EEVC/CEVE

European Experimental Vehicles Committee

EEVC Working Group 11 Report on the Development of a Front Impact Test Procedure

Presented to the 14th Conference on the Enhanced Safety of Vehicles, Munich, Germany
May 1994

Paper No. 94-S8-O-05

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ABSTRACT

Having developed a test procedure for side impact protection, the EEVC turned its attention to improving the requirements for car occupant protection in frontal impacts The potential for modifying existing Regulations was reviewed but it was concluded that an entirely new, and more realistic, frontal impact test incorporating dummies and biomechanical criteria was the most likely route to vehicle designs with improved occupant protection Examination of accident data from different sources and impact test results led to the conclusion that the most effective impact test configuration would be an offset impact into a deformable face This report describes the WG11 studies leading to this conclusion and the test programme performed to define the conditions for this test procedure

INTRODUCTION

The European Experimental Vehicles Committee produced its final report on the development of a side impact test procedure at the 12th ESV conference in 1989 (Ref 1) Having completed the task of developing a test procedure aimed at reducing the numbers and severity of injuries in side impacts, the EEVC turned its attention again to frontal impacts

Impacts, where the principal direction of force is essentially frontal, constitute about two thirds of all serious or fatal car accidents The protection of car occupants from injury in accidents has improved since the 1960s when the first impact performance requirements were introduced and the number of fatal and serious injuries have reduced in European countries as compulsory seat belt wearing regulations have been introduced Nevertheless, something like 15 000 car occupants in the European Union are killed each year in frontal impacts despite the very high usage of seat belts that now exists in Europe Outside Europe, the figures for Canada and Japan are about 1,200 and 3300 car occupant fatalities respectively in frontal impacts, while it is estimated that about 10 000 car occupants will be killed in the United States of America even with full implementation of driver side airbags

In 1990, the EEVC created a Working Group (WG11) with the objective of determining the most beneficial ways in which evaluation of the performance of vehicle in front impacts could be improved. The group commenced by reviewing existing European Regulations on impact performance, based on available accident information and on the wide experience of crash performance and impact testing of the group members

The Regulations considered were

- ECE Regulation 12 (EC Directive 74/297) Steering assemblies
- ECE Regulation 14 (EC Directive 76/115) Uniform Provisions Concerning The Approval of Vehicles with Regard to Safety-Belt Anchorages on Passenger Cars
- ECE Regulation 16 (EC Directive 77/541) Uniform Provisions Concerning The Approval of Safety Belts and Restraint Systems for Adult Occupants of Power-Driven Vehicles
- ECE Regulation 17 (EC Directive 74/408) Uniform Provisions Concerning The Approval Of Vehicles With Regard To The Strength Of The Seats And Of Their Anchorages
- ECE Regulation 21 (EC Directive 74/60) Uniform Provisions Concerning The Approval Of Vehicles With Regard to Their Interior Fittings
- ECE Regulation 25 (EC 78/932) Uniform Provisions Concerning The Approval Of Head Restraints (headrests) Whether Or Not Incorporated In Vehicle Seats
- ECE Regulation 33 Uniform provisions concerning the approval of vehicles with regard to the behaviour of the structure of the impacted vehicle in a head-on collision

It was concluded that modifications to the 'component' regulations were unlikely to produce a large effect The greatest benefit was considered to be achievable through a new frontal impact test, more representative of the impact conditions of car-to-car front impacts This could be regarded as a revision to Regulation 33, but the group concluded that the test should include the use of dummies and biomechanical criteria

In the interests of improving the possibilities of future harmonisation of test procedures, the EEVC invited the participation of experts from the governments of the United States of America, Canada, Japan and Australia In addition, experts from the automobile industries of Europe, the USA and Japan have provided advice to the Group

WG11 based the development of the test procedure on reviews of accident studies and on an impact test programme In 1992, the European Commission indicated its intention of considering a Directive based on the EEVC recommendations, once these were completed To assist the development of this test procedure, the EC granted financial aid in support of the test programme One part of the supported programme was a synthesis of available accident data relating to frontal impacts

SUMMARY OF ACCIDENT DATA

About 50 source documents were considered in the synthesis of accident data Some of these documents had been presented to EEVC WG 11 The remaining documents were highlighted by the reviewers as being relevant to the work of WG11 While some differences were apparent, the papers show considerable areas of common observations from different countries and different databases The main conclusions of this review can be summarised as follows -

For car occupants, frontal impacts are still the major cause of severe and fatal injuries even in countries with high seat belt use rates In general, European data suggest that frontal impacts account for between 40 and 66 percent of impacts causing severe or fatal injuries Canadian data suggest a lower figure for fatalities, with side impacts being more frequent Some variations between countries can be expected, but the general conclusion that frontal impacts are the single most important type of impact in serious and fatal accidents is unarguable (Refs. 2-17)

The car-to-car impact is the most frequent configuration in frontal impacts, varying from 45 to 66 percent in the references cited. Variations in distributions of object struck in these references may be due to sampling criteria or genuine differences between countries (Refs 2,4,9,11,14,18-20)

Impacts where both longitudinal members play a significant part in absorbing energy probably account for less than 25 percent of accidents with severe or fatal injuries In the majority of frontal impacts only one longitudinal member is involved, with some additional loading via the engine/bulkhead load path in a proportion of these impacts (Refs 2-7,9,11-16,18-29)

Consideration of the nature of loading and load paths strongly suggests that the partial overlap deformable barrier will provide a more realistic simulation of a typical car-to-car collision than is possible with any rigid faced barrier impact A frontal impact test with a small overlap should also help to control intrusion in accidents with greater overlap. But a test with greater overlap will not guarantee good control of intrusion in accidents with smaller overlaps (Refs 2,3,5,14-16,19,27)

There is a consensus that intrusion is a very important factor in the generation of more severe injuries Injuries to the lower leg may be particularly affected by intrusion, and are not currently addressed by the use of instrumented dummies Correct simulation of frontal impacts will not be achieved unless the improved frontal impact test reproduces the sort of intrusion seen in real accidents with current bodyshell design. This will require the test configuration to be such that the mechanism of loading, load paths and modes of energy absorption are the same as in real accidents (Refs 2-7,9-12,14,15,18-20,23,27,29-32)

When injuries of AIS 2 or more are considered, the head (including the face) is the most frequently injured area particularly for drivers, according to most databases Head and facial injuries caused by contact with the steering wheel are probably the single most important issue in frontal impact protection, even for belted drivers The use of a head injury criterion on instrumented dummies in a full scale crash test is necessary Some caution is necessary here though, as recent works suggests the tolerance work on which HIC was based used very different loading conditions on the head to those which occur in steering wheel impacts It is also clear that the use of HIC or some other head injury criterion in a single whole vehicle impact test is insufficient to address the problem of facial injuries, nor will it address the range of head impact locations seen in real accidents An additional component test is needed to address these other issues (Refs 2,4,6-9,11,15,16,18,23,24,29,31,33-38)

Leg injuries are particularly important among belted drivers surviving frontal impacts, if injuries of AIS 3 or more are considered They are probably the second most frequent type of injury This implies that particular attention must be paid to the lower facia and footwell areas, and also to interaction with the steering assembly. The use of the femur load criterion on instrumented dummies may help limit the risk of injury to the upper leg But a significant proportion of the leg injury problem relates to the lower leg and is not addressed by this criterion A criterion controlling intrusion would be appropriate in the medium term, as intrusion appears to be a major factor in injury causation in real accidents More sophisticated instrumentation in the dummy's lower leg could be used as well, although the problem of simulating bracing (a likely occurrence in real accidents) on the brake pedal may be difficult to solve (Refs 2,4,6-9,11,15,16,18,23,24,29-31,33-38)

Chest and abdominal injuries are generally of lesser importance to belted drivers, though for fatally injured occupants they are still important. (Refs 2,4,6,8,9,11,15,18,23,24,29,31,33,34)

For belted passengers, chest and abdominal injuries become relatively more important, though the head and face, and to a lesser extent the legs, must still be considered (Refs 2,4,6,8,9,11,13,15,23,24,29,31,33,34) The use of intrusion controlling criteria would be beneficial in terms of reducing the risk of head, face and thorax injuries One database showed increased risk of serious injury with intrusion of more than 100mm A recent analysis of the APR database used 250 mm as the definition of significant intrusion However, an earlier analysis of the APR database showed significant effects of intrusion using 150 mm as the critical level The choice of a particular level for analysis purposes does not exclude the possibility of lesser amounts of intrusion having significant effects Overall, the various analyses imply that intrusion levels as low as 100 mm (or possibly lower) increase the risk of serious injury being sustained The use of chest deceleration and/or chest deflection criteria would also be appropriate to control the risk of chest injury (Refs 2-7,9,10,14,15,17-19,23,26,27,29-32)

Several of the accident studies presented to WG11 have provided information regarding the distribution of Δ V in accidents These are summarised in table 1 Some of the figures for the table have required the interpolation of printed graphs

Impact tests performed by the US Insurance Institute for Highway Safety and presented to WG11 indicate that the calculation of Δ V for partial overlap accidents, where Crash 3 is used for this calculation, underestimates the actual velocity change This means that the proportion of the accident sample at or below the stated Δ V is likely to be an overestimate The data indicate that, to cover around one third of all fatals and about one half of those injured at severity AIS 3 or greater, an impact equivalent to an accident 'Crash 3' Δ V of 55km/h would be required

