STATUS REPORT OF IHRA COMPATIBILITY AND FRONTAL IMPACT WORKING GROUP

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ABSTRACT

The compatibility work of this International Harmonised Research Activity (IHRA) area has focussed on research with the aim of improving occupant protection by developing internationally agreed test procedures designed to improve the compatibility of car structures in front to front, and front to side, impact. A secondary aim was to consider protection in impacts with pedestrians, heavy goods vehicles and other obstacles.

Compatibility is a complex issue, but offers an important step towards the better protection of car occupants. Group members continue to work on active research programmes, which have enhanced understanding. This report gives an overview of the broad thrust and approaches of the work and associated research. Progress has been made towards the prospects for improved frontal evaluation procedures, although side remains a complex area.

Potential test procedures are being considered and the current position is discussed. The key prerequisite is better structural interaction to facilitate strength matching to maintain passenger compartment integrity. Compatibility also requires other aspects, such as deceleration characteristics, to be considered. Although the complex nature of compatibility was recognised when work began, and there is significant remaining work, the prospects are that a worthwhile step forward is achievable.

INTRODUCTION

For many years it has been recognised that the protection of vehicle occupants is influenced, not only by the characteristics of the vehicle they are travelling in, but also by the characteristics of the vehicle they collide with. Historically, the emphasis was on mass alone being dominant. But in recent years, there has been a very marked change with structural interaction, passenger compartment strength and frontal force now seen as key compatibility factors to be considered. (Compatibility can be defined as the ability of a vehicle to help protect not only its own occupants, but other road users as well.)

When the International Harmonised Research Activity (IHRA) on compatibility was set up, it was recognised that separate regulations on front and side impact did not address compatibility and that international co-ordination of research programmes would be beneficial.

Originally there were separate IHRA groups on frontal impact and compatibility and reports by the chairmen of both the compatibility and frontal impact WGs were given at ESV 2001. At that point, the Frontal Group suggested a first step towards frontal impact harmonisation based on using both existing frontal impact tests (offset and full frontal).

However compatibility was recognised as a longer term effort and the IHRA Steering Committee decided that future activity in both areas should be combined within one group. (The European Union and the European Enhanced Vehicle-safety Committee (EEVC) led in these areas and has continued to provide the chairman.)

AIMS OF THE GROUP AND BROAD APPROACH

The prime aim of the compatibility work is to develop internationally agreed test procedures designed to improve the compatibility of car structures in front to front and front to side impact, thus improving the level of occupant protection provided in these impacts. A secondary consideration for compatibility is to bear in mind any implications for protection in impacts with pedestrians, heavy goods vehicles and other obstacles. The prime focus up to the end of 2005 will be on front to front impacts (car to car including LTV/SUVs).

Research will continue on improved understanding of side impact compatibility to define the possibility for a side impact test procedure or, at least, to ensure that any front test procedure helps or does not disadvantage side impact protection. Similarly, research will continue to help ensure that steps to improve compatibility help or do not disadvantage frontal impact self-protection.

In approaching this work, there is not a distinct boundary between research and the initial development of potential test procedures. Co-operation on research to achieve a better understanding of compatibility inevitably involves developing tools to understand and evaluate what is happening in impacts. Such tools, while initially used as part of the research programme, offer the core elements for the development of potential frontal compatibility test procedures and criteria.

Car-to-car and car-to-LTV/SUV crashes have been the main focus, with LTV crashes the dominant concern in North America. Test procedures and assessment criteria should be capable of evaluating the compatibility of a wide range of vehicles within these categories given different regional priorities which in turn reflect regional fleet and accident patterns. Vehicles of interest are covered in more detail later.

Potential users of any test procedures could range ultimately from researchers, manufacturers wishing to evaluate the compatibility of their products, to regulators. The judgements and the administrative process in considering the suitability of any proposed test(s) as a potential basis for regulation would be individual to each region. The work of the group is also reported at the ECE Working Party on Passive Safety (GRSP) in Geneva. A last possibility is that a consumer car testing organisation could choose to evaluate or even adopt a compatibility test procedure. Whatever the final outcomes, shared research fosters a common or high degree of technical harmonisation between regions and groups.

INTERNATIONAL CO-OPERATION

Membership, Participation And Meetings

Current members represent governments in Europe, USA, Australia, Canada and Japan and industry members are nominated by industry in Japan, Europe and USA. There have been relatively few changes in the representatives since the merger of the front and compatibility groups. The EEVC has included representation from both its Frontal and Compatibility groups but these have now merged.

Opportunities are sought to have common technical sessions with EEVC compatibility (WG15) meetings. The IHRA group also hosted a workshop on potential test procedures in May 2002. (This continued the tradition set in earlier years when the group had attended workshops of similar format on topics hosted jointly by EUCAR and EEVC.) The workshop included a wide range of inputs from industry and government research organisations (21 presentations, around 35 delegates from all member regions). Such workshops are very worthwhile in terms of providing and sharing new information. In addition the meetings programme has also allowed members to view the cars crashed in some of the EEVC tests and in the Australian test programme being carried out by DOTARS with Subaru and Ford Australia.

Informal links with the IHRA Side Impact group continue through some common membership. The first joint meeting with this group is planned immediately after ESV 2003.

Recent Meetings

Since the last ESV, there have been 7 meetings.

12th meeting 11-12 June 2001 (12 June jointly with EEVC WG15) UTAC France
13th meeting 24-25 September 2001 DOTRS Canberra Australia
14th meeting 28-29 February 2002 DOTRS/Ford Melbourne Australia
15th meeting 27 May 2002 London England
16th meeting 23-24 September 2002 BASt Germany
17th meeting 5-6 December 2002 TRL England
18th meeting 23-24 January 2003 TRL England
Workshop 23/24 May 2002 London

There is an open flow of information on findings between members with normally at least a day per meeting devoted to this.

Presentations were also made at GRSP in December 2001 when both the ESV 2001 frontal impact and compatibility papers were given to cover work until the groups were merged. A further presentation giving an update on the compatibility work of the group was given at GRSP in December 2002.

