Technical solutions for enhancing the pedestrian protection

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ABSTRACT

Since October 2005, the European regulation for pedestrian protection is applicable to new vehicles.
Four impactors have been developed: leg, femur, child and adult heads for testing predefined areas on the front face of the vehicle.

This paper presents the technical strategy and the set of solutions which place PSA Peugeot Citroën as one of the best manufacturers for pedestrian protection with in particular Citroën C6, first and unique vehicle achieving 4 stars in EuroNCAP pedestrian protection assessment.
The scenario of head and leg protection is articulated around two requirements:

- keeping a space between the bonnet and the various hard elements of the engine, and behind the front bumper so that the impactors do not come into contact with rigid elements,
- softening the bonnet and the front bumper elements in order to generate a more progressive head and leg deceleration during the impact.

The level of constraint induced by these requirements penalizes heavily the style and the overhang of the vehicles. Massive development efforts have been invested in both fields of leg and head protection. The physical characteristics of the components and the design constraints have to be optimized under advanced computational analyses with finite elements model.

The protection of the leg requires the installation of two absorbers (upper and lower).
The head protection requires complex tuning of the stiffness of the bonnet and some components inside the engine compartment. For executive cars with long hood, like C6, it also implied the development of an active bonnet, triggered by fusible optic sensors, which is not only a technical challenge but also addresses outstanding issues in the field of quality and reliability.

The paper provides technical descriptions of the methods deployed by PSA Peugeot Citroën, associating numerical simulations and physical tests, for developing innovative solutions in the field of passive and active safety.

INTRODUCTION

Every year, approximately 8,000 pedestrians and cyclists are killed and 300,000 others injured in road accidents in Europe. The accidents are particularly frequent in urban zones. Even when cars are driving at relatively reduced speeds, very severe injuries can occur. Below a speed of approximately 40 km/h, it is nevertheless possible to considerably reduce the gravity of injury with modifications of the frontal parts of vehicles

Since 2005, a European directive (called “phase 1”) requires the car manufacturers to treat their new vehicles for the protection of the pedestrians in case of impact. This directive is planned to be reviewed in the future to include more severe requirements. The current expected schedule is 2010 and the update is called “phase 2” (see [1]).

Moreover, the consumerist organisation Euro NCAP assess the pedestrian protection offered by a new through component test configurations which are identical to those proposed at present time for the phase 2 of the directive. The level of pedestrian protection is then ranked by attributing the vehicle a given number of stars (four at most).

The aim of this paper is to present various technical solutions used by PSA Peugeot Citroën to improve the performance of its vehicles in terms of pedestrian protection.

TEST PROTOCOLS

The assessment of pedestrian protection offered by a vehicle is made through three different and independent component test procedures corresponding to different body segment:

- the first one is related to the assessment of the protection of the leg. The test is called “legform to bumper test”
- the second one is related to the upper leg. The test is called “upper legform to bonnet leading edge”
- the last one is related to the head, adult head impact and child head impact. The tests are called

“Adult and Child headforms to bonnet and windscreen test”

Four specific body form impactors are used in these tests. They are propelled against the front part of the vehicle (from the bumper up to the windscreen depending on the type of test) and they are equipped with several sensors in order to measure biomechanical criteria that are used to assess the risk of injuries (see Figure 1).

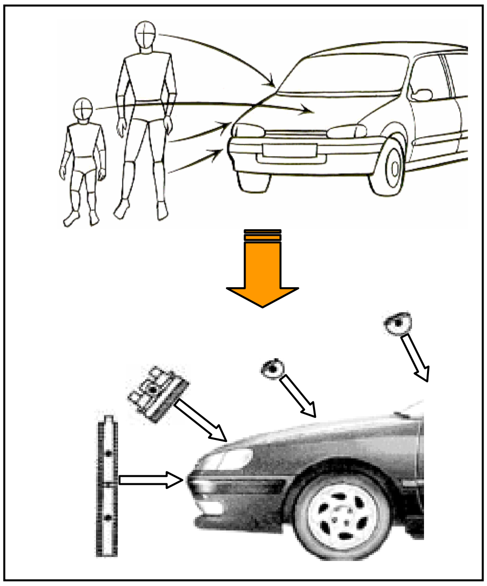


Figure 1. Pedestrian test made of 4 body form impactors propelled against the car front-end.