EEVC WG11 IMPACT TESTS

Following the indications from the accident studies that an appropriate test would be an offset impact and that the deformable nature of car-to-car impacts should be reproduced in the test, WG11 developed a test programme to evaluate the most appropriate parameters for the test conditions One of the guiding principles for the development of the test conditions was that, for

Table 1
Cumulative Distribution of Accidents by Velocity Change

Ref	Sample	ΔV km/h		
		50	55	60
	Fatal accidents			
23	Belted front seat occupants without rear loading (France)	12%	21%	32%
14	Restrained front seat occupants (UK)	21%	42%	54%
28	NASS data (USA)	19%	30%	45%
	MAIS 3+ accidents			
23	Belted front seat occupants without rear loading (France)	40%	51%	62%
14	Restrained front seat occupants (UK)	50%	59%	67%
15	Accidents at about 50% car-car overlap (Mercedes Benz cars Germany)	20%	40%	50%

a vehicle to perform well in the test, the design should be such that the vehicle would perform well also in a range of frontal impact accidents It was appreciated that there was a whole range of frontal impact overlap conditions and differing impacting vehicle designs For that reason, it was not intended that the test should reproduce one specific accident type, rather that the test condition would tend to direct the design of vehicles towards structures that would work well under as wide a range of conditions as possible For instance, the design concept for the deformable element required to reproduce the conditions of a car-to-car impact would be uniform across its width although real cars have a variable stiffness Reproducing one specific car front, or even a generalised variable stiffness, would tend to result in designs optimised to that construction

EEVC Test Programme

The test programme used offset car-to-car impacts as the baseline for comparing various test conditions The performance of one car when impacting another will depend to some extent on the design of the second car As a baseline for comparison, it was decided to impact each model with another example of the same model A 50 per cent overlap was selected for these baseline tests, not only because various accident studies indicated that the appropriate overlap lay between 40 and 60 per cent, but also because the higher overlaps usually involved engine to engine or engine to longitudinal impacts Design solutions for this condition would not necessarily work for lower overlaps, whereas solutions for lower overlaps (say up to 40 per cent) would be likely to work in higher overlap conditions Fifty percent overlap was selected as a good compromise as, with this overlap, it was unlikely for there to be significant engine to stiff member contact for the more sensitive longitudinal engines The impact speed was selected as 50km/h, not based on accident studies at that stage but for pragmatic reasons

For the purposes of the development programme, three vehicle models were selected which included a range of size and engine layouts and were popular in Europe It is important to note that they were not selected from any knowledge of their impact performance, neither should any criticism about these vehicle be inferred from the results of these tests since no vehicle has been designed with this test in mind at present The vehicle types selected were a small transverse engined front wheel drive car (Fiat Uno), a medium transverse engined front wheel drive car (Peugeot 405) and a large longitudinal engined rear wheel drive car (Ford Scorpio)

The test programme was designed to evaluate the overlap, impact speed and barrier face characteristics that most closely duplicated the important characteristics of these baseline tests within a limited test programme Complementary tests were performed by the other invited participants of the Working Group, providing supporting evidence for the decisions taken The programme included two review points at which lessons learnt from the earlier tests could be used to help to define the test conditions for subsequent tests

The initial dimensions of the deformable element were derived in a pragmatic way on the basis of logic and previous experience One possible design would be for the deformable element to be present down to ground level (as is the rigid face of existing impact barriers) However, this could lead to unrealistic loads to the front wheel giving misleading results as the wheel provides a loading strut through to the wheel arch and sill If the lower edge of the face were too high, it could lead to variable results as rigid structures either deformed the face or dived underneath due to instability at the face edge The height of 200mm was based on this reasoning and previous testing rather than any measure of 'typical' car front dimensions The height of the top of the face was selected such that it would be high enough to be impacted by most cars This dimension was not considered to be critical The minimum depth was selected to be sure that the material used for the deformable element (aluminium honeycomb) would be stable Tests using deeper barrier faces were included in the programme The test programme is shown in Table 2
Each vehicle contained two instrumented Hybrid III dummies, one in the driver's seat and the other in the front passenger seat The dummies were equipped with accelerometers in the head, chest and pelvis, femur load cells and with the standard chest deflection transducer In some tests, instrumented lower legs were used The vehicles were equipped with accelerometers at agreed locations on the base of each B-pillar, the passenger compartment tunnel and at various positions on the engine block Lap and shoulder seat belt forces were measured There was a comprehensive list of static measurements taken in order to quantify and compare the residual deformation of the important structures

Deformable Element design.

Some preliminary testing with a range of stiffnesses for the barrier face material indicated that the differences between deformable barriers of different practical stiffnesses were small in comparison with the difference between any of these and a rigid barrier face Thus, for pragmatic reasons, the initial 'normal' deformable element was made from 50psi aluminium honeycomb, similar to that used in the FMVSS 214 MDB face In some preliminary tests, some strong longitudinal chassis members penetrated the face, bottoming out on the rigid back plate As this occurred very late in the impact, it was thought that this would have little effect on the collapse mechanism of the structure However, to establish whether a deeper barrier design would have a significant and beneficial effect on the test method, a second layer of 250psi aluminium honeycomb was placed behind the first standard layer for the 'deep barrier' tests

Finally, a third design of deformable element was added to the programme at the second review stage This comprised the 'normal' element with a supplementary layer of 250psi material over the front of the lower half This has been called the 'normal element with bumper'

These three designs are shown in figures 1-3

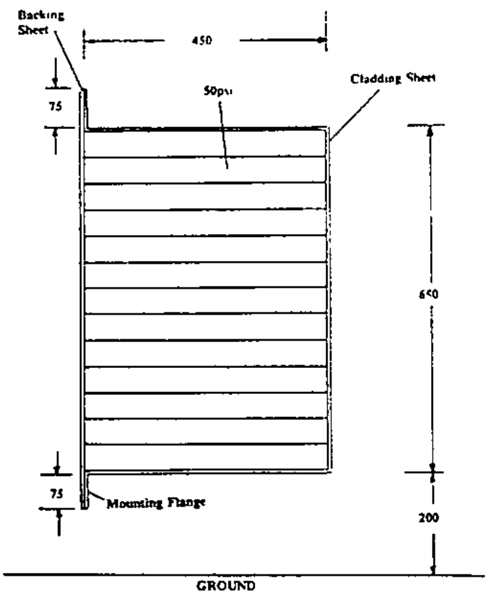

Figure 1 Normal Deformable Element

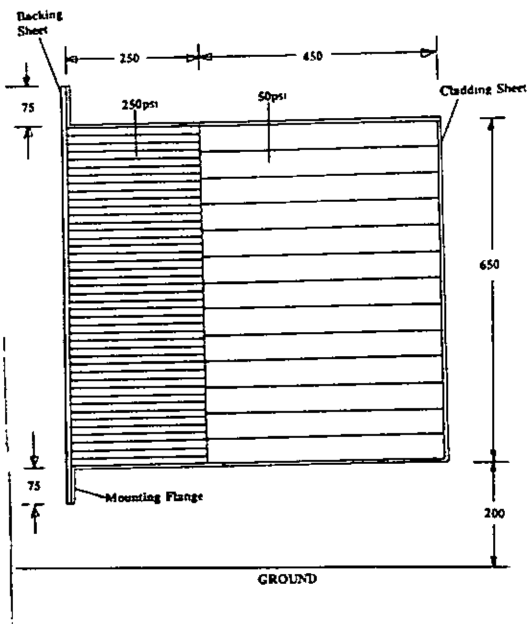

Figure 2 Deep Deformable Element

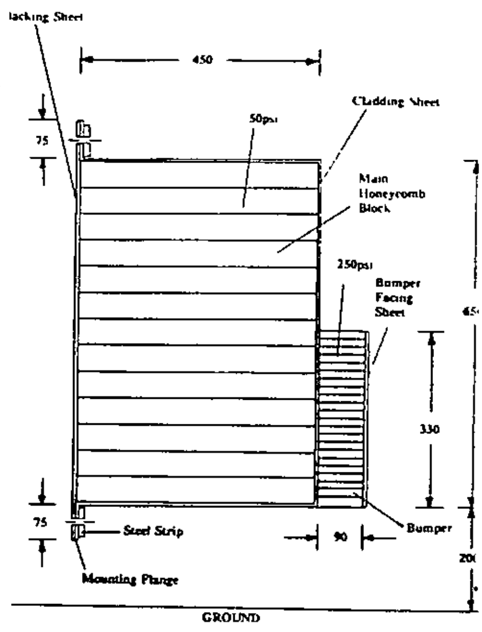

Figure 3 Normal Element with Bumper

Table 2
EEVC WG11 Test Programme for the Development of a Revised Front Impact Test Procedure

