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# STATUS REPORT OF IHRA VEHICLE COMPATIBILITY WORKING GROUP (as given to ESV 2001)

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## ABSTRACT

The International Harmonised Research Activity (IHRA) on compatibility 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 aided better understanding. The report of the group 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 candidate test procedures have been identified 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 significant work remains, the prospects are that a worthwhile step forward is achievable.

## BACKGROUND

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 has been on mass alone being dominant.

The International Harmonised Research Activity (IHRA) on compatibility was one of the six Working Groups set up following the Melbourne ESV (May 1996), as 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.

The European Union and the European Enhanced Vehicle-safety Committee (EEVC) were asked to be the lead for compatibility and, in turn, the United Kingdom was asked to provide a chairman for this working group. Following the setting up of the group, the first meeting was held on 5 June 1997.

## INTRODUCTION

The aim of the work was 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 front and side impacts. A secondary aim was to consider the protection in impacts with pedestrians, heavy goods vehicles and other obstacles. In practice the focus of research has been on the main aim.

Compatibility is a complex issue, and it was recognised in the last status report (ESV 98) that there was no clear way of achieving the goals by the next ESV in 2001. Nonetheless, improved compatibility was seen as a major next step forward towards improving the protection of car occupants.

### List and Locations of Meetings

There had been three meetings prior to the last ESV.

Since then there have been eight meetings plus two ad-hoc meetings. These are listed below.

Fourth meeting: 13-14 October 1998, Turin, Italy
Fifth meeting: 18-19 February 1999, London, UK
Sixth meeting: 6-7 July 1999, Berlin, Germany
Ad-hoc meeting: 28-29 October 1999, San Diego, USA
Seventh meeting: 1 February 2000, Madrid, Spain (plus joint meeting with IHRA Frontal Group on 2-3 February)

Ad-hoc meeting: 30 March 2000, Rhode, Germany
Eighth meeting: 14-15 June 2000, Crowthorne, UK
Ninth meeting: 16-17 November 2000, London, UK
Tenth meeting: 15-16 January 2001, Paris, France
Eleventh meeting: 15-16 February 2001, Wolfsburg, Germany

**Participation, Membership and Format of Meetings**

Since the last ESV participation in the group has widened considerably, including a full complement of industry delegates. Current members represent governments in Europe, USA, Australia, Canada and Japan plus industry in Japan, Europe and USA. A list of those recently involved is attached at appendix 1.

Members of the IHRA front and side impact groups are often also members of the compatibility group. Sometimes, attendance has been widened further, in a fairly flexible manner for specific meetings.

The format of meetings, since the last ESV, has typically been a day of technical presentations on the latest research or a chosen topic, followed by a day for wider discussion. Meetings are often linked to other activities as outlined later.

**Specific Co-operation with Other Groups**

Two meetings have had close links with the IHRA Advanced Frontal Impact Group, one being an ad-hoc meeting to respond to a specific request from that group and the other involving a common technical session.

Four of six recent meetings have involved a common technical session with the EEVC WG15. Links with EUCAR (European Council for Automotive Research and Development) work include invitations to two joint EUCAR and EEVC workshops. (The EEVC and European industry representatives also head these projects.)

## SUMMARY OF RESEARCH

### Work Plan

This was broken down into three broad categories.

- Problem definition (accident studies, analysis of real life accidents and vehicle structural surveys)
- Determination of key characteristics (crash testing and modelling which are linked to the behaviour of different aspects of car design, the likely role that they play in ensuring good compatibility and their relative importance)
- Assessment methods (methodologies which address individual or a range of aspects of compatibility and which could be used as the basis of test procedures or regulation)

Although some, or parts of, earlier elements in these categories have been completed, some members still have ongoing work on these topics or are likely to return to them in later activities. It is envisaged that work will continue through 2001 and beyond.

### Research Projects/ Members' Programmes

The IHRA compatibility group is fortunate in that its members are involved in active compatibility research programmes, the results of which are made available to the IHRA Compatibility Group as they emerge. A breakdown is not given on a member by member basis as many will report on their own programmes.

