# IMPROVEMENT OF CAR-TO-TRUCK COMPATIBILITY IN HEAD-ON COLLISIONS

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Paper Number 98-S4-O-12

## ABSTRACT

This paper presents the analysis of experimental crash program between small or large car and truck in order to characterize the effect of a Front Underrun Protection Device (FUPD) coupled with closing speed and overlap on mechanical and biomechanical characteristics. This device has been developped in order to improve the geometrical compatibility between cars and trucks in head-on collisions.

## INTRODUCTION

Accidents between cars and trucks are among the most fatal accidents because of the car underrunning. This phenomenon leads to serious and fatal injuries for car occupants because of intrusion of the car structure into the passenger compartment. The ECE/UN Regulation n°93 which consists of a rigid beam in front of the truck has been created in order to avoid the car underrunning.

This regulation has been created thanks to researches on the development of test procedure for energy-absorbing front underrun protection systems for trucks made by an EEVC Working Group (WG14). In the EEVC WG14 report of March 1995, there is a summary of accident analysis of several European countries, where we can read that of the 48000 fatally injured people in road traffic accidents in 1992, 13000 people were killed in accident with trucks involved, about 7000 were car occupants and 4200 of them were killed in car-to-truck frontal collisions.

In the same time, in 1994, a collaboration in France between Renault VI (truck manufacturer) and INRETS has begun. The research program set up is based on a experimental design to determine the effect of the vehicle masses, the overlap and the closing speed and the effect of the FUPD on mechanical and biomechanical characteristics. This experimental design is presented in the next part of the paper and the global and in-depth analyses are presented after.

## PRESENTATION OF THE EXPERIMENTAL DESIGN

The experimental design consists of a serie of 22 crash tests between small or large car and truck. The mass of the small car is about 1000 kg and the mass of the large car is about 1500 kg. There is no passive safety device such as pretensioner or airbag in all the cars we have used apart from the 3-pts retractor belt.

At the beginning of the program we have used two masses for the truck : 7.5 and 18 tons. But we have seen that there is little effect of the truck mass, so we have changed the 18 tons into 16 tons for technical reasons. For all the tests, the truck is stationary with transmission placed in neutral position and parking break disengaged.

We have also realized tests with one of the three following impact velocities for the car : 40, 56 and 65 kph and two overlaps : 1/3 and 2/3 of the car width. In most of the crash tests we have used two instrumented 50% Hybrid III dummies positionned on the front seats of the car.

Figure 1 presents one of the configurations we have tested : a crash between a small car and a truck fitted with the FUPD. The overlap was 2/3 and the impact velocity was 56 kph.

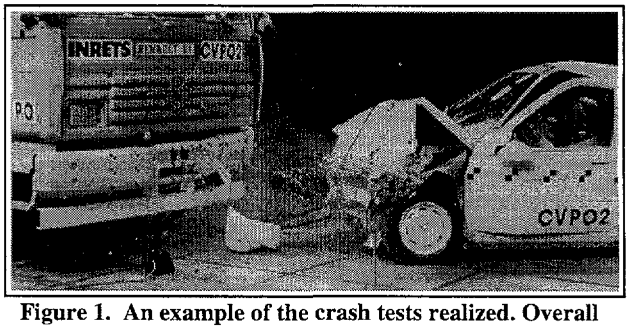

**Figure 1. An example of the crash tests realized. Overall front view after impact (small car, truck with FUPD, 56 kph of impact velocity and 2/3 overlap).**

Table 1 presents the characteristics of the 22 crash tests.

