese Supportive Research - Japan has been cooperating with the development of the AE-MDB, as a part of international harmonization research. Impact tests of cars have been conducted using this barrier face to compare the profile of deformation in tested vehicles (crashed vehicles) with the deformation resulting from crashes involving actual vehicles.

Impact tests were performed car-to-car (passenger car to passenger car), AE-MDB-to-car, SUV-to-car, MPV-to-car, etc. Unlike the EEVC WG13 tests, most of these tests were conducted with the centre of the barrier aimed at the R-point at that time. The results showed that the amount of deformation in test vehicles when crashed against AE-MDB tended to be greater than when crashed against passenger cars, but was likely to be smaller than in crashes with SUVs or MPVs. These results almost satisfied the specification target of the barrier face that simulates vehicles including compact SUVs. Regarding particular parts of crashed vehicles, there were some differences in the profile of deformation around B-pillar in test vehicles when crashed against actual vehicles and when impacted against the barrier face (Fig. 1). When tested with the barrier face, the deformation was smaller at the B-pillar than at the door, with the barrier face itself undergoing significant deformation in the centre. When crashed against actual cars, on the other hand, the amount of deformation was similar at the door and at B-pillar, with the front end of crashed cars showing extensive deformation. The difference is suspected to be due to the influence of the bumper beam that connects the right and left sections of the vehicle's front end.

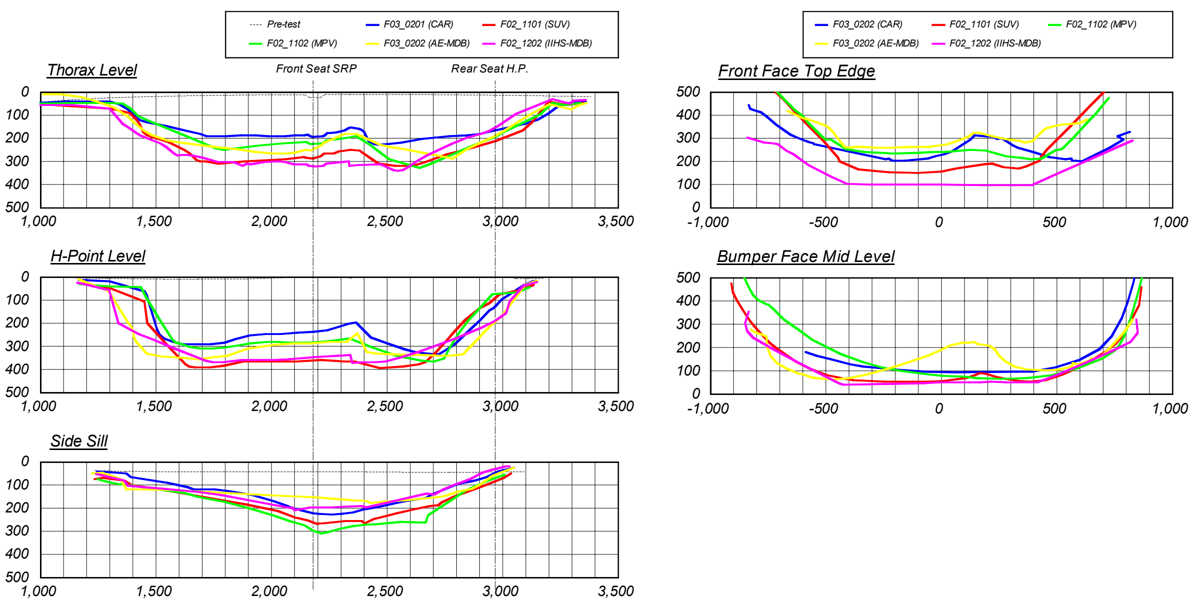

Figure 1. Deformation Profiles of Struck Vehicles (left) and Striking Vehicles (right)

