COMPATIBILITY ASSESSMENT PROPOSAL CLOSE FROM REAL LIFE ACCIDENT

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ABSTRACT

Accident studies show that incompatibility has become the main cause of fatal injury in car to car accidents. There is a general agreement today that improving compatibility is one of the most effective ways to reduce the number of road accident victims.
Therefore, structural car design must take into account other road users without decreasing self protection level supplied by all new passenger cars. In addition to these safety considerations, the front unit structural design has to account for an increasing number of constraints: improvement of real world performance in safety, fulfil current and future regulations like "CAFE" or pedestrian, reducing utilisation costs and so on.
Furthermore, European fleet is changing in mass and in size, as the world's ones, and new fashion vehicles appear different than the previous one.
This paper deals with the development of a more comprehensive approach in order to better take into account safety requirements coming from real life accidents and the work done over the past years on understanding the physic of compatibility. The aim of this paper is to propose a better assessment procedure and a new test methodology in a standard approach for improving compatibility.

INTRODUCTION

40 000 people die each year in Europe due to traffic accidents. In France there were 5 000 fatalities in a car and 2700 involved in car to car or car to vehicle accident. This figure represents more than half of people that die in a car collision. Our approach has been for many years to study real world accidents and try to understand what were and are the mechanisms of injury causation. Accident studies during the last twenty-five years clearly showed that car to car head-on collision is a major impact configuration to take into account in order to improve safety on the roads. With new self protection ratings all cars offer equivalent behaviour against a fixed obstacle. So, in the future, it is expected that the main progress will have to be made in car to car compatibility.
Compatibility between cars has for a long time been reduced to the simple image of heavy against light cars. Over the past ten years vehicle stiffness has been increased thanks to improved restraint systems. We also have a better understanding of the front end design energy absorption. Front end design is at the cross road of numerous contradictory constraints: self protection of occupants, protection of vulnerable users such as pedestrians, reparability, styling, aerodynamics, engine cooling and so on.
Therefore, each manufacturer has developed its own solution to solve this difficult equation which resulted in a wide variety of front end designs, structure and stiffness regardless of the overall mass of the vehicle.
Solutions however have been optimized against a rigid wall or soft obstacle but not in car to car configuration. The problem was first to understand the physics of car to car interaction then, to set design rules, to design for an improved compatibility. And finally, to find a test procedure and a set of relevant criteria in order to keep under control front end and passenger compartment design over the market production.
Whereas self protection can be achieved through a wide variety of structural design, compatibility (partner and self protection) can only be achieved through cooperative work and common design rules amongst manufacturers. This is what makes improvements in compatibility so difficult. To be effective in terms of lives saving, the procedure must absolutely take into account:

- accident research analysis
- heavy an light vehicles
- current self protection requirements
- current and future fleet
- current and future vehicle design.

CURRENT AND FUTURE EUROPEAN FLEET

In addition, research into compatibility must take into account the time taken to renew the fleet (figure1). Measures proposed for new vehicles must not create dangers for existing ones because the European market, as the other ones, is a mixture of old and recent cars.

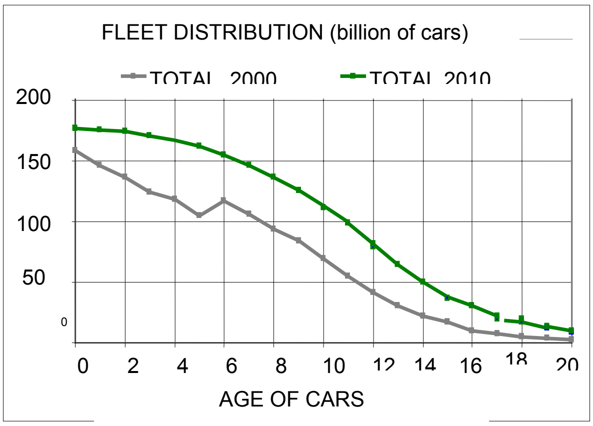


Figure 1: Age distribution of European fleet in 2000 and 2010 (estimate).

In marge of the global increase in weight, due to new fashion in car design, the vehicles segment distribution is changing into multi purpose or four wheel drive vehicles higher and heavier than the previous ones.