### Discussion of Research Approaches

The broad picture is one of ongoing research. This section groups the research contributed by members under general technical areas. Many aspects e.g. fleet studies, accident studies and geometric studies reflect a similar approach but crash testing and modelling reflect, to some extent, different individual concerns or views related to regional fleet or accident patterns.

**Fleet Analysis**: The broad picture is clear in different regions, although criteria (vehicle characteristics) used to define vehicle categories can vary, as can the depth of data.

**Accident Analysis**: NHTSA, Australia, Japan, EUCAR and EEVC have examined national data to study injury risk and vehicle aggressivity. Some members have also looked for links between injury risk and other vehicle characteristics. This work continues along with the examination of in-depth accident data.

**Structural Analysis**: The analysis of the geometrical characteristics of vehicles research has been similar in different areas essentially using the same twenty seven parameters. The numbers of vehicles assessed are NHTSA 97, EEVC 74, Australia 39 and Japan 113.

Some members (EEVC, EUCAR, NHTSA and Japan) went on to make use of other structural characteristics such as stiffness, using crash test and other data.

Note: In compatibility discussions, the term stiffness is frequently used to describe the resistive force generated by structural deformation and the deceleration of "massive" components throughout the impact rather than the slope of the force/deflection trace.

**Vehicle to Vehicle Crash Testing (Front)**: The research approach in Japan, EEVC, EUCAR and Australia has been to use co-linear offset frontal impacts in car to car crash tests whereas, in the US (NHTSA) frontal impact testing has focussed on oblique offset collisions (30 degrees and 50% offset). US tests have included a strong car to LTV element; overall, tests by NHTSA plus in-company tests from the US industry representative included car to car, car to SUV and car to small pick-up and LTV. The US industry work also included the use of a blocker beam to improve structural interaction. Outside the USA, the effort on LTV/SUV tests has been limited with a total of three tests in EEVC and Australia. In Europe (EEVC and EUCAR) and Japan, the focus has been on car to car tests (50% overlap co-linear). The EEVC, EUCAR, Japan and, in future, possibly Australia include cars experimentally modified in various ways. The degree of modification varies, but the spectrum ranges from changes to explore compatibility e.g. ride height, increased mass to structural changes aimed at improving it.

**Vehicle to Vehicle Crash Testing (Side):** Side impact tests (car to car) have been carried out by NHTSA, EEVC, EUCAR, Canada plus (barrier to car) tests by Australia. IIHS also reported on some of its side impact work. Australia examined changes to the trolley characteristics. EUCAR and NHTSA tests examined the height and mass of the bullet vehicle. EUCAR also explored stiffness and impact angle.

**Vehicle Models (FE):** The EUCAR programme has used simulation-based studies by manufacturers using their own "in house" FE models of cars. Some FE modelling studies have also contributed to the EEVC research, including a parameter study for side impact. NHTSA will have FE models for 4 typical cars and 6 LTV/SUVs to study vehicle interactions and to support the development of MADYMO models intended for use in overall fleet optimisation. All of these programmes have used both front and side models.

**Vehicle Models (MADYMO) and Optimisation:** Both EEVC and NHTSA have close links on the MADYMO models being produced, as a basis for exploring overall optimisation; TNO are producing the models of individual vehicles (6 to date). However the current and planned US work programme is to take this initial exploratory work appreciably further and will produce a detailed fleet model with representative vehicle types to analyse a variety of crash scenarios and vehicle classes to determine localised and overall injury patterns for prospective fleet mixes.

**Vehicle to Barrier Crash Tests (Fixed Barrier):** The largest number of tests are those available from the USNCAP (NHTSA) programme using a full frontal test. EEVC has also carried out full frontal tests in its research, but EEVC tests differ in that they use an additional thin 150mm deformable layer. In addition EEVC, EUCAR and Japan have drawn on offset barrier test results. EEVC and EUCAR tests were at 64 kph. Some work in EEVC and EUCAR looked at a different multi-layer ODB barrier; Japan also looked at various ODB barrier faces.

**Vehicle to Barrier Crash Tests (Load Cell Wall Data):** There has been a strong common strand, particularly in NHTSA and EEVC work, in looking at the output from load cell wall data, to better understand compatibility. In the US this has been primarily from the USNCAP (NHTSA) full width barrier tests (478 usable cases). The EEVC has used research data from a full width load cell wall (with a deformable layer) plus data from Euro NCAP type offset impact tests. This can help identify relevant vehicle characteristics, their importance and, in turn, how they might best be evaluated and controlled in test procedures. (Note: NHTSA has also added load cells to its MDB trolley.)