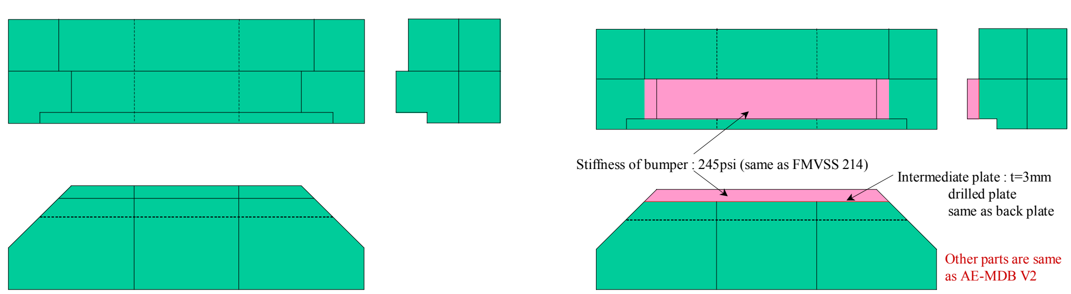

Figure 2. AE-MDB (left) and Japanese Prototype AE-MDB (right)

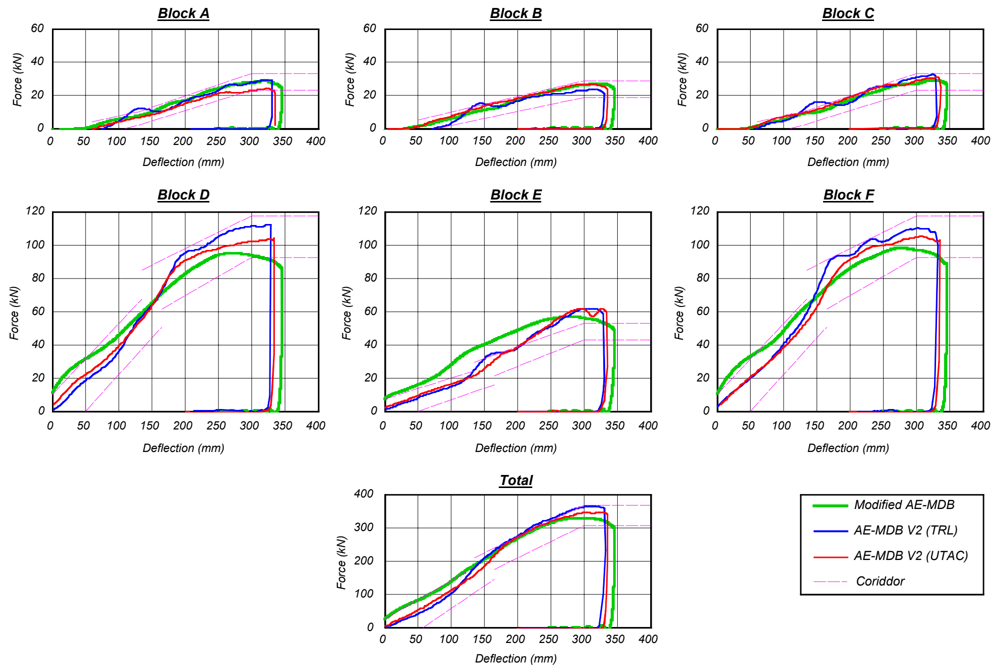

Figure 3. Characteristics of AE-MDB and Japanese Prototype AE-MDB

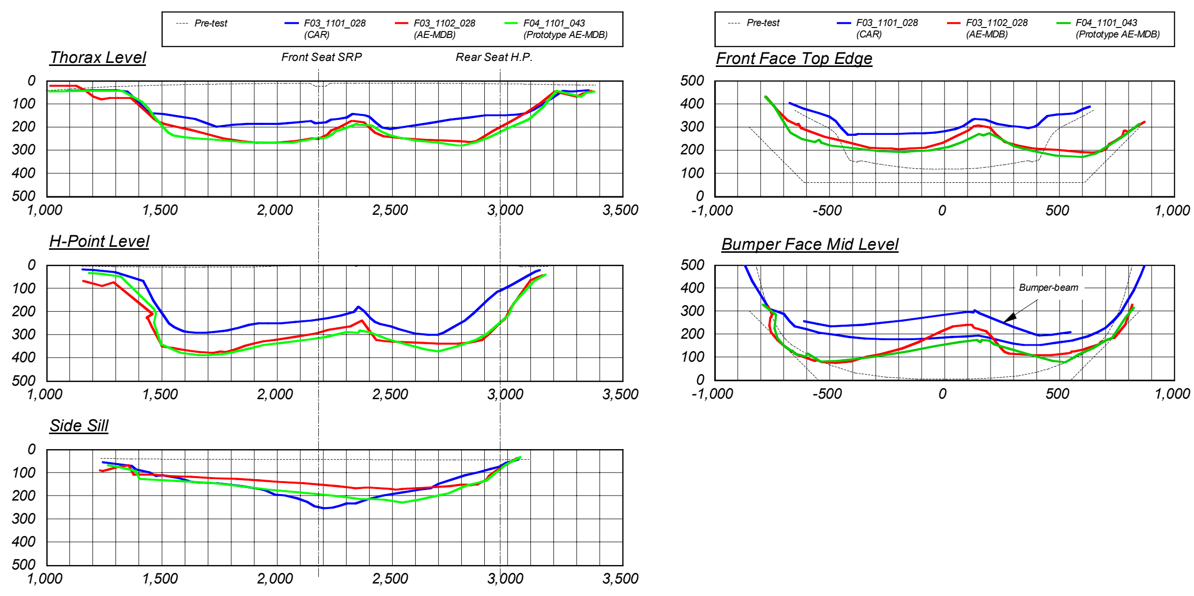

Figure 4. Deformation Profile of Struck Vehicles (left), AE-MDB and Japanese Prototype AE-MDB (right)

In order to decrease this variance, it was suggested to add a bumper to the barrier face. The improved barrier face was trial manufactured and tested for barrier characteristics verification test and for MDB-to-car crashes. The barrier face was improved by replacing the honeycomb sandwich structure at the protrusion of the bumper in the front end of the lower block with stiffer honeycomb to simulate the bumper (or bumper beam) that connects the left and right sections of the vehicle's front end (Fig. 2). This barrier face (modified AE-MDB) is characteristically stiffer at the entire lower block, as the malleable section in the lower block has been replaced with stiffer honeycomb. The lower centre section was found to be even stiffer due to the connection with the right and left blocks (Fig. 3).

Results of modified AE-MDB-to-car crash tests showed that deformation of the struck vehicle was closer to the deformation caused by car-to-car impact tests than that from the conventional AE-MDB. The absolute value of the amount of deformation, however, increased due to the greater stiffness of the barrier face (Fig. 4). The deformation profile of the bumper in the barrier face was similar to the deformation profile of bumper beam in the impacting vehicle in car-to-car tests.

