Options for Crash Tests of Four Wheel Drive (Sports Utility) Vehicles

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for Australian NCAP

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Introduction

Australian NCAP (ANCAP) commenced crash testing in accordance with EuroNCAP protocols during 1999. The main assessment involves a 64km/h 40% offset frontal crash and a 50km/h Moving Deformable Barrier (MDB) side impact crash. Each test can earn a maximum of 16 points. A star rating is derived from the combined score. To date the categories of vehicles tested in Europe and Australia according to this protocol have been conventional passenger cars and passenger vans ("people movers"). There are difficulties in the application of the protocol to some types of four-wheel-drive and commercial vehicles- in particular, the side impact test is not appropriate. The purpose of this document is to set out options for dealing with these vehicles.

Side impact tests

EuroNCAP / ECE95

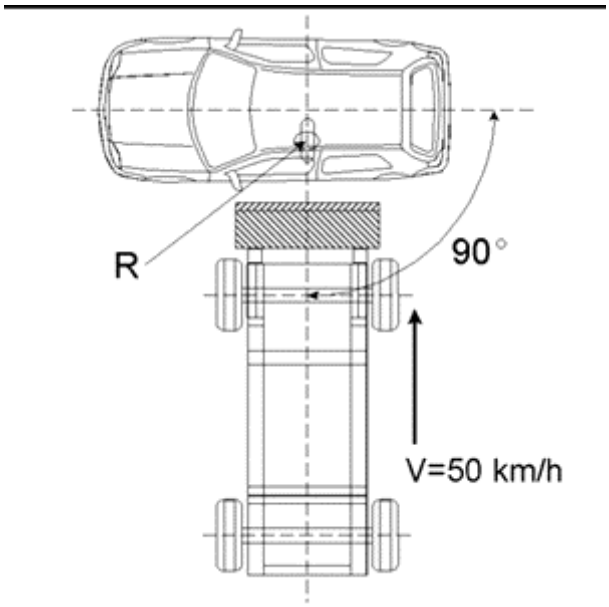

Figure 1. ECE95 side impact test (illustration byNHTSA)

The side impact test developed by EEVC is now incorporated in ECE Regulation 95 and applies to new conventional passenger cars. The EuroNCAP protocol assigns a zero score if the ECE injury limits are exceeded. A sliding scale applies up to "good' injury values, where four points are awarded. It can therefore be expected that most new vehicles will do reasonably well in the EuroNCAP side impact test. This is confirmed by analysis of EuroNCAP tests:

Table 1. Analysis of EuroNCAP scores

Vehicle Type (N)	Offset Score		Side Impact Score	
	Mean	Std Dev.	Mean	Std Dev.
Large/medium cars (17)	6.94	3.89	12.3	2.41
Luxury Cars (6)	10.36	1.97	14.56	1.33
Passenger Vans (4)	5.94	5.28	14.84	0.78
Small cars (22)	5.73	3.83	11.71	2.84
Overall (62)	7.03	3.77	12.57	2.6

Although no four-wheel-drive vehicles have been tested by EuroNCAP they can be expected to perform at least as well as the passenger vans. One reason is that the lowest height of contact of the moving barrier is 300mm above the ground. For many small cars the barrier will miss the sill and as a result the b-pillar and doors will take most of the loads. However, for most passenger vans and four-wheel-drive vehicles the barrier will engage the sill and significant intrusion of b-pillar and doors is less likely. The higher mass of these vehicles, compared with small cars, is also a major advantage since the moving barrier has a fixed mass of 950kg. The delta V of a relatively heavy vehicle will be less and therefore the loads on the dummy can be expected to be less.

ECE Regulation specifically exempts vehicles where the seating reference point of the lowest seat is not more than 700 mm from ground level. A large proportion of four wheel drive vehicles, commercial vans and people movers are therefore exempt from this side impact regulation.