Co-operation Within Regions

Aside from the links through IHRA, there is a significant amount of co-operation within and between the regional organisations involved in IHRA. Some direct links are outlined below.

EEVC and European industry – Links through industry representation in working groups and potential industry co-operation with VC-COMPAT
Individual EEVC members – co-operation with Renault. VW, Ford and others
NHTSA – co-operation with Ford, Australia, Canada, Europe, MIRA, Cellbond, TRL, Japan, Honda and VW
Australia – co-operation with Subaru, Ford, Renault, NHTSA

Japan – co-operation with JAMA, Renault

Outline Of Members' Research Programmes

The IHRA compatibility group is fortunate in that its members are involved in active compatibility research programmes, often with cross-links, and the results are made available to the IHRA Compatibility Group as they emerge. These programmes inevitably reflect regional emphases and timetables but, along with the open and rapid exchange of findings, they have enhanced understanding and given useful research gearing. The research programmes of members are often much larger than the cross–linked activities mentioned earlier.

There is a clear consensus on key elements in compatibility, and the focus has increasingly been on the development/evaluation of the potential test procedures. This has grown in importance given US moves towards formulating national proposals for a first step on compatibility.

Reviews of data provided by members in specific areas have been carried out – structural surveys by Japan, fleet composition by NHTSA, accident analysis by Canada and crash test data by EEVC. (A summary of the review by Japan is at Appendix 1 and a summary of the review by NHTSA is at Appendix 2.)

In addition to earlier studies drawing on in-depth accident data, recent EEVC work has reviewed UK and German in depth accident sources to identify and examine those cases with implications for compatibility.

Vehicle-to-vehicle crash testing has included frontal tests by Japan, EEVC, European industry, JAMA and Australia using co-linear offset frontal impacts in car-to-car crash tests. In the US (NHTSA) frontal impact testing has focussed primarily on oblique offset collisions (30 degrees and 50% offset). NHTSA and some US industry tests have included a strong car-to-LTV element. While tests in Europe, Japan and Australia have focused on car to car impacts, recent tests in Australia and Japan have included some car to SUV tests. Side impact tests were also reported on by Canada and NHTSA.

Vehicle FE modelling remains a central element of NHTSA's approach and modelling also contributes considerably to EEVC and European industry inputs. NHTSA will have FE models for typical cars and LTV/SUVs to study vehicle interactions and to support the development of MADYMO models intended for use in overall fleet optimisation.

A range of barrier tests, mainly vehicle to barrier, has been carried out to assess cars and to support barrier and criteria development for potential test methods (EEVC, USA, Australia and Japan.) Data from NCAP tests have been used by members in Europe, the US (NHTSA) and Japan (JNCAP) and the availability of this type of data should increase.

Load cell wall element size has been investigated by EEVC, European industry, Honda, NHTSA and Ford.

The research programmes of EEVC, NHTSA and others have not been exactly in step. Overall however, research phasing issues have been generally associated with regional timetables, procedures, funding mechanisms and priorities. In Europe, there has been a gap between the first and second main EEVC formal research programmes; this was partially filled by the ongoing national research in France, Germany and the UK plus a short one year EEVC programme. (These common EEVC programmes have funding support from the European Commission and some EEVC member governments.)

POSITION RELATIVE TO OTHER TESTS AND REGIONAL PRIORITIES

Frontal Impact Tests (Self-protection) - Position

The IHRA Frontal Group dealing specifically with self-protection tests gave its last Status Report to ESV2001. It agreed that it would be desirable for two frontal impact tests to be adopted universally and that this could be achieved most easily by the universal adoption of the European ODB test and the "restrained/perpendicular" element of the US full width test. The first was to control intrusion resistance and the second to control occupant deceleration.

Since then, potential compatibility test procedures have been the focus of the work of the merged group. However some members have reported on research or views on moving towards introducing an ODB test for self-protection and this section covers the current position.

Japan is now investigating the ODB test for introduction into regulations in the near future.

NHTSA is exploring introducing a (56 or 60) km/h ODB test, using 5^{th} and 50^{th} percentile H3 dummies both with advanced lower legs, which it feels could offer a further benefit beyond that already being achieved given the vehicle manufacturers response to its use in the US IIHS tests.

Australia has already introduced into regulations both an ODB and full width rigid test. It feels that achieving this outcome would meet the first stage recommendation made by the IHRA Advanced Frontal Group at the end of its term.

The full frontal rigid wall test (with dummies) continues to be used in member regions other than Europe. At present the EEVC research programme includes a proposal for a similar test, with or without deformable element, which it believes can provide a high deceleration frontal impact test and a compatibility assessment.

Relationship With IHRA Side Impact - Position

The proposals being developed by the IHRA Side Impact group are based on providing side impact protection with the existing bullet fleet in mind, so their emphasis is on self-protection. However, any frontal compatibility test that encourages homogeneity and good interaction with sill and passenger compartment pillars is likely to be beneficial in side impact. Frontal compatibility tests may limit the Average Height Of Force (AHOF) and will encourage frontal homogeneity.

At present a set of requirements aimed especially at side impact compatibility is not being worked on. Nonetheless, the IHRA compatibility and side impact groups plan to have a common technical session on developments in their areas this year.

Regional Priorities And Timetables (Compatibility)

The current US emphasis is on a short term compatibility measure. Others are not planning rule making in the same time scale and the processes would differ. Nonetheless compatibility is expected to deliver useful benefits.

NHTSA is currently exploring the development of national rule making as a first step to improve compatibility between cars and LTVs (with the emphasis on SUVs). It is expected that the near term focus will be on a simpler step and quantifying the supporting case. A US decision could be made about moving to a legislative test and the favoured type of test approach as early as 2004.

The potential of a US move toward a near term rule making is both a challenge and an opportunity for this area of IHRA activity. Others are not considering rule making in that time frame, but it does bring the issue of a first harmonised step towards compatibility into sharper focus.

