

EEVC RESEARCH IN THE FIELD OF IMPROVEMENT OF CRASH COMPATIBILITY BETWEEN PASSENGER CARS

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Paper Number 346

ABSTRACT

At the 2001 ESV-Conference the EEVC working group on compatibility (WG 15) reported the first phase of the research work to investigate the major factors influencing compatibility between passenger cars. Following this, WG15 performed an interim study, which was partly subventioned by the European Commission, the results of which are reported in this paper. In the next phase of work, it is intended to complete the development of a suite of test procedures and associated performance criteria to assess the compatibility of passenger cars in frontal impacts

The main areas of work for the interim study were:

- in depth accident data analysis
- the development of methods to assess the potential benefit of improved compatibility
- crash testing.

The accident analysis identified the major compatibility problems to be poor structural interaction, stiffness mismatching and compartment strength. Different methods to assess the potential benefit of improved compatibility were applied to in depth accident data. Full scale crash testing including a car to car test was performed to help develop the following candidate compatibility test procedures:

- a full width wall test with a deformable aluminium honeycomb face and a high resolution load cell wall
- an offset barrier test with the EEVC barrier face and a high resolution load cell wall
- an offset barrier test with the progressively deformable barrier (PDB) face.

The results of the interim study will be presented in detail and the proposed methodology of the next phase to complete the development of a suite of test procedures for the assessment of car to car compatibility in frontal impacts will be outlined.

INTRODUCTION

Following the introduction of the frontal and side impact Directives in October 1998, compatibility offers the next greatest potential benefit for improving car occupant safety and reducing road casualties. A Renault study (Steyer et al. 1998) has suggested that improved compatibility could reduce the number of serious injuries and fatalities by as much as a third where a car collides with one other vehicle.

Continuing the drive of the European Frontal Impact Directive and EuroNCAP the work performed to date for frontal impact has focused on the structural performance of the cars, with the aim of providing a safe environment in which the restraint system can operate. This approach is supported by the results of an accident study (Wykes et al. 1998), which show that the majority of the serious injuries received by belted occupants were contact induced as opposed to restraint system induced. Once the structure provides a safe environment within which the restraint system can operate, the next step for further improvement will be to control the compartment deceleration pulse. Following this, intelligent restraint systems could offer a way to cope with higher compartment decelerations, and give the occupant an optimised ride-down for a variety of impact severities.

The work performed in the 4th framework compatibility project has helped to understand compatibility. It concluded that for frontal impact an essential prerequisite for compatible cars is good structural interaction. Once this has been achieved some form of stiffness matching will be necessary to ensure that the impact energy is absorbed without exceeding the strength of the occupant compartment. The 4th framework project also outlined three possible test procedures to address these requirements in order to assess and control the compatibility of cars in frontal impact collisions. These are:

- A full width barrier test with a small depth of deformable barrier which uses a high resolution load cell wall to assess and control a car's local stiffness homogeneity. The aim of this test is to improve the structural interaction of cars in impacts.
- An Offset Deformable Barrier (ODB) test with a load cell wall. The aim of this test is to ensure that the global stiffnesses of cars are

matched. This test is similar to the current frontal impact Directive test, except the Directive test does not require load cell wall measurements.

- An ODB test at a higher impact speed with a load cell wall to test the strength of the occupant compartment. This test would not require instrumented dummies.

Following the completion of the 4th framework project, development of the test outlines above and work to further the understanding of compatibility, has continued under government funded projects, mainly in the UK. This work has been reported at EEVC WG15 meetings and international conferences (Edwards et al. 2001 and Edwards et al. 2002).

The French, mainly Renault, have also proposed a test procedure to address compatibility issues (Delannoy and Diboine 2001 and Diboine and Delannoy 2002). This is an ODB test, which uses a recently developed Progressive Deformable Barrier (PDB). The main aim of this test is to improve the structural interaction of cars in impacts, although it does control stiffness as well.

