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Development of test procedures and performance criteria to improve compatibility in car frontal collisions

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Abstract: Compatibility is now generally recognized as the next big step forwards for car occupant secondary safety. The work performed to date has focused on the structural performance of vehicles, with the aim of providing a safe environment for the protection of the occupants in which intelligent restraint systems of the future could operate. This paper outlines the present understanding of compatibility for frontal impact collisions and reports the current state of development of three possible test procedures to address the fundamental issues, namely structural interaction, frontal stiffness matching and passenger compartment strength. Recent advances in the development of a deformable barrier face for the full-width test to assess structural interaction, using high-resolution load cell wall measurements, are described. Analysis of the load cell wall data collected in EuroNCAP tests, to address the frontal stiffness problem, is reported together with initial work to investigate the repeatability of the passenger compartment strength test. In addition, for some of these tests, possible performance criteria are suggested. This research is being carried out in co-operation with the European Enhanced Vehicle-safety Committee and the International Harmonization of Research Activities Working Groups and is funded by the Department for Transport.

Keywords: test procedures, performance criteria, compatibility, car frontal collisions

1 INTRODUCTION

Following the introduction of seat belts, the European frontal and side impact directives and EuroNCAP, improved compatibility offers the next greatest potential for reducing car occupant injury and deaths. Indeed, addressing frontal impact compatibility is essential if the improvements in car secondary safety are to be fully realized in accidents on the road and future advanced restraint systems are to be effective.

In 2000 in Great Britain, two-thirds of the road accident casualties were in cars or light goods vehicles and occupants of these vehicles accounted for just over half of the fatalities and just under half of the seriously injured [**1**]. The cost to society of these casualties was about £6.3 billion. About two-thirds of these accidents are frontal, with about 85 per cent being an impact with another vehicle. Although the improved structural interaction aspects of compatibility are relevant for virtually all frontal impacts, the main benefits from stiffness matching are expected in car-to-car crashes.

From 1995, research carried out by TRL on behalf of the Department for Transport (DfT) has changed focus from frontal impact to compatibility. This has helped to initiate co-operative international compatibility research through the European Enhanced Vehicle-safety Committee (EEVC) and the International Harmonization of Research Activities (IHRA).

Initially this research was aimed at gaining an understanding of compatibility and the factors that affect it. Having achieved this, more recent research has focused on developing test procedures able to measure the most important characteristics. Prior to this research, conventional wisdom said that compatibility problems were limited to crashes between cars of different masses, where mass ratio had the dominant influence. Now it is clear that it is the effect that mass has on frontal stiffness that is responsible for this effect. Furthermore, the importance of good structural interaction between impacting cars has been highlighted. This aspect of compatibility plays a part in virtually every road crash. Without good structural interaction, the energy-absorbing capability of the frontal structure is compromised, leading to

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compartment intrusion in severe accidents. Once good structural interaction has been achieved, frontal stiffness matching between vehicles, combined with strong passenger compartments, should ensure that the impact energy is absorbed without passenger compartment intrusion. Beyond this, there is scope for better optimization of the car's deceleration pulse to minimize restraint-induced deceleration injuries. With good compatibility, cars should perform in a more predictable manner over a range of impact configurations, enabling the meaningful development of advanced restraint systems.

2 CURRENT COMPATIBILITY PROBLEMS

2.1 Structural interaction

In rigid block crash tests, the block totally controls the way the impact deformation is distributed across the car's front. Cars designed for such tests have obtained good test performance, with limited numbers of frontal load paths having small frontal areas interacting with the block. When such cars impact each other, the chances that their stiff structures interact is very limited. The offset deformable frontal impact test was intended to encourage manufacturers to increase the number of load paths being effective in car-to-car impacts. Unfortunately, so far, few manufacturers have taken advantage of the weight-saving opportunities of this approach. Most have simply increased the stiffness of the car's main longitudinals, although some have had to weaken very stiff engine subframes. For load spreading, all cars now have substantial crossbeams between the main longitudinals but few other frontal connections have been improved. No cars currently have effective lateral connections, at the bonnet latch platform level, and few have any significant vertical connections between the lower load path and any upper load path. Consequently, when two cars collide, there is little to prevent the lateral fork effect, where the stiff members of one vehicle penetrate the soft areas of the other vehicle, due to lateral misalignment, or the overriding of one car's structure by that of the other. With no control over the height of car structures, geometrical mismatches can give rise to overriding from static misalignment. Even when structures are aligned statically, dynamic overriding may occur.

An example of overriding in accidents has been reported previously [**2**]. Another example was in a 70 per cent overlap collision between a Ford Focus and a Renault Clio. In the impact, the relatively high bumper crossbeam of the Focus overrode the Clio's frontal structure and road wheel, resulting in more loading of the Clio's upper load path and greater passenger compartment intrusion at fascia level. The driver (male, 65) of the Clio was killed but the driver (male, 35) of the Focus had only minor injuries (Fig. 1). Although overriding occurred in this accident, the outcome might also have been influenced by other factors such as stiffness and mass differences and the drivers' ages.

The sensitivity of structural interaction with current cars has been demonstrated previously [**3**]. A 100 mm variation in ride height, in an impact between two identical cars, resulted in significant overriding of the raised car over the lowered car. The energy absorption capability of both cars was compromised, resulting in greater intrusion for the lowered car at fascia level and in the raised car at footwell level. Subsequent EUCAR simulation modelling indicated that overriding can occur with a height difference of only 25 mm, with identical cars [**4**]. Even where structures are aligned vertically, dynamic pitch during the impact can lead to misalignment if the area of interaction is inadequate.

In order to achieve good interaction, it is important that the structures of each car meet something substantial on the other car to react against. Current views are that this is best achieved by utilizing multiple load paths, with good links between them. These links may take the form of frontal interconnections or of shear connections set back from the front. Such structures should provide a more homogeneous front against which the other cars' structure can react.

In addition to the provision of a homogeneous front,

Fig. 1 Structure of a Renault Clio (left) overridden by a Ford Focus (right)

it is important that there is adequate vertical alignment. A low sports car could not interact with the front of a high off-road vehicle, even if they both had homogeneous fronts, because of their geometrical misalignment.

These aspects of compatibility are general to all impacts. They are not limited to those where there is a significant mass ratio between the cars. If impacting cars could be made to interact properly, their performance in accidents would become more predictable, in terms of energy absorption and deceleration. Apart from the resulting reduction in intrusion, this would help advanced restraint systems to perform correctly and predictably.

2.2 Frontal stiffness

All current frontal-impact crash tests place direct or indirect controls on energy absorption and deceleration of the car. If there is inadequate energy absorption in the frontal structure, intrusion occurs which, at some level, will be detected by the instrumented dummies. Similarly, the dummies are sensitive to the car's deceleration, which is detected through such factors as chest loading from the seat belt. However, there are currently no requirements controlling the frontal stiffness of the car. Indeed, the tests encourage heavier cars to be stiff, in comparison with lighter cars. As all the tests place a limit on the car's deceleration, through control of dummy loading, all cars tend to have similar stopping distances in the tests. The dummy's experience of deceleration is totally independent of the mass of the car in which it travels. Data from EuroNCAP tests show that most cars, irrespective of size, have an overall ride-down distance of 1200 (±200) mm (Fig. 2). This includes the depth of the deformable barrier face of 540 mm. As most manufacturers aim to limit the length of the front structure, for a variety of reasons, crush depths tend to be kept to the minimum.