US FMVSS 214

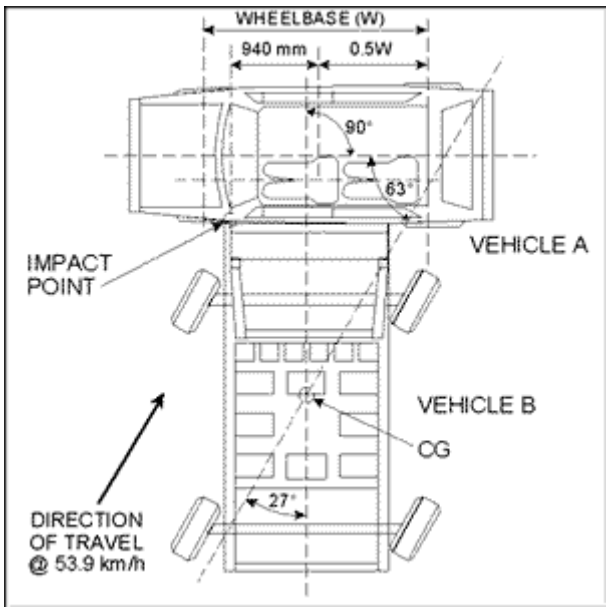

Figure 2. FMVSS 214 side impact test (illustration by NHTSA)

FMVSS 214 "Side Door Strength - Passenger Cars" differs substantially from ECE 95. It uses a heavier moving barrier (1367kg) that impacts with a crabbing motion that simulates forward motion of the impacted vehicle. High, heavy vehicles are also at an advantage under this test, compared with small cars. The regulation applies to most types of vehicle under 2721kg.

Under its NCAP program NHTSA has conducted and rated side impact tests of popular models for several years. A review of data for 2000 year models confirms that four wheel drive vehicles do well in this test.

Table 2. Analysis of NHTSA Side Impact Ratings for driver

Vehicle Type (N)	2 Stars	3 Stars	4 Stars	5 Stars
Large/medium cars (43)	2%	46%	44%	7%
Small cars (28)	7%	43%	39%	11%
Sports Utility Vehicles (15)	-	7%	13%	80%

Of the vehicles achieving five stars, 1 of 2 large/medium car and 4 of 12 4WDs had a head-protecting side airbag. Like the ECE 95 test, the FMVSS 214 test does not appear to provide sufficient discrimination between 4WD vehicles.

Figure 3. NHTSA side impact test of Ford Explorer.

Comparisons between US and European tests

In 1999 NHTSA conducted a comprehensive review of ECE 95 (EU 96/27EC) and FMVSS 214. This work was inconclusive but found fundamental differences between the tests. Further work is being conducted.

In 1998 the Australian Federal Office of Road Safety commissioned a study of the benefits of a "hybrid" side impact regulation, based on elements of the ECE 95 and FMVSS tests. This found that each of the regulations was cost-effective but that "the hybrid proposal has the potential to provide far superior HARM reductions to either of the two existing standards".

Neither the US nor Australian work considered the effects on four wheel drive vehicles.

Optional pole test

The EuroNCAP protocol gives manufacturers of certain vehicles the option of funding a pole impact test. This option is only available where the vehicle is fitted with a "head protecting side airbag" and the head score in the side impact test is the maximum four points. If the head injury result is good in the pole test then the vehicle earns a further 2 points. Only about eight pole impact tests have been conducted in Europe and in two of those cases the extra two points meant that the vehicle earned four stars instead of three. No pole impact tests have been conducted in Australia. Friedel (EEVC) and Knack (BASt) recommend that the pole test be included in the (mandatory) ECE Directive.

Although fully instrumented Euro-SID I dummy is used in the pole test, with 24 channels, only the head acceleration is currently used in the assessment. The relevance of the other injury measurements needs to be assessed.

With its concentrated load the pole test is much more demanding on the vehicle structure. Furthermore, the test vehicle is located on a trolley and is propelled sideways, at 29km/h, into the fixed, rigid pole so heavy vehicles need to cope with higher loads than light vehicles (with most pole impacts this would be the real world situation).

There does not appear to any public information about pole tests conducted on four wheel drive vehicles, other than a very recent IIHS (described below).