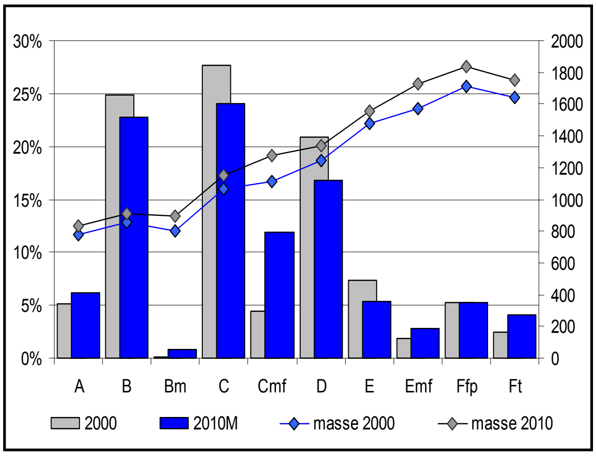


Figure 2: European mass and segment distribution change

It is necessary to point out that the procedure should last for a long time to avoid rupture effect in the vehicle fleet due to change in the rules. It is therefore better even if it takes some time, to opt directly for the best way of evaluating the compatibility, before adopting any standards.
So the future standards approach must be stable to avoid inhomogeneous fleet as we can see today. If not, the overall benefit of such measures may be severely compromised.

ACCIDENT RESEARCH FINDINGS

Accident configurations

Several generations of vehicles are now together on the same road network. By this term, we mean cars with different stiffness, in other words different crush force deformation. The introduction of ratings and reparability test over the past decade has led to stiffer cars and has increased the discrepancy between "old" and "new" generation of cars. There are now on the roads light cars which can be aggressive for heavy cars. There are also cars of the new generation which are aggressive for the same size of the old generation. The major difference between these cars is the stiffness of their compartment and front unit. This has clearly to be put under control through common assessment test.

Overlap and angle of collision

Thanks to the introduction of numerous actives safety systems helping the avoidance of crashes (ESP…), the overlap seems to decrease. However, the average is around fifty percent giving by current data. In the future we may need to consider decreasing this overlap.

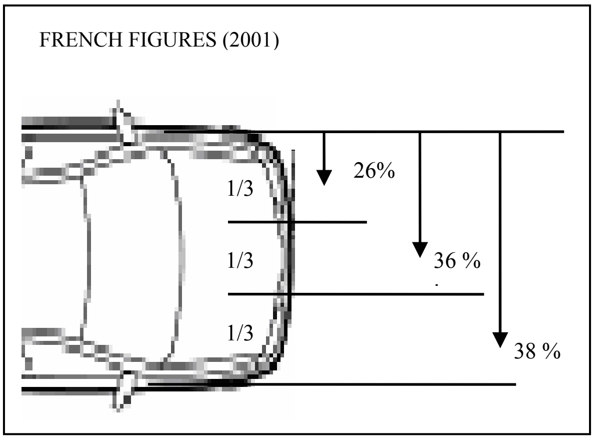


Figure 3: overlap distribution in head-on collision

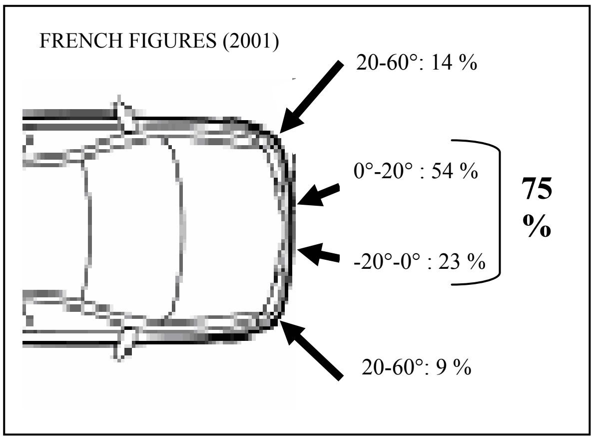


Figure 4: angle distribution in head on collision

This data (0° and 50% overlap) are largely accepted by the scientific community. Whether it be car to car ratings (ADAC, AMS), tests performed by different working groups (PREDIT, CEVE, EUCAR), by car manufacturers or states (Australia), all were carried out at fifty percent and zero degree angle. So, the future standard must take into account this point to be close from accident data and car to car test configuration.

Closing speed

The future frontal European regulation at 60 kph is linked to the fact that the improvement of the compatibility cannot be done to the detriment of self protection (especially heavy vehicle). It brings us to set the limit at 100 kph closing speed. Accident studies show us that 60% of people involved in the light car are covered (figure 5). It should be specified that these progress will be also applicable for higher closing speeds.

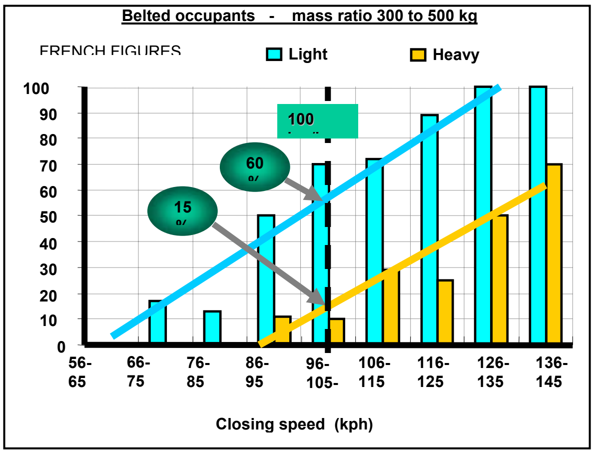


Figure 5: gravity rate covered vs closing speed

Breaking front unit clearance

In forty percent of cases, one of the two vehicles is in breaking (with the introduction of ABS, this information becomes more difficult to collect). The front structures are lowered (about 150mm) compared with the static position. Only a geometric treatment of frontal structures is therefore not sufficient to cover these cases.