With the energy absorbed being the integral of force against distance, the only way to maintain the same crush depth while at the same time to absorb the car's kinetic energy is for the frontal stiffness to increase with increasing vehicle mass. This means that, even without other influences, current frontal crash tests lead to a stiffness incompatibility between cars of different masses. Because stiffness is related to mass but is not available in accident statistics, mass ratio has historically been incorrectly identified as the cause of compatibility problems.

In order to overcome this aspect of compatibility, it is necessary to control frontal stiffness by limiting the force imposed by the car on its opponent, in the impact. This may be less of a problem than it might at first appear. Data from EuroNCAP tests is indicating that the stiffness of some small cars has increased and becoming more in line with that of larger cars.

In setting a force limit requirement for cars, there are a number of factors to be considered:

1. Whatever the force level is set to be, it will be necessary for the passenger compartments of all cars to be strong enough to resist this force without suffering significant intrusion.
2. If the force level is set to be low, heavy cars will have to increase their available crush depth and may require longer front structures.
3. If the force level is set to be high, light cars will have to become stiffer and the requirements for passenger compartment strength will also be high.
4. A limit on how high the force level can safely be set

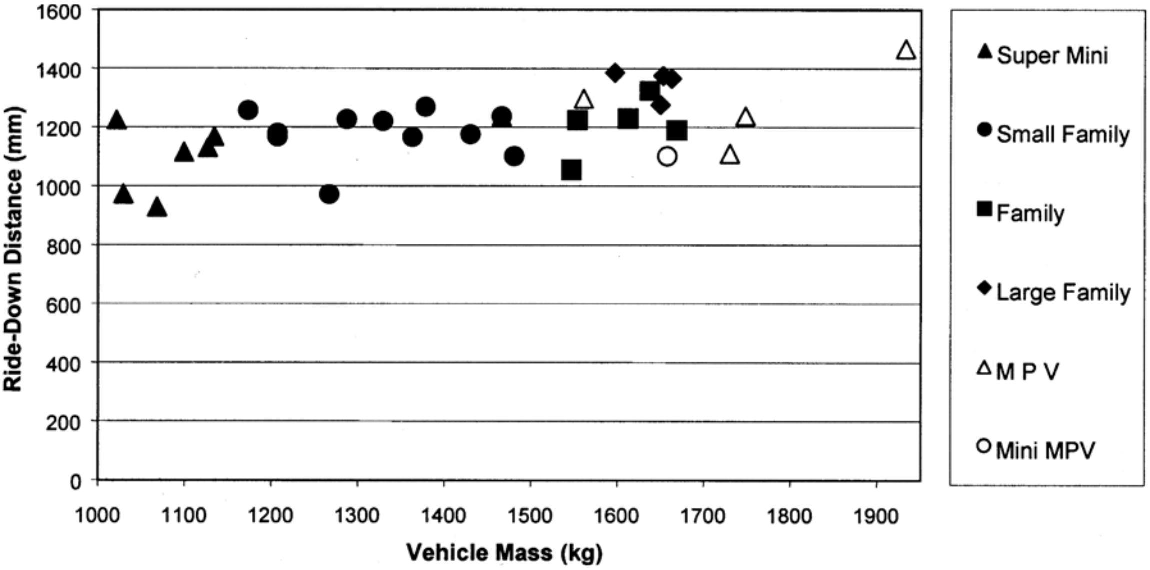

Fig. 2 Ride-down distances recorded from EuroNCAP tests showing little variation with increasing mass. Note that the ride-down includes a barrier depth of 540 mm

will come from the potentially increased risk of deceleration induced injuries from the restraint system. A worst-case situation would be where a low-mass car had a full-width frontal impact with a high-mass car and the occupants were frail or elderly. For these occupants, the velocity change and deceleration of their cars will be high and there will be a limit to the ability of even advanced restraint systems to provide an adequate ride-down.

5. With a high force limit, the need to understand the influence of deceleration pulse shape, in combination with advanced restraints, will become more urgent.

2.3 Passenger compartment strength

Although a limit can be set for the force that one car can impose on its opponent, this provides no guarantee that the passenger compartment can sustain the load imposed by another car. Inevitably, cars would continue to impose somewhat different loads on their opponent but they would only be verified as being capable of sustaining the load that they generate in a test. Consequently, where a car that generated a force well below the limit impacted a car that generated a force near to the limit, there could be no confidence that its passenger compartment would survive. Furthermore, any slight variation in the impact configuration might affect the force levels. For these reasons, it will be necessary to have a requirement for the strength of the passenger compartment, ensuring that it can resist forces greater than those used to control frontal stiffness.

It is clear that the strength of the passenger compartment is dependent upon the load paths used to transmit forces to it. In a frontal impact the most important load paths are the main longitudinals, the upper longitudinals and the engine subframe via the road wheel to the sill and via the engine to the firewall. The upper longitudinals and/or engine subframe may or may not be present. The way that the loads are distributed between these load paths is dependent upon the car design, the impact configuration and the characteristics of the object hit. As the distribution of loads between the load paths varies, so the effective strength of the passenger compartment also varies. In order to ensure survival of the passenger compartment, cars should be designed to be tolerant of the distribution of the impact load. In principle this could be achieved by having a passenger compartment which is strong enough, irrespective of some variation in load path use, or by having a frontal structure that controls the way loads are distributed to the various load paths. The indications are that good structural interconnections control adjacent load paths to deform together and help to achieve this.

3 PROCEDURES TO ASSESS AND CONTROL FRONTAL IMPACT COMPATIBILITY

The first requirement for compatibility is to ensure good structural interaction. It helps to address problems seen in all impacts and without it any control of stiffness would have limited effect. With good structural interaction, it will then be possible to control frontal stiffness and passenger compartment strength. An inevitable consequence of these actions to reduce passenger compartment intrusion is that car deceleration will increase together with associated injuries, unless they are mitigated by improved restraint systems. Although any increase in injuries from deceleration is likely to be small compared with the decrease due to improved passenger compartment survival, there is going to be a growing need to understand the importance of and potentially to control the shape of the deceleration pulse.

Potentially, three tests are required to assess and control structural interaction, frontal stiffness and passenger compartment strength. It would be advantageous if some of these requirements could be met with current tests. The IHRA Advanced Frontal Impact Working Group has recommended the universal use of two frontal tests: one is the offset deformable barrier (ODB) test, as used in Europe; the other is a full-width barrier impact as used in the USA. From its research programme carried out for the DfT, TRL has proposed the use of a full-width test to assess frontal homogeneity and hence structural interaction, a 64 km/h ODB test (such as EuroNCAP test) for assessing frontal stiffness and a high-speed ODB test to measure passenger compartment strength. All these tests use a high-definition load cell wall (LCW), behind deformable barrier faces. With this approach, it is hoped that only one additional test is required for compatibility, assuming that the other two tests are specified for frontal impact.