If the US were to favour a test based on a full width load cell wall, a closely comparable non-US proposal would be an EEVC full width test using load cells but with a deformable element.

In the interests of harmonisation, EEVC WG15 will consider early in 2003 whether a full width test with load cells, with or without a deformable element, should be a first step towards compatibility as well as providing a high deceleration frontal impact test.

This would be earlier than envisaged in the EEVC WG 15 work programme. (Its terms of reference had not envisaged a test proposal until September 2004. In theory, the VC-COMPAT research programme starting in 2003 might not reach a fully researched conclusion until much later, near the end of its three-year programme.)

Whatever happens, much would depend on both the US and others in the IHRA group remaining open to exchanging inputs through the process which could lead to a formal US rulemaking proposal in 2004. But, even were a NHTSA favoured choice to remain open to adjustment or amendment, links in the early stages of the process are the most important given the internal timetable of NHTSA decision points and procedures leading to any rule making proposal.

POTENTIAL COMPATIBILITY TEST PROCEDURES - NEEDS AND UNDERSTANDING

General

Any recommended compatibility test procedure would have to take into account the likely benefits (casualty savings) and bear in mind the likely implications for design changes that are judged practicable or worthwhile. The broad body of research/awareness on compatibility already influences some designs on particular models, for example design changes have been introduced to LTVs to improve structural interaction and allow improved energy management. Research by members has also included some purely experimental changes to vehicles introduced to investigate their effect on improving compatibility and how this relates to potential test criteria or measurements.

Introduction To Tables

In order to help discussions on the most appropriate choices of test procedure(s), the IHRA group, like the EEVC, has set out some of its thinking in tabular form. These are evolving rather than rigid documents.

Accidents To Address

Table 1 covers accidents which should be addressed in considering compatibility. There is a universal desire to address accidents involving cars (up to 2500 Kg GVW), followed in approximate order by MPVs and small SUVs, roadside obstacles, LGVs (light goods vehicles), large SUVs, sports cars (structural interaction may be more difficult), mini/super minis where there is a clear regional split (essential for Europe/Japan) and large cars (over 2,500 kg essential for US/Canada). There is least interest in car actions to interact with HGVs (only desirable in Europe). In terms of influence on other safety areas, there was a very strong interest in the effect on side impacts (excluding Europe) but generally much less on pedestrian accidents. It should be stressed that this does not reflect a formal political view and simply reflects regional technical judgements.

Table 1.
Accidents to Address in Considering Compatibility

	Essential	Very Desirable	Desirable	Not Important
Mini – Super Mini	E, J		A	C, US
Car	A, E, C, J, US			
Car >2,500 kg (GVW)	C, US		A, E, J	
Sports car	C, US	E	A, J	
MPV	C, J, US	A, E		
Small SUV	A, C, US	E, J		
Large SUV >2,500 kg (GVW)	C, US	A	E, J	
LGV	C, US	A, J	E	
HGV (Car actions)			E	
Roadside Obstacles (Car actions)	A, C	J, US	E	
Influence on others				
Side Impact	A, C, J, US		E	
Pedestrians	J	A	E, C, US	

(Note: LGVs are of least interest in Europe although some elements of any requirements applicable to SUVs in the USA might also be at least partially applicable to structural interaction aspects of light commercial vehicles in other markets.

Characteristics Required To Improve Compatibility

Table 2 sets out the characteristics which test procedures should seek to influence. Interaction height was universally regarded as essential, with frontal force, compartment strength and interaction area having strong support, followed by deceleration pulse.

Table 2.
Characteristics Required To Improve Compatibility

	Essential	Very Desirable	Desirable	Not Considered
Interaction - Height	A, C, E, J, US			
Interaction - Area	A, E, J	US	C	
Frontal Force	A, E, J, US	C		
Compt Strength (stability)	A, E, J	C, US		
Deceleration Pulse		A, E, J, US	C	
Mass				A, C, E, J, US

All felt that mass should not be considered as a characteristic to be controlled.

Understanding Of Compatibility

The universal understanding is that structural interaction, frontal force and passenger compartment strength are important issues for compatibility. Structural interaction is seen as a prerequisite and worthwhile in its own right. Mass influences stiffness as larger cars have to absorb energy in proportion to their mass in self-protection crash tests but the deformation distance does not increase in proportion. The result is that larger cars are stiffer and likely to absorb less energy in their own energy absorbing structure, the overall effect being a greater likelihood of passenger compartment intrusion in a less stiff car. Compartment strength is also a factor. The EEVC view is that intrusion (linked to these compatibility issues) is the dominant cause of fatal and serious injuries in Europe.

Currently, examples of poor compatibility can occur in many situations and such issues are applicable to all car sizes and mass ratios rather than just different masses.

There is naturally a mass ratio/momentum effect where the deceleration of a lighter car will be greater in an impact with a larger car even if near ideal compatibility is achieved. Although the dominant intrusion risk would have been addressed, it would be sensible to try to determine, for the longer term, an appropriate limit for passenger compartment deceleration reflecting occupant needs and the capabilities of advancing restraint systems to protect them. In addition, as compatibility improves and poor interaction, e.g. overriding/underriding, is reduced, decelerations in low severity accidents can increase, and this factor should also be borne in mind.

OUTLINE OF TEST PROCEDURES BEING CONSIDERED

The purpose of this section is to outline briefly the range of compatibility tests under consideration. It also includes in some groups the frontal impact (self-protection) tests in the harmonisation step contained in the report of the Frontal Group at ESV2001. Including both compatibility and frontal impact (self-protection) tests gives a broader picture in some cases; also some types of test are used in different ways or modified to evaluate aspects of compatibility and frontal (self-protection). The purpose of each test is noted in the list. (It is expected that members will cover individual test procedures in more detail).

The current focus is on considering tests or groups of tests that can address compatibility to help consider the most appropriate test procedures which could be further defined for wider evaluation to improve compatibility.

EEVC

Two families of tests are under consideration for compatibility and frontal impact.