It is important to underline that accident data analyses show that upper leg injuries are almost non-existent during an impact of a pedestrian against a car. For this reason, the European Directive Phase 1 does not impose any limit on the biomechanical criteria for upper leg impact. It only requires the test to be carried out for monitoring purposes.

This paper presents some technical solutions developed by PSA Peugeot Citroën for the legform and the headform tests. Therefore, the current chapter is dedicated the presentation of these 2 impactors and the performance levels asked in Phase 1 and Euro NCAP requirements.
Then, in the next chapters, we will present the technical solutions (theory + actual solutions implemented in our cars) for each type of impact.

Leg to bumper tests: Legform impactor

The legform impactor represents the leg of an adult. It is made out of two stiff elements corresponding to the tibia and the femur, which are connected by a articulation representing the knee joint. The different parts are covered with foam representing muscular tissues of the leg (see Figure 2).

Figure 2. Legform pedestrian test.

The test procedure consists in propelling the legform against the bumper, in free motion at 40 km/h. Direction of impact should be in the horizontal plane and parallel to the longitudinal vertical plane of the vehicle.

Three biomechanical criteria are recorded:
- the tibia deceleration (measured by an accelerometer on the tibia - non impacted side),
- the knee bending angle (measured by a potentiometer - on the top of the tibia),
- the knee shear displacement (measured by a potentiometer - on the bottom of the femur).

The biomechanical thresholds required by regulation are different than those required by Euro NCAP as shown in Table 1.

Table 1.
Biomechanical thresholds for leg to bumper tests required by regulation and by Euro NCAP.

Protocols	**European Directive “Phase 1”**	**EuroNCAP** (high performance limits)
Tibia deceleration (g)	200	150
Knee bending angle (°)	21	15
Knee shear displacement (mm)	6	6

It is important to notice that the requirements imposed by Euro NCAP for its high performance level covers those of the European Directive Phase1. Indeed, the test protocol is identical and the biomechanical criteria in Euro NCAP are the most severe.

Adult and child headforms to bonnet and windscreen tests: Headform impactors

The different head impactors are all built in a identical way by an aluminium spherical part covered with a rubber skin (see Figure 3).

The test procedure consists in propelling the head impactor, in free motion, according to a specific angle. The mass and the size of impactors, as well as the speed and the angle vary according to protocols as shown in Table 2.

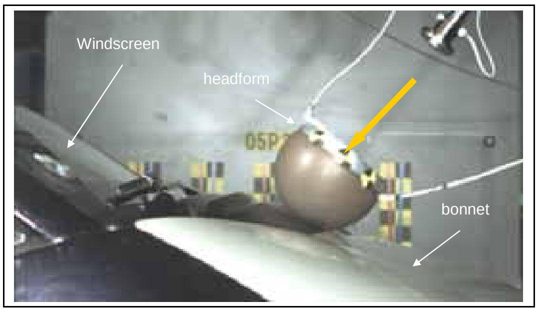


Figure 3. Headform pedestrian test.

Table 2.
Headforms characteristics as required by regulation and by Euro NCAP.

Protocols	**European Directive "Phase 1"**		**Euro NCAP**	
Type of headform	child	adult	child	adult
Mass (kg)	3,5	4,8	2,5	4,8
Radius (mm)	82,5	82,5	65	82,5
Speed (km/h)	35	35	40	40
Angle (°)	50	35	50	65

A single biomechanical criterion is measured to assess the level of protection: the HIC which is calculated from the head acceleration.

$$HIC = \max\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a\,dt\right]^{2.5}(t_2 - t_1) \qquad (1).$$

with: $(t_2 - t_1) \leq 15ms$

The biomechanical limits not to be exceeded during the headform tests vary with the protocols as shown in Table 3.

Table 3.
Biomechanical thresholds for head impact tests required by regulation and by Euro NCAP.

Protocols	**European Directive "Phase 1"**		**EuroNCAP** (high performance limits)	
Type of headform	child	adult	child	adult
Impact zone	B	W	B or W	B or W
HIC requirement	<1000 on 2/3 of the test area + <2000 on the area left	NA	< 1000	

B = bonnet W = windscreen

It is important to keep in mind that protocols are so different (in terms of mass, radius, and head impact speed), that the requirements fixed by the European Directive Phase 1 are not covered by the EuroNCAP ones and vice versa. Therefore, a vehicle fulfilling the Directive requirements is not sure to get a good score at the Euro NCAP rating, and conversely a vehicle with a good score in Euro NCAP pedestrian rating has no certainty fulfil the Phase 1 criteria.