3.1 Full-width structural interaction test

Cars with more homogeneous fronts offer the potential for good structural interaction with other cars. A full-width impact of a car against a high-definition LCW offers the potential to map the force deflection characteristics of the car's front. However, there are some issues that generate problems when a rigid faced LCW is used:

1. Localized stiff structures can hold off adjacent structures which are slightly set back.
2. Localized stiff structures effectively unload adjacent structures, which are slightly less stiff.
3. The parts of the car that first impact the wall are decelerated instantaneously, giving rise to large inertial forces, both within the structure and measured by the LCW. Such forces are not present in impacts with deforming structures, such as other cars.
4. When the engine impacts the wall, it is brought to

rest very rapidly again, generating high inertial forces. In a car-to-car impact, the engine can rotate or move slightly out of the way of the other car's engine, so reducing its deceleration.

5. No relative shear is generated in the front structure to exercise any shear connections between load paths.

In order to overcome these problems, a deformable barrier face is fitted to the front of the LCW. If the test is to also function as a high-deceleration test for frontal impact, the overall car deceleration should not be significantly affected by the addition of the deformable face.

3.2 ODB test for frontal stiffness

As with the full-width test, an LCW is used to measure the forces generated by the car in an ODB test at 64 km/h. This requirement can simply be added to the current EuroNCAP test. As previously reported [**2**], the load measured is a combination of the force coming from the deceleration of the passenger compartment (structural component) and the force coming from the deceleration of the mainly rigid masses ahead of the firewall (mechanical component), a large proportion of which is due to the engine and gearbox. In setting a limit for this force, it is necessary to consider the extent to which the engine force needs to be taken into account. In a car-to-car impact, some of the engine load directly acts on the engine of the other car and has little effect on the structure. The remaining load does act on the structure, either directly or indirectly. The deformable face can attenuate the force to decelerate the engine and this may allow the maximum total force measured by the LCW to be used.

There may also be a need to set a minimum force level for the car front, so producing a range for the acceptable forces. This would prevent the design of small cars with excessively soft fronts, where the deceleration pulse might have to increase rapidly, when the front structure bottoms out on the strong passenger compartment. Such deceleration pulses are known to be injurious. It is unlikely that a minimum force requirement would come into play for larger cars, as there is no indication that any manufacturer has an interest in producing a long soft-fronted car.

3.3 Passenger compartment strength test

The frontal stiffness test only provides information about the car's ability to cope with loads up to that generated by the car itself. It is necessary to be able to show that its passenger compartment can survive the forces imposed by another car, which may generate a higher frontal force but still be within the requirements. This requires that an assessment be made of the passenger compartment's strength. It is proposed that this should be measured in a further ODB test carried out at an elevated speed. Currently a speed of 80 km/h is being used. It should be noted that there is no intention to require cars to provide a survivable performance for the occupants, at this severity. The test is simply designed to measure the strength of the passenger compartment.

If the passenger compartment becomes unstable in the impact, it will be necessary to ensure that the strength measured is prior to any major intrusion occurring. Once the passenger compartment becomes unstable, the measured load can be expected to reduce but it might again increase if subsequent structural blocking occurs. However, with conventional car designs this is unlikely.

4 CURRENT DEVELOPMENT STATUS OF TEST PROCEDURES AND ASSOCIATED PERFORMANCE CRITERIA

4.1 Full-width deformable barrier test

A series of full-width tests with a deformable barrier face have been performed with current cars varying in size from small family to an off-road vehicle, using an impact velocity of 56 km/h. High-resolution LCW measurements were recorded using a wall, which consisted of 128 load cells of size 125 mm by 125 mm arranged in a 16 by 8 matrix. The deformable barrier face used consisted of an aluminium honeycomb element 150 mm deep with a longitudinal crush strength of 0.34 MPa. These results have been reported previously [**5**].

The depth and stiffness of the barrier face for these tests were chosen primarily for three reasons. The first was so that, compared with a rigid wall test, the initial high decelerations at the front of the car were attenuated to make the test more representative of a vehicle-to-vehicle impact. The second was to reduce the magnitude of the engine deceleration loading on the wall to avoid high engine loads masking the loads from the car structure. The third was to minimize the effect that the face had on the occupant compartment deceleration pulse so that the test could also be used as a high-deceleration frontal impact test similar to US FMVSS 208.

Unfortunately, the results of some of these tests have shown that localized stiff structures on the car can form preferential load paths which dramatically reduce loading from adjacent structures indicating that the barrier depth and/or stiffness may need to be altered. An example of this effect is seen with a family-sized car, which has several such structures, namely a towing eye and radiator mount brackets located on the engine subframe (Fig. 3). Examination of the deformed car and barrier face showed that the front crossbeam of the engine subframe applied load to row 7 of the LCW with over 50 per cent of this load being applied to the two cells in columns F and K (Fig. 4). This arose because the radiator mount brackets penetrated the deformable barrier face to make direct contact with the LCW to

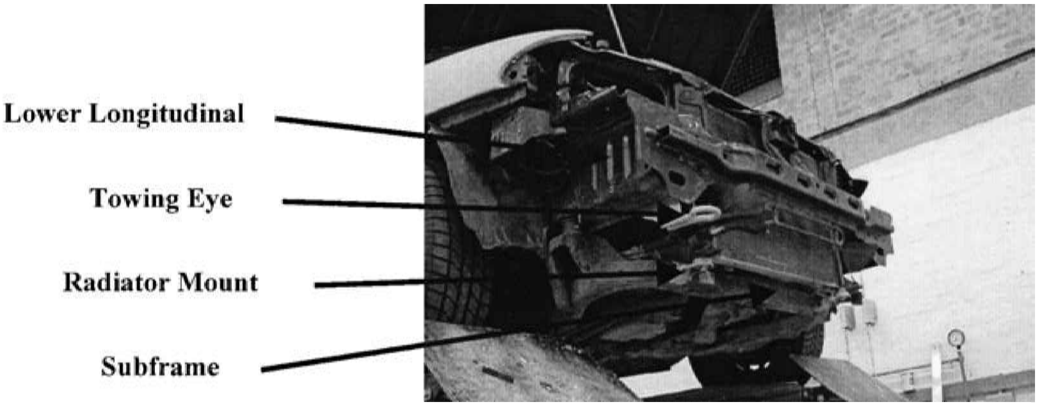

Fig. 3 View of a family-sized car structure showing the towing eye and radiator mount bracket protruding structures