Following further development, it is expected that these tests should form the basis of future legislation and / or consumer testing to improve compatibility. The 5th framework compatibility project, which will continue this work, is not expected to start until November 2002. This project was initiated to continue the development of the tests in the intervening period. The results and recommendations from this project will be used as input for the 5th framework project. A consortium of European research institutions and a motor manufacturer was formed from members of EEVC WG15 (compatibility) to participate in this project.

The partners were:

BASf on behalf of Germany.

Fiat on behalf of Italy.

TRL Ltd. on behalf of the UK.

UTAC on behalf of France.

OBJECTIVES

This project concentrates on the further development of the test procedures described above for frontal impact compatibility, accident analysis and a benefit analysis. The objectives of this project are:

- To further develop the crash test procedures detailed above.

- To perform an analysis to estimate the benefits of implementing compatibility measures for frontal impact.
- To perform accident analyses to further aid the understanding of compatibility and to support the cost benefit analysis.

EXECUTIVE SUMMARY

Following the introduction of the European Frontal and Side Impact Directives in October 1998, compatibility offers the next greatest potential benefit for improving car occupant safety and reducing road casualties. For frontal impact the work performed to date has focused on the structural performance of the cars, with the aim of providing a safe environment in which the restraint system can operate. Having achieved this, intelligent restraint systems could offer a way to cope with higher compartment decelerations, and give the occupant an optimised ride-down for a variety of impact severities.

The work performed in the 4th framework compatibility project has helped to understand compatibility. It concluded that an essential prerequisite for compatible cars is good structural interaction. Once this has been achieved some form of stiffness matching will be necessary to ensure that the impact energy is absorbed without exceeding the strength of the occupant compartment. The 4th framework project also outlined a number of possible test procedures to address these requirements in order to assess and control the compatibility of cars in frontal impact collisions. There are currently four candidate test procedures, which are expected to form the basis of future legislation and / or consumer testing to improve compatibility. These are a full width deformable barrier test to assess structural interaction, an ODB test to control stiffness, a high speed ODB test to control the compartment strength and a Progressive Deformable Barrier (PDB) test to assess both structural interaction and control stiffness.

The main aims of this project were:

- To further develop the crash test procedures detailed above.
- To perform an analysis to estimate the benefits of implementing compatibility measures for frontal impact.
- To perform accident analyses to further aid the understanding of compatibility and to support the cost benefit analysis.

It is expected that the 5th framework VC-COMPAT project, due to start in November 2002, should continue this work. This project was initiated to continue

the development of the test procedures in the intervening period between the 4th and 5th framework projects. The work in this project was divided into 3 work packages, namely, accident analysis, benefit analysis and crash testing.

Accident analysis

Examples of the poor structural interaction, stiffness mismatching and compartment strength compatibility problems were observed in the CCIS and Hanover accident databases for GB and Germany, respectively. For GB, poor structural interaction was found to be a major problem, with less than 2 percent of the car to car frontal impact accident cases examined, showing reasonable structural interaction. For both GB and Germany, stiffness mismatching and / or compartment strength was found to be a large problem. For GB and Germany, indications of the problem were found in 68 and 43 percent of the cases, respectively, where it was possible to identify it. For GB, structural interaction problems were also identified in some single vehicle accidents indicating that a benefit from improved compatibility could also be expected for this type of impact. It should be noted that structural interaction is the primary problem and it is not known how much it contributes to the stiffness mismatching and /or compartment strength problem.

It is recommended that further accident analysis should be performed to better quantify the magnitude of the compatibility problems for Germany. For both Germany and the UK further analysis should be performed in the future to check the conclusions of this work remain valid, as the vehicle fleet is constantly changing.

Benefit analysis

Initial analyses to estimate the benefits of improved car compatibility were performed using GB and German accident data. Two different approaches were used. The first aimed to identify the number of casualties that could be expected to experience some reduction in injury risk from improved compatibility. The second aimed to predict the casualty savings resulting from the improved compatibility of cars. The second approach was only applied to the GB accident data.