**Vehicle to MDB Testing:** Work in the US has a strong and continuing element of MDB testing. One significant factor for NHTSA was the ability to carry out oblique offset tests and a desire to specifically include mass. Some MDB tests (offset but co-linear) have also been carried out in EEVC and Japan. Two NHTSA LCMDB (load cell mobile deformable barrier) tests have recently been carried out, one co-linear full frontal impact and one offset. Results are not yet available. Australia will include car to MDB tests (using a two stage deep barrier element) and a preliminary test to ensure that the element does not bottom out has been conducted (50% overlap, 50 km/h, car and trolley mass 1750 kg each). Australia will use the NHTSA LCMDB to examine crash forces in MDB to car tests.

**Overload Testing:** The EEVC, EUCAR and Japan have all carried out work on overload testing. The EEVC and also one of EUCAR partners independently explored the possibility of using a car from a previous full width and offset impact respectively; if successful, the ability to re-use a car could offer reduced costs for such a test method. Although EEVC has not yet done a single impact overload test with a new (undamaged) car, EUCAR members and Japan have carried out several tests with new cars. EUCAR has also carried out one test with a re-used car. Within EUCAR an attempt was made to model overload performance using an FE car model.

## SOME FINDINGS OF RESEARCH

This section concentrates on broad findings, including implications for test procedures.

### Fleet Analysis /Fleet Data

**Fleet Composition:** There is an appreciable difference among the fleet composition between different regions. The USA (and Canada to a similar but lesser extent) have significant and growing LTV/SUV sales (50%) and population (33%) whereas Japan and Europe have a much smaller SUV population, (around 5%). Australia has an intermediate situation with LTV/ SUV sales about 25%. Japan has an appreciable population of minicars (16%) and minivans (11%).

**Mass:** The average masses of new passenger vehicles in Japan and Europe are close (about 1150 and 1200 kg respectively for new registrations) and the US has appreciably heavier passenger vehicles, especially when LTVs are taken into account. The midsize US car group is 1360 to 1590 kg and LTVs are typically 400 kg heavier (and growing) than the average US car. In contrast 85% of European sales are dominated by cars up to the C/D class which has an average mass of 1325 kg.

Average mass and the spread in mass has increased to varying degrees, a tendency reported by the US, Japan and EUCAR. This trend would be more pronounced in markets with growing LTV/SUV populations.

### Accident Analysis

Accident analyses studies using broad national data highlight the mass influence, but this is not altogether surprising as mass is one of the very few relevant and simple parameters which can be clearly related to national statistical databases. This does not mean that other effects may not be present but they may not be readily disentangled; they may be more subtle or complex or change in parallel to mass to some degree.

An aggressivity metric (AM) derived by NHTSA for driver fatalities indicated metric ranges from 1.2 to 4.3 in the U.S., depending on the specific category of the LTVs and its size. Cars ranged from the least aggressive 0.61 for subcompacts to 1.39 for large cars. NHTSA analyses highlight the mass effect; but, in the US, they have also shown that, for the same mass, LTVs are more aggressive than conventional cars. For example, a compact pick-up is approximately 50% more aggressive than a similar mass midsize car (i.e., AM 1.65 vs. 1.12). In examining these two categories, geometry and frontal stiffness are obvious factors which could influence this aggressivity.

Australian and Japanese data gives a similar broad picture of a higher risk with SUV to car impacts. (Japan gave an overall ratio of 3.1 for SUVs.)

The indications (in US analyses) are that the relative differences in aggressivity will persist in the future, even though the absolute levels of risk are falling considerably due to improved self protection provided by passenger vehicles.

In the US and Australia, the higher aggressivity of pick-ups, vans and SUVs, compared to cars, can also be seen in both front and side impact. The evidence of a target car mass effect, in side impact, is less clear in a EUCAR analysis. Australian research identified a bullet vehicle size effect in side impact, where the bullet vehicle was large. It was not clear whether this was due to mass or other effects. The EEVC found that the bullet vehicle bonnet height had an influence on injury risk in side impact.