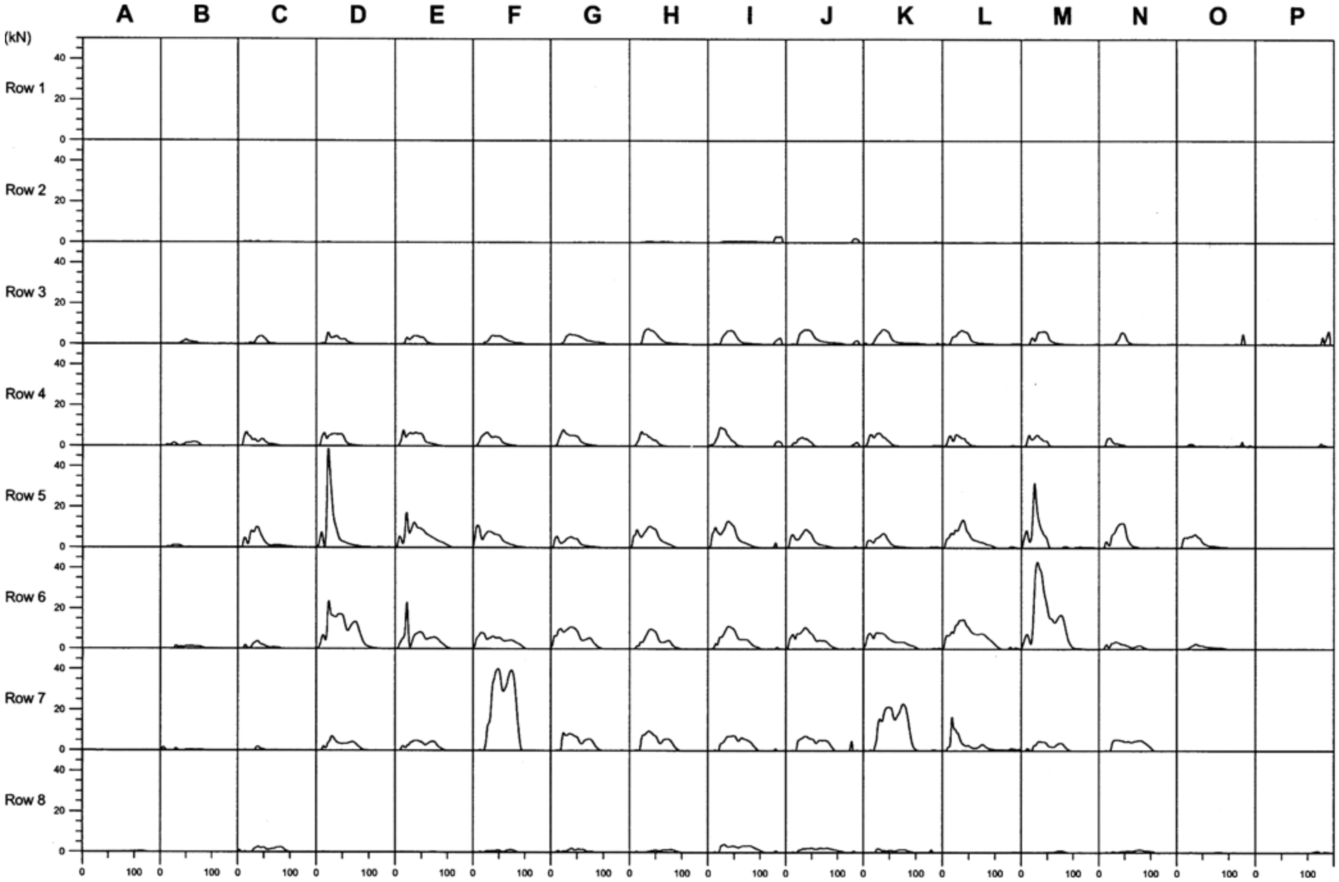

Fig. 4 Load (scale, 0–50 kN)–time (scale, 0–150 ms) curves for a complete LCW with a 0.34 MPa barrier face. Row 7 shows loading from the engine subframe crossbeam with substantially higher loads recorded on cells in columns F and K caused by preferential loading of these cells by radiator mount brackets

form preferential load paths. These unloaded the adjacent crossbeam structure. Unfortunately, this load distribution is not representative of the stiffness homogeneity of the crossbeam structure.

To attempt to resolve this problem the test was repeated using a stiffer deformable barrier face (1.71 MPa) of the same depth. The radiator mount brackets penetrated the barrier face but did not contact the wall, which allowed the rest of the crossbeam to load the wall (Figs 5 and 6).

However, even though this stiffer barrier face appeared to solve the preferential load path problem, it was not a viable solution as it dramatically increased the engine deceleration load. This is shown by the

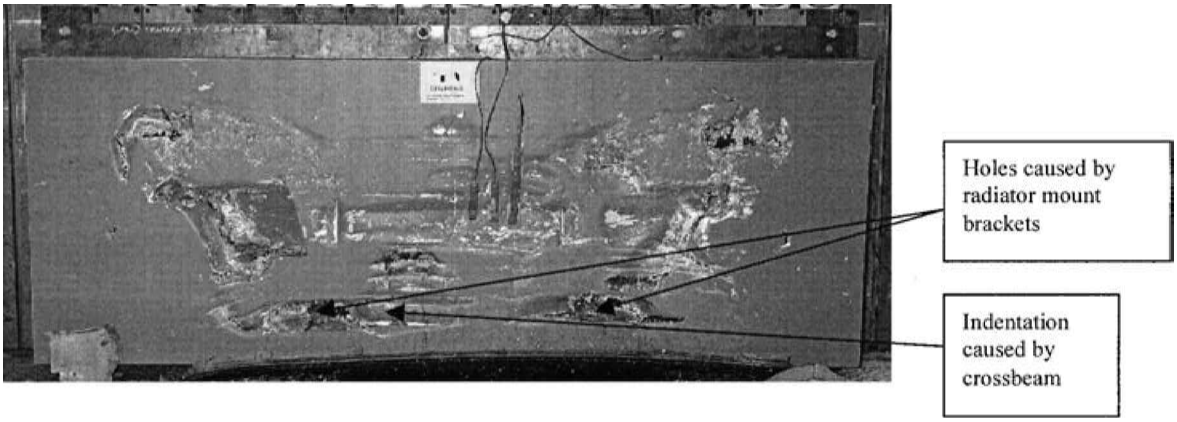

Fig. 5 Stiffer deformable barrier face (1.71 MPa) showing where the radiator mount brackets penetrated and indentation caused by crossbeam loading