Based on the above results, Japan believes that the next-generation barrier face for side-impact tests could be the AE-MDB with a simulated bumper (or bumper beam). The characteristics of the modified AE-MDB (with a simulated bumper) manufactured here will need to be improved to simulate the stiffness more appropriately within the corridor.

IIHS MDB Test Procedure

The IIHS MDB test consists of a stationary test vehicle struck on the driver's side by a moving barrier fitted with an IIHS side impact deformable face (version 4) ballasted to 1500 kg. The barrier has an impact velocity of 50 km/h (31.1 mph) and strikes the test vehicle on the driver's side at a 90-degree angle. The impact point of the barrier is dependent on the wheelbase of the test vehicle. For a vehicle struck on the left side, the impact point is defined as the distance rearward from the struck vehicle front axle to the left edge of the deformable barrier face when the deformable barrier face makes first contact with the struck vehicle.

The impact point is calculated as follows:

- If wheelbase < 250 cm, then impact reference distance (IRD) = 61 cm
- If 250 cm ≤ wheelbase ≤ 290 cm, then impact reference distance = (wheelbase ÷ 2) – 64 cm
- If wheelbase > 290 cm, then impact reference distance = 81 cm

The horizontal and vertical impact tolerances at the point of contact between the MDB and the vehicle shall be less than ± 25 mm.

The moving deformable barrier (MDB) is accelerated by the propulsion system until it reaches the test speed (50 km/h) and then is released from the propulsion system 25 cm before the point of impact with the target vehicle. The impact speed is clocked over a 1 m length of vehicle travel ending 0.5 m before the vehicle's release from the propulsion system.