The general aggressivity of LTV/SUVs and their high sales makes them the dominant interest in the USA. But in some markets the presence of these vehicles is low and the car is the dominant presence.

While EEVC broad statistical research identified mass in car to car impacts and did not successfully disentangle some car to car factors in broad statistical analysis, examples of poor compatibility were often found when examining individual collision cases.

In their accident analysis of car to car impacts, EUCAR found that mass and compartment stiffness are important in frontal impact, whereas height difference between bumper and sill is of main concern in side impact. In frontal impacts, other items like front-end stiffness and differences in bumper height were not identified as having direct influence. Since these factors are indirectly responsible for compartment collapse, they nevertheless were taken into account within the EUCAR project to ensure compartment integrity.

Intrusion is seen as a significant cause of serious injury. This was commented on by some members and is seen in accident data linking overcrushing to more severe and fatal injuries.

The importance of controlling structural interaction is still open to quantification, but its importance as a factor is accepted.

**Structural Analysis**

The EEVC analysis examined the geometric features of the resistant front and side elements in the car body, as inferred from vehicle measurements. It concluded that there are some characteristics of the car body which influence the geometric properties, such as: engine orientation, number of doors or car body type. But, in general terms, there is no linear relationship between the size of the vehicle (defined by its mass and length) and the geometry of the main resistant elements.

Based on the statistical analysis for the geometry of structural elements, the average heights of the top and the bottom of the longitudinal member front ends are similar in Europe and Japan.

**Vehicle to Vehicle Crash Testing (Front)**

In general, this work illustrates how poor structural interaction can result in less efficient use of energy absorption in tests with existing cars, which can result in passenger compartment excessive crush and points to the benefit of having good structural interaction.

NHTSA frontal tests showed good correlation between the aggressivity metrics of the striking vehicles and the measured injury criteria in the struck vehicles. (It might be a factor that the vehicles examined are mainly LTV/SUVs which have geometry and structural differences e.g. higher structures compared to cars.)

In car to car tests exploring the sensitivity to non-ideal structural interaction, there were numerous examples of over-riding, including identical cars but with artificially induced ride height changes. These differences varied from 160 to 100 mm but other computer modelling of impacts suggests that smaller height differences can also cause over-riding or explain it when encountered in real impact tests. Over-riding is typically associated with a greater risk of intrusion (mainly of the over-ridden car) and inefficient use of the car's energy absorbing structure with less ability to absorb energy.

Tests with better frontal connections tend to have more homogeneous frontal deformation and avoid over-riding although, changing the ride height can lead to over-riding even in cars that would be expected normally to interact well.

Japan carried out car to car tests using different car sizes and one of its conclusions was that for a small car the deformation and injury risk to the driver can be underestimated in an ODB test compared to that in a small car to medium car crash.

**Vehicle to Vehicle Crash Testing (Side)**

The general picture including Australian trolley tests and some EEVC simulation work is that, apart from test speed, geometry had the greatest effect and that mass and stiffness had appreciably less effect.

The EUCAR work examined a number of aspects; the results indicate that there was not a mass effect, sill interaction helped and initial and local stiffness may have had some influence. The angle of impact was not seen to have an appreciable effect for this test configuration. (No judgement is made on how these would translate over to higher impacting vehicles where the structural interaction may be less.)

For side impact the NHTSA tests showed modest correlation with the aggressivity metric or mass. (Most bullet vehicles were LTVs). However, NHTSA is exploring mass and height effects further in side impact tests with modified vehicles.

IIHS tests showed evidence of the front structure of the bullet vehicle bending sideways, when the target vehicle was moving; resulting in reduced effective frontal stiffness of the bullet vehicle.

The IHRA side impact group’s thinking on key factors was outlined and considered in discussions.

**Vehicle Models**

Modelling work has mainly been in support of crash test work or as a supplement. Some of the results are alluded to in those sections.

The work on MADYMO modelling has been available to the group via the EEVC. In addition the US fleet model continues to be constructed with trials of limited aspects to date.

**Fixed Barrier Load Cell Wall Data**

This section covers barrier tests using essentially current test procedures. (Overload tests are discussed later).