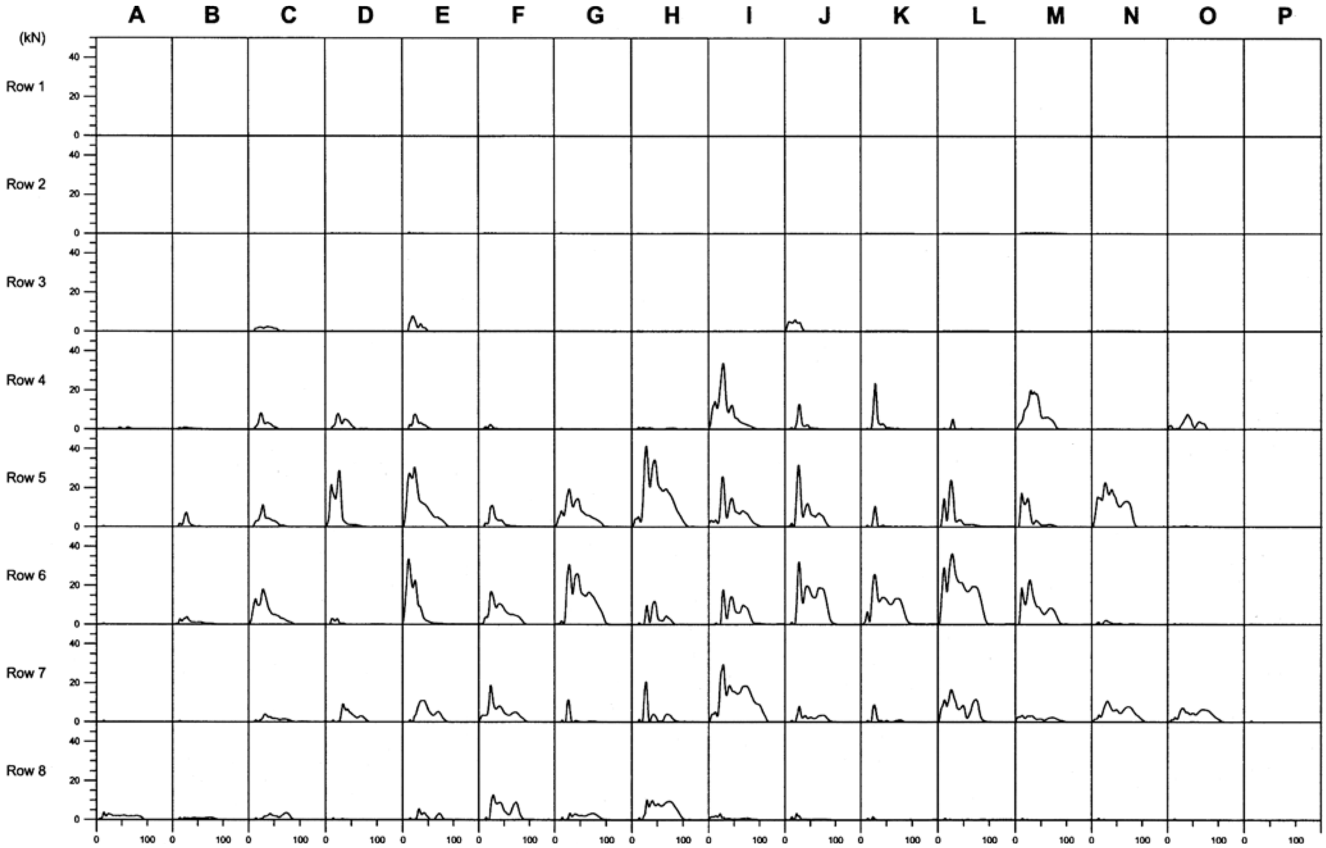

Fig. 6 Load (scale, 0–50 kN)–time (scale, 0–150 ms) curves for a complete LCW with a 1.71 MPa barrier face. Compared with the 0.34 MPa face, row 7 shows a more even distribution of load with no high loads recorded on the two cells in columns F and K

substantial increase in the peak force recorded on the wall for this stiffer face (1.71 MPa) compared with the previous less stiff (0.34 MPa) face (Fig. 7).

To combine the good features exhibited by both barrier faces and to attempt to resolve both the formation of preferential load path and the engine deceleration problems, the test was repeated again using a two-layer honeycomb barrier face. Each layer was 150 mm deep, the front and rear layers having crush strengths of 0.34 MPa and 1.71 MPa respectively. Examination of the face following the test showed that the radiator mount brackets had penetrated the stiffer rear layer of the face but had not made direct contact with the LCW, which allowed the rest of the crossbeam to load the wall. Comparing the LCW results for the double-layer face with those for the 0.34 MPa face shows this. The double-layer face results show a more even distribution of load on row 7 with no high loads recorded on the two cells

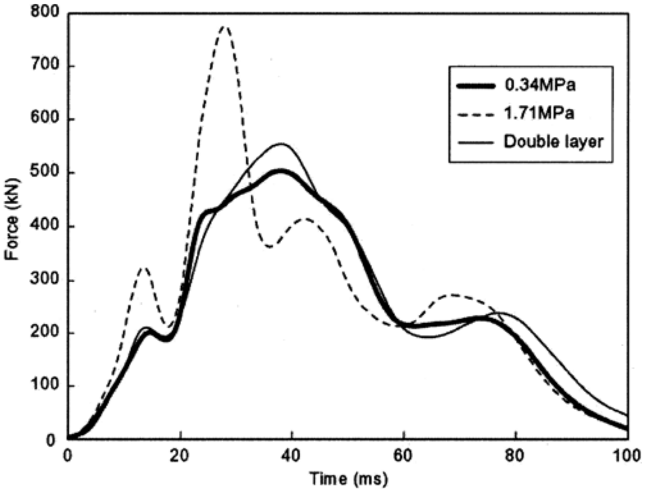

Fig. 7 LCW total force for 0.34 MPa, 1.71 MPa and two-layer barrier faces showing a substantially higher peak force for 1.71 MPa face caused by high engine deceleration

in columns F and K (Figs 4 and 8). Examination of the peak load on the wall shows that the engine deceleration load for this double-layer face was comparable with the single-layer 0.34 MPa face (Fig. 7).

The two-layer deformable barrier face appears to solve the problem of the formation of preferential load paths by localized stiff structures and does not increase the engine deceleration loading. Unfortunately, it causes another problem. The stiffer rear layer of the barrier face has sufficient shear strength to bridge load cells that are slightly recessed (about the order of 0.5 mm) for small loads (up to the order of 10–20 kN). This causes a redistribution of the load measured on the LCW (completely unloading some cells), hence giving an incorrect representation of the stiffness homogeneity of the car front being measured.

To overcome this problem a two-layer barrier face with the rear stiffer layer segmented into individual blocks was proposed. The individual blocks were the same size as the load cells so that each block could be aligned with a load cell behind the barrier face. It was expected that segmenting the rear layer should effectively reduce its shear strength and overcome the load cell bridging problem that occurred with the previous barrier face design. The barrier face configuration proposed was as follows: front layer 150 mm deep, 0.34 MPa crush strength honeycomb; rear layer 150 mm deep, 1.71 MPa and segmented. Because of technical difficulties in the manufacture of this proposed face, which were later overcome, a face was made with a rear layer depth of

Fig. 8 Load (scale, 0–50 kN)–time (scale, 0–150 ms) curves for a complete LCW with a double-layer barrier face. Compared with the 0.34 MPa face, row 7 shows a more even distribution of load with no high loads recorded on the two cells in columns F and K

85 mm which was tested. The LCW results from this test are shown in Fig. 9.

Comparison of the LCW results from this test with those from the test with the unsegmented rear layer (Fig. 8) shows that the segmented face gives a much more even force distribution along the row which was loaded by the engine subframe crossbeam (row 7). In addition, there are no unloaded cells where forces should be expected, e.g. the cell in row 7, column L. This indicates that segmenting the rear layer solves the load cell bridging problem that occurred with the unsegmented face.

In summary, a revised deformable barrier face was developed that overcame the preferential load path problem while still meeting the three requirements of the initial face listed in section 3.1.

In order to assess the stiffness homogeneity of the vehicle from the LCW results, objective criteria are required. Various statistical techniques have been tried to date using data from ten tests with a deformable barrier face 150 mm deep of crush strength 0.34 MPa. The coefficient of variance (CV), which is defined as follows was found to be one of the most promising criteria:

$$\mathrm{CV} = \frac{\text{standard deviation}}{\text{mean}}$$

This has been reported previously and shown to distinguish adequately between a family car exhibiting features likely to benefit compatibility, such as an engine subframe load path, and a less compatible off-road vehicle [**5**].

CV could be used to control a vehicle's stiffness homogeneity over its frontal crash footprint but, to ensure good structural interaction, these footprints need to overlap. One way to achieve this would be to control the height of the centre of force measured on the LCW as proposed by the National Highway Traffic Safety Administration (NHTSA) [**6**]. The centre of force height may also need to be controlled throughout the duration of the impact. However, this would still not guarantee overlap of two vehicles' footprints. Another way to achieve this would be to define a given area on the LCW over which the vehicle must apply a minimum specified load. This would ensure that both vehicles have structure over the defined area that would interact in a collision. The geometry of current vehicle structures will need to be reviewed to define the specified area. Work is ongoing to address this issue and to specify the minimum load requirement.