Test Institute	Car	Test No	Overlap %	Speed (km/h)	Barrier
BASt	Fiat Uno	A	50	50	car-to-car
FIAT	Fiat Uno	1	40	60	normal
FIAT	Fiat Uno	2	50	60	normal
FIAT	Fiat Uno	3	60	60	normal
FIAT	Fiat Uno	9	40	50	normal
FIAT	Fiat Uno	8	40	55	normal
TNO	Fiat Uno	19	50	55	normal
INRETS	Fiat Uno	18	40	60	deep
BASt	Fiat Uno	17	40	55	with bumper
FIAT	Fiat Uno	21	40	57.5	with bumper
TRL	Peugeot 405	B	40	50	car-to-car
TRL	Peugeot 405	C	50	50	car-to-car
TRL	Peugeot 405	D	60	50	car-to-car
INRETS	Peugeot 405	7	50	60	normal
INRETS	Peugeot 405	12	40	55	normal
INRETS	Peugeot 405	13	40	60	normal
INRETS	Peugeot 405	23	40	55	with bumper
BASt	Ford Scorpio	E	50	50	car-to-car
TNO	Ford Scorpio	4	40	60	normal
TNO	Ford Scorpio	5	50	60	normal
INRETS	Ford Scorpio	6	60	60	normal
BASt	Ford Scorpio	10	40	55	normal
BASt	Ford Scorpio	11	40	65	normal
TNO	Ford Scorpio	20	50	55	normal
TRL	Ford Scorpio	14	40	65	deep
TRL	Ford Scorpio	15	40	55	deep
TNO	Ford Scorpio	16	50	65	deep
TRL	Ford Scorpio	22	40	55	with bumper

Summary of Testing with the Fiat Uno

The smallest car selected for the EC testing was a Fiat Uno with 45 HP (FIRE) engine The cars to be tested were bought from the used car market and were left hand drive cars of model year 1990 or younger One "baseline test" - both cars moving at 50 km/h with an overlap of 50% - and nine car to fixed deformable barrier tests were to be compared to the baseline test In three tests overlap was varied (40%, 50%, 60%) at 60 km/h impact speed One additional test was performed at 50% overlap and a slightly lower speed of 55 km/h The influence of impact speed (50km/h, 55 km/h) was examined at 40% overlap In three tests the deformable element design (see figures 1 and 2) was evaluated under minor variation of impact speed

The tested vehicles were instrumented and equipped as set out in a standard test protocol This car model was mainly tested at Fiat and the test data were be evaluated in a very detailed way

__Overlap Effect Analysis__ - Evaluation of the appropriate overlap concentrated initially on the structural deformation observations

The overlap effect was studied at this vehicle at the relatively high impact speed of 60 km/h Vehicle acceleration analysis was performed mainly by using mean acceleration values at 70 and 120 ms after impact The mean acceleration vs time is calculated at any instant T after impact event at T_0 by dividing the speed change between T_0 and T by $(T-T_0)$

As can be expected in general the vehicle decelerations were higher with higher overlap At the highest overlap of 60% the individual parts of the crash pulses were different from the car to car test, in the first part of the acceleration trace (16g vs 12-13g of car to car test) as well as the second part (15g vs 10 5-11 5g) In the 50% overlap test the main difference was observed in the second part of the impact pulse with higher values of mean accelerations at 120ms (14g vs 10 5-11 5g) The first part of the crash pulse resulted in a slightly low value for the mean acceleration at 70ms due to the deformation of the element being too large between 30 and 50ms At the highest overlap there was evidence of overloading to the firewall/tunnel (peak of mean tunnel acceleration 24 7g vs 23g of the car to car test) With decreasing overlap overloading of the engine at firewall/tunnel was lower (20 7 resp 17 6g vs 23g) The extra test at 50% overlap and 55 km/h showed a good reproduction of car to car crash pulse (mean acceleration at 70ms 11g vs 12-13g and mean acceleration at 120ms 10 8g vs 10 5-11 5g) There was hardly an engine contact with no overloading of the tunnel (12 4g vs 23g) Concerning vehicle accelerations the severity of this test was too low in comparison to the car-to-car test

Vehicle static deformation and compartment intrusion clearly increased with decreasing overlap The intrusion levels at 50% and 40% overlap at 60km/h were more severe than those in the car to car test, especially the 40% test In the 60% overlap test the intrusion levels were less severe than in the baseline test The extra test (50% overlap at 55 km/h) correlated quite well with the car to car test but seemed to be a little bit less severe

Concerning dummy loadings for the Fiat Uno tests a general remark should be made. In many tests the dummy on the driver seat was trapped in the region of the lower extremities but the transducer readings remained fairly low No clear conclusions could be made on the dummy measurement values, although there is good agreement between the car-to-car and the 40% overlap tests, particularly for the passenger The head and chest measured values showed an increase as the overlap increased

Overall, the overlap most representative of the car-to-car test was at 40 percent

Impact Speed Analysis - This influence was studied at an overlap of 40% at 50 and 55 km/h impact speed The 40% overlap 55 km/h test represented the acceleration levels of the car-to-car test quite well especially for the mean acceleration values at 70 and 120ms The test at 50 km/h was less severe No or low overloading of the engine into the firewall/tunnel was observed Again the higher intrusion at the waist level was observed (140 mm higher than in the car-to-car test).

Barrier Design Analysis - The tests with the Fiat Uno showed that the forces generated by the normal EEVC element (see figure 1) were too high forces at the waist level in comparison to the car-to-car test This caused a 'triangular' shape of the car deformation in side view within the engine compartment, particularly noticeable in the orientation of the engine The displacements at the waist level (difference of displacements between suspension turret and wheelbase) were 137-158 mm higher than those measured in the car to car test The detailed analysis of vehicle deformations and compartment intrusions by the Fiat engineers led to the requirement for the deformable element to generate higher forces in the bumper/floor pan level At the second break of test data review the deformable with a bumper simulation was designed (see figure 3) The deep deformable face had been designed at the previous break

The test against the deep barrier (40% overlap and 60 km/h) was much severe than the car to car test Acceleration characteristics were different from those measured in the baseline test although mean accelerations at 70 and 120ms did not differ too much. The distribution of static displacements and intrusions were completely different to all other tests Almost all intrusion measurements with the deep barrier were much more severe than those measured in the car-to-car test

Two tests against the "bumper element" were performed at 55 and 57.5 km/h impact speed The crash pulse of the baseline test was in both tests very well reproduced (mean accelerations in both tests 10 9g vs 10 5-11.5g of the car to car test)

There was no or only minor overloading of the tunnel/firewall (15.8g vs 23g for the car to car test)
In both tests the shape and depth of deformations were quite well reproduced in comparison with the baseline test In particular there was good correlation of intrusion levels at waist and floor pan level The test at the higher speed seemed to be slightly more severe than the car to car test

Fiat Uno Test Conclusions - All the fixed deformable barrier tests represented the car-to-car test much better than any rigid wall test would have done although the front stiffness of this car model is quite homogeneous

The best representation of the car to car test was produced by a car to deformable fixed barrier test procedure with the following parameters

- Overlap: 40-50%, probably closer to 40%
- Test Speed: 55-56 km/h
- Barrier Design: "normal" barrier 50 psi with bumper 250 psi

Summary of the Testing with the Peugeot 405

The purpose of the tests on the Peugeot 405 cars was somewhat different from that of the tests on the Fiat Uno and the Ford Scorpio cars Firstly, three car-to-car tests were performed to provide information about the effects of varying the overlap extent, in car-to-car impacts at the same speed Secondly, three fixed deformable barrier tests were performed to give some information on choice of overlap extent and impact speed Although less than for the other car models, this information helped to indicate which configuration was the best match for the car-to-car tests All the cars tested were new from the manufacturer They were 1993, Peugeot 405 GL 1 4 Saloons

Overlap Effect Analysis - The car-to-car tests were all performed at 50 km/h with overlaps of 40, 50 and 60 percent The car to fixed deformable barrier tests consisted of two tests at 40 percent overlap with speeds of 55 and 60 km/h and one test at 50 percent overlap at a speed of 60 km/h (table 2) In each of the fixed deformable barrier tests, a single 50 psi element barrier face was used. (See figure 1)

The 50 percent overlap car-to-car test was the 'baseline' test with which the barrier tests were to be compared The other car-to-car tests, at overlaps of 40 and 60 percent, were to examine the car's sensitivity to variations in overlap extent. Left hand drive cars were used with impacts on the driver's side because some car manufacturers suggested that, with the gearbox on that side of the car, there would be more sensitivity to variation in overlap It was also expected that larger overlaps would produce higher car decelerations and smaller overlaps would produce more intrusion into the passenger compartment However, analysis of the vehicle acceleration traces showed no tendency for vehicle deceleration to increase with overlap, within the range of overlaps tested The greatest peak accelerations for B-posts, tunnel and firewall all occurred in the 50 percent overlap test Little difference could be seen in the fore/aft decelerations of undeformed parts of the cars, with the exception that the peak values occurred slightly earlier as the overlap increased. This was probably due to the different extents of barrier crush early in the impact Comparing the engine top accelerations, on the impacted side, an early peak was seen in the 50 percent and 60 percent overlap tests In the case of the 40 percent test, the peak was much smaller In none of the impacts was the engine loading large

Comparing the static intrusion measurements, there was no identifiable trend towards greater intrusion as overlap extent was reduced In some instances, the variation in intrusion between the two cars in the same test was as large or larger than the variation between tests with different overlaps This may have been a consequence of one car 'over-riding' the structure of the other, in one test This over-riding phenomenon could be seen on the high speed film and was confirmed by the vehicle damage The over-riding was present to a lesser extent in the other two tests