**Table 1.**
**Characteristics Of The 22 Crash Tests Planed and/or Performed According to The Experimental Design**

| car type | FUPD | velocity of impact car (kph) | overlap | weight of truck (t) | Date of test |
|---|---|---|---|---|---|
| small | with | 56 | 2/3 | 7.5 | nov-94 |
| small | with | 40 | 1/3 | 7.5 | dec-94 |
| small | without | 65 | 1/3 | 7.5 | may-95 |
| large | with | 40 | 1/3 | 7.5 | jun-95 |
| large | without | 40 | 2/3 | 7.5 | jul-95 |
| large | without | 40 | 1/3 | 18 | dec-95 |
| small | without | 40 | 2/3 | 7.5 | feb-96 |
| large | without | 75 | 2/3 | 7.5 | mar-96 |
| small | with | 65 | 2/3 | 7.5 | apr-96 |
| small | without | 56 | 1/3 | 7.5 | may-96 |
| large | without | 56 | 2/3 | 7.5 | sep-96 |
| large | without | 65 | 1/3 | 7.5 | nov-96 |
| small | without | 56 | 2/3 | 18 | dec-96 |
| small | with | 65 | 1/3 | 16 | feb-98 |
| small | with | 40 | 2/3 | 16 | apr-98 |
| large | with | 75 | 2/3 | 16 | |
| small | with | 75 | 2/3 | 7.5 | |
| large | with | 56 | 1/3 | 16 | |
| large | without | 65 | 2/3 | 16 | |
| large | with | 75 | 1/3 | 7.5 | |
| large | with | 65 | 2/3 | 7.5 | |
| small | without | 75 | 1/3 | 16 | |

The data measured during these crash tests are standard data : accelerations and displacements for the car and the truck structures and accelerations and forces for the two Hybrid III dummies. In order to characterize and analyse the effect of a Front Underrun Protection Device (FUPD) in relation with the effect of closing speed and overlap, we have selected for comparison some of these mechanical and biomechanical data. The mechanical data choosen are the acceleration of the left B-pillar, the lower left external windshield corner displacement, the vertical and longitudinal steering-wheel displacement. The biomechanical data choosen are the driver HIC, the maximum 3 msec chest acceleration, the maximum femur and tibia driver compressive forces. All these data are relative to the impacting car.

The FUPD used for some of the test is a rigid one and it has been developped in order to improve the geometrical compatibility between cars and trucks in head-on collisions.

At the end of this research program we will be able to determine the characteristics of a deformable FUPD in order to distribute the energy absorption of the crash between the car and the truck structures.

As we can see in Table 1, 15 crash tests have been already realized. So we are not able to analyse entirely the effect of all the characteristics we have choosen. But we can assess some tendancies if we analyse in a global way the 15 crash test performed and if we analyse more closely the tests pair by pair as we will do later in this paper.

## GLOBAL ANALYSIS

In this part, we are going to analyse the results of 13 of the 15 crash tests already performed in a global manner. That is to say that we will just classify the tests regarding the presence of the FUPD or not.

We have classified the 13 tests firstly by the presence of the FUPD or not, and secondly by the increasing magnitude of the acceleration of the left B-pillar. We can see that when there is a FUPD, the acceleration of the left B-pillar is directly related to impact velocity at the first order and then, for the same impact velocity, to the overlap (see figure 2). This is not the case for the crash tests without FUPD (see figure 3).

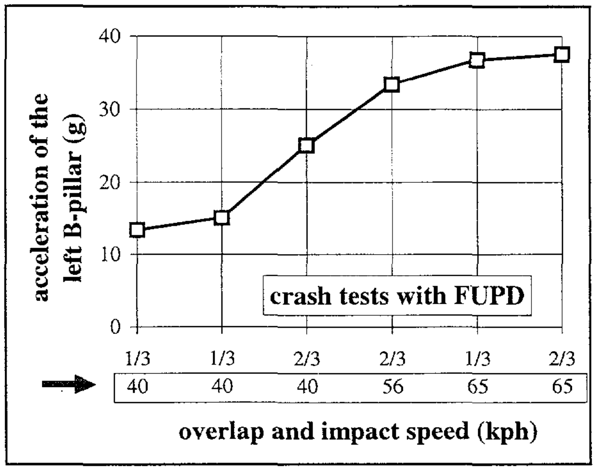

**Figure 2. Influence of the impact velocity and of the overlap on the acceleration of the left B-pillar for crash tests with FUPD ***