In summary, at present it appears that at least two criteria will be needed: one to control a vehicle's stiffness homogeneity and one to ensure that there is adequate vertical geometric alignment between vehicles.

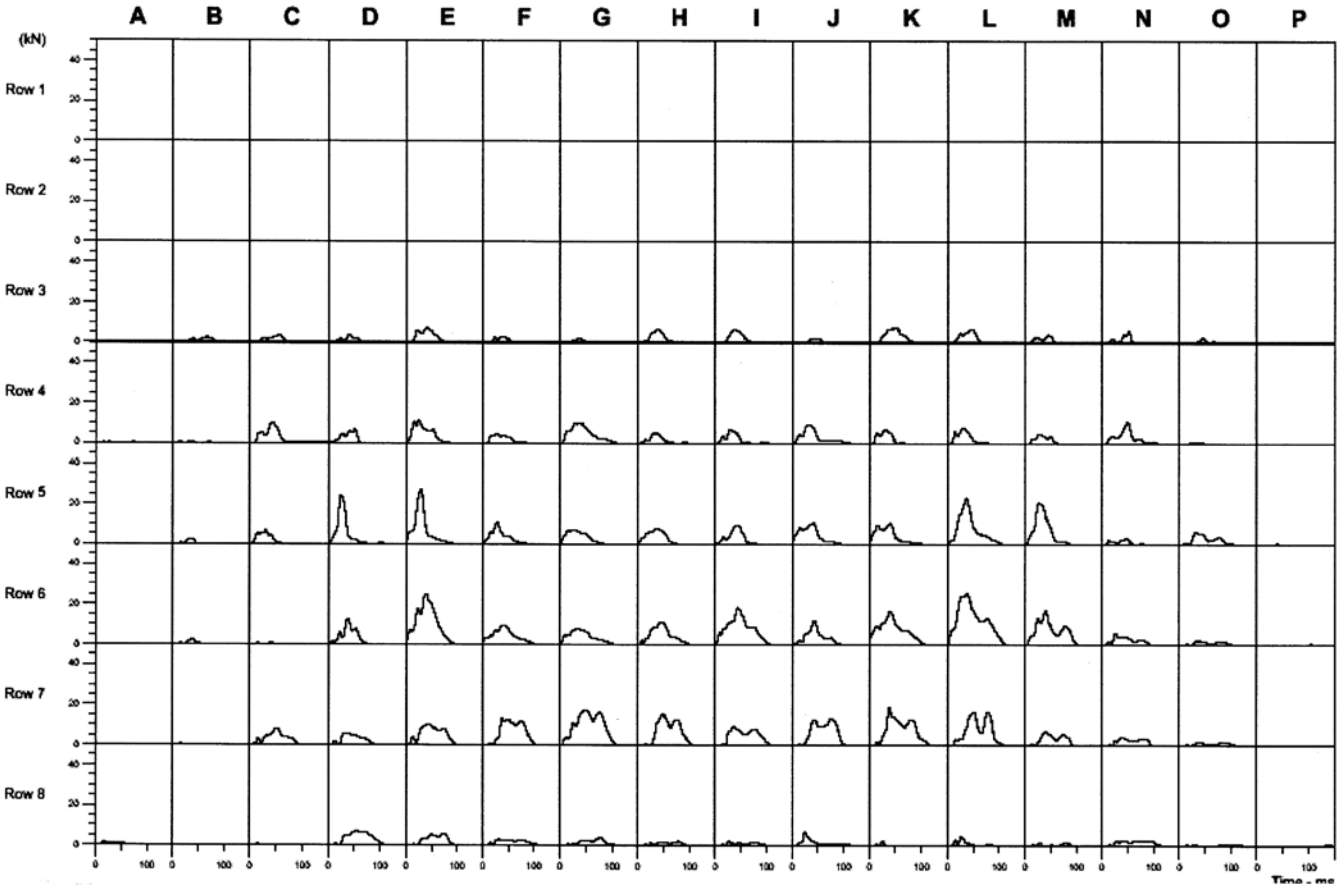

Fig. 9 Load (scale, 0–50 kN)–time (scale, 0–150 ms) curves for a complete LCW with a double-layer barrier face with segmented rear layer 85 mm deep

4.2 Frontal stiffness test

The potential of controlling a car's stiffness by using the peak LCW force measured in a 64 km/h ODB test has been demonstrated and reported previously [**5**]. A 50 per cent overlap car-to-car test, with a closing speed of 112 km/h, was conducted between two small cars with a mass ratio of 1.01. Intrusion measurements showed that the car, which had recorded a lower peak LCW measurement (240 kN; cf. 310 kN) in the 64 km/h ODB test, suffered relatively more intrusion in the car-to-car test than in the ODB test.

As mentioned previously (section 3.2) the LCW force is a combination of the force coming from the deceleration of passenger compartment (compartment component) and the force coming from the deceleration of the mainly rigid masses ahead of the firewall (mechanical component), a large proportion of which is due to the engine and gearbox. For a typical car, the 'mechanical' component is relatively constant, because the engine and gearbox decelerate gradually, as the car deforms the barrier (Fig. 10).

However, in a small number of cases, the magnitude of the mechanical force component increases significantly towards the end of the impact, which increases the peak LCW force recorded (Fig. 11). This arises because the engine has 'bottomed out' the deformable barrier face and directly loaded the wall.

It would be more difficult for cars that exhibit this behaviour to comply with an LCW force maximum limit. However, it is not believed that this would be detrimental as, generally, these cars have little structure ahead of the engine, making them more aggressive. On the other hand, small cars could use this approach to help to comply with a minimum force requirement. Further work is necessary to determine whether this could be a significant problem.

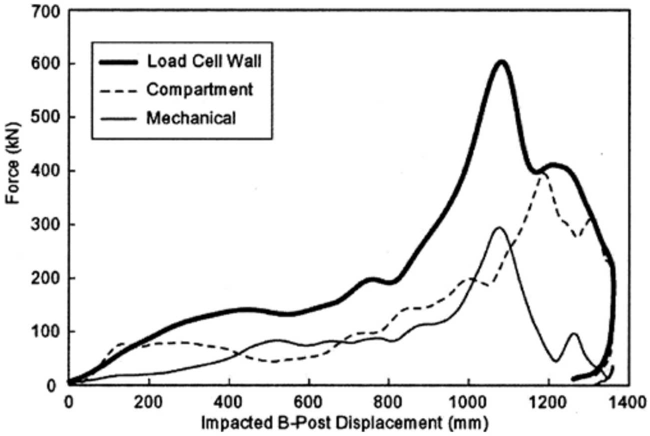

Fig. 11 LCW force measured for a 64 km/h ODB test of a large family car showing a large mechanical force component towards the end of the crash

As part of the continuing development of this test procedure, LCW peak force measurements have been taken for many recent EuroNCAP tests (Fig. 12). Examination of the data shows that the peak forces lie in the range from 200 to 500 kN. From this information a first estimate for a maximum force limit could be 400 kN and for a minimum 300 kN. To determine whether these suggested values are appropriate and practicable, much further work is necessary to address the issues noted in section 2.2; these are the passenger compartment strength, the deceleration pulse and the need to increase the crush depth in heavier cars.