A full width barrier impact (with load cells) is intended to measure the homogeneity of the distribution of force generated across the front of the car. It is hypothesised that improved homogeneity will lead to improved structural interaction between impacting cars. In general an ODB could demonstrate variations in vertical homogeneity, although rotation prevents its use to measure variations in the lateral plane. Overall such data could be also be drawn on to control force time history.

The load cell output patterns from NHTSA and EEVC full width barrier tests clearly show the build up and pattern of crash forces, and longitudinals, which are the most localised elements for LTVs, are clearly seen.

NHTSA's early work has not found clear links between the aggressivity metric and general geometric/ stiffness criteria, while its more recent efforts have shown the influence of the average height of force (AHOF) for segments of the fleet on aggressivity. Particularly, the AHOF of SUVs has been shown to have a clear influence on the increase in risk of death to drivers in its collision partners. Generally AHOF data derived from full frontal barriers can reach 700 mm for large LTVs but can be below 400mm for small cars. There is appreciable variation within each car size and LTV group. The spectrum of differences in AHOF for cars is around 140 mm, i.e. greater than the artificial height differences which can give rise to over-riding in otherwise identical cars in crash tests.

NHTSA continues to look at potential criteria and EEVC work is examining potential force and uniformity criteria, which would indicate homogeneity. This work is at a very active research stage in determining if further interpretations of the load cell data are meaningful. The question of an area of interaction has also been raised.

It is possible that side and front compatibility may have different stiffness requirements. In side impacts, only the initial frontal stiffness of the bullet car, say for the first 100 mm, may be of relevance.

The measurement of crash forces on a load cell wall in order to encourage better matching of vehicles has been covered in presentations of data. No decisions have been taken but the EEVC reports that adequate interaction between different sizes of cars appears feasible and their frontal stiffness does not have to be radically different.

The barrier tests in the EEVC and Japan explored a number of different faces. The EEVC reported that the ADAC barrier loaded the front of the car in an unrealistic way. Japan also explored rigid and compound barriers, in an attempt to reproduce the over-riding seen in car to car crashes. The vertical structural connections were exercised by these tests. However, they did not reproduce over-riding in a realistic way.

It is not yet clear whether or not the generation of shear, in the frontal structure, is a necessary requirement for the test. The full width test being investigated does not generate significant shear in the front structure. If the generation of shear is necessary, a different test will need to be considered. A possibility is an ODB test with a deep deformable face. EUCAR has carried out tests with a progressive deformable barrier (PDB). However, so far, no objective assessment criteria have been suggested for such a test. Furthermore, the progressive barrier has the potential disadvantage of increasing the energy absorption capacity of the face used in the ODB test.

**MDB Testing**

A fixed mass MDB test allows mass ratio to be taken directly into account. Potentially it can generate a realistic delta v and vehicle acceleration pulse. It may also properly represent an angled approach.

The NHTSA view is that an MDB test would offer the best overall coverage of US accidents. NHTSA's goal is to develop a test procedure that can be used to evaluate both frontal crash protection and vehicle compatibility. While MDB testing will continue to be a strong element in its research, NHTSA is not fundamentally opposed to a fixed barrier approach if it can provide equivalent protection. Recent more discriminating data may reduce the angle necessary to be reproduced in an oblique impact below the 30 degrees previously considered.

Concerns aired about an MDB include its proneness to over-riding, repeatability and reproducibility issues (especially for a type approval regime). If the MDB mass is less than that of the test car, there is the possibility that a car may be developed with insufficient energy absorption capacity within its frontal structure. However, this potential limitation might be addressed in a number of ways. The mass of the MDB could be ballasted for vehicles heavier than the nominal MDB weight. Alternatively, the energy absorption requirements may be controlled by requirements in the full frontal test. Regarding the reproducibility and repeatability, NHTSA feels that the MDB test, with the car stationary, is as repeatable and reproducible as existing regulatory MDB-based tests. NHTSA also feels that proneness to over-riding, if realistic, may not be a bad feature if such behaviour can be eliminated by vehicle designs.

EEVC and Japan both observed over-riding in their MDB tests. In Japan this occurred with the three types of barrier face explored. In all cases of over-riding, broader comments were that the MDB over-rode the car and over-riding was greater when the car was stationary.