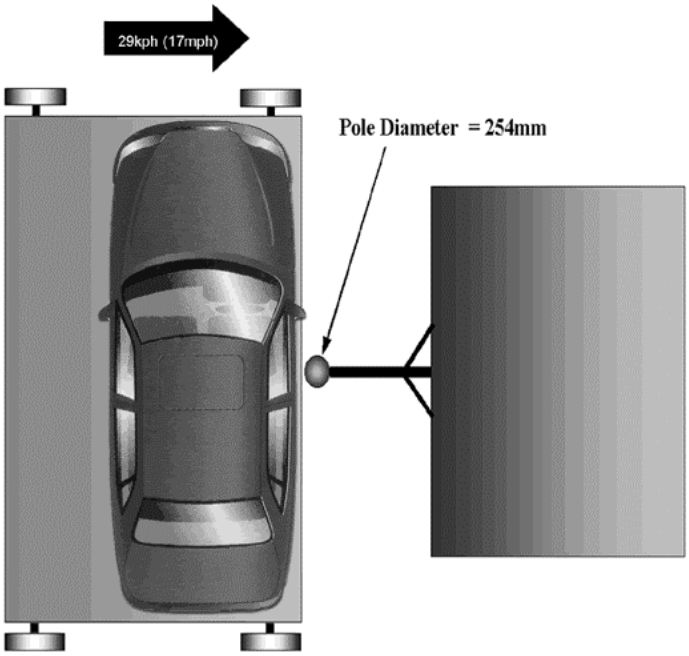

Figure 4. EuroNCAP illustration of pole test

In the USA the Insurance Institute for Highway Safety has conduced several pole tests for research purposes. Apparently no consumer tests are planned at this stage.

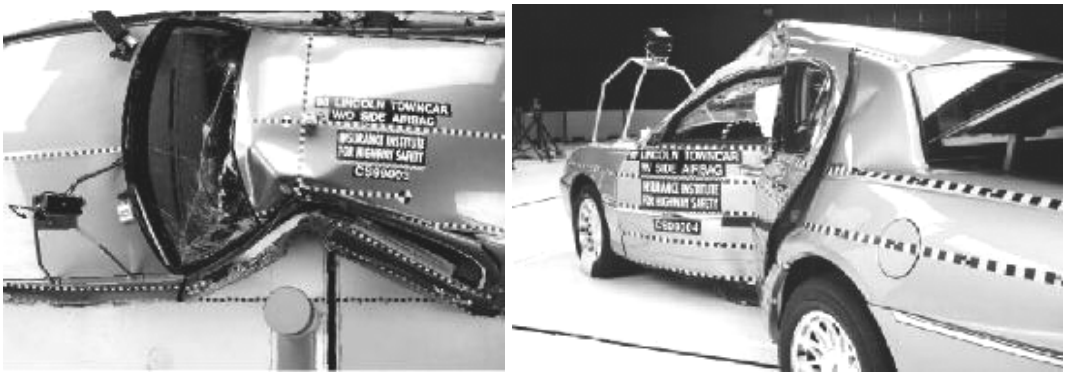

Figure 5. IIHS Pole Tests

In September 2000 IIHS issued a status report 'Side Impact Crashworthiness Evaluation Program Development'. This describes some work with a modified FMVSS 214 test where the barrier geometry and mass where changed to more closely match those of typical sports utility vehicles. The MDB mass is 2000kg (FMVSS 1367kg) and 100mm higher. This is a much tougher test on conventional cars than the prescribed FMVSS 214 test. Indeed, the aim seems to be to encourage passenger car designs that are better able to cope with being struck by the increasing number of sports utility vehicles on the road - the most likely outcome is the use of head-protecting side airbags.

It is possible that the IIHS test procedure could be applied to large sports utility vehicles although IIHS does not appear to have conducted such tests. Further details about the barrier are described in a December 2000 status report. The modified barrier includes a curved (40mm radius) corner plate along most of the top edge to provide a smooth surface for head contact instead of the head striking the sharp corner of the aluminium cladding.

In December 2000 IIHS issued a News Release that pointed out the benefits of head-protecting side airbags. They provide the example of a pickup truck striking the side of a Volvo S80 fitted with head-protecting side airbags.

The IIHS News Release also provides limited information about pole tests conducted with a BMW X5 4WD vehicle and the Volvo S80 sedan. In each case the head-protecting side airbag contributed to low HIC readings for the driver.

Side impact tests in Australia.

Prior to aligning with EuroNCAP the ANCAP assessments were based largely on those used by the US Insurance Institute for Highway Safety, using essentially the same offset test as that now used by EuroNCAP. However, the ANCAP program also included (from 1992) 56km/h full-frontal crash tests, as carried out by NHTSA in the USA. When the EuroNCAP protocol was adopted in Australia the full frontal crash test was replaced by the EuroNCAP side impact test.

No pole tests have been conducted in Australia, although Crashlab has the capability to conduct such tests.

Australian Design Rule 72 "Dynamic Side Impact Occupant Protection" calls up the ECE requirement, including the exemption for high seat vehicles. The ADR permits FMVSS 214 as an alternative standard. Manufacturers conduct their own tests to demonstrate compliance with ADRs and the test results are not made public.