A

56km/h	Deformable full width (structural interaction, also self-protection high deceleration frontal test)
64 km/h	ODB Frontal force (also self-protection, high deformation)
80 km/h	ODB Passenger compartment strength (no dummy requirements)

B

60 km/h PDB	Partner protection (structural interaction and frontal force), no dummy requirements
60/64 km/h	ODB Self-protection, high deformation
[56] km/h	Full width Rigid, high deceleration frontal (self protection)

Australia

Compatibility

Constant energy PDB – (variable speed, constant energy (equivalent to 48 km/h for 2.5 tonnes and no limit on speed e.g. 74 km/h at 1060kg), with dummy requirements - Partner protection, compartment strength (for smaller cars), frontal force

Frontal impact

56 km/h	Full width (high deceleration frontal self protection)
[60] km/h	ODB Self-protection, high deformation

(Note Australia considers that ODB may still be necessary for cars heavier than [1400kg] as these are not tested at high speed into the PDB.)

USA

Compatibility

Stage 1

56 km/h full width (rigid/deformable?) Compatibility criteria (including AHOF, initial force, force distribution)

This test is being researched for either rigid or deformable mode.

Stage 2

MDB based or functionally equivalent test procedure (Collinear/angled?, use of load cells. Possible criteria AHOF, force distribution, total force.)

Frontal

Stage 1

56/60 km/h ODB test (self-protection, high deformation)

Stage 2

MDB based offset test

Japan

Stage 1

55 km/h full width rigid/deformable

Stage 2

64 km/h ODB test and 80 km/h overload

Notes

(1) The PDB is an offset test.

(2) In high severity tests, speeds currently in use for the ODB range from 56 km/h as the lowest (regulation) speed to 64 km/h in consumer testing in JNCAP, IIHS, ANCAP and Euro NCAP. The full width test varies for belted occupants from 48 km/h to 56 kph speed depending on the region and whether it is in regulation or consumer testing.

(3) The use of load cell walls is a key factor in most compatibility approaches and could be an extra feature for all, certainly for total loads.

Characteristics of Candidate Test Procedures

Table 3 summarises views on the characteristics of each test procedure in whether and how far they address specific aspects. This will continue to evolve.

Table 3.
Characteristics of Candidate Test Procedures

	Full Width Rigid +LCW	Full Width Deform. + LCW	ODB @ 64 km/h + LCW	ODB @ 80 km/h + LCW	PDB + LCW @ 60 km/h	PDB Constant Energy + LCW @ 48 km/h min	Offset MDB + LCW @ 56 km/h
Interaction - Height	Yes [1, 2]	Yes [1]	Yes [3,9]	Yes [3,9]	Yes [4]	Yes [4]	? [5]
Interaction - Area	? [2]	Yes	No	No	Yes [4,10]	Yes [4,10]	Yes [5]
Generates Longitudinal Shear in F/A Vertical Plane	No	Yes [1]	Some	Some	Yes	Yes	?
Generates Longitudinal Shear in F/A Lateral Plane	No	Some	Yes	Yes	Yes	Yes	Yes
Frontal Force	Yes [1, 3, 6]	Yes [1]	Yes [3]	No [11]	Yes [7]	Yes [12]	Yes [14]
Compartment Strength	No	No	No [13]	Yes	No	Some [8]	Some [8]
Deceleration Pulse (average)	High	High	Low	N/A	Low	High [8]	Mid

[1] For limited deformation
[2] May be influenced by local projections
[3] May be influenced by engine bottoming out
[4] May be influenced by variation in honeycomb stiffness/only final value
[5] Depends on barrier face and influence of pitch
[6] May be influenced too much by inertial forces from structure
[7] May be limited by honeycomb strength
[8] Low mass cars
[9] May be influenced by load spreading
[10] Concern over effect with stiff cross beams on rotation
[11] May be calculated from Force/deflection trace
[12] Up to test severity, Also requires self protection
[13] Unless compatibility protection speed is reduced
[14] Unless inertial effects of accelerating honeycomb are not negligible and cannot be accounted for.

TEST PROCEDURES - RESEARCH FINDINGS AND EXPERIENCE

This section covers some of the recent work of members. It is meant mainly to illustrate some of the issues relating to test procedures but is not a summary of the range of work presented by members and others on various aspects of compatibility.

A significant factor since the last ESV has been the ongoing development or exploration of potential test procedures and improvements to the procedures themselves so that the test works as envisaged in the concept.

Individual tests are sometimes part of a broader family covering different aspects of compatibility or self protection; discussion here centres on the test or aspects where significant development effort has been made by individual members.

All test tools have advantages and limitations and some of these are mentioned elsewhere in the paper. Some of the advantages or limitations reflect characteristics which are inherent in the test approach taken.

There are two main types of fixed barrier used in compatibility tests, the full width test with or without a deformable element and the offset progressive deformable barrier PDB which is being studied by the EEVC (fixed speed) and the Australian (constant energy, variable speed) tests. Experience in one area can sometimes transfer to other test types.

Findings (Examples Of Incompatibility)

Vehicle-to-vehicle tests and examinations of specific accidents in in-depth accident databases continue to show examples where incompatibilities exist between cars. This reinforces the case for test procedures.

Full Width Rigid Barrier

This NHTSA proposal is based on a full width frontal rigid barrier test (FWRB) at 56 km/h, as used in the US and elsewhere, and uses a high definition load cell wall (LCW) to assess and control compatibility criteria such as the AHOF, initial force and force distribution measured on the LCW.

Past work has illustrated the basic approach where a load cell array allows the pattern of forces on the barrier to be monitored throughout the impact. This is used to determine potential assessment criteria such as AHOF, initial force or the vehicle's footprint on the barrier and the homogeneity of the distribution of forces within it.

The emphasis in the US work is mainly on the existing full width rigid barrier. (NHTSA has not excluded the deformable element as a possibility within a short term approach and has carried out some evaluation work including modelling.)

Interpretation Of Data (Method): The techniques used can include AHOF (weighting the AHOF to the height at which the higher loads are transferred), estimation of initial force and estimates of force distribution.