The first approach, to determine the problem scope, indicated that a significant proportion of current road accident casualties would benefit from improved compatibility. In GB, for car frontal crash victims, it was predicted that approximately half (45 to 61%) of

the fatalities and 2/3 (66-85%) of serious injuries would experience some reduction in injury risk as a result of improved compatibility. In Germany about half (33-67%) of current frontal crash victims would experience a reduction in injury risk.

It is expected that improved vehicle compatibility will result in far better occupant compartment integrity in frontal impact accidents. Thus, for the second approach it was assumed that improved vehicle compatibility would, pessimistically, eliminate injuries related to either contact with intruded parts of the vehicle interior, or optimistically, eliminate injuries related to contact with the vehicle interior whether it had intruded or not. It was then assumed that removal of these injuries from the existing accident data would quantify the benefits for the applicable occupant population. For GB, assuming compartment integrity is maintained for all impact severities, it was predicted that fatalities should be reduced by 40 to 60 percent and serious injuries by 11 to 29 percent, for car to car frontal impact collisions. These predictions can be regarded as an upper limit as it is unlikely that compartment integrity could be maintained for high speed impacts.

It is recommended that that an analysis to estimate the benefit of improved compatibility, in terms of the number of lives saved as opposed to the reduction in injury risk, should be performed for Germany. For GB, it is recommended that the benefit calculated for the car to car frontal impacts should be extended to cover other car accident configurations. Also, once more is known about the performance of a compatible car the assumptions made should be refined and the analysis repeated.

Crash testing

For this work package, 6 full width deformable barrier tests, 5 PDB tests, 1 car to car test and 9 EuroNCAP load cell wall (LCW) measurements were performed. This is 1 full width test and 2 EuroNCAP LCW measurements more than originally contracted. Full width deformable barrier test to assess structural interaction: Two tests using a Mondeo car were performed to help redesign the barrier face to overcome the problem of small stiff protruding structures forming preferential load paths. The remaining tests were performed with an Astra, modified Astra, Laguna II and Rover 75. Subjective comparison of the results from the Astra and modified Astra tests showed that the modified Astra had a more homogeneous LCW force distribution which is consistent with the better structural interaction seen in the modified car to car test. However, the engine subframe to lower rail

shear connection was not loaded as much in the full width tests as the car to car tests indicating that the full width test may not generate as much shear force across this type of connection as a car to car test. In the Laguna and Rover tests both lower rails and one lower rail bottomed out the barrier, respectively, to perform preferred load paths and apply large loads on the LCW, which most likely reduced the loads applied by other structures such as the subframe. Further work should be performed to ascertain whether this probable reduction in homogeneity is representative of the car's structural interaction performance in car to car collisions. Also the question of how far back a secondary load path can be positioned and still be able to contribute significantly to improving a car's structural interaction performance should be addressed. It is intended that the LCW results from the above tests will be used to help develop objective criteria to evaluate and quantify the changes observed between different vehicles in future work.

PDB Test to Assess Structural Interaction and Frontal Unit Energy Absorption PDB tests were performed with a Mondeo, Range Rover, Astra, Smart and Volvo S80. It was concluded that the use of the load distribution measured on the LCW behind the barrier face did not give an accurate enough indication of a car's stiffness homogeneity to be used as an assessment measure. For the Mondeo test a part of the barrier remained attached to the car after the test. This would cause severe difficulties in measuring the barrier final deformation profile objectively, which the PDB approach is completely reliant upon. For this test the version 6 of PDB was used. For the Volvo S80 and the Smart tests version 7 of the barrier was used. This new version with a thicker front sheet may reduce or solve this problem. The PDB barrier was defined to represent an average car and its stiffness is such that bottoming out is unlikely, even for large cars with homogeneous front end. However, on the Range Rover test this barrier bottomed out. The implication of this should be considered in relation to current and future regulations and consumer testing. The test data collected in this project completes a crash test matrix, which will form a useful data set for future work to continue the development of the current assessment criteria.