SCENARIO FOR PROTECTING THE LEG

Protection of the leg requires the implementation of two absorbers behind the bumper:

- the first one located at the lower level of the tibia,
- the second one located at the level of the knee.

An example is shown in figure 4 which present the position of the two absorbers on the Citroën C4 Picasso.

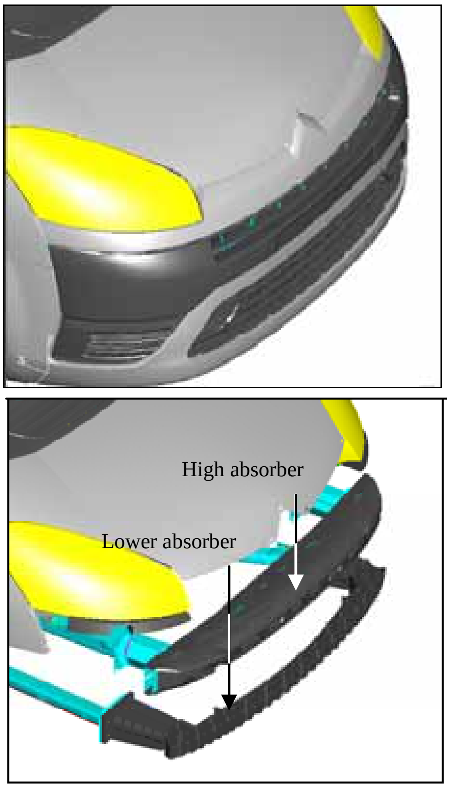


Figure 4. Citroën C4 Picasso – Position of the two absorbers designed to protect the leg of a pedestrian.

For this car model, impact energy is 825 J. A large part of this energy will be absorbed by the front face of the vehicle according to the following distribution:

- lower absorber: 20 %
- upper absorber: 40 %
- bumper: 40 %

Although dissipating a large part of the energy of the impact, the stiffness adaptation of the bumper for leg, is limited by its conception which is often limited by strong constraints of style and quality. Therefore, the tuning to match as much as possible the requirements is made on the lower and upper absorbers.

Description and role of the lower absorber

The lower absorber is made of a plastic or metal beam. Its role is to limit the bending of the knee during the impact thanks to its stiffness. He is hung either on the structure of the vehicle or directly moulded with the spoiler (see Figure 5 and Figure 6).

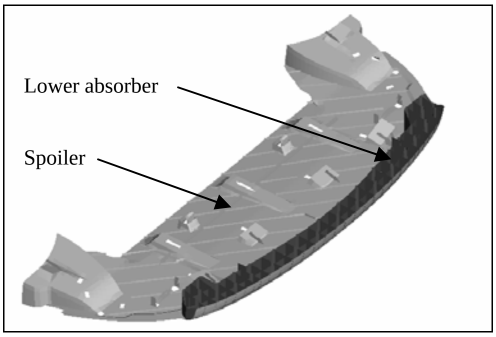


Figure 5. Lower absorber and its attachment on Citroën C4 Picasso.

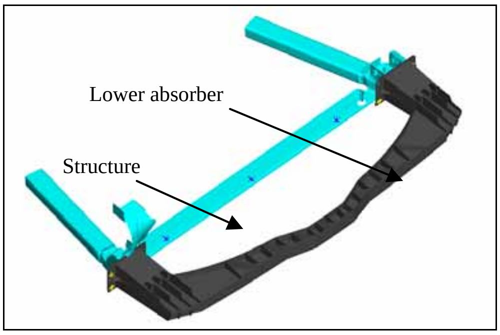


Figure 6. Lower absorber and its attachment on Citroën C4.

Note: Citroën C4 and Citroën C4 Picasso scored the full score (6 points out of 6) in the legform tests, in their Euro NCAP rating.

The upper absorber

The upper absorber is located on the level of the knee, and is hung on the rigid structure of the vehicle. It is constituted by a plastic skin whose stiffness is designed to be crushed gradually, thus to create a progressive deceleration for the leg during the impact.

Figure 7 presents the cross-section of the upper absorber on Citroën C4.