Related Work: An important element of NHTSA work has been using existing (rigid) load cell wall data and simulations to consider potential relationships between variables (AHOF and others) and a NHTSA aggressivity metric for driver fatalities. This work, partly linked to recent refinements in the method of statistical analysis, is giving a more detailed picture and a clearer indication of expected benefits in front and side impact; the results of the refined analysis should be available soon. US data shows a significant spread of AHOF for LTVs of around 400-650mm and an appreciable (400-550mm) but lesser extent for cars.

Load Cell Wall Size: An element in US and other past work has been load cell size. Many now use or are introducing higher definition load cell walls, typically using a cell size of around 125mm. This is felt to offer a reasonable high definition. Earlier European industry work (EUCAR) comparing a full width load cell wall using 125 mm and one using 50 mm dimensions indicated that 125 mm offered sufficient definition. A similar comparison is planned by NHTSA and Ford to check whether the smaller load cells give better definition, e.g. when determining the load footprint. (This may include an extra test with a deformable element.)

Full Width Barrier With A Deformable Element

This EEVC proposal is a full width frontal test at 56 km/h with a deformable barrier face (FWDB) mounted on a high definition load cell wall to assess and control structural interaction. A focus of this work is to control the force distribution measured on the LCW, to encourage the development of structures that behave in a more homogeneous manner. In the full EEVC family of associated tests, additional information would be generated from other tests to control (within a range) the peak force generated in a 64 km/h self-protection ODB test and a new high speed ODB test, possibly 80 km/h, purely to assess passenger compartment strength.

Recent work on the full width deformable barrier, FWDB, has concentrated on the ability to measure and quantify the homogeneity of forces generated by the car frontal structure. Tests have shown that multiple loads could be identified and, in a recent EEVC test, it could distinguish between a standard (unmodified) car and one modified to improve frontal homogeneity, which is consistent with better structural interaction seen in the modified car in a car-to-car test. However there are indications that the FWDB may not generate as much shear force across some types of structural connection as in a car-to-car impact.

Interpretation Of Data (Method): Data is collected in the same manner as the rigid full width test and each allow similar measurements such as AHOF. But an important element of EEVC work has been how to determine objectively the homogeneity of forces in the vehicle footprint as seen by the barrier. The current approach is briefly described.

A footprint area, provisionally based on the dimensions of the vehicle being tested, has been chosen for the development and evaluation of a possible assessment measure. The method used smoothes the forces from each load cell within the area to minimise the problem of structural members bridging adjacent load cells, and quantifies the variation between each smoothed load cell force and a derived target load level over the footprint. The work presented to date has shown how the assessment measure can be used to calculate the variation between rows and columns to give an indication of vertical and horizontal homogeneity. While still under development, this approach may offer an objective means of measuring the homogeneity of footprints.

An initial trial used the technique to consider 5 vehicles plus 2 modified vehicles and the results ranked these vehicles in a way that was considered to reflect their correct order in terms of the degree of expected structural interaction.

Barrier Improvement: Test data from the EEVC indicates that the revised composite barrier behaves in a similar manner to an earlier version where desired, and successfully solves a problem where preferential load paths could give high local loads and unload other load paths which would be significant in accidents. This problem was found with the earlier version which had a single deformable layer. (It would also apply to a rigid wall barrier). A new rear and much stiffer layer, segmented to match the load cells, allows such features, e.g. towing eyes, to penetrate it without generating unrealistic load paths. The outer layer continues to retain the original version's improvements over a rigid wall e.g. limiting engine inertial loads while minimising the effect on compartment deceleration pulse; a minimal effect is desirable, given that it is based on a self-protection test.

Progressive Deformable Barrier (Fixed Speed)

This EEVC proposal involves a 60 km/h ODB test with a Progressive Deformable Barrier (PDB) face. The aim of the PDB offset test is to control a car's structural interaction and frontal stiffness up to an equivalent energy speed (EES) of 50 km/h using measurements of the barrier's final deformation profile. (The PDB test is intended to be used in conjunction with the 60/64 km/h ODB test which would check that the force generated in that test is above a minimum value.)

The PDB generates higher shear in both vertical and lateral planes. Generating high shear may have advantages in testing structural interconnections between load paths. Examples of loaded or failed connections are found among the EEVC results. The pattern on the deformation face can reflect examples considered to have good and poor structural interaction although the EEVC assessments to date have been based on a visual examination of the barrier face post impact.

Interpretation Of Data (Method): The PDB approach seeks to control two aspects by interpreting the final deformation pattern on the PDB face post impact; firstly, depth of deformation level associated with a desired control on maximum force and secondly structural interaction by a variation of depth measurement to reflect local force variations which are in turn linked to a height criteria. (More uniform deformation would indicate a more compatible structure.) A proposed appraisal method is outlined below.

The barrier surface is first digitised. Separate areas from different regions of the face, which have the same degree of deformation, are grouped to give a total area for that deformation. A height is then associated with each grouped area. These zones of comparable deformation are then compared against the desired deformation limit and a height criteria. The control on height of these areas reflects an approach analogous to the height of the cumulative resultant forces in the impact – comparable to AHOF but arrived at in a very different manner. The vehicle has to have a good performance in both deformation (force) and height criteria. The boundary chosen for evaluation excludes the edges of the barrier face, especially the outer edge which suffers additional deformation as the vehicle rotates around the barrier during impact. Work is ongoing to determine the best way to deal with these derived measures in a numerical appraisal method leading to an overall result. While the barrier surface can reflect structural interaction and numerical values have been derived, generating objective results reliably from barrier deformation measurements seems more difficult in this approach.

Recent EEVC work explored whether a load cell array behind the PDB barrier could be used to give information on the homogeneity pattern of loads being imposed by the vehicle on the barrier surface in the impact. However the depth and stiffness of the barrier spread the loads and allowed bridging of load cells. The EEVC did not see this approach as viable.

Barrier Improvement: The current version of the PDB includes a front sheet (now thickened). This improvement was introduced on the PDB face to resist localised tearing found on some tests. This made interpretation of the deformation surface difficult, when it occurred. Tearing should not be a problem on compatible cars.