Car to Car Test The results of the Yaris to Clio car to car test demonstrated the poor structural performance of the Yaris. It should be noted that both of these cars had a EuroNCAP 4 star performance rating with the Yaris rated 'best in class'. It is recommended that this car could be used as a possible benchmark to help verify the full width and PDB tests and set the

limit values for structural interaction performance for the proposed assessment criteria.

EuroNCAP test LCW measurements The peak LCW forces measured were within the range measured for previous tests for vehicles of similar mass. However, the peak load cell distribution for the SUV was extremely inhomogeneous as the majority of the load was applied to a single load cell by the vehicle's lower rail. It was observed that the vertical distribution of the peak cell forces was in some cases influenced by the interaction of the engine and crossbeam with the load cell wall edge. This observation is important if it is proposed that the vertical force distribution measured in this test should be used as a criterion to control compatibility, as it may invalidate such a criterion.

Summary of Conclusions

The conclusions for each of the work packages, namely, accident analysis, benefit analysis and crash testing are summarised below.

Accident Analysis

For GB and Germany, it was confirmed that the compatibility problems for car to car frontal impacts are structural interaction, stiffness matching and compartment strength.

Poor structural interaction was seen to occur in a number of different ways, namely the fork effect caused by lateral misalignment and under/override caused by vertical misalignment. Two types of the vertical misalignment problem have been identified, static and dynamic. Static misalignment is caused by an initial geometric mismatch of the vehicle's structures. Dynamic misalignment occurs for structures, initially approximately aligned, deforming to become misaligned during the impact.

For GB, poor structural interaction was found to be a major problem. Of the 162 cases examined only 2 had structural interaction that could be described as reasonable. However, some of the cases had poor structural interaction caused by low overlap, which improved compatibility is not expected to address. 100 (62%) cases had structural interaction problems that improved compatibility is likely to address. For Germany, it was found that structural interaction problems could probably only be quantified using detailed case studies. Unfortunately, unlike the UJK, detailed case studies were not performed for all the selected cases. However, it is intended that this should be done in the VC-COMPAT project.

For GB and Germany stiffness mismatch / compartment strength was found to be a large problem. For GB, the problem magnitude was quantified by identifying the cases where there was a significant intru-

sion difference between the colliding vehicles. In the data sample there were 78 cases where at least one of the vehicles had intruded and therefore it was possible to identify an intrusion difference. A significant intrusion difference was identified in 68 percent of these cases indicating that stiffness mismatch / compartment strength is a large problem. For Germany, the problem magnitude was quantified by identifying the cases where one vehicle had injury causing intrusion and the other no intrusion. In the data sample there were 76 cases where at least one of the vehicles had intruded. From these 76 cases, 33 (43%) had no intrusion in one vehicle and injury causing indicating that stiffness mismatch / compartment strength is a large problem. It should be noted that the extent to which poor structural interaction contributed to this problem is unknown.

For Germany, from the 135 accident cases examined it was found that the 14 MAIS 3+ injuries correlated well with compartment intrusion, i.e. no MAIS 3+ injuries occurred unless the compartment had intruded. This confirms the results of previous studies that show that intrusion is the major cause of deaths and serious injuries (Wykes 1998). However, there was no correlation of MAIS 3+ injuries with the Vehicle Deformation Index (VDI).

For GB, structural interaction problems were also identified in some single vehicle accidents indicating that a benefit from improved compatibility could also be expected in this type of impact.

Benefit Analysis

For GB the potential benefit of improved frontal impact compatibility for car occupant casualties involved in frontal impact collisions was estimated to be:

- *some* reduction in injury risk for between 415 (45%) and 567 (61%) fatalities per year (currently out of 931 frontal impact car occupant fatalities per year on average¹).
- *some* reduction in injury risk for between 8216 (66%) and 10470 (85%) seriously injured casualties per year (currently out of 12385 frontal impact seriously injured car occupant casualties per year on average).