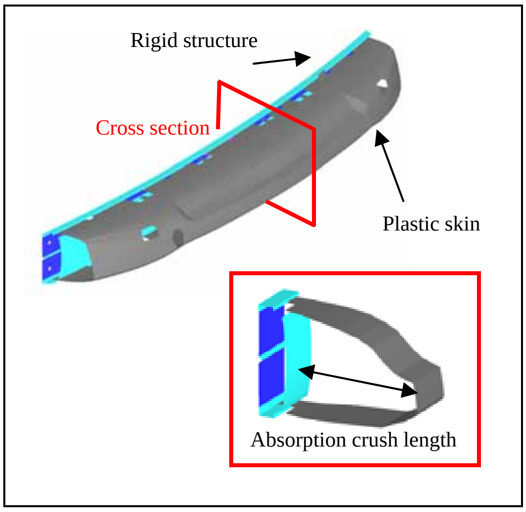


Figure 7. Cross section of the upper absorber on Citroën C4.

The kinematics of the impact

Figure 8 gives details of the Kinematics of impact on the Citroën C4.

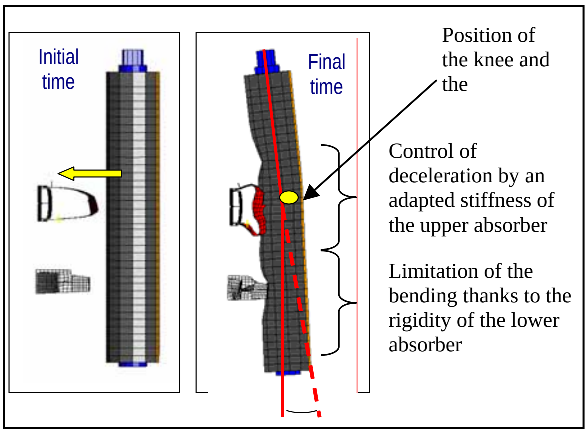


Figure 8. Kinematics of impact on Citroën C4 (cross section).

Figure 9 presents the deceleration curve measured on this impact.

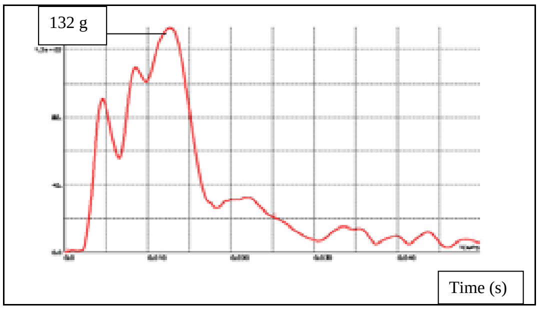


Figure 9. Deceleration curve on the legform for Citroën C4.

A too short length of absorption, and/or a too important flexibility of the upper absorber would cause a secondary peak of deceleration on the legform which could exceed the thresholds defined by the protocols. Furthermore, the addition of this upper absorber under the bumper increases the overhang of the vehicle and penalizes strongly the style. So the optimization of this length of absorption is of high importance.

Difficulties

During the impact of the legform on the front-end of the car, it is necessary that no rigid element interact and disturb the kinematics of impact. Otherwise, a too important peak of deceleration could be generated. According to the style of the vehicles, headlight can be sometimes found in the absorption length devoted to the leg. For this reason, sometimes, headlight should also be controlled for legform impactor test. This is the case for the Citroën C4 headlight, as shown in Figure 10.

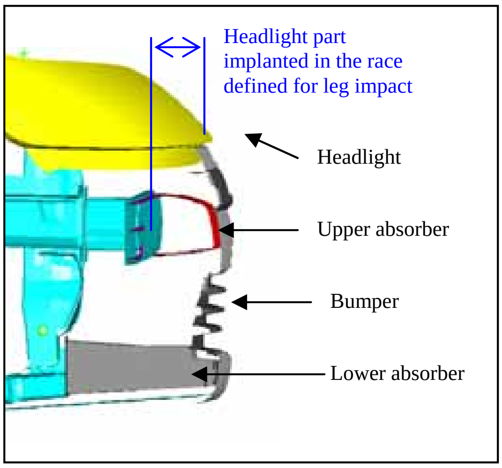


Figure 10. Positioning of headlight compared to the absorbers on the Citroën C4 (cross-section).

One of the solutions used, when the stiffness has to be controlled, is the use of replaceable fixing brackets (see Figure 11). These special brackets will allow the headlight to move backward during the impact with the legform. The breaking efforts are then tuned so that to be consistent with the crush vs stiffness laws specified for the absorbers.