The curved longitudinal box sections in these cars deformed almost as much as their surrounding structures However, the frontal deformation was not uniform either across the car or vertically In all the cars, there was more deformation at the waistline than at the level of the bumper No significant differences could be identified in the way the cars' structures collapsed, when impacted with the different overlap extents In none of the cars was there significant loading of the engine onto the firewall There was no engine to firewall contact in the 40 and 50 percent tests and only minor contact in the 60 percent test. The attachment of the facia rail to the firewall, on the driver's side of the car, became partially or totally detached in every car

Dummy head acceleration was seen to increase with increasing overlap However, the chest, femur and pelvis measurements did not show any definite trend Femur load was seen to be very dependent upon the actual structure hit by the knee and its stiffness

On the basis of internal deformation, the 50 percent overlap test at 60 km/h was a poorer match than each of the tests at 40 percent overlap

All three of the cars impacted into fixed deformable barriers sustained damage that was similar to that seen in the car-to-car tests The match of all of the tests to the car-to-car tests was much closer than would be expected with any configuration of rigid wall test

Dummy response data is the least suitable for the selection of overlap The car acts as a filter to the dummy input and the dummy cannot distinguish between speed effects and overlap or barrier stiffness effects Consequently, the conclusion drawn from dummy response in these tests was seen to be of less importance However, the dummy response also suggested that the 40 percent overlap test at between 55 and 60 km/h was the closest match

In conclusion, the analysis regarding overlap by comparisons between the car-to-car test at 50 percent overlap and 50 km/h showed, on the basis of external deformation and crush measurements, the tests at 40 percent overlap gave the closest match

Impact Speed Analysis - The frontal deformation of the 50 percent overlap test at 60 km/h, was the poorest match In this test, the right hand side of the engine received much more significant loading and was displaced rearwards much more As a result the interaction with the firewall was much greater than that seen in any of the car-to-car tests

On the basis of the internal deformation and crush measurements the situation was less clear The facia displacement was seen to be most closely matched by the 55 km/h test at 40 percent overlap but the collapse of the front door was more closely matched by the 60 km/h test at 40 percent overlap These parameters are usually thought to be linked and frequently door opening deformation is used as a surrogate for facia intrusion The differences here may be due to the failure of the facia to A pillar connection A stronger connection, which did not fail, would result in reduced facia level intrusion, in which case door opening deformation might be a better parameter to match Overall, on the basis of static vehicle deformation, the closest match to the reference car-to-car test was the 40 percent overlap test at 55 km/h However, this test was less severe and the important front door collapse parameter was closer at 60 km/h This suggested a best match speed of between 55 and 60 km/h

The vehicle dynamic response data shows the worst match to the reference test to be the 50 percent overlap at 60 km/h In this test, the vehicle accelerations are too high The most useful data came from the left B pillar accelerometer, which was situated close to the seat belt anchorage point From this accelerometer, the best match appeared to be the 40 percent overlap test at 60 km/h However, if the mean acceleration was considered, the best match was with the 40 percent overlap test at 55 km/h

In conclusion regarding impact speed, it was clear that the closest speed match would have been between 55 and 60 km/h The nearest match speed would be dependent upon which parameters were given the greatest weight With some important exceptions, the majority of parameters pointed towards 55 km/h being nearer than 60 km/h

Barrier Design Analysis - Alternative barrier face designs were not evaluated with the Peugeot However, some comment can be made regarding the logic used to move to a barrier with a bumper

In analysis of the Fiat Uno tests, concern was expressed over the loading from the barrier at the waistline compared with that at bumper level This aspect was investigated for the Peugeot tests Two comparisons were made Firstly, the relative displacement of the suspension turret top and the A pillar lower end and secondly, the relative displacement of the door pillar at the waistline and its base In the first comparison, the barrier tests produced a larger displacement of the suspension turret top relative to the A pillar lower end However, in the second comparison, the differences were virtually the same In conclusion, there was some indication that the barrier face loaded the car at the waistline a little more than another identical car For this car, a change to the barrier which reduces this effect was thought to be desirable but not essential

Peugeot 405 Test Conclusions - All of the fixed deformable barrier tests gave a good representation of the car-to-car impact. Any of them would be a substantial improvement over any rigid wall test

The 50 percent overlap impact gave the poorest match to the car-to-car test and the main reason for this appeared to be due to the way the engine was loaded and it loaded the firewall This higher engine loading gave rise to a high vehicle deceleration and slightly less realistic vehicle deformation

The 40 percent overlap tests gave a very good match, with the only difference being related to the test speed It was clear that the closest speed match would have been between 55 and 60 km/h With some important exceptions, the majority of parameters pointed towards 55 km/h being nearer than 60 km/h

Summary of the Testing with the Ford Scorpio

The car type selected was the hatchback type 21 carburettor version without sunroof or power steering The evaluation concentrated on the three parameters which were varied in the test programme, the overlap extent, barrier depth and finally the impact speed The comparison of test results was based on visual inspection of the crashed vehicles, static deformation measurements, injury criteria and signal time-histories The data that have been used for the comparisons are.

- B-pillar base left acceleration [g] vs time
- B-pillar base left acceleration [m/s²] vs displacement
- B-pillar base left mean acceleration [$\bar{g}$] vs time

- Engine displacement relative to B-pillar base left [m] vs time.
- Injury criteria such as HIC, chest acceleration, pelvis acceleration, belt loads, femur loads, and chest deflection

Many static post crash measurements and dynamic results were collected in tables and put into bar charts for easier analysis In this summary, for every test parameter a brief comment is added together with a general conclusion for the particular parameter

To compare injury criteria the driver and passenger dummies' HIC, chest g and chest deflection were chosen The question can be raised whether or not the injury criteria measured are capable of relating to the anticipated actual injuries sustained in a similar accident. The dummy's lower extremities are a particular point of concern here In all the tests performed by TNO, the forces and moments acting on the lower legs of the dummies were measured. High values for both forces and moments could be observed. Unfortunately no correlation could be found with the severity of the test The fact that the dummy's ankle was broken in some tests could not be explained by the measured signals The crash pulses of the cars in the car-to-car test were very comparable For that reason the average of the two was used for all the vehicle results in the comparison

In the analysis of the vehicle results it has to be noted that, by definition, it is impossible to achieve the same crash pulse with the car-to-car impacts as with car to deformable barrier impacts because the tests involved different values of Δ V, so less attention should be paid to the timing and level of the accelerations of the car A more relevant parameter, the mean acceleration, was used for analysis. Special attention was paid to the engine displacement relative to the car body, since the engine can load the car structure in a severe way During the Ford Scorpio car-to-car baseline test, no engine to car contact occurred and the side members hit outside each other A deformable barrier impact should simulate this phenomenon correctly.

Overlap Effect Analysis - The engine behaves in the 40 per cent overlap situation much closer to the car-to-car test than it does in 50 per cent overlap. Relative engine displacement shows that 60 per cent overlap is not a good simulation of the car-to-car crash In the car-to-car tests there was no engine contact against firewall detected In the 40 per cent overlap tests there was slight contact and with 50 per cent overlap there was clear contact Some other arguments can be derived from the geometric aspects of the impact (figure 4) In the plan view sketch of the major parts of the Ford Scorpio it can be seen that the engine finally hits the wheel in the car-to-car crash and no other hard parts of the other car

In conclusion, the analysis of the tests points clearly to the 40 per cent overlap car to deformable barrier being the closest approximation to the 50 per cent overlap car-to-car impact

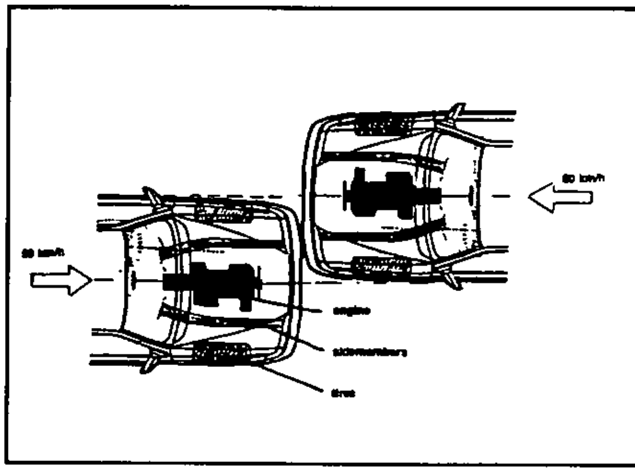

Figure 4 Plan view of car-to-car 50% overlap test configuration (Scorpio)

Impact Speed Analysis - The severity of the crash is much more dependent on the impact speed than other parameters The 65 km/h crashes were much too severe when compared with the car-to-car test. Results of the 55 km/h barrier tests are closer to the car-to-car then results of the 60 km/h barrier tests However, some of the vehicle measurements for the 55 km/h tests are low in comparison with the car-to-car test which means that a velocity between 55 and 60 km/h could be more appropriate.