The MDB braking system, which applies the test cart's service brakes on all four wheels, is activated 1.5 seconds after it is released from the propulsion system. The brakes on the struck vehicle are not activated during the crash test.

APROSYS plans to conduct an evaluation test program of the IIHS MDB and the AE-MDB, specifically investigating the possibility that one of these could be considered a worst case condition. This work is delayed due to specification of the AE-MDB not being finalised.

Transport Canada has conducted an extensive evaluation of the IIHS barrier for comparison with various vehicle to vehicle crashes. Residual deformation and dummy responses from the IIHS barrier were consistent with vehicle to vehicle tests (Arbelaez et al 2002). In addition to the IIHS barrier, Transport Canada evaluated the feasibility of the use of the SIDIIs dummy and concluded that the SIDIIs was suitable (Tylko et al, 2004).

NHTSA position - NHTSA decided early on that the barrier research would entail considerable amount of work before an acceptable design could evolve. However, in the interest of a quick evaluation of the suitability of the IIHS test, comparison testing was undertaken. NHTSA conducted five crash tests to compare the FMVSS No. 214 barrier to the IIHS barrier at FMVSS No. 214 and US NCAP speeds. Initial findings from this research concluded that the IIHS barrier stiffness distribution was not representative of pickups and SUVs analysed and the stiffness was relatively high compared to the Ford F-

150. It was also concluded that a higher profile is essential to simulate the then existing fleet in the early 2000.

NHTSA also noted in the early testing, the front-end design may not be quite suitable for crabbed test procedure and the sill engagement was totally absent which had the potential for making the side structures excessively stiff. However much research was necessary to properly design a barrier that would accurately simulate the characteristics of the fleet involved and at the same time not drive vehicle designs that will overly increase their side stiffness. NHTSA noted that AE-MDB and other designs would have to be looked at in more detail and a considerable amount of testing would have to be undertaken before zeroing in on an acceptable design.

VEHICLE TO NARROW OBJECT (POLE) TEST

The real world crash data clearly indicated that vehicle impacts into narrow objects was an area that needed to be addressed. There was considerably more consensus on the requirements of a vehicle to pole test procedure than for the MDB test. The following has been proposed:

- Moving vehicle to pole test.
- Oblique impact @ 75 degrees to the longitudinal plane of the test vehicle
- Speed of 32 km/h.
- Pole impact to evaluate at least head and thorax protection.
- Mid-sized adult male test device.
- Rigid pole diameter of 254 mm.
- Pole to span at least below sill height to above roof height.

The main area of discussion has been the diameter of the pole and how this relates to the wish to load the head and thorax simultaneously. These two body regions were identified as being the main causes of trauma in impacts into narrow objects. A larger diameter pole was expected to better achieve head and thoracic loading at the same time as well as resulting in a more repeatable test. All regions except the USA initially supported a 350 mm diameter pole. The current FMVSS 201 dynamic pole test utilises a 254 mm diameter pole as does the consumer crash testing procedure used in various countries.

APROSYS has analysed four pole tests with a Subaru Legacy vehicle (equipped with thorax and curtain side airbags) using WorldSID and ES-2re at 90 degrees and 75 degrees. The oblique condition for WorldSID resulted in reduced head and neck responses, while thorax and abdomen responses were generally higher than the 90 degree condition. For ES-2re all responses were generally lower in the oblique condition than in the perpendicular condition. The experimental program was extended by virtual testing study conducted by Subaru. This study found the pole diameter had negligible influence on dummy responses and structural deformations. The Subaru study found that dummy responses were more sensitive to variations impact characteristics under the oblique condition than in the perpendicular impact condition.

As reported elsewhere in this ESV, Transport Canada has conducted three paired tests comparing WorldSID dummy responses in oblique and perpendicular pole tests. Two additional paired tests in the oblique condition were also performed with ES-2re and WorldSID.

While WorldSID dummy responses were generally higher in the oblique condition, head responses were dependent on airbag effectiveness and head positioning. Increased thoracic and abdominal responses in the oblique test were found to be due to a forward shift in impact location and increased impact energy rather than impact angle.