* there is no distinction between small and large cars

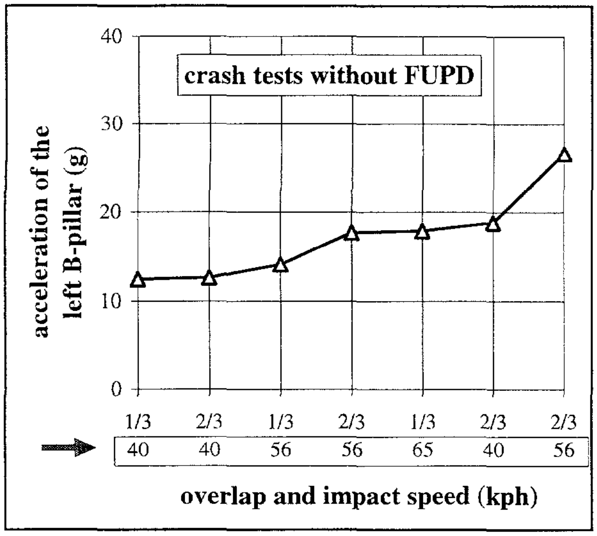

**Figure 3. Influence of the impact velocity and of the overlap on the acceleration of the left B-pillar for crash tests without FUPD ***

We also have classified the 13 tests firstly by the presence of the FUPD or not, and secondly by the increasing magnitude of the driver HIC (see figure 4). We can see that when there is a FUPD, the maximum 3 msec chest acceleration is increasing with the driver HIC (see figure 5). This is not the case for the crash tests without FUPD (see figure 6).

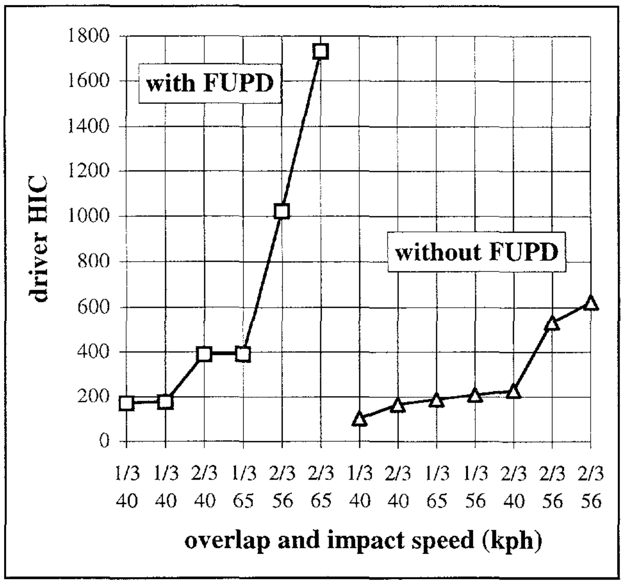

**Figure 4. Classification of the crash tests with and without FUPD by increasing driver HIC ***

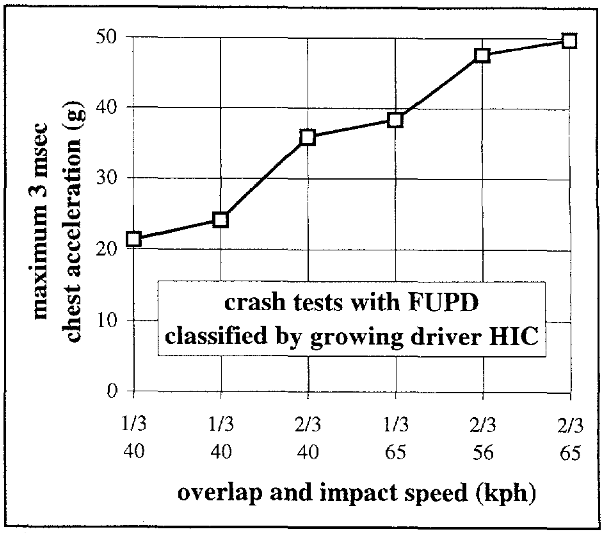

**Figure 5. Evolution of the maximum 3 msec chest acceleration for the crash tests with FUPD classified by increasing driver HIC ***