For GB the benefit has been estimated for one particular type of accident only, namely a car frontal impact with one other car. For this accident type there were on average 254 fatalities and 5557 serious injuries annually in recent years in GB. From the analysis performed, using the assumptions that optimistically 'compatible' cars should prevent contact related injuries and pessimistically 'compatible' cars should pre-

vent injuries caused by intrusion up to a given impact severity, the following predictions were made:

- If it is assumed that improved compatibility offers increased protection for all impact severities, it is predicted that between 102 (40%) and 152 (60%) fatalities and between 587 (11%) and 1605 (29%) serious casualties would be prevented.
- If it is assumed that improved compatibility offers increased protection up to an impact severity of 56 km/h ETS, it is predicted that between 25 (10%) and 46 (18%) fatalities and between 389 (7%) and 1167 (21%) serious casualties would be prevented. It should be noted that compatibility is expected to offer some benefit above an impact severity of 56 km/h ETS, so these predictions are most likely low.

It should be recognised that much further benefit can be expected for other accident types, especially car to vehicle frontal impacts, most likely car frontal collisions with roadside obstacles and possibly for side impacts as well. The seriously injured casualty category defined to the Police's injury severity rating covers a wide range of injury severities. It should be noted that the benefit from, for example, reducing a MAIS 4 serious injury to a MAIS 2 serious injury is not accounted for in the analysis performed.

For Germany, the potential benefit of improved compatibility for car occupant casualties involved in frontal impact collisions based on accident data for the year 2000 has been estimated to be:

- some reduction in injury risk for between 9,317 (33%) and 18,736 (67%) seriously injured car occupants per year, (there were 27,967 frontal impact car occupant seriously injured casualties in the year 2000).

An estimate was also made for fatalities. However, it is possible that this result was not statistically significant as the GIDAS database, on which the analysis was based, contained only 33 fatalities for this impact configuration. Noting this caveat, the estimate was:

- some reduction in injury risk or for between 287 (14%) and 572 (28%) fatalities per year, (there were 2,066 frontal impact car occupant fatalities in the year 2000).

Crash Testing

The conclusions are listed below for each of the different types of tests performed.

Full width deformable barrier test to assess structural interaction

- Two tests using a Mondeo car were performed to help in the redesign of the barrier face in order to overcome the problem of small stiff protruding structures forming preferential load paths. The second test demonstrated that the redesigned face

overcame this problem, whilst still achieving the aims of the initial barrier face which were:

- To prevent unrealistic decelerations at the front of the car.
- To attenuate the engine inertial loading
- To have a similar compartment deceleration to an equivalent rigid wall test.
- The multiple loads of the Opel Astra and modified Astra could be identified from the homogeneity of the load cell wall (LCW) force distribution recorded in the full width tests. A difference was distinguished between the Astra and modified Astra, the modified Astra showing better homogeneity for the LCW force distribution, which is consistent with the better structural interaction seen in the modified car to car crash test. However, the engine subframe to lower rail shear connection was not loaded as much in either of these tests compared to the car to car tests. This indicates that the full width test may not generate as much shear force across this type of connection as in a car to car impact.
- The LCW results from the Renault Laguna II test showed that the Laguna II did not exhibit good stiffness homogeneity. This was due to the lower rails bottoming out the barrier and applying large loads directly on the load cell wall and the low loading applied by the centre of the bumper and subframe crossbeams due to their failure. The bottoming out of the lower rails formed preferential load paths, which most likely reduced the load applied by other structures, such as the subframe. The stability of the lower rails was most likely helped by the good vertical connections. The formation of a preferential load path was also seen in the Rover 75 test, in which one lower rail bottomed out the barrier.
- Ideally, a test method to evaluate compatibility needs to be able to deform a car as much as it is deformed in accidents so that all the possible load paths and the shear connections between these load paths are exercised. The tests performed in this project have shown that the frontal unit deformation achieved may not be sufficient to adequately check all these load paths and the shear connections, especially if they are positioned some distance behind other paths, for example, a subframe positioned more than about 150 mm behind the front of the lower rails.