It was observed that during oblique pole impacts the geometry of the ES-2re shoulder, by design, prevented compression of the shoulder and encouraged the shoulder and arm complex to rotate forward, leading to reduced rib deflection readings. WorldSID in contrast has a compliant shoulder which compresses laterally under load, the WorldSID ribs are consequently loaded more severely than the ES-2 ribs.

In the abdominal region, high abdominal deflections in WorldSID were not matched with high abdominal force readings in ES-2re.

NHTSA Position - A recent test program by the USA has shown that an oblique impact using a 254 mm diameter pole was able to load the chest and head simultaneously. NHTSA believes that an oblique impact angle would serve the safety need because the test is likely to result in wider inflatable head protection systems and thus protect occupants over a wider range of impacts with narrow objects and improve crash sensing for air bag inflation. In addition, NHTSA has determined that air curtain systems could be effective in preventing or reducing complete and partial occupant ejection through side windows.

NHTSA has found the oblique pole test to be beneficial for enhancing side crash safety because of the necessity of advanced air bag and window curtain designs that will become necessary to meet the oblique pole test requirements. NHTSA found the test procedure to be very repeatable in terms of impact line and closing speed. Additionally, in comparison to the FMVSS 201P procedure (perpendicular pole impact), the oblique procedure consistently produced significantly higher head injury measures. The head air bag system designed for the 201P test was found to be sensitive to seat track position and seat back angle changes. In one tested model, a failure to deploy the side airbags was observed. NHTSA contends that the sensors designed for the perpendicular test could not detect narrow object impact against the door when forward of the specified seating position.

This test procedure is intended to simulate real world side crashes with narrow objects such as trees and poles. The goal is to utilize an oblique pole side impact test procedure to evaluate countermeasures for head and chest protection in higher severity side crashes.

In narrow object side crashes, half of the seriously injured occupants are in crashes of delta-Vs 32 km/h or higher. Only 16% are in crashes with a principal direction of force around 90º while 63% are in frontal oblique narrow object crashes. The optional FMVSS No. 201, rigid pole side impact test is at 90º and an impact speed of 18 mph (29 km/h) while the oblique pole test is at 75º and 20 mph (32 km/h).

INTERIOR HEADFORM IMPACT TEST

The real world crash data indicated that head injuries were a significant part of side impact trauma even though the results of current regulatory MDB tests do not show a head injury risk. Consequently it was proposed that the IHRA harmonised side impact test procedures include a supplementary interior surface headform test to ensure that the potential contact points for head impact are evaluated.

The proposed IHRA interior surface test procedure is being based on research being carried out by EEVC WG13. The outline of the developing test procedure was presented by EEVC WG13 at the 2003 ESV conference. The key research that has taken place since the previous IHRA report has been a quest to have a highly repeatable test procedure with minimal scope for misinterpretation and have one that can adequately assess active head protection systems and give credit for them if they can be shown to give good all round protection. This research has now progressed to a point where EEVC WG13 has been able to release it for wider evaluation. WG13 has noted that some issues in the procedure will require confirmation as there are differing ways of trying to achieve the same goal neither of which appears to be significantly better that the other. It is acknowledged that the best way of clarifying these issues is via a wider evaluation, in a range of different vehicles and with different types of head protection system. These issues will need to be resolved before the procedure could be considered fit for consideration as a regulatory test procedure.

The headform used is the same as that specified for use in the US FMVSS 201 standard, using a free flight projection system. Key impact points are selected in a similar way to that used in FMVSS201 but defined within an area bounded by horizontal and vertical planes, based on defined limits of occupant seating position. In a desire to test 'worse case' impact positions the prime target positions can be moved based on structural considerations and the ability to test the particular point. The headform is a non-symmetrical impactor and the potential exists to incur multiple or secondary impacts with uncertified parts of the headform. Procedures are included to try and minimise these risks in a repeatable manner. It is noted in the procedure that it defines strategies to manipulate the headform, to reduce the risk of secondary impact and the fact that the use of a symmetrical headform could potentially reduce some of these noted problems. The potential of adopting an alternative impactor is mentioned but is not discussed, even though such a device is now included in other regulatory test procedures (EC pedestrian impact). It is noted that some restrictions are needed in defining potential contact zones and impact vectors to areas of the car that can be realistically contacted by an occupants head and ones that are 'sensible to evaluate'. The EEVC procedure now includes 'test limitation zones' and recommendations of impact vectors, based on simulations of a range of impacts. These will need to be validated.