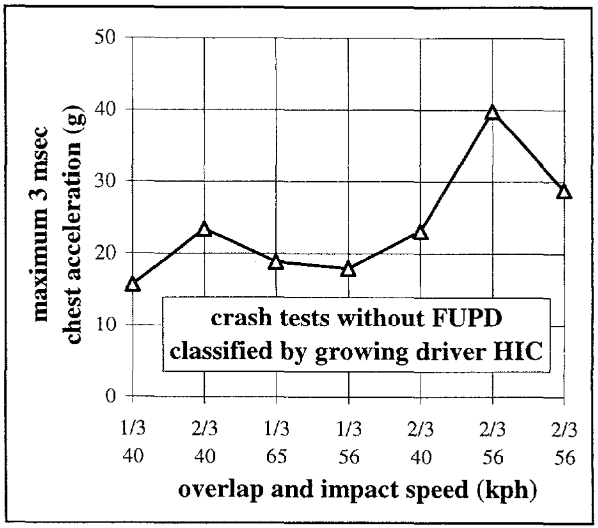

**Figure 6. Evolution of the maximum 3 msec chest acceleration for the crash tests without FUPD classified by increasing driver HIC ***

During the tests the thoracic deflexion was measured ; however this parameter seems to be independant from the test conditions, and then we have decided not to use it in the comparative analyses.

We can also notice that even if the driver HIC is greater than the criterion limit (HIC limit = 1000) for two tests with FUPD, all the 13 values of the maximum 3 msec chest acceleration are under the limit (max. 3 msec chest acceleration limit = 60 g).

In order to study the influence of overlap, FUPD and impact velocity on the mechanical and biomechanical characteristics choosen, we have grouped some of the 13 tests by pairs. For every pair, the two tests have the same characteristics except for one of the parameters mentionned before. As the analysis has shown a very small influence of the truck mass on test results, we have not taken into account the mass of the truck to group the tests by pairs.

## IN-DEPTH ANALYSIS

The two first pairs we are going to study are tests with small car and 2/3 of overlap. The impact velocity is 40 and 56 kph and for each pair there is one test with FUPD and the other without FUPD.

After this analysis, we will study two other pairs : with small cars, with FUPD and with two impact velocity (40 and 65 kph). For each pair there will be one test with an overlap of 1/3 and the other with a 2/3 overlap.

### Influence of the Front Underrun Protection Device

As we have mentionned before, all the results we will analyse in this part are relative to crash tests with the small car and 2/3 overlap. In figures 7 to 10, we present the results of the characteristics relative to the car structure (acceleration of the left B-pillar, lower left external windshield corner displacement, vertical and longitudinal steering-wheel displacement).

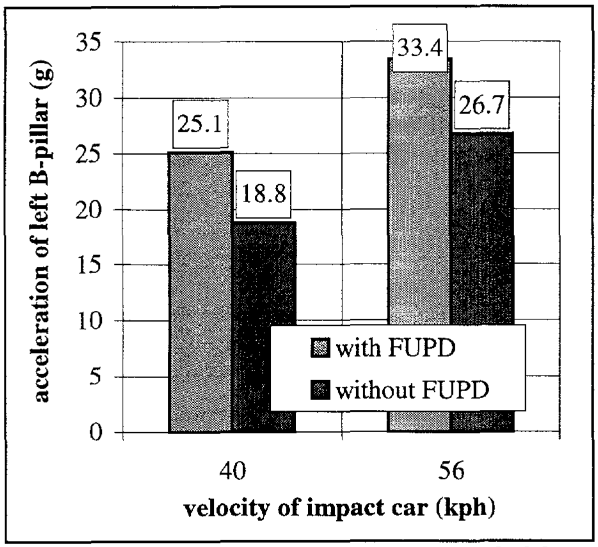

**Figure 7. Influence of the presence of FUPD and of the impact velocity on the acceleration of the left B-pillar**

We can see in figure 7 that the acceleration of the left B-pillar is greater when there is a FUPD whereas this is the contrary for the lower left external windshield corner displacement (see figure 8).