STUCTURAL POINTS TO INVESTIGATE

The front end is collapsible whilst the occupant compartment must keep its integrity and play its role of survival cell. As a result, the intrusion into the occupant compartment has been greatly reduced thus reducing the risk of contact injury. Car design for front crash reflects also the ability to balance intrusion reduction which means stiff front structures and acceptable deceleration from the occupant point of view. Recent developments in restraint systems such as seat belt with load limiters, airbags and so on, have helped to make level of compartment deceleration acceptable, which would have killed people some years ago.
In order to reach the desirable intrusion level, the engine compartment has to absorb a certain amount of energy. Usually this is achieved through different load paths which absorb energy and transmit the load from the front to the occupant compartment. These load paths are designed and tuned against two types of obstacles: rigid barrier or deformable barrier. So far test s carried out on deformable barrier showed bottoming out phenomenon. This means that the front end design is not controlled by the barrier stiffness because the structure collapses with the help of the rigid wall behind the barrier. In each case the obstacle is far from representing a car front unit. That's why structural behaviour in car to car accidents are different due to bad connexion between load paths (figure 6), bad spreading surface in front of the load paths (figure 7 and 8) that cause fork effects, insufficient engagement and weak structural interactions.

Figure 6: Rupture of the connexion between subframe and longitudinal

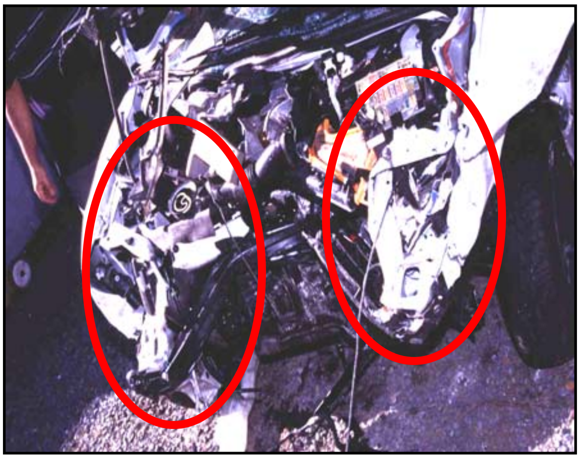


Figure7 : Undeformed longitudinals

Figure 8: severe intrusion in side impact due to local stiffness of the striking car.

Finally the amount of vehicle deformation should a least put under control. The total length of the frontal unit must be tested to detect structural behaviour and even the farthest away from the front end structures (figure 9). Sometimes, these structures help for a better engagement and structural interactions. The future procedure must be severe in order to check the front unit at least up to the compartment

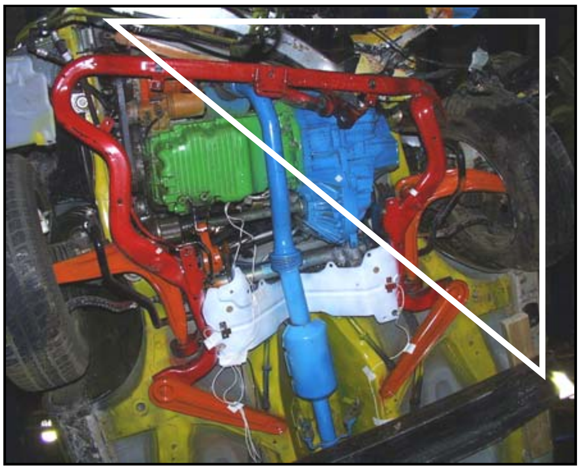


Figure 9 : Front unit area often involved in car to car accident

Energy absorption principles

Looking at real world car to car accidents, it is clear that the first cause of occupant death is due to intrusion of aggressive structural parts into the passenger compartment (figure 10). Unfortunately, structural behaviour and intrusion mechanism are completely different from those observed against in test with rigid wall or soft obstacle (EEVC barrier).

Figure 10: Overloaded compartment

This is where incompatibility arises. One definition of incompatibility between two cars is when one of the two cars is absorbing most of the crash energy whilst the other remains mostly undeformed.
The scientific community now agrees that mass does not play a direct role in compatibility. Its indirect role is through the stiffness or the deformation force.