In conclusion, the analysis of the test results for impact speed indicate that the speed of 65 km/h is too high judging from the deformation of the vehicles Even 60 km/h seems to be too high compared with the car-to-car results The results at 55 km/h are closest to car-to-car at 50 km/h. However, a speed somewhat higher than 55 km/h would probably be closer, based on residual static deformations and injury criteria

Barrier Design Analysis - The results of the early phases of the test programme pointed to the use of a deep barrier based on engine relative displacements and B-pillar base acceleration against deformation . On the other hand a lot of static measurements of the vehicle show better correlation of the normal barrier with the car-to-car test This contradiction could be caused by the actual speed of test 15 (55 km/h, 40 per cent overlap, deep barrier) being only 52 8 km/h. A correct speed would have brought the table values of the deep barrier closer to car-to-car Energy evaluation shows that the vehicle travel would increase by about 80 mm with correct speed This would then lead to higher values of the relevant vehicle deformations in the table, closer to car-to-car

Table 3
Injury results lower legs driver, filtered according to J211B

Test No		LHS lower tibia	RHS lower tibia
Test 4 40% overlap 60km/h normal barrier	F_x	25 6 kN	6 0 kN
	M_y	8 4 daNm	4 7 daNm
Test 5 50% overlap 60km/h normal barrier	F_x	26 5 kN	7 2 kN
	M_y	8 2 daNm	8 4 daNm
Test 16 50% overlap 65km/h deep barrier	F_x	27 9 kN	3 5 kN
	M_y	10 5 daNm	6 8 daNm
Test 20 50% overlap 55km/h normal barrier	F_x	2 1 kN	8 6 kN
	M_y	25 1 daNm	4 4 daNm

Acceleration values suggest that perhaps the starting stiffness of the barrier should be greater and, for the deep barrier, the second part should have the same stiffness as the normal barrier The car-to-car acceleration graphs show relatively high values in the beginning of the crash, whereas the deformable barrier crashes show lower values This might be due to the fact that in car-to-car the first contact is harder and in the deformable barrier the vehicle intrudes the barrier with low force level In the end the accelerations in the deformable barrier tests are higher then in the car-to-car

The dynamic vehicle time history results of the test with barrier with bumper provided the barrier characteristic as described above and confirmed that these characteristics gave a good representation of the car-to-car tests There were only minor differences in the other test data that were considered

In conclusion, the analysis regarding barrier design concluded that, while the deep barrier configuration looked favourable from the results of the first phases of the test programme, the results of the barrier with bumper are even closer to the car-to-car test results The barrier face should be equipped with the bumper used in the later phase of the test programme

General Observations - Scorpio Tests - Inspection of the cars demonstrates that the crash modes of the structure look very much the same for all the deformable barrier Ford Scorpio tests, including the car-to-car tests There are some small differences looking at the details details

Photographs of the post-test deformation of the vehicles tested with the normal barrier and the normal barrier with bumper are compared with the deformation pattern in the car-to-car test in figures 5-7 The close similarity in the vehicle damage patterns can be seen For comparison, a similar vehicle that has impacted a 30° angled rigid barrier with Anti Slide Devices is shown in figure 8

Injury to the driver is difficult to judge because of the particular contact against the steering wheel Film analysis and dummy position after the crash often indicate that severe injury would be very likely but this was not registered by the dummy instrumentation A better way should be found of measuring the injury risk due to intruding parts than with the existing Hybrid III dummy instrumentation

Lower leg forces (F_x) and moments (M_y) were measured in tests 4, 5, 16 and 20 (table 3) Although dummy ankles were broken in tests 4 and 5, no higher bending moments were recorded in the lower tibia compared with test 16 where the ankle was not broken Knowing that the footwell intrusion of test 16 (65 km/h) looked much more severe than test 4 and 5, makes this all somewhat confusing Attention should be paid to the reliability of the dummy signals (biofidelity) in relation to the severity of injuries of the lower legs

Scorpio Test Conclusions - It was concluded from this study that the "55 km/h, 40 per cent overlap, barrier with bumper" test configuration shows the best correlation with the baseline car-to-car impact at 50 km/h Further investigations should concentrate on a possible impact speed between 55 and 60 km/h Furthermore it has to be noted that conclusions from this analysis are based on one vehicle model and may not apply to all large vehicles

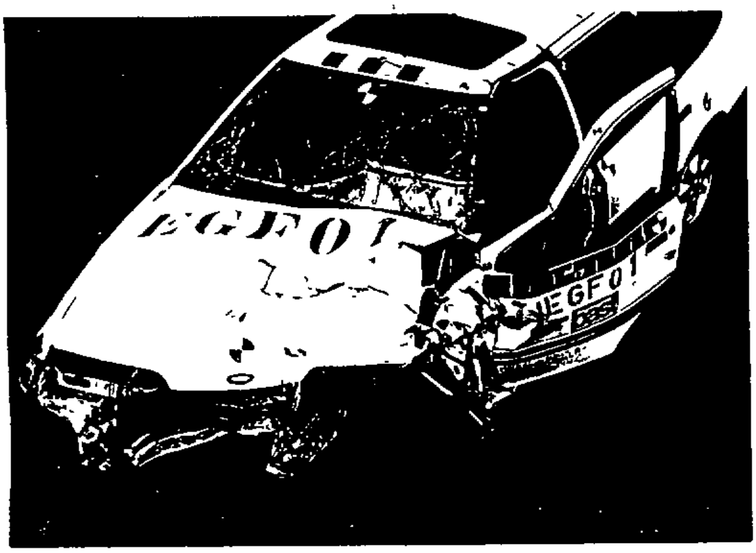

Figure 5. Ford Scorpio, after impact with another Ford Scorpio at 50% overlap, 50km/h

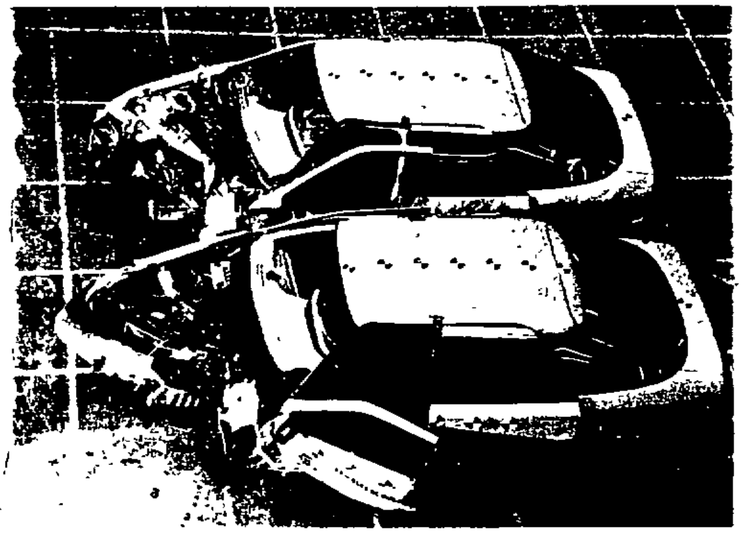

Figure 6 Ford Scorpio, after impact with 'normal' deformable barrier at 60km/h and 50% overlap (top), 40% overlap (bottom)

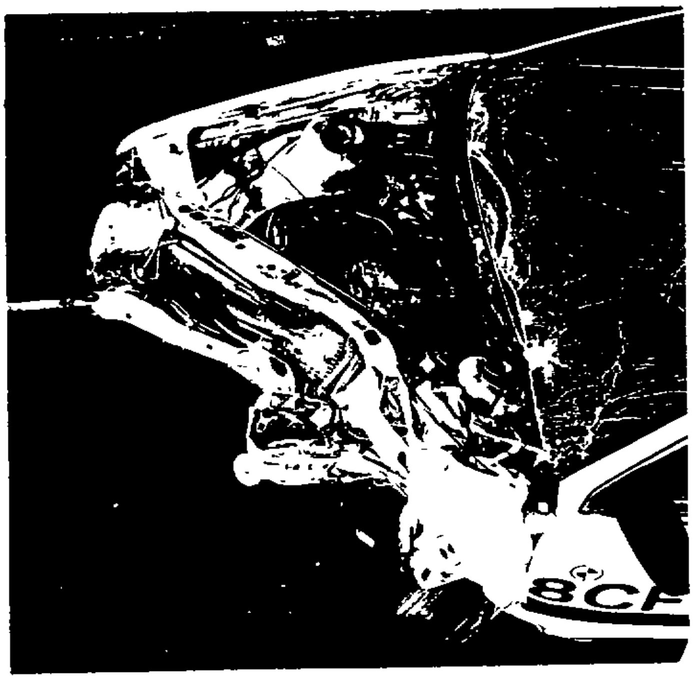

Figure 7 Ford Scorpio, after impact with normal element and bumper at 55km/h, 40% overlap

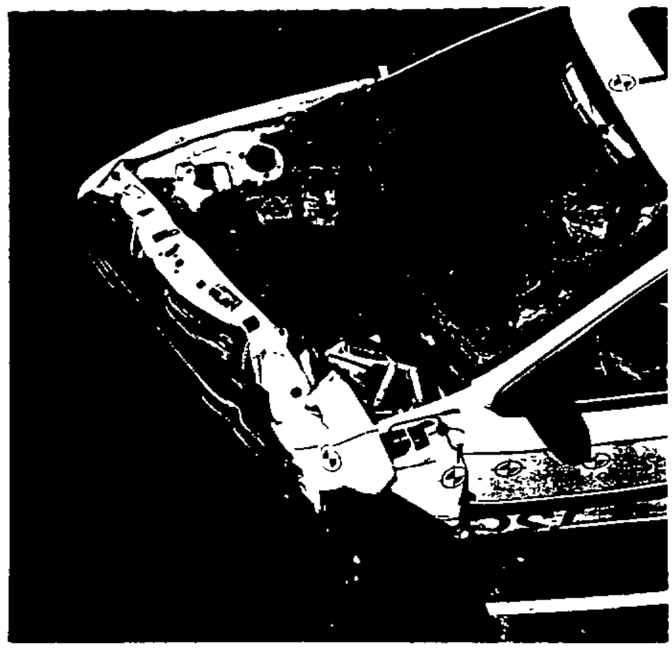

Figure 8 Ford Scorpio after impact with 30° angled rigid barrier with ASD at 50km/h