PDB Test to Assess Structural Interaction and Frontal Unit Energy Absorption It should be noted that the purpose of the PDB test is to assess structural interaction and the frontal unit energy absorption up to an Equivalent Energy Speed (EES) of 50 km/h. An impact speed of 60 km/h was calculated to give a

vehicle EES of 50 km/h, which takes into account the energy absorption of the barrier and the vehicle stiffness. A fixed overlap width of 750 mm is used to ensure that the barrier generates the same load for cars of different widths.

- The use of the load distribution on the LCW behind the PDB does not appear to give an accurate enough measure of a car's stiffness homogeneity and hence is not worth pursuing further as an assessment method. This is because problems similar to those encountered with the full width tests, such load cell bridging caused by the shear strength of the honeycomb, occur to some degree with this test. This conclusion is supported by a separate French study, which found an uneven load distribution was recorded on the load cell wall for an impact against the PDB using a trolley with a flat rigid face.
- In the Mondeo test a part of the barrier remained attached to the car after the test. This would cause severe difficulties in measuring the barrier final deformation profile objectively, which the PDB approach is completely reliant upon. For this test the version 6 of PDB was used. Version 7 of the barrier has a thicker front sheet, which may reduce or solve this problem. The lack of penetration of the barrier front sheet in the test with the Volvo S80 indicates the improved performance of version 7 of the barrier in this respect.
- The PDB barrier was defined to represent an average car and its stiffness is such that bottoming out is unlikely, even for large cars with a homogeneous front end. However, on the Range Rover test this barrier bottomed out. The implication of this should be considered in relation to current and future regulations and consumer testing.
- The Smart is a very light car. It was judged to be a non aggressive car based on the shape of the barrier deformation after the impact, even though its stiffness is very high.

For the Volvo S80 the deformation shape of the PDB was relatively homogenous, so based on a subjective assessment of the barrier deformation this car was judged to be non aggressive.

Car to Car Test

- The Toyota Yaris has a design consisting of one main load path, the lower rails. The Renault Clio has a multi-level load path design. Examination of the cars prior to the test showed that there was good structural alignment between them, which indicated that good structural interaction between the lower rails might be expected. However, poor structural interaction was seen in the test caused

by dynamic effects. When the Toyota Yaris lower rail impacted against the Renault Clio one, the Yaris lower rail bent upwards resulting in poor interaction with the Clio structure. As a result of this the Yaris occupant compartment intruded significantly and became unstable. The Clio compartment performed well without significant intrusion.

- A comparison of the relative performance of the Yaris and Clio in the car to car test and the EuroNCAP tests based on the intrusion measurements showed that the Clio performance was slightly worse in the car to car test compared to the EuroNCAP test. In contrast, the Yaris performance was significantly worse in the car to car test. It is believed that the main reason for this difference was the change in the structural performance of the Yaris, namely the lower rail, caused by poor structural interaction, which in turn was a result of the Yaris having a design based on a single main load path.

EuroNCAP test LCW measurements

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- LCW measurements were taken for 10 vehicles varying in mass from 1245 to 2060 kg. The peak load cell wall forces measured for the vehicles tested were between 400kN and 500kN, which was within the range measured for previous tests for vehicles of similar mass.
- By using data from accelerometers mounted on the vehicle the contributions of the LCW force from the deceleration of the transmission package (mechanical forces) and occupant compartment (structural forces) were calculated. The force from the deceleration of the occupant compartment was typical between 60 to 70 percent of the global peak force recorded by the load cell wall.
- The vertical distribution of the peak cell forces varied from test to test. Examination of the vehicles post test indicated that this distribution was in some cases influenced by the interaction of the engine and crossbeam with the load cell wall edge. This observation should be taken into account if it is proposed that the vertical force distribution measured in this test should be used as a criterion to control compatibility, as it may invalidate such a criterion.
- Although the peak force applied by the body on frame SUV was less than some large family cars, the peak load cell force distribution measured was extremely inhomogeneous as the majority of

the load was applied to a single load cell by the vehicle's lower rail.