In order to reach the same level of self-protection, the level of intrusion is roughly the same regardless of the vehicle mass. The increase in length of the car size does not usually compensate for the increase in energy to be absorbed. As a result the front end and the compartment deformation forces as to be increased to reach a higher stiffness. In addition, design against deformable barrier with bottoming out results directly in even stiffer heavy cars because this test is more severe for large car than for small ones. The fraction of energy absorbed in the barrier is roughly the same regardless of the car mass resulting in a higher fraction of energy to be absorbed by the large vehicle than by the small one.

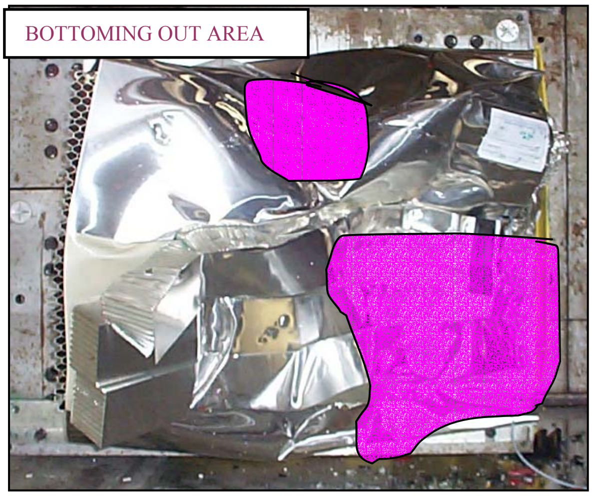


Figure 11: Current bottoming out phenomenon on EEVC barrier

FRONT END DESIGN AND COMPATIBILITY LIMITS

Front design limits

Front end design is at the cross road of a large number of conflicting requirements such as: aerodynamics, engine cooling, styling, pedestrian protection, accident protection or reparability. There are also some other constraints which at first sight does not appear related to crash performance but which could have an effect: overall length (cars have to fit into cities and allowed to be parked easily). In addition, the lower lip of the front bumper cannot be too low with respect to the front overhang in order to avoid difficult access to ramps.

Compatibility limits

Compatibility has two aspects: on one hand, self protection, which is controlled trough test against barrier. This can be achieved trough a variety of compartment force and design. On the other hand, partner protection is very seldom addressed. There is no agreed test methodology, neither regulation. This is typically a safety subject which has to be solved on an international cooperative basis as compatibility usually

involves two cars of different manufacturers. So there is only limited interest at designing its own range to be compatible.
Due to the requirement for self-protection and the wide range of vehicle's size, mass and stiffness, we have to define a limit for compatible design. For example, a car can only be made compatible up to a certain speed. Furthermore, this limit must be in line with other regulations. Then, if we take for instance an MPV of 1800kg at 60kph against the EEVC barrier (future ECE94 regulation), the corresponding EES is around 55kph. The intrusion level set by the regulation will make heavy cars much stiffer than small ones. One might think that we could always increase the length of the heavy cars but we have already seen that it is impossible before. The result is that heavy cars cannot be made compatible, in term of stiffness, with small ones at EES55 without decreasing their self protection. Thus, we have to choose a lower limit at EES50 which corresponds to a closing speed of 100kph. In such a crash configuration, two cars can be said compatible if the intrusions observed on both side are close to those observed in ODB test at 60kph.

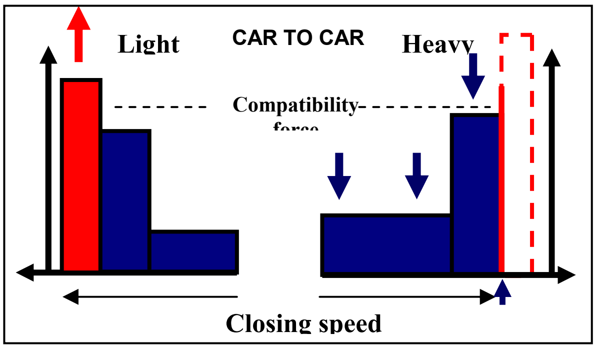


Figure 12: Car to car energy distribution

Structural improvements

As mentioned above, stiffness is one part of a compatible design. In order to take advantage of all the potential for energy absorption of both cars, their structure must interact correctly. This goes along with preventing over-ridding which is a specific aspect of energy deficiency. Improving energy deficiency is now something which is generally accepted.