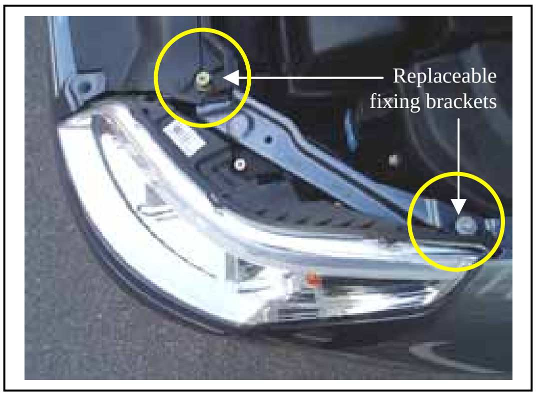
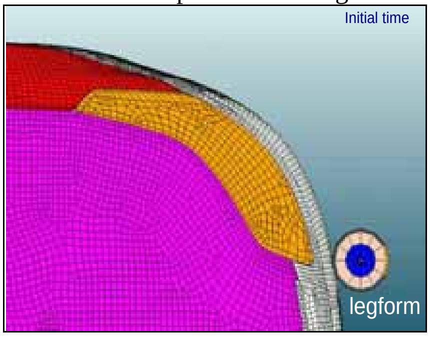
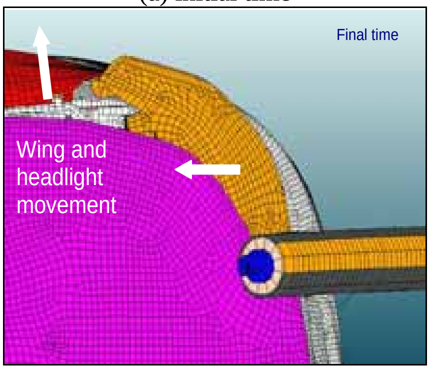


Figure 11. Replaceable fixing brackets of the Citroën C4 headlights.

Moreover, in order to give enough space for the headlights to move backward, it could also be needed to equip the wings with the same type of replaceable fixing brackets. This is also the case for the Citroën C4 as it is presented in Figure 12.



(a) initial time



(b) final time

Figure 12. Kinematics of headlight and wing on the Citroën C4 (Top view) - (a) initial time, (b) final time.

Note: this type of kinematics is also used as a technical solution for the “reparability” impact (damageability test performed at 16 km/h) during which the minimum of parts must be changed, to limit the cost of repairs.

SCENARIO FOR PROTECTING THE HEAD

The head protection is driven by two requirements. On the one hand it is necessary to preserve a space under the bonnet so that the impactors do not come into contact with rigid elements such as the engine. On the other hand, it is also vital to soften the constitutive elements of the bonnet in order to control the head deceleration in a progressive way during the impact.

Figure 13 present the kinematics of impact of the headform test on the Citroën C4 Picasso. And Figure 14 presents the deceleration curve measured on this headform impact on the Citroën C4 Picasso.

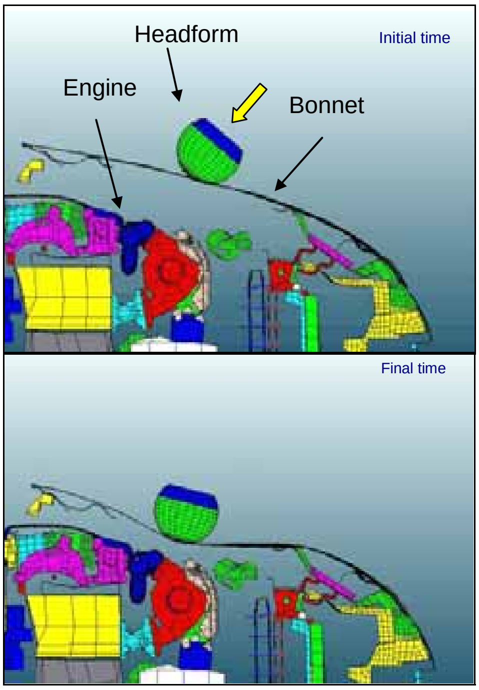


Figure 13. Kinematics of impact on the Citroën C4 Picasso (cross-section).