SUMMARY OF ALL OTHER TESTING REPORTED TO WG11

To complement the EEVC test programme described above, other testing conducted in Australia, Canada, Japan and United States were reported to this Group These programmes are described below

In **Australia**, the Federal Office of Road Safety is participating in the work of the EEVC to develop a globally acceptable test procedure for offset frontal crash testing This test procedure will be used as the basis of a new Australian Design Rule (ADR) for offset frontal crash protection to be implemented towards the end of the decade The crash test programme consists of three tests

- 40% overlap test into a deformable barrier at 60km/h
- 50% overlap test into a deformable barrier at 60km/h
- 50% overlap car-to-car crash with each vehicle travelling at 50km/h (to be performed)

The tests were set up as closely as possible to the EEVC test protocol to assist comparison All vehicles used were 1993 Toyota Corolla Liftbacks and Hybrid III dummies were installed in each front seating position and restrained by the vehicle's lap sash seat belt A deformable barrier face using 50psi aluminium honeycomb conformed to the original EEVC 'normal' barrier face specification was used So far, only the 40 and 50 percent barrier impacts have been reported in detail to WG11 The comparison of these tests indicated that

- the 50% overlap gives a slightly higher vehicle deceleration pulse with earlier onset
- the 50% overlap gives a slightly higher head and chest injury criteria for both dummies and higher femur loads for the driver
- the 40% overlap gives more intrusion
- the 40% overlap gives higher lower leg injury criteria for the driver
- the barrier faces bottomed out in both test but this occurred late in the crash
- in both tests, there was significant upwards rotation of the brake pedal It is unclear if this is vehicle specific
- the 40% overlap is reported to be closer to the car-to-car test from the structural damage but, at 60km/h, the deformation and engine movement are greater in the barrier test

The current view is that ADR69 (perpendicular, rigid, full overlap impact) for full frontal impact protection will test the vehicle's restraint system in a high deceleration crash situation The offset test will test the vehicle's structural integrity and, with lower leg injury criteria applied, the vehicle's ability to prevent debilitating leg injuries

In **Canada**, Transport Canada has conducted four offset frontal crash tests to provide information relevant to the activities of EEVC WG11 To determine the effect of impact angle on vehicle deformation, two tests were conducted in which a ballasted Ford Taurus struck a stationary Honda Accord In both tests, the overlap was 40 per cent and the nominal velocity change was 54km/h In the first test, the vehicle paths were parallel In the second, the path of the striking vehicle was oriented at 15 degrees towards the target vehicle The rearward displacement of the engine and chassis elements forward of the firewall was substantially greater in the angled collision, though the displacement of the A pillar was less

Two further tests were performed in which a Honda Accord struck a fixed deformable barrier at 53 km/h with 40 percent overlap In the first test, the deformable element was identical to that specified for the moving barrier in the FMVSS 214 side impact standard, including the bumper element In that test, the deformable element bottomed out relatively early in the collision, causing significant interaction between engine and firewall The pattern of deformation differed from both the parallel and 15 degree vehicle to vehicle collisions in significant details In the second test, a deformable element of aluminium foam was used It had the same shape and nominal yield strengths as the FMVSS 214 barrier but was 250mm deeper It was expected that the increased depth of the barrier and the rising force-displacement characteristic of the foam material would preclude direct contact between the vehicle and the rigid mounting block In fact, the aluminium foam core failed extensively in tension around the impact region The consequent loss of load diffusion into the undeformed part of the barrier reduced its effective stiffness The resulting vehicle deformation was not significantly different from that observed with the honeycomb barrier face It was concluded that the currently available aluminium foam is not a practicable material for deformable barrier faces

In **Japan**, JASIC is conducting a study on crash test methods Three car-to-car tests at 50 km/h with 50 per cent overlap area have been planned as reference tests Two car models are considered a small car (1100kg) with a transverse engine and a medium one (1400kg) with a longitudinal engine The programme includes two car-to-car impact tests with the same car models , while the third is between the two different models The first two tests have been reported to WG11 Four car to deformable barrier offset tests have been performed at 55 km/h with an overlap of 50 per cent two tests with the small car and two tests with the medium car against different deformable elements (normal barrier with and without bumper) A fifth test was conducted with the small car at 55 km/h against a deep barrier with an overlap of 40 per cent From a first analysis of test results comparing the car to barrier tests with the car-to-car tests that have been performed, it appears that the 40 per cent overlap test against a deep barrier reproduces better the vehicle deformations in a horizontal plane and the decelerations, and that a bumper on the deformable element is useful to reproduce the deformation shape in a vertical longitudinal plane This latter observation was based on a 50 percent overlap test

In the **United States**, NHTSA defined a frontal impact research programme which is under way for developing improved injury criteria, test devices, and test procedures This programme is investigating higher severity crashes, other occupant sizes, and additional body regions and improved injury criteria

A series of eight car-to-car, frontal offset tests have been conducted using a Honda Accord as the bullet vehicle The airbag equipped test vehicles were the Geo Metro, Isuzu Stylus, Chevrolet Corsica, Dodge Dynasty, Saab 9000, Volvo 740, Honda Accord Wagon, and Ford Taurus The closing speed was 116 km/h with 60 percent engagement of the test vehicles A belted fiftieth percentile Hybrid III driver dummy was used Only the Geo Metro failed any of the FMVSS 208 injury criteria (HIC and femur load), while all of the vehicles indicated the potential for serious injury to the tibia Similar frontal offset tests were then conducted with engagements of 50 and 70 percent of the Chevrolet Corsica For these tests, only the tibia load indicated the potential for serious injury

In late 1993, a 30 degree oblique, frontal test was conducted with an engagement of 50 percent of the Corsica. The Corsica driver dummy exceeded the head, chest and tibia criteria NHTSA also conducted 48km/h (unbelted) and 56km/h (belted) full rigid barrier tests alternating the fifth and ninety-fifth percentile Hybrid III dummies in the driver and front passenger seats. The ninety fifth percentile dummy in the passenger seat exceeded the HIC criteria during the 48 km/h test Sled testing with bucks derived from a Toyota Celica and an Acura Legend is being used alsoto study the effects of occupant size

A first conclusion is that occupants using a belt with an air bag are unlikely to get serious head or chest injuries without severe intrusion Tibia and lower extremity injuries can occur in offset crashes

The Insurance Institute for Highway Safety also carried out car-to-car and deformable barrier tests with GM Cutlass Cieras at 56 km/h Car-to-car tests at 50 per cent overlap were compared with rigid barrier tests at 100, 50 and 40 percent overlap and deformable barrier at 50, 40 and 30 percent overlap The deformable barrier test configurations were also carried out at 64km/h In these tests, good agreement with the car-to-car tests was obtained with the 40 percent deformable barrier. For each of the cars tested, the deformation data were input into the Crash3 program and calculated **ΔV** was compared with the measured impact speed In all cases, the calculated **ΔV** was lower than the impact speed and this difference was greater for lower overlaps It is concluded that the accident data under estimated impact speeds in partial overlap crashes andmany injuries in such real world crashes are occurring at higher speeds than sugested by the accident data .

The American Automobile Manufacturers Association (AAMA) and its member companies provided comparison data obtained in barrier impact of front wheel drive (FWD) and rear wheel drive (RWD) cars designed to meet FMVSS 208 requirements The results of the following tests were reported.

- Full frontal perpendicular and 30° angled rigid barrier (with anti slide devices) at 48km/h (30 mile/h)
- Full frontal perpendicular rigid, offset rigid and offset deformable barrier (FMVSS 214 element) barrier at 56km/h (35 mile/h)
- Car-to-car impacts at 60 per cent overlap and at 56km/h (35 mile/h)

AAMA and its member companies also provided advice on Hybrid III performance criteria suitable for use in the proposed EEVC front impact test procedure.

CONCLUSIONS FROM TEST RESULTS.

The results of the impact tests with all three models used in the EEVC test programme showed that the deformable offset impact test gives a very good reproduction of the car-to-car impact conditions, particularly regarding the structural loading For all three car models, the results indicated that the closest approximation to the 50 percent overlap, 50km/h car-to-car impacts were the **40 percent overlap** impacts to the **standard barrier with bumper attached** at an impact speed **slightly above 55km/h.** The impact to the deformable fixed barrier needs to be at a higher speed than for the car-to-car impacts since with the latter the crash energy of two cars is absorbed only by deformation of two cars With the fixed deformable barrier, a little of the energy of the impacting car is absorbed by the deformable face Consequently, to ensure that the equivalent amount of energy is absorbed by the tested car structure, the impact energy (speed) has to be a little higher Similarly, the offset in the barrier test would be expected to be less than for the equivalent car-to-car test since, unlike the deformable face, cars tend to be less stiff towards the outer edge

Although the accident data indicate that the appropriate test speed should be higher than 56km/h, the limited test results available from this test programme suggest that current designs would need substantial modification to achieve good results at 60km/h It would seem to be advisable to initiate testing at 56km/h until the design methodologies required to deal with the higher energies are better understood

The study has been based on three car models with widely differing characteristics The fact that results for all three lead to the same conclusion lends confidence that the results are generally applicable However, it would be wise to evaluate the test procedure against a larger vehicle design base EEVC WG11 plans to validate this proposal using a wider range of vehicle designs and types

PROPOSED EEVC FRONTAL IMPACT TEST CONDITIONS

The Impact Test recommended is an offset impact of the subject vehicle into a deformable face attached to a rigid static barrier

Deformable Face

The deformable face should have the characteristics shown in figure 3. The main block of the face is constructed from 50psi aluminium honeycomb covered in a sheet of 0.81mm aluminium and the additional block covering the lower half of the front face is constructed from 250psi aluminium honeycomb and has a sheet of 1mm aluminium to its front face The lower edge of the deformable face is at 200mm above the ground level

Overlap.