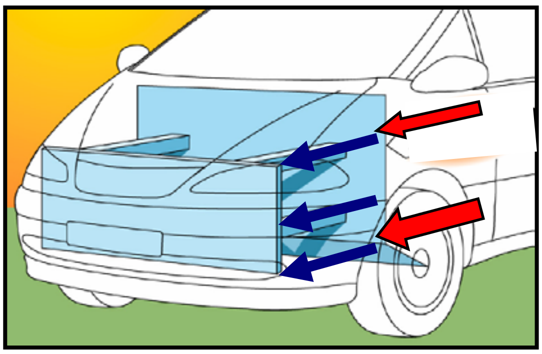


Figure 13 : Compatible front end

The problem now is to find common test procedure and criteria which will be representative of this phenomenon in order to put this item under control.
In term of design, one way to achieve structural interaction is to offer a front surface which is homogeneous in stiffness over a surface which is large enough. To illustrate this point, we have to imagine that we put a wall between both cars. The concept of the wall is to have a homogenous stiffness over a large surface. To achieve this result, the stiffness on the front block must be distributed along multiple load paths. Having this is not enough, as they cannot ensure that the stiffness is homogeneously spread over the front surface. The additional requirement, which is also confirmed by real world accident analysis, is that the different load paths must have strong connection both vertically and horizontally. To finish with, this result avoid to have localised load paths on small surfaces.
Equal stiffness also means corresponding deformation forces. Theses forces must be as close as possible for both cars in order to allow an equal deformation for both. As seen previously, this "compatibility" force is different from the self protection one.

PROPOSAL FOR A RELEVANT COMPATIBILITY ASSESSMENT

There are no effective proposed improvements unless they are applied by all manufacturers and for all passenger cars. The only way to reach that target is to define and apply a new standard project.
Several international task forces are working in that direction. Some orientations resulting from the preceding principles are proposed and can be discussed in that context. As we have seen before, the two main principles for a better compatibility are first to enforce a minimum resistance of the compartment, then check its stability and finally put under control the energy absorption and the force level of the front end of the car (called Bulkhead Principle by some compatibility experts);
We consider at the present time that one test is needed to cover these two issues. This procedure is a little bit different than the previous one proposed by Renault.

The procedure must check:

- load path positions and stiffness
- structural links among them
- global front unit and compartment force
- compartment stability

The procedure must generate:

- local and global longitudinal shears
- local and global horizontal shears
- compartment strength (overloading)
- large deformation depth

The procedure must be in line with:

- current and future regulations

- light and heavy vehicles

The assessment could be based on:

- barrier deformation
- force load measured behind the barrier

In other words, to cover the maximum of cases the procedure must reproduce a frontal car to car accident structural loading.

Several test procedures are proposed for compatibility assessment: against different rigid wall or soft obstacle (with bottoming out phenomenon) and different overlaps (between 40 to 100%). Unfortunately, as we have seen before against a rigid wall or soft barrier, the various load paths are not working the same way as they do in car to car interaction. The deformation process is at imposed displacement, whereas in car to car, the deformation is at imposed pressure or force.
A rigid wall might seem simpler; unfortunately it is not representative of a car front block and far from real world accident observations.

Test procedure

The objective is the ability to quantify:

- the capacity of the front unit to absorb energy corresponding to an 100 kph closing speed
- the capacity of car compartment to resist and be stable.

We have seen that heavy cars are stiffer than light ones due to their design only. Today we have to take into account the non aggression for the other car users (80% of cases). So, it is important to develop a testing procedure to put under control the energy absorbed by each car before reaching its self protection force. A car designed to be very stiff can reach the self protection force in an early phase of the crash and be very dangerous because it has not enough energy absorption capacity.
We are able to propose a new test procedure for all car range, after having analysed real world accidents, considered new and future generation of cars and current European regulation and all the work done by international experts.
If we focus on what we want to control in the test design the following configuration is proposed:

- offset :For controlling the strength of the lateral connections between the different load paths and generates global shears.
  Proposed offset: 50%

- obstacle : Progressive Deformable Barrier (PDB) is aiming at checking front unit in stiffness and geometry, generating shears in the vertical and the horizontal

- Mobile barrier (second step):
  The mass is supposed to be that of a medium car in Europe. The test progressively switches from a light car overload to a heavy car partner protection test.
  Proposed mass in Europe: 1300kg. Mass can be adapted with the continent fleet.

- Test severity : to be defined
  To be in line with 100 kph closing speed, current and future regulation.
  Fixed barrier: around 60 kph to 64 kph
  Mobile barrier: closing speed around 90 kph

In other words, the test procedure is fully representative of real world accident. Test dummies are employed – It could become a restraint-system dimensioning test also, but further investigation is required.

Barrier

The barrier is now well known (derived from ADAC barrier). The main difference is a progressive increase in stiffness in the depth, and two height dependant stiffnesses, which contribute to its name: PDB as Progressive Deformable Barrier (Figure 14). The barrier allows to checking the thrust surface of the vehicle, and the links between the transfer paths. Its dimensions and stiffness make the bottoming-out phenomenon very unlikely.
In car to car there is no bottoming out, thus the barrier must be designed in such a way as to prevent this phenomenon (figure 14).
Thus, the compression on the front block exhibits an increasing stiffness. Furthermore car force distribution in height should be represented; the lower front load path is usually stronger than the upper one.