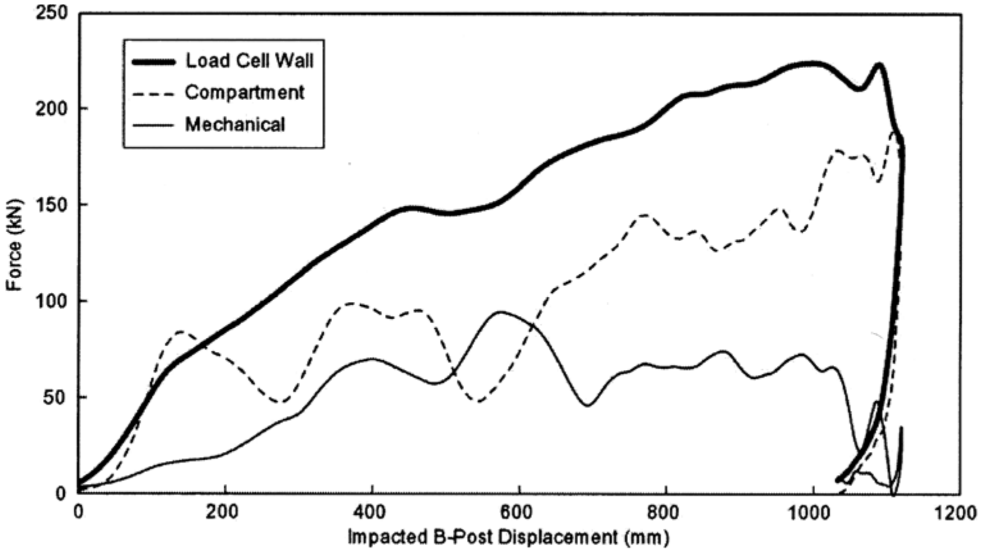

Fig. 10 LCW force showing the passenger compartment and mechanical components for a typical car in a 64 km/h ODB impact

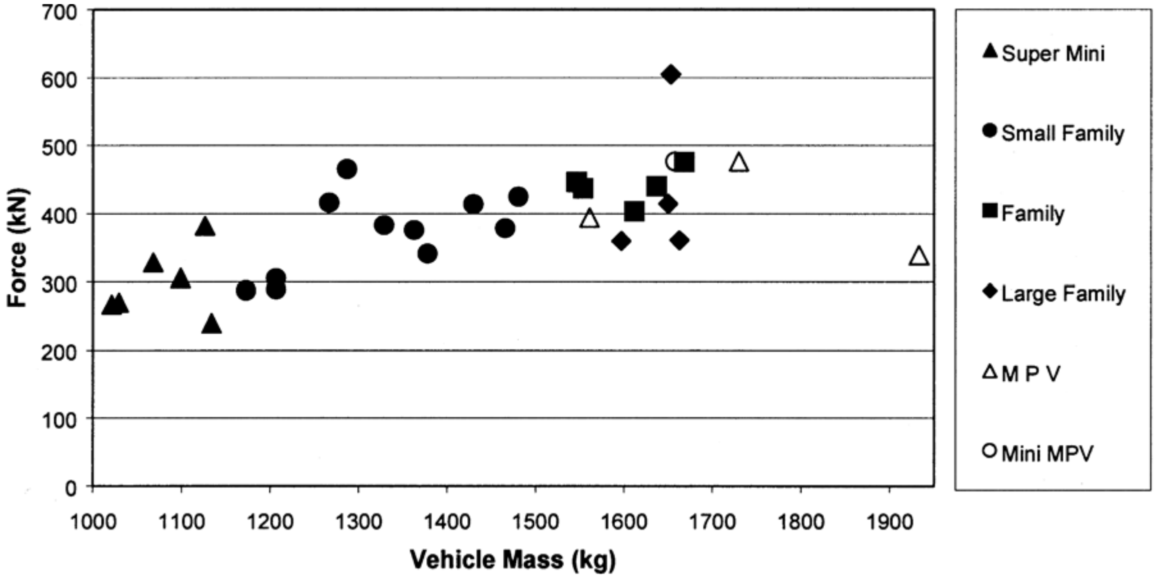

Fig. 12 Peak LCW measurement for EuroNCAP tests

4.3 Compartment strength test

Typically, in an 80 km/h ODB test, towards the end of the impact the engine has 'bottomed out' the deformable barrier face and stopped decelerating so that the LCW force consists mainly of the passenger compartment force component (Fig. 13). The LCW force at this point is termed the 'end of crash force', a phrase first used by Renault [**7**]. This force represents the load imposed on the compartment and hence can be used as an indication of a minimum load that the compartment can withstand for this loading configuration. From the limited number of tests performed, it appears that the time at which the average engine deceleration records a minimum can be used to determine the time at which the 'end of crash force' should be measured. It is possible that the end of crash force requirement may be achieved with just one load path, e.g. via the road wheel to the sill. To ensure that this does not occur, intrusion limits may also be necessary, in particular at waist rail level. Further work is necessary to address this issue.

Some concern has been expressed about the possible repeatability of this test especially if the passenger compartment becomes unstable [**4**]. Two similar tests have been performed for a super-mini-sized car with an impact speed of 80 km/h. These show good repeatability for the LCW force (Fig. 14) and the car's deformation (Fig. 15) even though the load path through the door beam has become unstable.

The compartment strength measured in this test will be dependent on the load paths used. One possible concern, which requires further investigation, is that

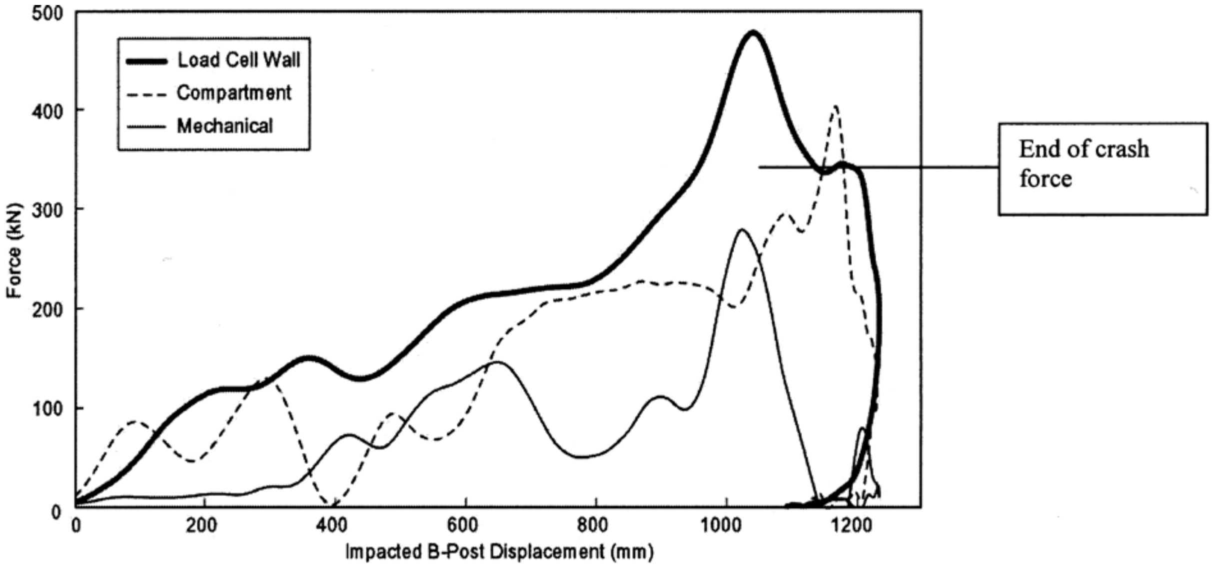

Fig. 13 LCW force showing the compartment and mechanical components for an 80 km/h ODB test