PDB (Constant Energy Test)

This Australian approach uses the fixed PDB barrier in a constant energy test, the aim being to stiffen small cars and soften large cars, to control compartment strength and improve structural interaction. The test configuration is with 40% overlap, dummy criteria and load cell wall behind the barrier.

Interpretation Of Data (Method): The aim is to control the maximum total force and potentially AHOF, variation between individual load cells (rows and columns) or the PDB deformation profile. Australia considers that the latter aspects need investigation to see which is best at predicting structural interaction or controlling override/underride. The interpretation method deals with the same issues as the EEVC, although Australia may not have experienced load cell difficulties to the same extent.

The test appeared able to correctly assess (visually) an incompatible small car (soft) and a compatible small car but did not predict overriding in the impact of two medium size cars.

Mobile Deformable Barrier

This approach offers the ability to provide for mass and carry out angled (oblique) offset tests. The US regards a mobile deformable barrier (MDB), in conjunction with existing tests, as offering improved coverage of US accidents and in a later phase could be used to address frontal impact and compatibility. The MDB, if considering frontal impact self-protection, would not ensure that all the energy can be absorbed in the vehicle frontal structure unless the MDB mass is increased for heavier vehicles.

The US view on recent tests is that the LCMDB (MDB with load cells) crash tests are somewhat harsher than vehicle-to-vehicle tests but that an MDB can reasonably replicate vehicle to vehicle crashes. Tests in Japan indicated bottoming out and over-ride of the MDB affecting the results and suggested that the current MDB face should be investigated. Australia independently examined a PDB faced MDB but test conditions did not allow a conclusion to be drawn. (However, in principle, Australia would not be opposed to such an approach as a possible test.)

Past European MDB tests had encountered a proneness to over-ride and the EEVC has not developed any active interest in the MDB as part of its research programme. There are options of one or both moving (MDB and vehicle). There are however practical considerations such as high test speed (if one moving), test laboratory capability and site approach distances (one or both moving). As the impact point changes during the impact, it may make filming difficult. It would not equalise frontal force but the use of load cells offers information on frontal force and interaction which could be controlled.

Passenger Compartment Strength

This EEVC test is intended to assess the strength of the passenger compartment to ensure that it is strong enough to resist the forces imposed by impacting cars. It would not require instrumented dummies.

A recent repeat 80km/h compartment strength test in Europe gave very similar results in both tests.

Japan reported on a series of tests using two minicars which included an 80km/h passenger compartment strength test. In broad terms the end of crash force levels of the tested minicars (with different characteristics) were of a comparable order for minicar-to-ODB 64km/h, minicar-to-large car tests (55km/h each) and the 80km/h passenger compartment strength test. (One minicar, which was considered to have good compartment stiffness/strength showed a higher force level in the compartment strength test.) In these tests Japan concluded that both good structural interaction and compartment stiffness are important for minicars.

POTENTIAL CASUALTY REDUCTION BENEFITS

Compatibility issues can arise in all frontal impacts and are not only those associated with high mass ratios as historically imagined. This widens the scope for potential gains if successfully addressed by test procedure(s).

Recent EEVC work indicates a significant potential for worthwhile safety gains in frontal car-to-car impacts. (This EEVC work examined detailed frontal impact accident cases in UK and Germany in which car to car impacts dominate.) Analysis of the data suggests that, in car-to-car frontal impacts (11 to 1 o clock), approximately half of the fatalities and 2/3rds of serious injuries would experience some reduction in injury risk as a result of improved compatibility.

This recent EEVC work using detailed accident cases has been a valuable step given the difficulty in identifying and disentangling the effect of detailed aspects of car design in national statistical databases.

Recent US work suggests worthwhile benefits in front and side impact in the latest US work, mainly LTV-to-car.

These two individual studies are given as illustrations. The EEVC study is small and more work would be needed before an overall estimate of casualty benefit could be made.

Although this work is based on analyses in specific regions and accident patterns and circumstances can differ, it seems reasonable to expect that other regions could see benefits in comparable accidents. More work would be appropriate to quantify this.

In some cases, improvements aimed at compatibility should give benefits in other types of accidents e.g. some single vehicle accidents, although these have not been included in the benefit estimates.

However, in other cases, considering a widening of the potential benefits might reduce regional differences in accident patterns which in turn determine regional priorities. For example Europe has a low number of SUVs but could consider whether overall benefits would be usefully enhanced, if compatibility measures were to address commercial LGVs. (Some can be comparable to LTVs but practical compatibility measures might have to be limited to structural interaction only.) The US could give car-to-car impact an extra priority for harmonisation reasons, even though a measure that quickly tackles LTV-to-car impacts is its prime concern.

OVERALL POSITION / SUMMARY

General

IHRA has proved effective at bringing researchers together for the open and early exchange and critique of findings, offering useful research gearing compared to individual regional work and helping generate co-ordinated forward research.

The close links with the EEVC group and workshops work well. Industry involvement has also been a healthy aspect.

EEVC, NHTSA and other research programmes have different emphases but considerable common interest. Where there is a different emphasis, this usually (and naturally) reflects regional interests or concerns. Nevertheless, these may limit the degree to which harmonisation is possible technically in the later stages of implementing some compatibility aspects. (This is separate to more immediate issues.)

Whatever the level of short or long term success in achieving common outcomes, shared research in IHRA helps foster technical harmonisation between regions and groups.

There is consensus on structural interaction, passenger compartment strength and frontal force, which are now seen as key compatibility factors to be considered. Good structural interaction is seen as a prerequisite and a valuable step in itself.

Benefits In Casualty Reduction

Recent work points to worthwhile benefits in EEVC and NHTSA.

Test Procedures / Technical points

Test procedures are sometimes part of a broader family intended to cover different aspects of compatibility (and sometimes also self-protection).

A significant factor since the last ESV has been the ongoing research to explore and develop potential test procedures and improvements to the procedures themselves.