The headform procedure, as proposed by EEVC WG13, includes a perpendicular pole test to evaluate active head protection systems. Currently it uses the

ES-2 dummy, without the rib extension modification. This procedure is based on that used by the EuroNCAP consortium which in turn is based on the optional pole test included in the existing FMVSS201. The IHRA suite of procedures includes an oblique pole test. Since WG13 has no experience with the oblique pole test the perpendicular pole test is included in this procedure 'until it can be shown that the oblique pole test is at least as stringent as is the perpendicular one'. Further details of this procedure are reported in the EEVC WG13 status report (Langner et al, 2005).

The biggest change and extension to the EEVC procedure, since the previous report, relates to proposals to evaluate deployed head airbags to ensure that protection is encouraged at all realistic occupant head contact positions, in addition to the single contact position evaluated in the full scale pole test. If adequate protection can be proven the procedure will allow reduced level (lower velocity testing) to vehicle structures that are covered by an active system, provided that full severity protection can be proven for all possible head positions when the system is deployed. An outline procedure had been detailed but will need to be validated before it could be recommended for regulatory application.

The EEVC work confines impact zones to those that are contactable by restrained occupants in side impacts. With front seatbelt wearing rates approaching 80% in the USA, NHTSA has agreed to look at the EEVC's "restrained-only zones" in the validation phase.

NHTSA FMVSS201 interior surface headform compliance testing for recent model vehicles shows very few test results exceeding the HIC(d) of 1000, the highest of these results only being around 1100.

APROSYS will evaluate two vehicles under the proposed interior headform test, with a focus on the rear seating position. BAST and German vehicle manufacturers will evaluate performance of rigid roof convertible interiors and supported structures.

OUT-OF-POSITION SIDE AIRBAG EVALUATION

Initially, it was agreed that NHTSA and Transport Canada would draft the evaluation procedure based on ISO TR 14933 and the NHTSA/Transport Canada research. Later it was agreed that the recent work under the chairmanship of the Insurance Institute for Highway Safety (IIHS) would also be taken into consideration.

In August 2000, the Side Airbag Out-of-Position Injury Technical Working Group (TWG) chaired by the IIHS released the *"Recommended Procedures for Evaluating Occupant Injury Risk from Deploying Side Airbags"*. The procedures were developed in response to a request by the National Highway Traffic Safety Administration (NHTSA) that industry develops public standards which their member companies would adhere to in the design of future side airbags. The TWG procedures recommend Anthropomorphic Test Devices (ATDs), instrumentation, test procedures, and performance guidelines that should be used for assessing the injury risk of interactions between a deploying side airbag and a vehicle occupant. The IHRA SIWG agreed to take these test procedures into the validation phase which may result in further refinements.

The TWG recommendations are intended to minimise the risk of out-of-position injury for that segment of the population believed to be at greatest risk, namely small women, adolescents and children. As such the ATDs deemed most appropriate by the TWG for the evaluation of risk include the SID-IIs, the Hybrid III 5th percentile female and the Hybrid III 6 and 3-year old child ATDs. A series of test procedures has been developed for each of the following inflatable system types: seat mounted airbags, door or quarter panel mounted airbags and roof-rail mounted inflatable systems. Each test is intended to quantify the level of risk to a designated body region and/or to evaluate the risk of a specific injury mechanism.

The fundamental premise of the TWG recommendations requires that the full complement of tests for a given system be carried out to ensure that a thorough evaluation of the system has been completed. The use of sound engineering judgment is strongly recommended to guide additional tests perhaps with slight variations, for systems demonstrating elevated risks.

NHTSA has been monitoring the risks to children both by closely analyzing real world crash data and also by undertaking statically testing side air bags with child dummies placed out-of-position in the test vehicles. To-date no serious injuries have been reported to children and small adults in the crash cases that have been investigated under NHTSA's special crash investigations. Since finalizing the test procedures and requirements developed by the TWG, many manufacturers have been following those procedures to check voluntarily if there are any such risks from their air bag designs. While no real world injuries have been observed, it is necessary to continue to monitor side air bag designs since changes are likely to occur as manufacturers change their designs to meet various requirements such as the IIHS and NCAP ratings and other requirements.