International Research on Side Impacts

The following information was provided by Keith Seyer, Chairman of the Side Impact Working Group, International Harmonised Research Activities (IHRA).

The Australian Transport Safety Bureau has not conducted any pole tests. The IHRA Working Group has drafted an outline of a new side impact test procedure that includes a pole test. There may also be a Moving Deformable Barrier (MDB) test with a raised ground clearance (maybe 400-450mm) for those countries that have a large SUV population (eg USA).

As part of the project IHRA commissioned an analysis to look at the prevalence of pole impacts. 4WDs did not appear to be over-represented in pole impacts and there were very few 4WD to 4WD side impacts. Single vehicle rollovers on rural roads stood out.

The Working Group is interested in the work by IIHS involving a moving deformable barrier with increased ground clearance for possible side impact tests of 4WDs.

Real world accidents

Germany

An analysis of about 1000 German *single car* fatal accidents found that 52% involved side impacts (Langwieder 1999). In 83% of the cases of fatal single car accidents (including frontal impacts) the main object collided with was a pole or tree. This suggests that more than 40% of all single car fatal accidents involved a side impact with a pole or tree. The author recommended that a 35km/h pole test be required under EU safety standards.

The situation may be unusual in Germany, particularly given the unrestricted speeds on Autobahn.

USA

The December 2000 IIHS New Release provides data about side impact crashes in the USA: "38% of single vehicle side impact crash deaths occur when vehicles strike trees or poles on the dead

occupant's side of the vehicle. In two-vehicle side impact crashes 38% of car occupant deaths occur when a pick-up or sports utility vehicle strikes the car". Around 30% of all US passenger vehicle fatalities occur in side impacts. More than 50% involved fatal head injuries. There were 2957 single vehicle side impact fatalities and some 1120 involved a tree or pole - this indicates that about 3.5% of all US passenger vehicle fatalities involve a side impact into a tree or pole. 7.9% of all passenger vehicle fatalities involved a pickup or sports utility vehicle striking the side of a car.

NSW Mass Data

The annual statistical report on road accidents in NSW includes a table for 'object hit in first impact. That table excludes vehicle to vehicle impacts. It also excludes objects hit in secondary impacts - some of which may be injurious. For the 1995 report striking a pole or tree comprised 19% of all fatal accidents, 13% of all serious injury accidents and 7% of all reported accidents. Trees and poles accounted for 56% of the 188 fatal accidents where an object (other than another vehicle) was hit. This tentatively suggests that pole/tree impacts are significant in NSW but not as predominant as Germany.

NSW Crashed Vehicle Study

Provisional data from the 1995-98 NSW Crashed Vehicle Study was analysed. A total of 469 records for 4WD style vehicles were extracted. Subject to caution about coding of the data, side damage accounted for 26% of a total of 88 crashes involving fatal or serious injuries to the occupant of a 4WD. This compares with 28% for all 469 4WD vehicles in the database. Rollovers accounted for 22% of fatal/serious cases and 14% of all cases. In 25% of rollover cases the primary damage was to the side of the vehicle (these cases are included proportions with side damage listed above).

CDs with images of crashed vehicles are available and these could be analysed to determine likely cases where a pole test would be relevant. This was not done for the current project.

Potential benefits of pole test

A difficulty in assessing the merits of a pole test is the lack of examples of large vehicles that have undergone the test. Subject to this uncertainty, *possible* vehicle design improvements to provide better occupant protection during the EuroNCAP pole impact test are:

- head-protecting side airbags
- stronger roof side rails
- stronger sills and doors
- stronger b-pillars
- transverse bracing of the roof (between b-pillars)
- improved seat design

Each of these would have potential benefits in other types of accidents. For example IIHS has pointed out that head-protecting side airbags could help to address vehicle incompatibility problems (aggressive front of a large vehicle striking the side of a smaller vehicle).

Improvements to roof strength would be beneficial in some types of rollover crash. In particular a serious structural problem in rollover crashes is side-sway of the roof and pillars. The report "Passenger Car Roof Crush Strength Requirements" notes this problem with rollovers crashes (Henderson and Paine 1997). That report also debunks early criticism of increased roof strength - that rollover propensity will be increased from the higher centre of gravity of the vehicle (the relative increase in mass is negligible) and that rolls will be prolonged (most of the roll energy is

absorbed when the underside of the vehicle contacts the ground). These observations are also relevant to design changes to deal with pole impacts.