In researching a full width wall test (with a deformable element) for homogeneity, a problem with preferential load paths was encountered and addressed in developing the current deformable element. This could be a relevant factor in any comparison with a full width rigid wall for compatibility testing.

The full width rigid and the full width deformable barriers with load cells are potentially very close in terms of overall deceleration pulse if considering their use as a self-protection test. Work would be appropriate to compare the latest version of the deformable element and the full width rigid in more detail, given the issues raised on a phase one approach.

The PDB barrier generates higher shear in the lateral and vertical planes. Generating high shear may have advantages in testing structural interconnections between load paths. Examples are found in the crash test results. It also generates the greatest deformation, being an ODB test.

A full width test with deformable element generates some shear.

A homogeneity assessment method for the full width (with deformable element) load cell wall data has been suggested and results derived. A PDB assessment has relied on a visual interpretation but an approach is being worked on, using an analysis of the final deformation pattern, in terms of deformation (force), uniformity of deformation (homogeneity) and height criteria. Numerical values have been derived, although currently generating objective results reliably seems more difficult with this approach. Work continues on all methods.

EEVC experience is that the load profile and time history is not reliably available from a LCW with a PDB. This points to a difficulty in determining detailed initial or intermediate structural interactions if desired.

A potential MDB test is longer term but there could be merit in reconsidering the deformable face currently used.

Test Procedures / General Considerations

There are several potential test procedures to address compatibility and frontal impact requirements. All have advantages and limitations and these are reflected in an earlier table and discussion. Some advantages or limitations reflect characteristics which are inherent in the test approach taken.

To achieve both harmonisation and benefits in all regions, ideally any test (including any phase one test) should be capable of catering for fleet and accident differences. Such tests should deliver benefits in LTV-to-car as well as car-to-car crashes.

The aim of some tests is to control more than one aspect within the same test e.g. force as well as homogeneity so a vehicle would be expected to have a good performance in both respects. Others address a single aspect per test.

In considering a phase one approach, factors might include:

- Is phase one likely to provide sufficient benefits.
- Is it likely to move vehicle design in the right direction.
- Can it address the needs of each region.
- Can it be sufficiently developed or be implemented in the timeframe(s) for interaction with the US.

All procedures remain possible tests for future use in later phase(s) but a possible phase one test assumes more importance given the US moves towards a national requirement.

In Europe there is currently no full width test but there is a recognition (in EEVC) that this test would further increase self-protection because it is a demanding test for occupant restraint systems. Additionally a full width test has potential for compatibility assessment.

Canada, Japan and the US support a first step towards compatibility using the full width rigid/deformable test with load cells. Australia believes that Europe should introduce such a test for self-protection and is open to its use as an initial compatibility test subject to further research. The EEVC will consider such a test for a first step towards compatibility.

At a minimum, such an approach provides for an improvement in structural interaction by addressing the geometric alignment of structural loads, through the assessment of average height of force. Such an approach also has the potential of providing a homogeneity assessment of the crash loads and some measure of initial structural stiffness. Further research is needed to determine the value of such measures in the assessment of compatibility.

In the end a judgement has to be made between different approaches if there is to be a harmonised phase one test defined on a common basis. It must also offer the possibility of early implementation to NHTSA. In any event, whatever decisions are taken, IHRA and NHTSA should remain open to mutual changes when evolving test procedures.

Specific Test Requirement For Side Impact

The immediate priority is tests for compatibility in front to front conditions. But improving some aspects of vehicle fronts may also help in side impacts. However, a comprehensive set of test criteria aimed specifically at enhancing compatibility for side impact would be more complex and would be a further stage, if achievable.

Summary Of Overall Position

There is a consensus on important factors affecting compatibility, although regional priorities do vary, reflecting differences in fleet and accident patterns. All the potential test methods have advantages and limitations; their characteristics are viewed by the group on a collective basis. All remain potential test procedures but, especially given the US move towards a national requirement, a harmonised first step could deliver worthwhile benefits. If a common phase one approach is to be taken, the test criteria and requirements should remain open to adjustment so that they reflect the needs (car-to-LTV and car-to-car) in all regions. The implementation of any procedure may also be a factor for individual regions.

CONCLUSIONS

Frontal compatibility test procedures have somewhat different characteristics. All test procedures have advantages and limitations and could be developed for a two stage approach.

It was recognised in the previous Status Report to ESV that improving frontal structural interaction would be beneficial in itself and a pre-requisite to enable strength matching to be effective in providing for compartment survival.

The US consideration of near term rule making is both a challenge and an opportunity. A harmonised IHRA first phase test is achievable. A recommendation would have to take into account several factors including offering advantages or benefits to all member regions and a judgement of the level of readiness of the test.

Canada, Japan and the USA support a first phase using a full width barrier rigid/deformable test. Australia believes that Europe should introduce such a test for self-protection, and is open to its use as an initial compatibility test subject to further research. The EEVC will consider such an approach for a first step toward compatibility.

The substantial effort for development of test procedures should not be underestimated. Even a phase one approach addressing structural interaction would be the subject of further development including the precise definition of the assessment criteria.

The broad range of tests would still remain candidates for a later phase.

A special test or requirement is some way off for side impact though some aspects of a frontal test should help.

In Brief

Compatibility work is showing promise. The growing understanding and the considerable development work on potential test procedures gives real encouragement. This is reinforced by very recent European and US research quantifying worthwhile benefits in addressing compatibility. Reaching a first phase test that can address the needs of each region will require further effort but offers the potential for early gains.

ACKNOWLEDGEMENT

The spirit of co-operation and contributions of all those who have been involved in the work of the IHRA Compatibility and Frontal Impact Working Group are gratefully acknowledged. In addition, thanks is due to many others who made presentations either directly to the group or at meetings to which the group was invited.

APPENDIX 1

RESEARCH FINDINGS

Structural Survey (Japan)

<u>**Geometrical Data Analysis Japan:**</u> The geometry of vehicle structures was investigated based on the data provided by the EU (74 models, 1997), US (97 models, 1993-2000), Australia (35 models, 1999) and Japan (113 models, 1998). Vehicle models in the data were selected according to their sales numbers. The measurement locations in frontal structures are shown in Figure 1.