The vehicle should impact the deformable face such that the barrier face overlaps the front of the car by 40 percent of its width on the driver's side Thus the impact should be directed to the side containing the steering column such that the edge of the barrier face is displaced from the vehicle centreline in the direction of the impacted side by 10 percent of the maximum external width of the vehicle (excluding mirrors etc) Many vehicle models may be intended for left and right hand drive layouts and the design may be asymmetric, particularly with transverse engines and gearboxes It would therefore seem to be desirable to test both or, if it can be determined, the worst case

Impact Speed

The vehicle speed at the point of impact to cover a reasonable range of current serious and fatal injuries should be 60km/h Indeed this may be an underestimate However, for practical reasons it may be advisable to reduce this initially to 56km/h This appears to be the appropriate impact speed for the deformable face impact that is equivalent to a car-to-car impact at 50km/h and is in harmony with the NHTSA standard impact speed of 35mile/h used in the NCAP test The test procedure should ensure that the vehicle reaches a steady speed over a sufficiently long period for inertia devices, such as seat belt retractor locking mechanisms, to be in their stable neutral position prior to impact

Dummies

Hybrid III fiftieth percentile dummies are placed in each of the driver and front outer passenger seating positions Generally, it is recommended that the seating conditions follow those specified in FMVSS 208 except that, for consistency with other European Regulations, the backrests should be set at 25°

PERFORMANCE PARAMETERS

The performance requirements for the EEVC frontal impact test have been selected to control the risk of injury to the front seat occupants for the principal serious injuries observed in frontal impacts As far a possible, biomechanically based performance criteria have been selected, making much use of recommendations and current practice used by the AAMA members (39) However, recognising that, for a test that might be used in a legislative requirement, it is practical to test with only one dummy size to protect all occupant sizes, and that the phenomenon of intrusion discussed above should be controlled

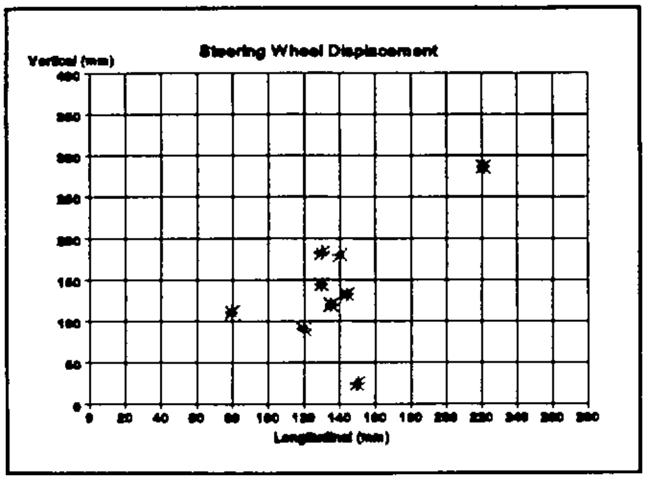

Figure 9 Steering Wheel Displacement

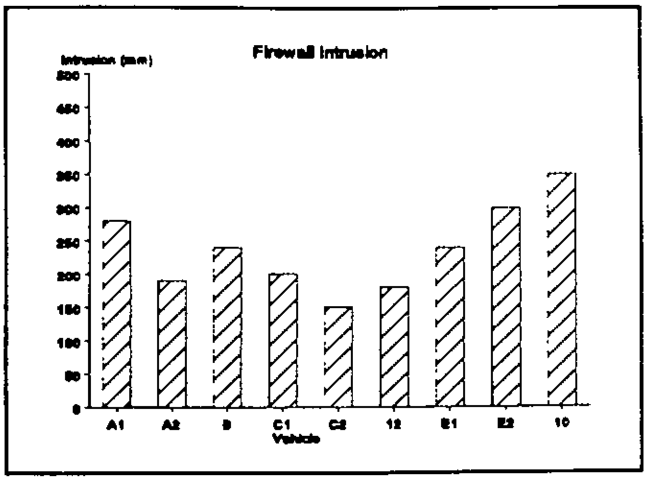

Figure 10 Firewall Intrusion

in some way, it is considered essential to include additional performance requirements

The review of available accident analyses has indicated that passenger compartment intrusion is a major injury producing factor, especially in accidents with partial overlap Lower extremities are affected by intrusions in the footwell area Injuries of lower legs are frequent and often require long term rehabilitation Another problem, in severe accidents, is the trapping of legs which leads to difficulties of evacuating occupants Chest and head impacts into steering wheels are responsible for a large portion of severe and fatal injuries to restrained drivers Large steering wheel displacements will most certainly increase injury risk but may not be indicated by the chest response of the fiftieth percentile dummy

In the EEVC test programme, residual intrusions were measured at a number of locations inside the compartment Figures 9 and 10 show steering wheel displacement and intrusion at the firewall in some of these tests Both diagrams show large variations in intrusion None of the three selected car models fulfils the proposed requirement for steering wheel displacement Yet, similar tests with other car models have shown that the proposed requirements can be met Though intrusion is considered to increase injury risk in accidents, requirements on intrusions have not been well developed yet Static intrusion criteria does not take in account important factors such as intrusion velocity and deformation characteristics of intruding components

Therefore injury criteria, measured in the dummy, are regarded as the best available measurement tool for injury severity in most cases Exceptions from this philosophy are steering wheel intrusion and the ability to remove the dummy after test Large steering wheel displacements are believed to give a substantial increase of injury risk Since various head trajectories and occupant sizes are not covered in the test method, a requirement for steering wheel displacement has been considered as a necessary complement to dummy criteria

The proposals included for intrusion are a compromise between the desire to limit only those features that can be demonstrated to produce injury risk and the desire to protect the widest range of occupant sizes with a single size dummy with limited instrumentation The performance requirements are therefore considered under two categories, those dealing with the biomechanical criteria linked to dummy measurements and the other dealing with aspects that cannot be controlled by the available dummy instrumentation

Dummy

Head - The HIC is recommended as the protection criterion to be used as a measure for head injury risk This criterion, while it has some deficiencies, is considered to be the best available and the parameter with which there is greatest experience The proposal to replace HIC with a simple requirement for a peak resultant head acceleration of 80g will be examined in future testing

Neck - The recommended neck injury performance criterion is based on figures 11-13 (Ref 39)

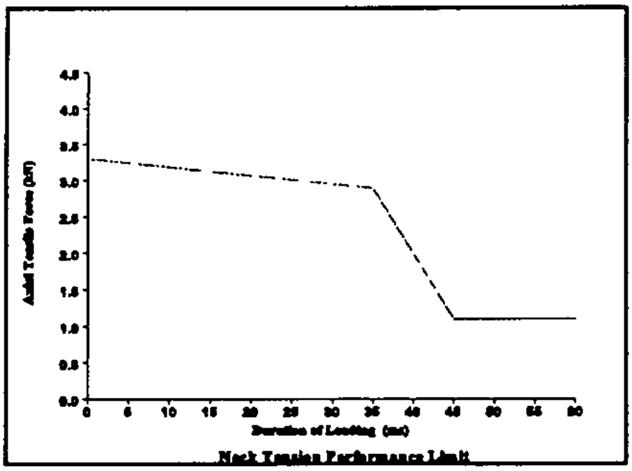

Figure 11 Neck Axial Tension Performance Limit

Chest - Chest deflection not exceeding 50mm unless the impact forces are distributed over the thorax by an airbag, in which case the deflection limit should be 65mm

Viscous Criterion The value of V*C should not exceed 1.0m/s The recommended method for calculating V*C is given in the Annex

Abdomen - The compression of the abdomen should be limited, but more experience with a penetration detection method is required before this can be specified

Femur - The femur force should not exceed the force-time performance criterion given in figure 14 (Ref 39)

Tibia - The axial compression of the tibia should not exceed 8kN and the Tibia Index (= M/M_c + F/F_c) should not exceed 1, where M_c (critical bending moment) = 225Nm and F_c (critical compressive force) = 35 9kN (Ref 39) The movement of the sliding knee joints shall not exceed 15mm