Recommendations

The recommendations resulting from each of the work packages, namely, accident analysis, benefit analysis and crash testing are listed below.

Accident analysis

For Germany, it is recommended that further analysis should be performed to quantify the magnitude of the structural interaction problem. For both Germany and the UK, it is recommended that further accident analysis should be performed in the future to check that the conclusions of this work are still valid, as the vehicle fleet is constantly changing. Additional accident variables such as improved deformation measurements and harmonised impact severity measures would help future analyses.

Benefit analysis

In order to obtain a more complete benefit estimate for GB, it is recommended that a similar benefit analysis to that performed for the car frontal impact with one other car or van type of accident should be conducted for other car frontal impact accident types. For Germany, it is recommended that an analysis to estimate the benefit of improved compatibility, in terms of the number of lives saved as opposed to the reduction in injury risk, should be performed. The benefits predicted are largely dependent on the assumptions made for how 'compatible' cars will perform. Hence, it is recommended that once more about a 'compatible' car's performance is known, the assumptions made should be refined and the analysis repeated.

Crash testing

It is recommended that principles on which the full width and PDB tests are based should be validated, i.e. for the full width test is the homogeneity measured on the LCW representative of a car's structural interaction potential and similarly for the barrier deformation measured in the PDB test.

For the full width test objective assessment criteria require development. At present differences in the performance of the vehicles are based on subjective analysis of the load cell wall force distribution. Criteria should be developed to evaluate and quantify the changes observed between different vehicles. This will require additional crash test data to be generated from a larger range of vehicle designs to validate the procedure and set definitive limit values.

For the full width test for the Laguna and Rover 75 tests preferential load paths were formed because the

lower rails bottomed out the barrier. This most likely reduced the load carried by other structures set further back in the car, such as the subframe, resulting in the reduction of the homogeneity of the load recorded on the wall. A study should be performed to address the following questions:

- Does the current barrier design give a representative homogeneity measure for cars with high local stiffnesses?
- Approximately, how far back can a secondary load path be positioned from the front of the main load path and still be able to contribute significantly to improving a car's compatibility?

For the PDB test the current assessment criteria require further development. At present these criteria are based on the shape of the barrier face final deformation. A formula has been developed to assess the barrier deformation in terms of its height and depth, but limit values for these parameters still need to be defined. The test data collected in this project completes a crash test matrix, which will form a useful data set for future work to continue the development of the current assessment criteria. However, further data will be required to validate the procedure and set definitive limit values.

The current PDB barrier face is based on the stiffness of a small to medium European car. The suitability of the current barrier face design should be considered in terms of its likely effect on the future vehicle fleet design and the vehicle classes which are likely to be included in future regulatory and consumer testing. An example of a parameter that should be investigated is the stiffness distribution between its upper and lower sections.

The Renault Clio to Toyota Yaris crash test demonstrated the poor structural interaction performance and possibly low compartment strength of the Toyota Yaris. It is recommended that this car could be used as a possible benchmark to help verify the full width and PDB tests and set limit values for structural interaction performance for the proposed assessment criteria following verification of the Yaris compartment strength.

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REFERENCE

A Study to Improve the Crash Compatibility Between Cars in Frontal Impact
for the Directorate General for Energy and Transport
European Commission
Reference: E3-3 B2702/SI2.318663/2001 TRL

ACKNOWLEDGEMENTS

The study was partly funded by the Directorate General for Energy and Transport of the European Commission.

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