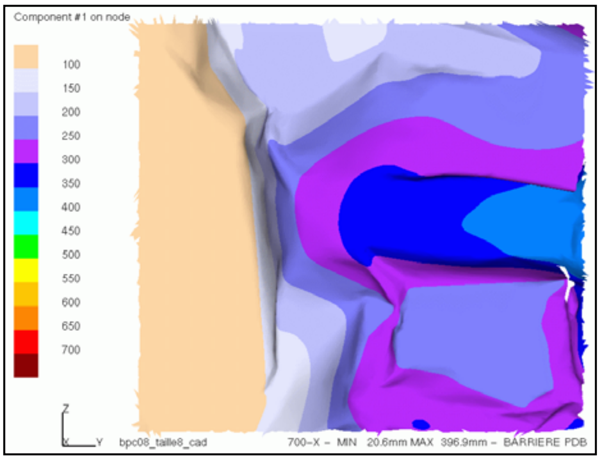
Figure 14: PDB barrier version 7 - Vehicle collapse without the help of the rigid wall behind

Measurements

All criteria and investigation are based on the deformation of the barrier and the global force deflection measured behind. It looks like car to car accident or test analysis, except that in this case, the

barrier deformation is investigated instead of the car. An aggressive vehicle would be identified by large and non homogeneous deformation.
The PDB barrier is able to detect local stiffness but also transversal and horizontal links among load paths. The barrier represented on figure 15 clearly shows front cross member, lower cradle subframe and pendants that improve vehicles compatibility. That is the reason why the assessment is based on deformation in height and in depth.

Figures 15: Footprint of the car front unit recorded by the PDB barrier- deformation is far from the wall

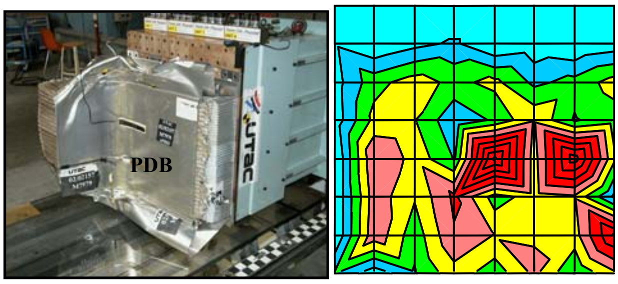


Figures 16: Contour plot representing front unit force distribution

Since the use of the last PDB version 7 with improved front sheet, localised tearing disappeared. Digitisation and interpretation is become easier.
Two limits are considered in the assessment: geometric in height and stiffness in depth. Both limits can be adapted with the fleet and what kind of cars we want to protect. The formula describes each colour surface weighted by its height (Z position) and its deformation (X position).

Load cell wall measurements

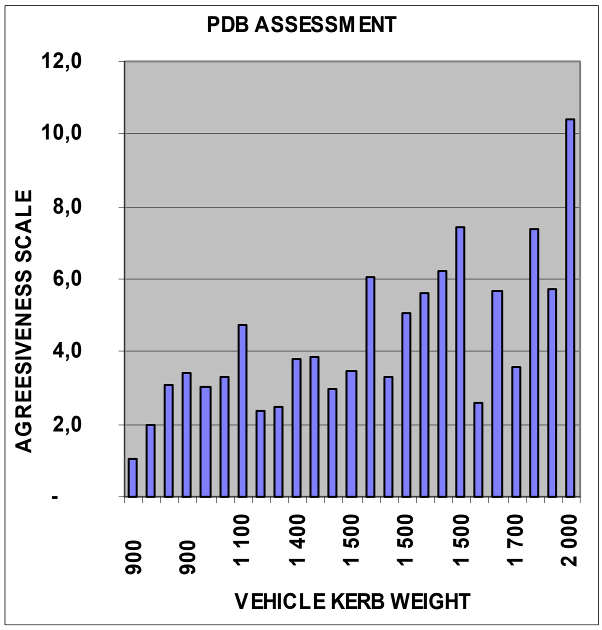
Before eventually using load cells wall behind the PDB, several tests have been performed to validate and control the accuracy of the measurement. Unfortunately, force measurement doesn't work well. In fact, the force distribution was not the expected one. The expected result could have been a homogeneous pressure because tests were performed with a rigid plan wall.
Unfortunately, the force was concentrated on one load cell (figure 17). The flatness of the multi load cell seems to be responsible for that result. Furthermore, the force measurement distribution seems to be better and more accurate without honeycomb. Further work is needed to clarify this point.



Figures 17: Force distribution corresponding to a plane rigid wall impact.

Tests already performed / Assessment

More than thirty tests have already been performed all around the world and the results confirm the previous ones. Vehicles have been selected for their front units in terms of design and stiffness, different size and mass, different generation and different driving position. These tests are often accompanied with a car-on-car test in order to validate the PDB assessment. The figure 18 shows the result vs kerb weight of the car.