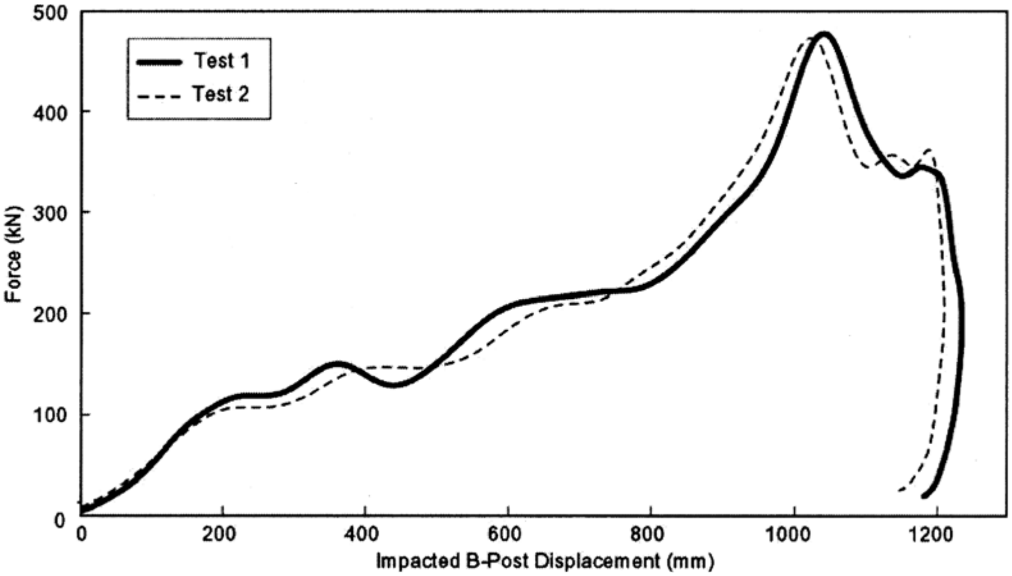

Fig. 14 LCW force for two 80 km/h ODB tests with a super-mini-sized car showing good repeatability

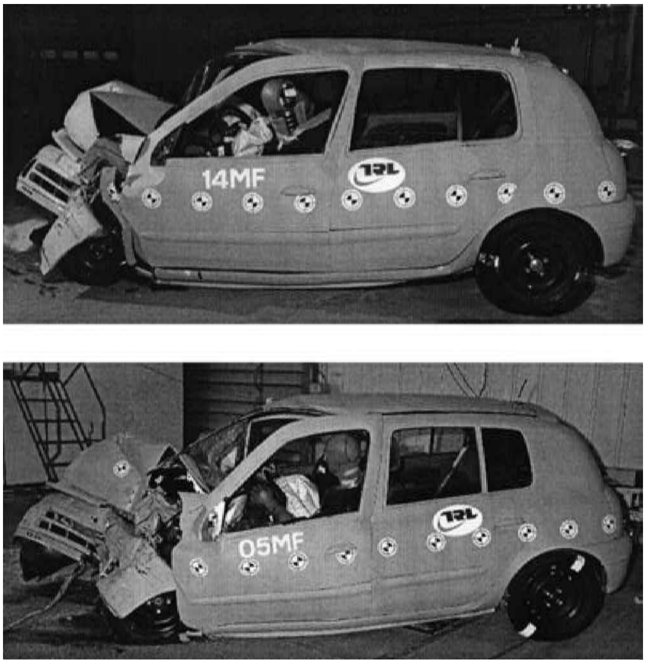

Fig. 15 Deformation for two 80 km/h ODB tests with a super-mini-sized car showing good repeatability

the wheel to sill load path is used more in this test configuration than it would be in accidents.

If a maximum force level of 400 kN is set for the frontal stiffness test, a suggested minimum limit for the end of crash force to control the compartment strength may need to be somewhat greater, say 450 kN. However, it may be possible to set the limit lower and still allow a sufficient safety margin. In a car-to-car impact, some of the engine load acts directly on the engine of the other car and does not act on the passenger compartment. It is possible that not all of the engine component of the LCW force measured in the frontal stiffness test acts on the passenger compartment in a car-to-car collision; therefore this may allow a sufficient safety margin to set the limit lower. One advantage of a lower limit would be to minimize the risk of car designs where the deceleration pulse might have to increase rapidly when the front structure bottomed out on the strong passenger compartment. Further work is required to check that the suggested value of 450 kN is appropriate and practical.

5 CONCLUSIONS

The issue of frontal impact compatibility is now well understood. For improved compatibility, cars need to interact in a predictable manner to absorb the impact energy with minimal occupant compartment intrusion, over a broad range of collision types. To achieve this, an essential prerequisite is good structural interaction. Following this, some form of stiffness control will be necessary to ensure that the impact energy is absorbed without exceeding the strength of the passenger compartment.

In order to address these issues and to improve compatibility, three test procedures to assess and control both compatibility and frontal impact are under development. These are as follows:

1. A full-width test at 56 km/h with a deformable barrier face and high-resolution LCW would be used to assess and control structural interaction. This will be achieved by controlling the force distribution measured on the LCW, to encourage the development of structures that behave in a more homogeneous manner.
2. A 64 km/h ODB test (the current EuroNCAP frontal test) with a high-resolution LCW would also be employed. From the load cells, the car's frontal

stiffness could be controlled by specifying that the peak force recorded should lie within a specified range. In the future, control of the pulse shape could be used to manage the passenger compartment deceleration and restraint loading.

3. A high-speed, possibly 80 km/h, ODB test with an LCW to assess the strength of the passenger compartment. This test would not require instrumented dummies.

One advantage of this set of tests for frontal impact is that the full-width test would generate a ‘hard’ deceleration pulse on the vehicle and restraint system, whereas the 64 km/h ODB test would generate a ‘soft’ pulse. This would ensure that optimization of restraint systems to one pulse is not encouraged. Another advantage is that, assuming that the full-width and 64 km/h ODB tests are specified for frontal impact, only one additional test is required for compatibility.

The current state of development of these test procedures has been reported, covering issues such as the optimization of a deformable barrier face for the full-width test. Some performance criteria values for the frontal stiffness and compartment strength tests have been tentatively suggested. However, further work is required to ensure that these suggestions are appropriate and practicable.

Implementation of these three test procedures should be sufficient to control intrusion and to provide a safe environment within which the restraint system can operate. This should address contact-induced injuries but not restraint-induced injuries. A next step to help to reduce injuries caused by the restraint system could be to control the shape of the car’s deceleration pulse. This is an evolving area and much further work is required to complete the development of these procedures to a level suitable for consumer and/or legislative use.

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