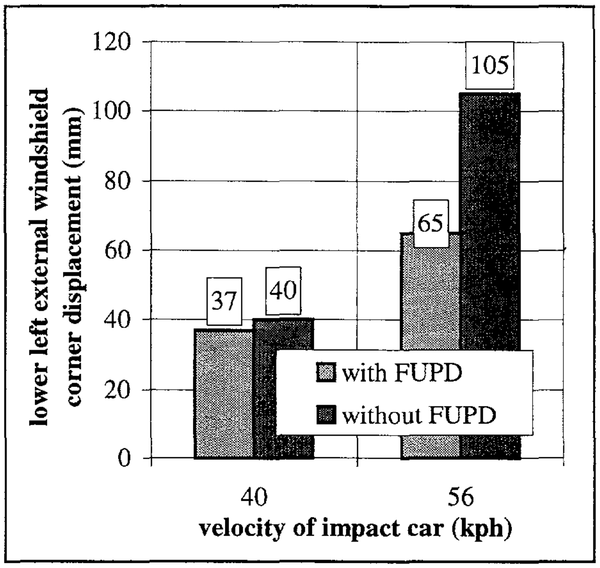

**Figure 8. Influence of the presence of FUPD and of the impact velocity on the lower left external windshield corner displacement**

We can also see that the evolution for the vertical steering-wheel displacement is the complete opposite of the evolution of the longitudinal steering-wheel displacement (see figures 9 and 10).