Some members of the IHRA SIWG are unconvinced of the benefit of OOP side airbag testing, particularly if they do not have any reported cases of serious injury attributed to this condition. IHRA SIWG members have not proposed any test conditions in addition to those developed by the TWG. Further evaluation of OOP side airbag tests is planned within the APROSYS programme.

DEVELOPMENT OF HARMONISED TEST DEVICE

The WorldSID Task Group initially had funding and development resources for the mid-sized adult male test device only. ISO Working Group 5 has now given a mandate for the development of a small adult female test device. APROSYS is contributing to the development of this dummy. Production 50th percentile WorldSID dummies have been available since March 2004.

CONCLUSION

Overall, the IHRA SIWG has made significant progress in harmonising research and drafting a set of side impact test procedures to maximise harmonisation with the objective of enhancing safety in real world side crashes.

The IHRA Side Impact Working Group has been successful in fostering a great deal of cooperation between members who have contributed resources and research outputs to specific objectives set by the working group. Most members aligned their research programmes with the work activities of the IHRA Side Impact Working Group.

Delays in some of the contributory work programs for the IHRA SIWG have limited the group's ability to make strong recommendations on detailed test procedures at this time. However, the large body of research data that has been generated and the basic principles of the proposed suite of test procedures are valuable outputs. There are several research programs already underway that will progressively yield data that may form the basis for decisions regarding suitable test procedures.

RECOMMENDATIONS

In its 7-year term, the group has drafted and partially evaluated a set of test procedures that might form the basis of a harmonised side impact regulation. The members believe that there needs to be:

- Completion of the evaluation work already in progress and an assessment of the suitability and efficacy of the proposed suite of test procedures.
- Continued coordination with the WorldSID Task Group and the IHRA BWG to evaluate harmonised test device(s).
- Recommendations for appropriate test devices and injury. This may require further validation testing to ensure that the recommended test procedures remain practical and that any test redundancies are identified and eliminated.
- Continued coordination with the IHRA Vehicle Compatibility group to ensure that solutions in one area do not result in disbenefits in another.
- Examination of the feasibility of improving side impact protection for occupants on the non-struck side and develop a test procedure to evaluate such protection.

As before, the success of this work is contingent upon the commitment of resources from IHRA members.

Subject to endorsement by the IHRA Steering Committee, it is anticipated that the test procedures could be submitted to the WP29 regulatory process and may be used as a basis to develop a new harmonised side impact regulation.

REFERENCES

Arbelaez, R.A.; Dakin, G.J.; Nolan, J.M.; Dalmotas, D.J.; and Tylko, S. *IIHS side impact barrier: development and crash test experience,* IMechE Conference Transactions: International Conference on Vehicle Safety 2002, 73-88. London, United Kingdom: Professional Engineering Publishing Ltd.

Dakin, G et al, *Insurance Institute for Highway Safety Side Impact Crashworthiness Evaluation Program: Impact Configuration and Rationale*, Paper No. 172, 18th ESV Conference, Nagoya, 2003.

Insurance Institute for Highway Safety, *Crashworthiness Evaluation Side Impact Crash Test Protocol (Version IV)*, December 2004

Langner, T; van Ratingen, M.R.; Versmissen, T; *EEVC Research in the Field of Developing a European Interior Headform Test Procedure*, Paper No 05-0158, 19th ESV Conference, Washington DC, 2005

Lund, A (Chairman, The Side Airbag Out-of-Position Injury Technical Working Group - A joint project of Alliance, AIAM, AORC, and IIHS), *Recommended Procedures for Evaluating Occupant Injury Risk from Deploying Side Airbags*, July 2003

Roberts, A; Ellway, J; *The Development of an Advanced European Mobile Deformable Barrier Face (AE-MDB)*; Paper No 05-0239, 19th ESV Conference, Washington DC, 2005

Roberts, A. et al, *The Development of the Advanced European Mobile Deformable Barrier Face (AE-MDB),* Paper No. 126, 18th ESV Conference, Nagoya, 2003.