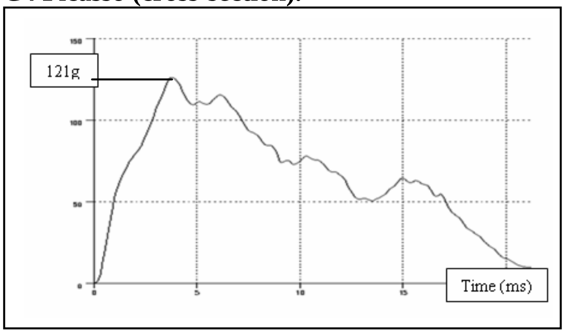


Figure 14. Deceleration curve measured on this headform impact on the Citroën C4 Picasso.

Therefore, all the elements likely to be impacted by the headform must have an adapted stiffness and usually may need to be softened (bonnet, scuttle, headlight…).

For this reason, the free space under the bonnet must be sufficient in order not to avoid a hard contact that will result in an important peak of deceleration that may increase the HIC value. This will have a consequence on the compaction of the engine.

Difficulties

Collapsible bonnet arrester

During the impact of the head on the bonnet, the bonnet arresters which ensure its correct positioning during the whole life of the vehicle, should not behave like hard points. One of the solutions is to use collapsible arresters which retract under a specific load.

The principle of function of a collapsible arrester is presented in Figure 15. The Citroën C4 Picasso example is shown in Figure 16.

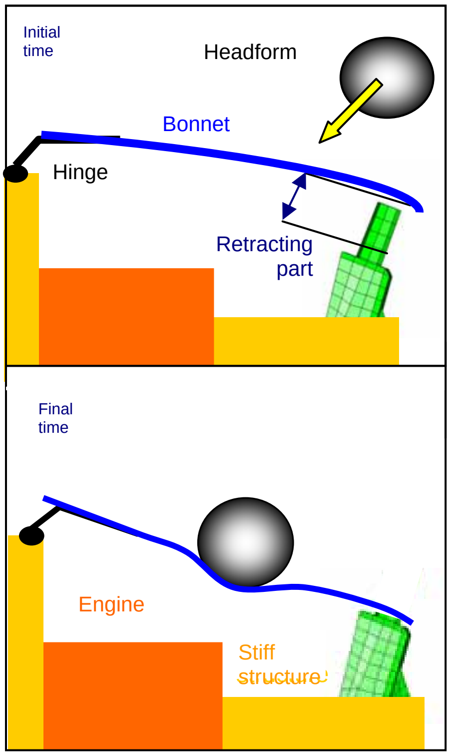


Figure 15. Principle of function of a collapsible arrester.

In its kinematics of impact, the head will first deform the bonnet. This one will then deflect and therefore press on the arresters which will be able to collapse. Therefore, the head will not be prevented to go downwards.

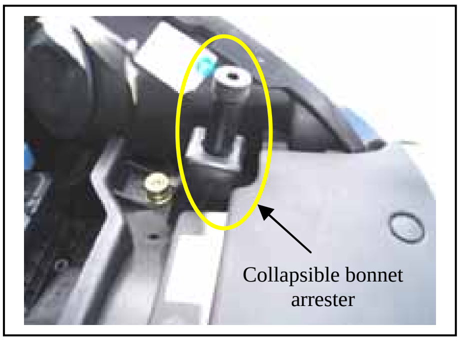


Figure 16. Bonnet arresters on the Citroën C4 Picasso

Active bonnet

When space under bonnet is insufficient, for instance with large engines, an active bonnet can be another solution to prevent the head from impacting hard points. This active bonnet will deploy as soon as an impact with a pedestrian is detected and then, the space under bonnet will be artificially increased.

The Citroën C6 is one of the first car model to be equipped with such a technology.

The sensors, located under the bumper, identify the type of obstacle according to stiffness and force parameters. When a pedestrian impact is detected, the springs positioned near the windscreen will lift the bonnet of 65 mm in less than 15 ms .So that the pedestrian's head is kept clear from the hard parts of the engine.

The principle of function of the C6 active bonnet is shown in Figures 17 and 18.