However, Keith Seyer points out that the pole test is extremely demanding on the vehicle structure and there appears to be little opportunity to significantly influence the outcome of a pole impact through structural changes alone.

Full frontal crash test

The 56km/h full frontal crash test, as conducted under NHTSA's NCAP program is a possible alternative to the pole test. Due to mainly to concerns about the occupant restraint systems Germany has proposed that EuroNCAP conducts full frontal crash tests of all vehicles (in addition to offset and side impact tests).

Experience in Australia prior to the adoption of EuroNCAP protocols indicated a wide range in full frontal performance for 4WD vehicles (Griffiths, Paine and Haley, 1999). Reintroduction of the full frontal test might be an alternative EuroNCAP side impact test, which is not suitable for most 4WDs.

Vehicle to vehicle compatibility

An issue related to large 4WDs is vehicle to vehicle compatibility. These vehicles are generally much stiffer, heavier and higher than conventional passenger cars. Impacts into the side of passenger cars are a particular concern because of the risk of head and chest contact with intruding components.

The recent IIHS News Release confirms there is a problem in the USA with 4WDs and pickups striking the side of cars (7.9% of all passenger vehicle fatalities).

Since 1998 MUARC has prepared "Aggressivity Ratings" for Australian vehicles, based on real world crashes (Newstead et al 2000). This measures the risk of the driver of other cars being killed or admitted to hospital when involved in a collision with the subject model. The data was adjusted to take into account confounding factors such as speed limits, driver age etc.

As is evident from Figure 6, several large 4WDs stand out as highly aggressive, with double the risk of small cars.

An IHRA Working Group has been looking at the issue of compatibility (Rodgers 1998). The final phase of its workplan is to look at developing test protocols that "when adopted into regulations, will ensure that vehicles become more compatible". It appears that there could be many obstacles to the development of such mandatory regulations, particularly given the motor industry's increasing reliance on the 4WD sector of the market. However, there might be an opportunity to fast-track introduction of compatibility testing through NCAP consumer testing.

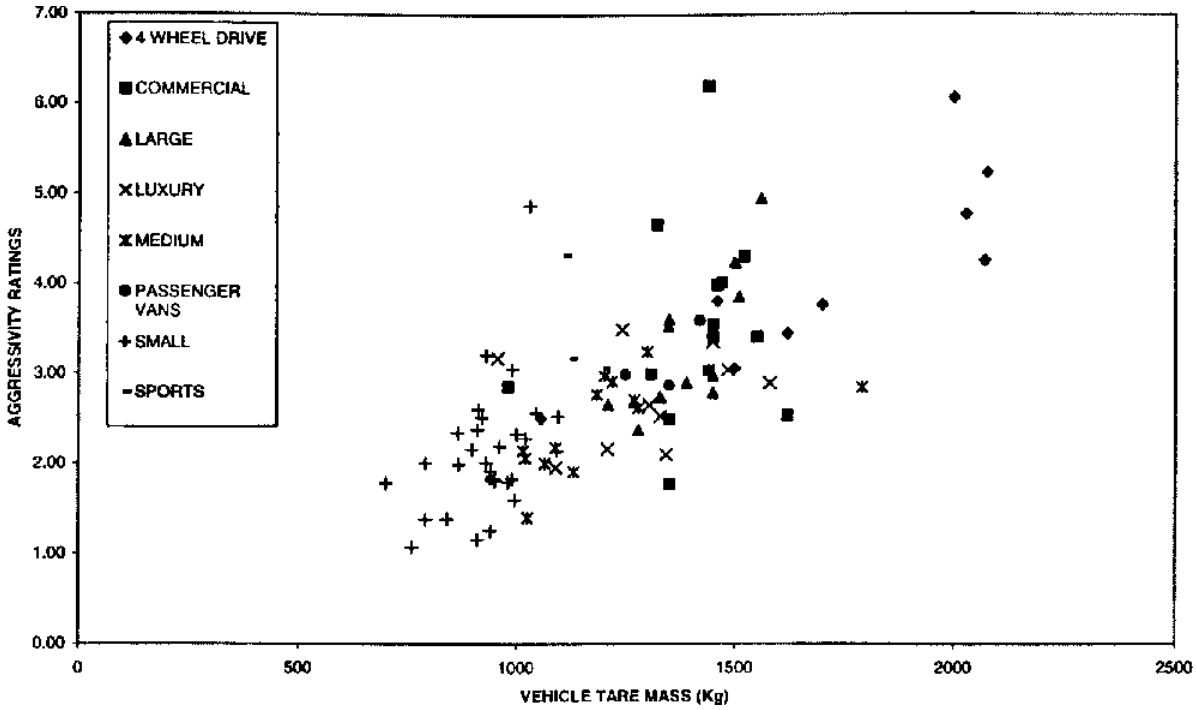

Figure 5 Aggressivity ratings (Figure 3 from Newstead et al 2000)