At an earlier meeting, held in response to a request from the Advanced Frontal Group, the MDB was not seen as an essential pre-requisite to control compatibility. Although individual views differ, the overall position is that advantages are currently outweighed by disadvantages for a compatibility test.

An MDB may not be the only way of changing the severity of impact with mass. If required, the speed of fixed barrier tests could be adjusted.

A load cell equipped MDB is being tested by NHTSA and results are still emerging. A wider issue for the MDB would be the difficulty of choosing MDB characteristics, such as mass and height, for a world market given the variations that exist in different markets. It may be necessary and desirable to try to ensure that vehicles in individual markets share a reasonable burden in compliance.

**Overload Testing**

This is a severe test aimed only at assessing passenger compartment strength and is carried out with an uninstrumented dummy. Two overload test options were explored.

**Overload Test Using a Previously Impacted Car:** EEVC results indicated that such a test should be carried out on a new undamaged car – the problem being linked to the trial use of a previously impacted car which gave an unrealistic loading pattern. EUCAR had also carried out one test with a pre-impacted car. Again, this two stage test suggested that pre-deformed load paths behave differently in a second crash.

**Overload Test (Single Impact on New Car):** This test is aimed solely at assessing passenger compartment strength and currently no further criteria have been considered. Such a test would need to be practicable.

The impression was that for some cars tested the occupant compartment did not collapse to the extent that might have been feared, although it was thought that some of these may have been close to or beginning to collapse. However in one or more cases (small car and minicar) the car passenger compartment showed appreciable evidence of collapse. (It must be stressed that this comment is based only on a broad impression, not a systematic comparison of Japanese and EUCAR results.) Three repeated overload tests resulted in different compartment deformation extents and failure modes. This raises questions but an overload test or overload criterion could still be part of a compatibility evaluation.

The key point is that such a test is challenging but potentially achievable, given that some cars seem to have performed better than might have been anticipated.

In any overload test procedure, an important aspect would be to ensure that the collapse test mode(s) are appropriate and generate structural behaviour that is related to behaviour encountered in car to car impacts. It would also be necessary to specify appropriate pass criteria, including the definition of passenger compartment strength. Further research will be necessary on the test conditions and methodology, even if a sympathetic approach is taken to the criteria.

An open question is whether, in some cases, sufficient evidence of overload capacity can be determined from lower speed tests (64 km/h). Results reported at the EUCAR crash test workshop indicated that, in some tests, evidence of compartment strength could be obtained from a 64 km/h ODB test. However, in the case of the car tested in Japan, the force level in the overload test was higher than that in the test at 64 km/h.

Overall, there seem to be too many uncertainties in using a damaged car to determine strength given the variables and severity of the test; there are variables even in a test on a new car. Currently there are no proposals to pursue a two impact approach within IHRA, EEVC or EUCAR.

## OVERALL POSITION / OVERVIEW

### Basic but Important Points

Compatibility requires a unified approach if it is to be effective; compatibility benefits, whether partial or full, cannot be delivered without consistent requirements for key characteristics within a vehicle fleet. In brief, doing nothing is not an option; it would both deter progress and lose opportunities.

Test procedures should seek to promote a unified approach within and between markets. (The ideal test(s) should not require adjustments to take into account, often appreciable, differences between regions and changing trends within markets.)

Compatibility approaches discussed in the group have focussed only on technical safety aspects and the vehicle sizes and categories present in regional fleets.

### The Broad Position Following Research to Date

The active research programmes of members have advanced understanding of this complex issue. Although compatibility remains work in progress, and significant work remains, the research underpins potential steps forward.

The varied composition of the fleet and accidents in different regions is significant and slower long term trends are also apparent.

Mass is a feature that broad statistical research clearly identified in national accident data. While such broad analyses have not successfully disentangled other factors, some tend to change with mass, e.g. stiffness, and some are difficult to identify, where analysis is limited by the small size of data subsets when detailed configurations or criteria are considered. Nonetheless broad statistics show LTV/SUVs to be more aggressive than cars of equivalent mass. Geometry and stiffness are factors at work. Also, examples of poor structural compatibility were often found when examining individual collision cases.