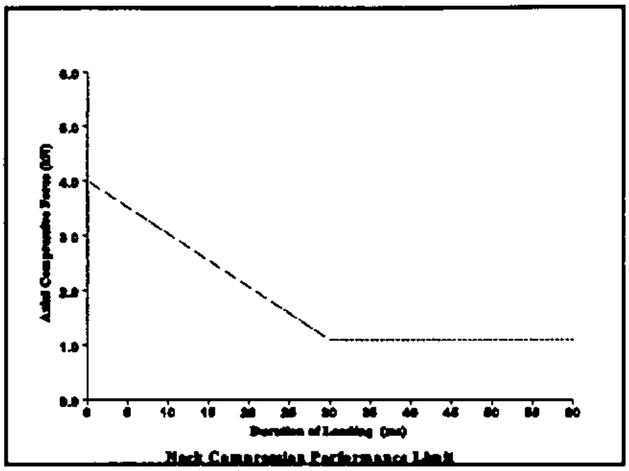

Figure 12 Neck Axial Compression Performance Limit

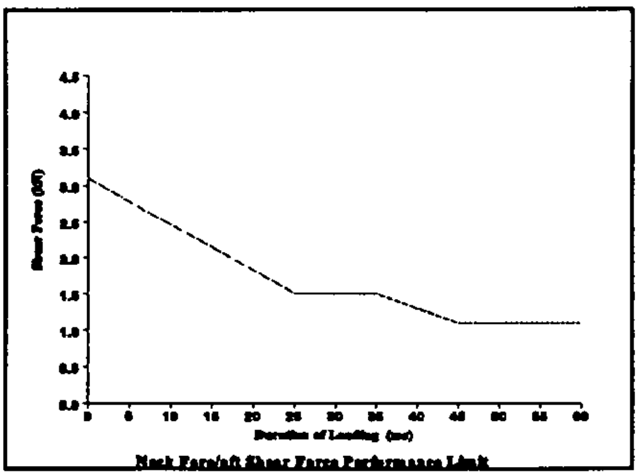

Figure 13 Neck Shear Performance Limit

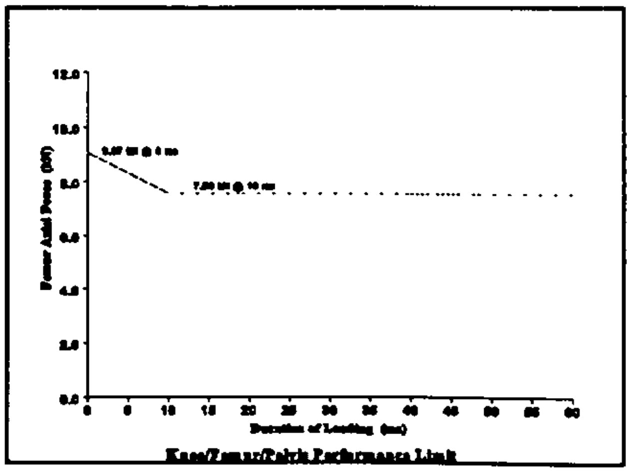

Figure 14 Femur Axial Compressive Force Performance Limit

Intrusion

Residual steering wheel displacement, measured at the centre of the steering wheel hub, shall not exceed 80mm in the vertical direction and 100 mm in the rearward horizontal direction Upward rotation of steering column and wheel shall be less that 25°

The dummies shall be capable of being removed without tools and without adjustment of the seat position Furthermore the dummies should not be broken during the test, should remain within certification and be in a condition suitable for use in a further test

SUPPLEMENTARY TESTING

The full scale test evaluates a number of very important aspects of the injury risk to the vehicle occupants in a frontal impact There are a number of aspects that cannot be assessed in this single test and which the EEVC WG11 feels need to be addressed

Steering wheel impacts

Even if head or face to steering wheel contact does occur in the full scale test, the single test will evaluate only one single point impact of the wheel Accident studies clearly indicate a wide range of actual contact locations on the steering wheel (23) EEVC WG11 strongly advocates the use of an additional supplementary test to evaluate the facial and brain injury from steering wheel impact. How this should be addressed in the event of the presence of an airbag needs to be considered EEVC WG12 is currently considering face to steering wheel impact evaluation

Seat and seat attachment

The strength of the seats and seat attachment cannot be fully addressed in this test In particular, the effect on the dynamic performance of the seat, if it is possible to leave the adjuster out of engagement or partially engaged, needs to be considered by design requirements or a separate dynamic test The ability of the rear seat backs to withstand the impact forces of luggage was considred for incorporation in the full scale test, but it was decided that it would be simpler to evaluate this also in a separate test

Seat belts and anchorages

Similar considerations led to the decision that the dynamic performance of an adjustable upper anchorage that could be left in an intermediate position would be better dealt with elsewhere It was considered that it would be desirable to maintain a component test of the seat belt to enable simple and inexpensive routine testing for production conformity to take place This would be necessary also for such aspects as durability and wear The need for a requirement on anchorage strength would remain as the proposed test procedure would only assess anchorage strength up to the 50th percentile person at this impact severity

Fuel leakage

It is considered that the fuel leakage requirements of ECE Regulation 34 could be incorporated into the proposed test procedure, making that part of R34 redundant

COMPARISON OF PROPOSAL WITH OTHER CURRENT FULL SCALE TEST REGULATIONS/STANDARDS

The European philosophical approach differs from that of USA, Canada, Australia and Japan This comparison is therefore presented separately for these two groups

European Regulatory Situation

In Europe, the approach has been basically a geometrical one

The safety requirements of the current Full Scale Test (FST) Regulations (Regs 12, 33 and 34 for the frontal impact) are limitations in the amount of intrusion and of the fuel spillage

In spite of the fact that the European Community has recognised the superiority of the biomechanical approach since 1974, the first finalised proposal of a FST with biomechanical criteria for the Frontal Impact Protection is likely to become a regulation only this year

The test procedure is defined as a 30° impact against a rigid barrier with Anti Slide Device (ASD) Even if the effectiveness of the test procedures has not yet been demonstrated, there is a general consensus that the offset frontal impact against a deformable barrier, as outlined in this paper, reproduces the car-to-car frontal collision better than the 30° impact The introduction of a deformable barrier could be a promising step forward towards a future compatibility approach

US, Canadian, Australian and Japanese Regulatory Situations

These four countries have some similarities in their current Full Scale Tests Regulations, even if they are in a different development stage of the individual regulatory process their approach is philosophically different from the European one in that,

- No regulation with requirements similar to the ECE Reg 33 has been developed in the past in these countries

- They support a test procedure based on a symmetrical 0° frontal impact against a rigid wall, stressing the severity of the test rather than the representation of the road accident situation. FMVSS 208 also requires compliance in ± 30° frontal impact without ASD

USA in addition is looking at the crashworthiness rating of cars based on tests performed at a higher speed (56km/h) than the standard one There are requirements on the windshield intrusion and mounting (FMVSS 21-219) and on the fuel system integrity (FMVSS 301), to be checked also in 0° FST

Thus the USA FMVSS 208 requirements are based on biomechanical requirements in tests which are more severe for the restraint system, while European tests have been based on deformation limits for the passenger compartment. In addition, the US test conditions assume that active restraints are not used whereas the other countries test with dummies restrained by active seat belts, where provided

Finally it has to be noted that the limitation in the rearward displacement of the steering wheel is the most harmonized FST Regulation (FMVSS 204 and ECE Reg 12)

The participation of experts and officials of these countries into the EEVC Working Group activity is promising for the future harmonization in the frontal impact FST.

SUMMARY

The most profitable way of reducing the numbers of seriously or fatally injured car occupants in frontal impacts would be to develop and introduce a more realistic frontal impact test procedure

An offset impact into a deformable barrier is the next step forward in improving the characteristics of a full scale frontal impact test to simulate better a car-to-car impact

The closest representation of the general conditions of a 50 percent overlap car-to-car impact at 50km/h was found to be a 55km/h 40 percent overlap car impact into a deformable barrier based on 50psi aluminium honeycomb with a bumper element

In order to cover a reasonable range of seriously or fatally injured car occupants, the impact speed should be 60km/h, but it may be advisable to introduce the test at 56km/h initially.

The requirements should be basically in terms of biomechanical criteria measured on a Hybrid III dummy However, some additional performance requirements are considered necessary to cover aspects with which current dummies and a single dummy size cannot deal

The cooperation between the EEVC, national authorities outside Europe, and industrial experts from within and beyond Europe offers the opportunity for a degree of international harmonisation on impact test procedures

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ACKNOWLEDGEMENTS

The test programme used to develop the conditions of the recommended EEVC Offset Frontal Impact Test Procedure was supported by EC DG VII, but the views given in this paper are those of the EEVC and not necessarily those of DG VII

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ANNEX

Calculation Procedure for the Viscous Criterion for Hybrid III dummy

The Viscous Criterion, **V*C**, is calculated as the instantaneous product of the compression and the rate of deflection of the rib Both are derived from the measurement of rib deflection The rib deflection response is filtered once at Channel Frequency Class 180. The compression at time t is calculated from this filtered signal and is expressed as the deflection of the chest as a proportion of the chest depth of the Hybrid III dummy (0 229metres) -

$$C_{(t)} = \frac{D_{(t)}}{0.229}$$

The rib deflection velocity at time t is calculated from the filtered deflection as -

$$V_{(t)} = \frac{8*[D_{(t+1)}-D_{(t-1)}] - [D_{(t+2)}-D_{(t-2)}]}{12\delta t}$$

where $D_{(t)}$ is the deflection at time t in metres and δt is the time interval in seconds between the measurements of deflection The maximum value of δt shall be $125*10^{-6}$ seconds