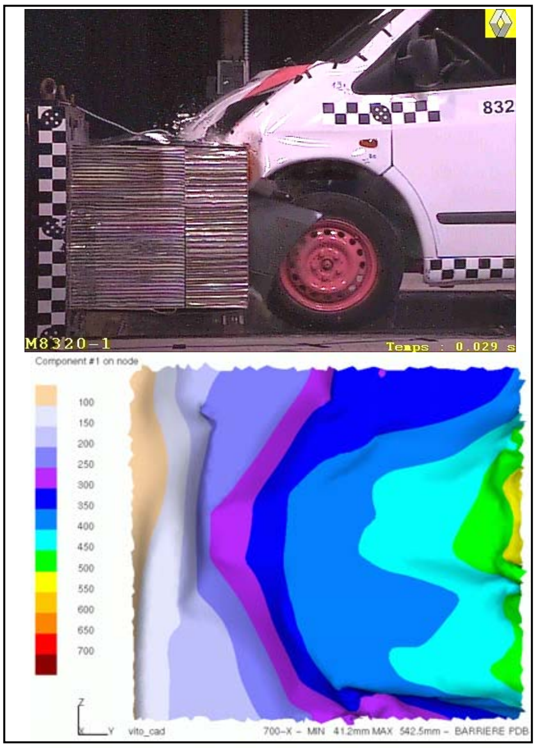


Figures 18: PDB assessment at 60 kph

Heavy vehicle performances

Some heavy cars have a better rank than small ones, because only the front unit behaviour is responsible for.

It is not a mass dependant test. Let's take for example a 1950 kg light commercial vehicle fitted with lower load paths (figure 19).

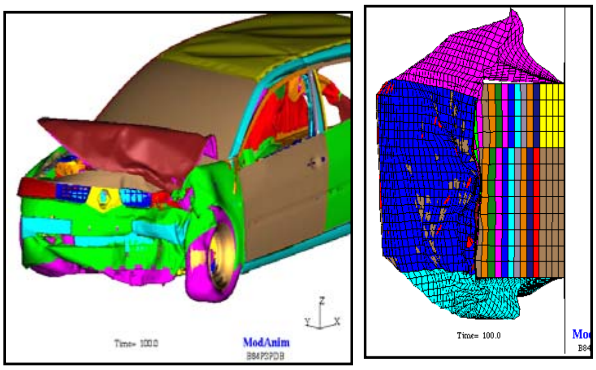


Figures 19: PDB assessment corresponding to a 1950 Kg Light Commercial Vehicle.

Multiple and moderate load paths force and good connexions among them allow to this vehicle getting acceptable compatibility assessment even if kerb weight is close from 2000 Kg.

FE model development

To complete the study, a numerical approach is needed. That's why, a Finite Element model of the PDB is under development. Actually, new test proposal must be easy to simulate. It will become a help to design the future compatible car.



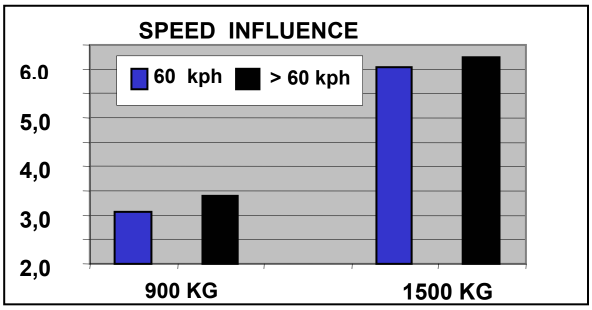
Figures 20: Family vehicle against PDB

The first approach is encouraging, however, further development are needed to tune the FE PDB. After that, the model will be marketed.

PROPOSAL TO ASSESS COMPATIBILITY

First step proposed by France – Mid term

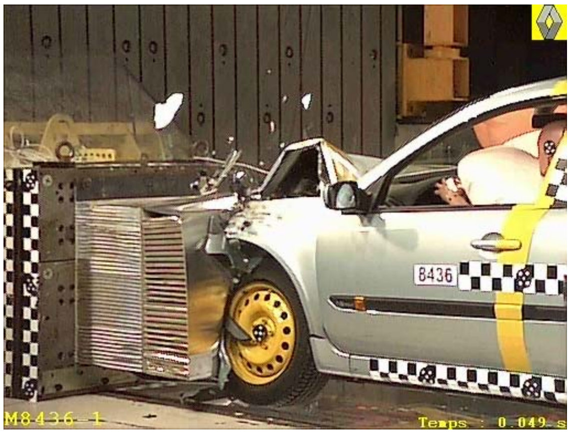
The possibility to check both self and partner protection against PDB barrier was investigated. First results are encouraging to continue in this way. Up to now, two cars have been performed in this configuration.