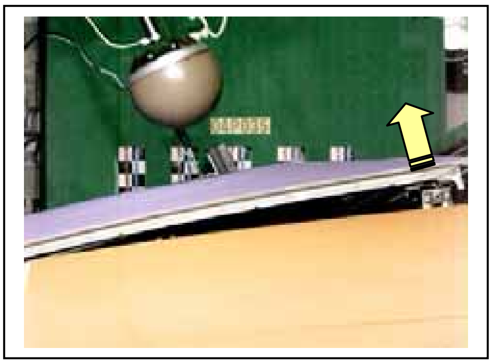


Figure 17. Example of the active bonnet of the Citroën C6.

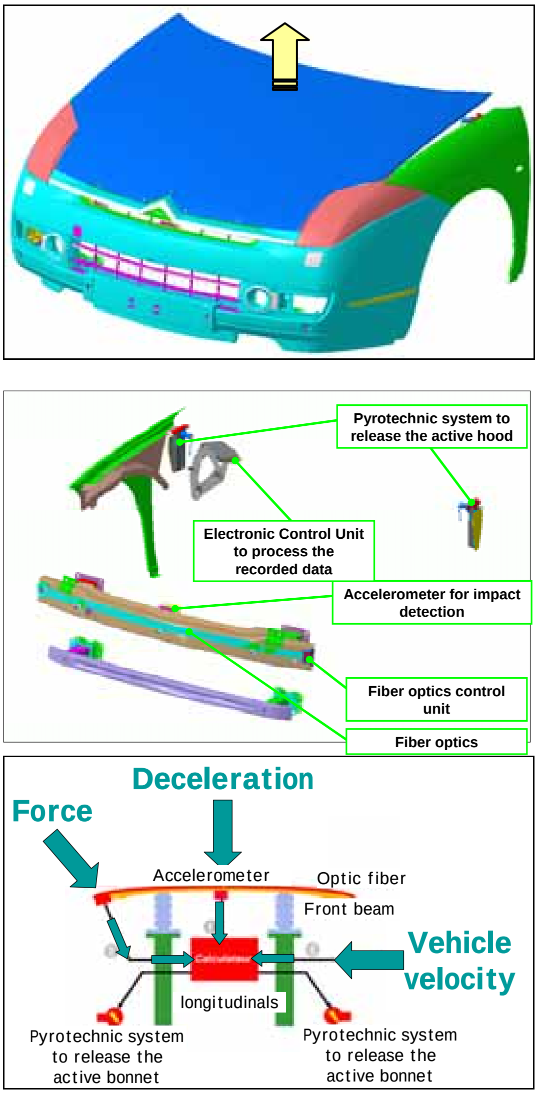


Figure 18. Principles of detection of a pedestrian impact for the Citroën C6 active bonnet.

Note: Citroën C6 and Citroën C4 Picasso respectively scored 9,64 and 8 points out of 12 on the child headform tests in their EuroNCAP rating.

METHOLOGY FOR DESIGNING THE FORNT-END COMPONENTS

During the development phases of a vehicle, in order to limit the tests on expensive full prototypes, the various parts of the front-end are firstly designed thanks to C.A.D (virtual testing). Then during the manufacturing of the first components, their stiffness is validated thanks to component tests. In these tests, the components are fixed on a rigid frame and crushed using a rigid guided impactor which represent the leg or the head impactor.

With this methodology, the crush vs stiffness laws of each component of the front-end are validated for the pedestrian protection even before the first test on a complete prototype.

Some component tests are presented in Figure 19 to 22.

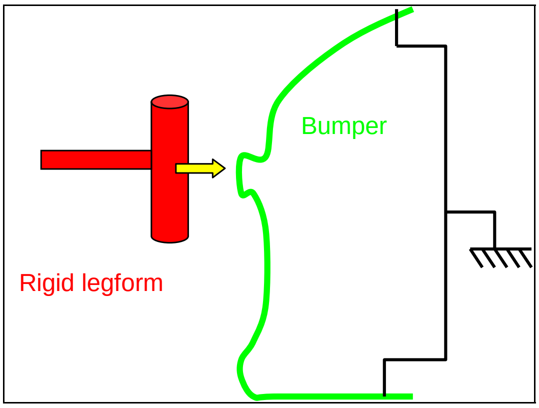


Figure 19. Principles of the component test carried out on the Peugeot 207 bumper