One way of addressing the aggressivity issue is to conduct a side impact test between two vehicles of the same model. It would then be in the manufacturer's interest to minimise the aggressivity of the front of the vehicle. A difficulty with this approach is that it would involve the cost of wrecking two vehicles (although the impacting vehicle may be repairable). This could be addressed by specifying a test that normally uses the raised MDB being developed by IIHS but give the manufacturer the option of supplying, at no cost to ANCAP, a second vehicle to use in place of the MDB.

Pedestrian tests

The issue of pedestrian protection tests also needs to be resolved. The EuroNCAP tests include upper legform impacts into the leading edge of the bonnet and child headform impact onto the bonnet. In each case the geometry of large 4WD vehicles might not be appropriate for these tests.

Presentation of results

A dilemma with conducting pole tests *in place of* the current side impact test is that it would not be fair to compare the resulting overall star ratings with those of cars that have not undergone the pole test. Although the NCAP publications point out that vehicles of different mass or body style should not be compared it is inevitable that such comparison will be made. On the other hand, it is possible that, with demonstrated over-involvement in rollover crashes, there should be concern about the roof and side strength of 4WDs. Similarly, a rating that takes into account compatibility or aggressivity would address additional road safety concerns about some 4WDs.

A further issue is how to deal with smaller types of 4WD and commercial vehicles that have the same seat height as conventional cars. These could undergo the EuroNCAP side impact test (indeed, many will need to be tested by manufacturers for ECE 95 certification purposes) but it would be unfair to include them in lists with other 4WDs that have been rated on the basis of a pole test. A

better approach may be to subject all 4WD and commercial vehicles to a pole test and to ensure that ratings are listed separately from those of conventional cars.

Conclusions

The current EuroNCAP side impact test is not appropriate for assessing 4WDs with high ground clearance. Alternatives to the EuroNCAP test have been considered:

- EuroNCAP Pole Test. It would be inappropriate to replace the EuroNCAP side impact test with the pole test for purpose of assessing crashworthiness of 4WDs. The pole test is very demanding on the vehicle structure and is therefore unlikely to provide useful information about structural performance. The limited experience to date suggests that head protecting side airbags are needed to ensure good results in the pole test.
- Full frontal crash test. EuroNCAP is considering introducing a full frontal crash test for all vehicles. If this goes ahead then there will still need to be a replacement for the EuroNCAP side impact test in the case of 4WDs. Full frontal crash tests could be conducted as an interim measure and might show up deficiencies in 4WD restraint systems, as was observed in earlier ANCAP full frontal crash tests.
- Modify the MDB along the lines currently being evaluated by IIHS so that it has increased mass and higher ground clearance (to simulate a collision between two 4WDs). Either the EuroNCAP 90^{o} impact or the FMVSS 214 oblique impact could be considered.
- Use an identical vehicle in place of the MDB in the side impact test (this could be an option for the manufacturer and might encourage less aggressive frontal designs in 4WDs)

It is recommended that further information be sought about the IIHS initiative, including the possibility of conducting some trial crash tests in Australia (perhaps to the EuroNCAP procedure). DETR and the IHRA Working Group may be interested in participating in such tests. Side impacts of 4WDs into identical 4WDs should also be considered.

Update December 2001: A combination of the last two options may be feasible. This would involve setting the height of the moving deformable barrier to the height of the bumper bar of the vehicle undergoing the test. The barrier mass could also be set to the mass of the vehicle under test. In this way manufacturers of vehicles with less aggressive frontal designs will be at an advantage in the side impact test. Manufacturers could be given the option of supplying a second test vehicle to use in place of the moving deformable barrier so that low-aggressivity features were rewarded.

It is stressed that these options are intended for consumer crash test programs that are designed to show differences in crashworthiness between similar-sized vehicles.

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