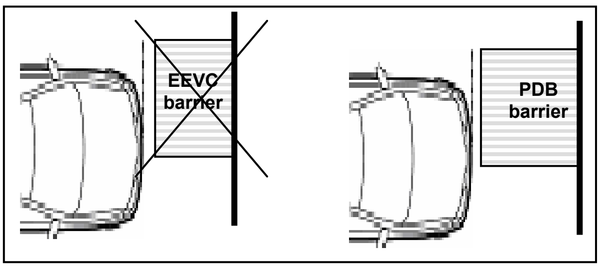
Figures 21: PDB assessment vs speed

The test speed was higher than 60 kph. We have seen that in both cases, the barrier was able to keep in mind the front unit footprint because the PDB assessment didn't change (figure 21). It means that the barrier seems not to be linked to the speed.

The French proposal (PSA Peugeot-Citroën, Renault and UTAC) is to replace the EEVC barrier by the PDB one (figure 22). The test speed could be eventually higher than the future regulation (60kph) and fixed for all cars. Furthermore, this proposal could generate higher deceleration pulse and could be able to combine both acceleration and intrusion. However, further researches are needed to set the optimal test speed.



Figures 22: New PDB test proposal with instrumented dummies.



Figures 23: First step proposal to assess compatibility

Second step proposal – long term

To be closer to real life accident and be able to answer both partner protection especially for heavy cars and self protection especially for light cars with only one test. The PDB could be fixed on a mobile trolley as Australia investigated last year (figure 24). A quick energetically approach shows clearly than this test due to conservation of momentum associated to different energy absorbed in the barrier allows to progressively switch from a light car overload to a heavy car partner protection test (figure 25). We think that test answer all compatibility test configuration problems. However and before proposing this test as a standard, we have to investigate it.

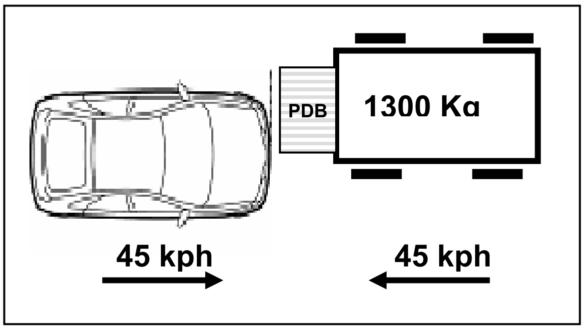
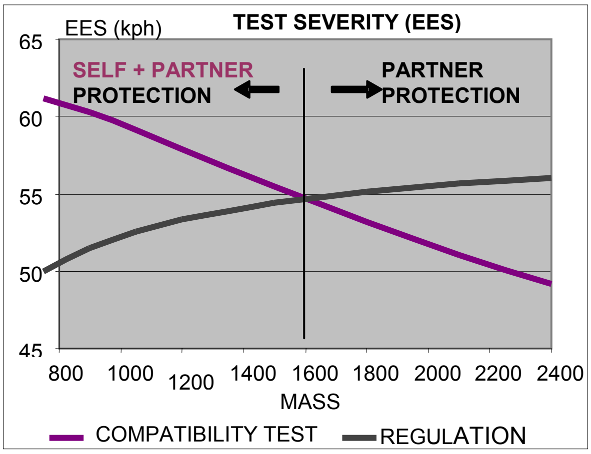


Figure 24: Second step proposal closer from real life accident



Figures 25: EES severity between future regulation at 60 kph and compatibility test vs mass

CONCLUSION

Improving compatibility is the most effective way to reduce the number of road accident victims. The study we made and the tests we conducted have showed that the front-end stiffness and compartment have an influence on compatibility.

A good structural interaction is a prerequisite to obtain a well balanced energy. It is not possible to separate stiffness and geometry of the front end. Furthermore, improvement that could be made on future vehicles for front impact will also produce benefit for side impact.

To answer these statements, the design constraints described (self protection, heterogeneous vertical distribution of stiffness and high local stiffness in front end) lead to define two compatibility targets:

- First of all, partner protection: vehicles should have an homogeneous front end and absorb a certain amount of energy before reaching self-protection force
- Then, self protection: vehicle should have a certain compartment crush force capacity and stability.

The development of future vehicles with respect to these targets would result in a compatible fleet of new vehicles. Moreover, considering the time taken to renew all the vehicles, it is necessary to propose measures that will limit dangers for existing vehicles and doesn't change every time to avoid rupture in the fleet.

The PDB test procedure already showed its capacity to verify the behaviour of new vehicles in regard to the partner protection targets. Aggressiveness assessment is allowed. The studies in progress confirm that statement. The concept, close from real life car to car accidents, clearly show the capacity of the front unit to be aggressive or not. Thanks to the propriety of the deformable element and the test configuration. Furthermore, interpretation is become easier with the current PDB version 7 that avoid rupture and tearing.

However, this test doesn't control the overload of compartment and nor answer the question of self protection. That is the reason why doing both self and partner protection with this test is investigating.
In a first step, that kind of evaluation could be introduced as a fixed barrier.

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