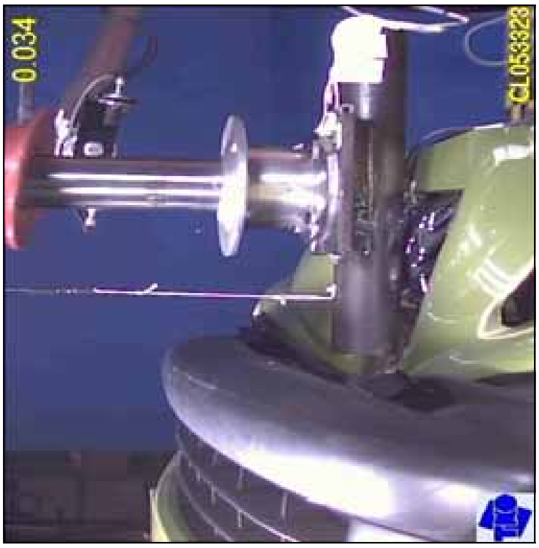


Figure 20. Example of a component test carried out on the Peugeot 207 bumper.

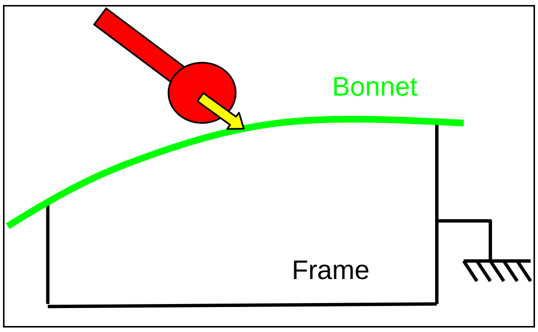


Figure 21. Principles of the component test carried out on the Peugeot 207 bonnet.

Figure 22. Example of a component test carried out on the Peugeot 207 bonnet.

DISCUSSION AND CONCLUSION

These solutions result from technical researches carried out by PSA Peugeot Citroën and convey the will of its Direction to improve the pedestrian protection and to anticipate the European Directives. They allowed PSA Peugeot Citroën to take place among the best car manufacturers in term of pedestrian protection.

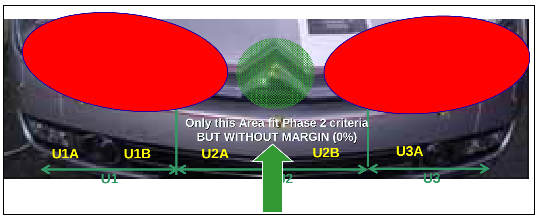
Nevertheless, the text of the European Directive foresees an increase in the required performance for 2010 for the new vehicle types. This is called “Phase 2” and its requirements come from the EEVC WG17 proposal of procedure, which is currently used by Euro NCAP.

Currently, only one vehicle achieved a 4 stars pedestrian protection rating: it is the Citroën C6. But, it is important to highlight that despite this excellent score, Citroën C6 could not fulfil all the requirements defined in the EEVC WG17 proposal. Indeed, some points in the head and upper leg zones still exceed the EEVC WG17 threshold limits. This clearly shows that even with an improved and innovative technical solution, the EEVC WG17 requirements are too stringent.

Figure 23 and Figure 24 present the Citroën C6 overall results on the bonnet and on the bonnet leading edge.

Red Areas could not be “approved” regarding the EEVC WG17 requirements (HIC level too high)

Figure 23. HIC results on the Citroën C6 headform tests with respect to the EEVC WG17 / Phase 2 requirements.



Red Areas could not be "approved" regarding the EEVC WG17 requirements

Figure 24. Upper leg results on the Citroën C6 with respect to the EEVC WG17 / Phase 2 requirements.

Moreover, these technical constraints for the pedestrian protection are most of the time in contradiction with other important car requirements such as: visibility for the driver or mass reduction

Actually, pedestrian protection requirements tend to increase the bonnet height which is in contradiction with visibility requirements for the driver.

Furthermore, pedestrian protection requirements tend to increase the mass of the vehicle by adding extra components such as the upper and lower absorbers. These requirements also tend to decrease the overall volume of the engine in order to prevent the head to impact the stiff parts of the car front-end. This is in total contradiction with the Euro 5 standard requirements that force the engine to be wider and larger because of added components for antipollution control.

So to improve even more pedestrian safety, it would be necessary to investigate solutions linked to road infrastructures or linked to primary safety. For example, one proposal is to encourage the car manufacturer to equip their vehicles with a brake assist system.

REFERENCES

[1] EEVC WG17 Report – improved test methods to evaluate pedestrian protection afforded by passenger cars.