The influence of substantial compartment intrusion in serious and fatal injuries is recognised. Preventing this should give corresponding benefits and would be largely independent of any debate on the precise contribution to injury from specific mechanisms, whether involving mass, stiffness or other factors.

Overall, progress has greatly enhanced the prospects for improved frontal evaluation procedures, although side remains a complex area.

Relevant aspects for frontal impact are:

- Good structural interaction
- Maintaining passenger compartment integrity by ensuring that the passenger compartment is sufficiently strong so that the impact energy is absorbed in the frontal structures of the impacting vehicles
- Predictable performance of car structure in crashes
- Control the deceleration time histories of impacting cars to protect against deceleration induced injuries

All agree that good structural interaction is a key prerequisite in tackling compatibility. Reasons include the link between over-crushing or structural intrusion in serious and fatal injuries plus instances of poor interaction in accidents and crash testing. In addition engineering common sense suggests that good structural interaction is the foundation on which to build consistent and controlled interaction of vehicles. Improved structural interaction should help in all impacts.

### Test Procedures

The research has concentrated on advancing the fundamental understanding that should lead to test procedures. The following outlines the possibilities, but translating these into detailed proposals will require further work and development, followed by an evaluation phase.

**<u>Frontal Test procedures</u>:**
Possible candidate test procedures have been identified for a frontal test. There is a broad range of candidates; the issues relate to the choice of procedure and research on definition, refinement and evaluation.

Broadly speaking the candidate approaches are:

- Full frontal barrier test with load cells, with or without a thin deformable element
- Offset deformable barrier (ODB) with load cells
- Overload test (passenger compartment integrity) using ODB (This is linked to any approach using the bulkhead concept.)
- Barrier elements to explore shear if needed, e.g. a progressive deformable barrier (PDB)
- MDB has been explored or suggested in various modes both offset (co-linear or oblique) and full frontal (co-linear). (Latest US MDB is fitted with load cells).

Nothing has been ruled out, at present. The first three are independent but complementary. Specific test aspects are discussed below.

Load cells: A load cell based approach, to control structural interaction, looks promising. Work on average height of force (AHOF), derived from load cell data on fixed barriers, is showing some links with accident data. But area based load cell requirements are currently also considered necessary. Other variations are also being explored as possible criteria; in addition, requirements for homogeneity of the vehicle front will be necessary. Resolution of load cells is an open issue.

Overload test: Irrespective of the approach to shared energy management, a bulkhead capability is necessary. Evidence of this could be provided by an overload test or, possibly, by evidence of this capacity in other tests. The criteria for an overload test are to judge the passenger compartment strength prior to collapse. Pass criteria have yet to be defined.

Energy management: No decisions have been taken on the optimum approach to energy management in impacts. Achieving a common limit on maximum force for the front structure for all cars would offer the greatest degree of compatibility in terms of optimising combined deformation, thus giving the most favourable outcome in compatibility terms. Moving towards this degree of compatibility means that, at least some, small cars should be stiffer than at present. For larger cars, some would need to be less stiff, with increased crush depth. Issues will include the degree to which energy management should be required, whether this should also be reflected in less severe impacts, the extent to which this should apply to large cars and LTVs and how to set a single or progressive level that has the best balance within or between fleets.

MDB: Although offering other potential benefits, the use of an MDB is not seen as being essential to control compatibility. Individual views differ but most currently consider that the advantages are outweighed by the disadvantages.
NHTSA sees the MDB as the focus of its research into test procedure development. For self protection in frontal and oblique impacts the use of an MDB may be necessary. This stems from a desire to include mass and oblique impact effects. Concerns aired about an MDB include the observed over-riding in crash testing, reliability/repeatability issues (especially for a type approval regime), and the possibility that, in some test scenarios, larger cars might be less able to absorb their own energy which is necessary for compatibility. (Note: In the MDB test, the MDB mass could be adjusted for vehicles heavier than an established level to ensure that they are able to absorb their own energy.)

The NHTSA view is that an MDB test would offer the best coverage of US accidents overall. Its goal is to develop a test procedure that can be used to evaluate both frontal crash protection and vehicle compatibility. NHTSA is not fundamentally opposed to a fixed barrier approach if it can provide equivalent protection.

Note: An MDB is not necessarily the only way of changing the severity of impact with mass; if required the speed of fixed barrier tests could be adjusted.