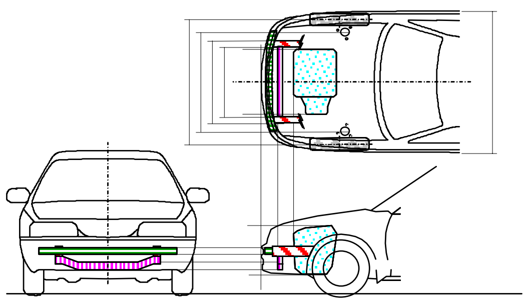

Figure 1. Measurement locations in frontal structures.

The number of SUVs in relation to the overall number of vehicles differed among countries; EU (11%), US (38%) and Japan (38%), though the designs of many SUVs in Japan were derived from car models. The EU (average 1228 kg) and Japan (1322 kg) had a similar mass distribution. The US had a heavier weight distribution (1634 kg), while that of Australia (1343 kg) ranged between the US and Japan.

The structural interaction will be affected by the geometry of front structures. The ground heights of structures are summarized in Table 1.

In all regions, the locations of SUV front structures or engines are higher than those of cars. For example, the top and bottom height of longitudinal member front ends which were averaged for all regions, were 506 and 386 mm for cars, and 545 and 429 mm for SUV, respectively (Figure 2).

Table 1.
Summary Of The Geometry Of Structures (Unit mm)

egion	Vehicle	N	.ength	Mass (kg)	Width	Bumper		Longitudinal member			Lower cross		Engine		Side sill	
						ottom eight	op eight	ottom eight	op eight	ist. etwee ng.	ottom eight	op eight	ottom eight	op eight	ottom eight	op eight
EU	Car	66	4236	1175	1685	381	532	410	519	1024	-	-	185	807	215	336
	SUV/LTV	8	4503	1664	1785	382	624	451	554	1088	-	-	268	896	297	431
	All vehicles	74	4265	1228	1696	381	542	414	523	1029	-	-	194	817	224	346
US	Car	60	4674	1459	1756	380	525	380	502	1081	-	-	185	803	281	341
	SUV/LTV	37	4916	1917	1839	451	630	432	550	890	-	-	299	1002	428	486
	All vehicles	97	4767	1634	1788	407	565	401	521	1007	-	-	229	879	336	397
Australia	Car	19	-	1117	-	402	516	407	527	-	239	296	-	-	231	330
	SUV/LTV	16	-	1610	-	526	619	458	559	-	367	449	-	-	386	491
	All vehicles	35	-	1343	-	462	566	430	542	-	297	366	-	-	302	403
Japan	Car	69	4224	1236	1686	414	497	362	490	968	244	299	248	732	193	342
	SUV/LTV	44	4043	1457	1692	477	564	413	533	938	278	339	303	815	221	368
	All vehicles	113	4166	1322	1689	439	525	381	507	957	257	314	269	764	207	355
Total	Car	214	4388	1269	1707	389	521	386	506	1021	243	298	207	780	234	338
	SUV/LTV	105	4588	1659	1762	465	608	429	545	926	312	381	298	902	331	438
	All vehicles	319	4444	1397	1724	413	550	400	519	991	270	331	236	817	267	373

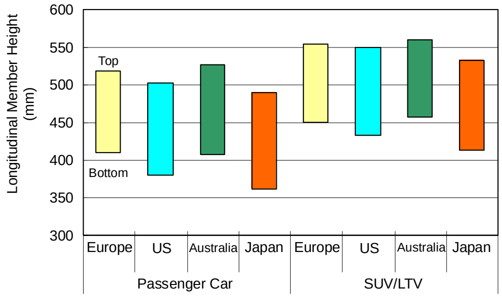

Figure 2. The height of front end of longitudinal member.

The average section heights (top – bottom) of the longitudinal member front ends were similar between cars (120 mm) and SUVs (116 mm). Therefore, the longitudinal member of SUVs was on average slightly higher than in cars. The heights of the lower cross members were obtained from Australia and Japan data. From Australia data, the ground height of the lower cross member of SUVs (average 367 mm) was lower than the bottom of longitudinal members of Australian cars (average 407 mm), which may be effective to help prevent overriding. The widths of the engine as well as the lateral distance between longitudinal members are greater for transverse engine cars than longitudinal engine cars.

In side impacts, the structural interaction between an impacting vehicle's longitudinal members or engine and the struck vehicle's side sill will be significant. When comparing the height of front and side structures, the side sills of cars (bottom 234 – top 338 mm) were lower than the bottoms of longitudinal members of cars (386 mm) as well as the cross members of SUVs (Australia 367 mm.)

Geometry analysis reveals clear differences in the height of structures between cars and SUVs. Therefore, it can be concluded that the distributions of vehicle mass and geometry of front structures in each region depend on the number of SUV registrations in a given area.

It should be also noted that measuring methods can differ among regions. From comparison of data for the same vehicle models measured in different regions, there were large differences in the measured values among regions. For one thing, the measuring location and definitions differed from region to region. Thus, for accurate comparison of vehicle geometry, standard measuring procedures must be developed and used in every region.

APPENDIX 2

Fleet Studies (USA)

In examining the data provided by the working group members, it is seen that there are appreciable differences in the fleet composition among the different regions represented on the IHRA working group. The United States (and Canada to a similar but lesser extent) have significant and growing LTV/SUV sales (50 percent) and population (37 percent) whereas Japan and Europe have a much smaller SUV population, (around 6 percent). The combined segment of the European fleet that is similar to the U.S. light truck and van category accounts for 17 percent of that fleet, i.e., about half the percent of LTVs in the U.S. fleet. However, this segment is the fastest growing segment of the European fleet. Australia has an intermediate situation with LTV/SUV sales about 26 percent. Japan has an appreciable population of minicars (19 percent) and minivans (13 percent.)