Samaha, R.R. et al, *NHTSA Side Impact Research: Status and Update, Paper No. 492*, 18th ESV Conference, Nagoya, 2003.

Seyer, K., *International Harmonised Research Activities Side Impact Working Group Status Report*, Paper No. 579, 18th ESV Conference, Nagoya, 2003

Tylko, S; Dalmotas, D, *SID-IIS Response In Side Impact Testing*, SAE Paper Number 2004-01-0350

Van Ratingen, M.R. et al, *Development of a European Side Impact Interior Headform Test Procedure*, Paper No.138, 18th ESV Conference, Nagoya, 2003.

Yonezawa, H et al, *Investigation of New Side Impact Test Procedure from Japan*, Paper No. 328, 18th ESV Conference, Nagoya, 2003.

ACKNOWLEDGMENTS

APROSYS is a European Commission funded project TIP3-CT-2004-506503.
The IHRA Side Impact Working Group wishes to acknowledge the support of all manufacturers and organisations that supported programs with vehicles, parts and other resources:
Audi
Daimler-Chrysler
Fiat
Ford
Renault
Subaru
TMC Europe
Volkswagen
Volvo
WorldSID Task Group
European governments supporting the EEVC

APPENDIX

TEST PROCEDURE SPECIFICATIONS

The IHRA Side Impact Working Group has been evaluating a draft suite of complementary test procedures aimed at improving side impact safety.

The group has not yet concluded its work and is not in a position to provide recommended detailed test procedures. This appendix is intended to provide some information on the test procedures being considered and evaluated by the group.

It should be noted that, in many cases, tests may not have been conducted in strict accordance with the specifications described below. Most notably, different dummies may have been used. Other deviations from the nominal procedures may also have been used to investigate sensitivity of test results to changes in test parameters.

MOBILE DEFORMABLE BARRIER TO VEHICLE TEST

Two candidate procedures are under evaluation by the IHRA SIWG:

- the AE-MDB which is designed to represent a car or small SUV; and
- the IIHS MDB which is designed to represent a large SUV.

AE-MDB
The specification for the AE-MDB has not yet been finalised by EEVC WG 13. Further detail on the development of this barrier may be obtained from the EEVC WG13 status reports from ESV 2003 and ESV 2005 (Roberts et al, 2003 and Roberts et al 2005). AE-MDB tests conducted to date have been based on early drafts of this test procedure, with some deviations including different dummies and modifications to the deformable barrier face.

IIHS
The base specification used for evaluating the IIHS barrier has been the Insurance Institute for Highway Safety Crashworthiness Evaluation Side Impact Crash Test Protocol (Version IV). This procedure is available from the IIHS website www.iihs.org. Dummies other than the SID-IIs (specified in the IIHS protocol) have been used in testing.

VEHICLE TO POLE TEST

The IHRA SIWG has evaluated a range of pole impact conditions using both physical tests and computer simulation. The group agreed to consider the oblique pole test proposed recently by the NHTSA, but has also conducted perpendicular pole tests in an attempt to understand the advantages of the oblique configuration.

The oblique vehicle to pole impact procedure under evaluation was that proposed by the NHTSA in their recent Notice of Proposed Rulemaking (NPRM) [Docket No. NHTSA-2004-17694] available from the NHTSA website. http://www.nhtsa.dot.gov/cars/rules/rulings/SideImpact/index.html.

Oblique pole tests have been conducted with various dummies including ES-2re, ES-2 and WorldSID.

In addition, perpendicular pole tests have been conducted, with test specifications based on the EuroNCAP or FMVSS 201P procedures, again with some deviations from these specifications including the use of various dummies.

INTERIOR SURFACE HEADFORM TEST

The interior surface headform test being considered by the IHRA SIWG was developed by EEVC WG13 and is reported in detail at this conference (Langner et al, 2005).

OUT-OF-POSITION TESTS

The out-of-position test procedures under consideration by the IHRA SIWG are those prepared by The Side Airbag Out-of-Position Injury Technical Working Group (Lund, 2003). These procedures are available from the IIHS website www.iihs.org.