Next step: A key near term focus should be the better understanding of how load cell data is to be interpreted and defined as test criteria for good structural interaction. Such a test could form a first stage and also constitute a fundamental building block, underpinning any additional requirements.

**Side Test Procedures:**

While progress has been made towards the prospects for improved frontal evaluation procedures, side remains a complex area.

However, frontal proposals that encourage homogeneity and good interaction with sill and passenger compartment pillars are likely to be beneficial. (Frontal tests may limit AHOF and will certainly encourage frontal homogeneity.)

Key elements affecting aggressivity in side impact are known.

- Geometry has the greatest effect
  Mass and stiffness have an appreciably lesser effect.

- Vertical intrusion profile
- Stiffness distribution of bullet vehicle
  Only frontal stiffness (distribution) of bullet vehicle in say first 100mm is relevant.
- Promote sill engagement
- Distributed loading of occupant
  Front structure of bullet vehicle must not produce a thoracic lead.

The IHRA side impact proposals will be designing side impact protection with the existing bullet fleet in mind and with the emphasis on dealing with self protection.

Currently, it would be difficult to define an envelope of desirable vehicle characteristics which was sufficiently flexible, given the range of possible variables and their complex interactions. Taking such a step, would require more research to define requirements and be confident that it would deliver a benefit. Any future requirement would adapt to, rather than influence, cars meeting the envisaged side impact requirements, currently being developed in the side impact group.

A speculative possibility is that it might be possible to set aside or optimise the first part, say 100 mm, of frontal crush to enhance side impact compatibility; the crucial forces for frontal compatibility do not occur until a later deformation stage for most cars.

**Issues (Research/ Technical)**

The outline and detail of candidate test procedures have to be developed. (Research should deliver proposals and key criteria) This would be followed by a period of wider evaluation.

Are deviations from existing frontal fixed barrier tests necessary? In particular, is a deformable element essential in the full frontal barrier test? If so, what are its appropriate characteristics?

What should be the definition, e.g. mass and structural characteristics, of an MDB test, if it were to be an international approach?

If a pragmatic decision is not possible on an appropriate approach to energy management, there may be a need to develop a mechanism to support the best choice within and across fleets. Factors have not been discussed but some, potentially complex, might include safety benefits, cost, environmental aspects or others.

A brief study could check for desirable or neutral effects on interaction with truck under-run devices and roadside furniture.

## GENERAL ISSUES

The focus has been on moving towards a consensus on key elements in compatibility.

IHRA has provided an effective forum bringing together researchers from around the world, for the open and early exchange and critique of research findings, to facilitate the development of ideas, minimise needless duplication and to help generate co-ordinated forward research programmes.

The close links with the EEVC group and joint presentation sessions work well. Industry involvement has also been a healthy aspect, e.g. the links to EUCAR/EEVC workshops.

Progress on compatibility is clearly very dependent upon research. Members are likely to continue to work on compatibility up to at least the end of 2003 so a collective mechanism such as IHRA would be worthwhile, if it did not already exist.

## CONCLUSIONS

It was recognised at the last status report (ESV 98) that there was no clear way of achieving the goals by ESV 2001. But the belief, that test procedures are achievable, is proving justified in the case of front impact, although some way off for side impact.

For frontal impact compatibility, improving structural interaction will itself be beneficial and is recognised as being a necessary pre-requisite to enable strength matching to be effective in providing for compartment survival.

A range of tests, including some based on existing fixed barriers, and an MDB are candidates.

Compatibility issues can arise in all impacts and are not only a problem associated with high mass ratios. If structural interaction (possibly enhanced by additional tests) is successfully developed into a test procedure, this will offer wider potential scope for safety gains than historically imagined.

A staged approach is possible. A load cell based structural interaction test would be a valuable step in itself and a pre-requisite for additional requirements.

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**APPENDIX 1 (Those recently directly involved with the Group)**

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P Castaing, UTAC, EEVC
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K Seyer FORS, Australia
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K Tateishi, JARI, Japan
K Oki, Toyota, Japan
S Takizawa, Honda, Japan
Y Kadotani, Honda, Japan

Others who represented some of the above in individual meetings are also thanked.