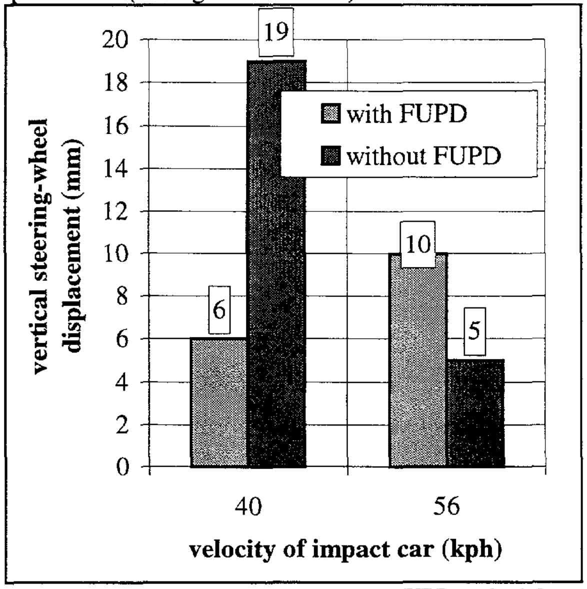

**Figure 9. Influence of the presence of FUPD and of the impact velocity on the vertical steering-wheel displacement**

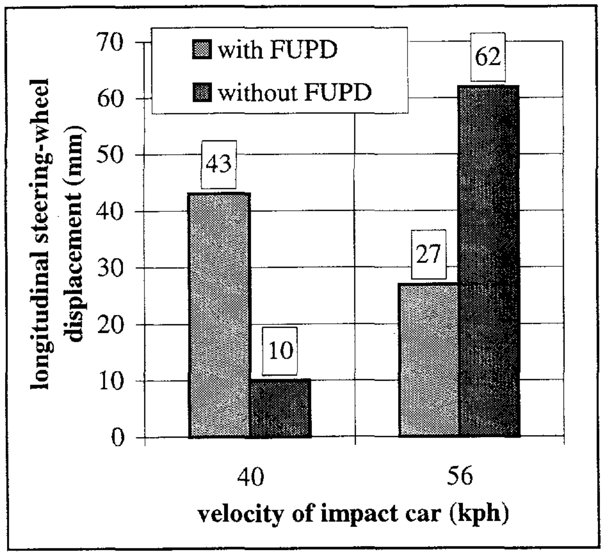

**Figure 10. Influence of the presence of FUPD and of the impact velocity on the longitudinal steering-wheel displacement**

In figures 11 to 16, we present the biomechanical results (driver HIC, maximum 3 msec chest acceleration, maximum force for femurs and tibias).

We can see in figure 11 that for one configuration (with FUPD at 56 kph) the driver HIC exceeded the limit HIC (1000). But we have to recall that there wasn't any passive safety device in the impacting car. The most important to say is, as we have noticed for the acceleration of the left B-pillar, the driver HIC is greater when there is a FUPD. We will comment it later.

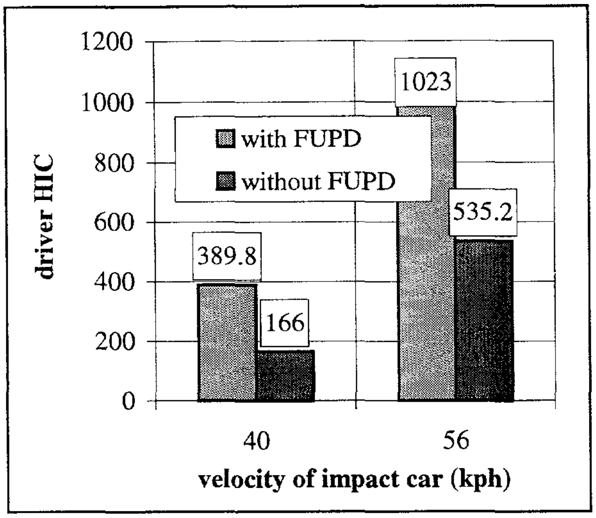

**Figure 11. Influence of the presence of FUPD and of the impact velocity on the driver HIC**

The same observation can be made for the driver HIC and the maximum 3 msec chest acceleration in agreement with the observation we have made in the global analysis part.

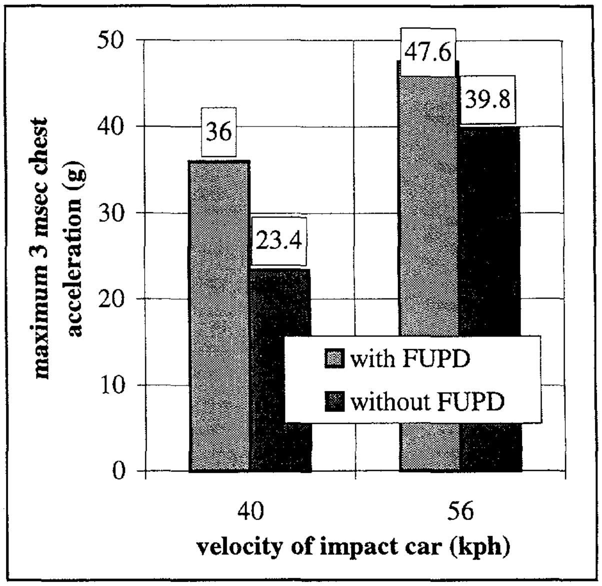

**Figure 12. Influence of the presence of FUPD and of the impact velocity on the maximum 3 msec chest acceleration**

The measure we have choosen for femurs is the maximum compressive force during 10 msec in order to have results to compare with the plateau limit (7560 N). In one case for the femur measures and in one test for the tibia measures we don't have any value. It is represented in the figure by the "?" symbol (see figures 13 to 16).

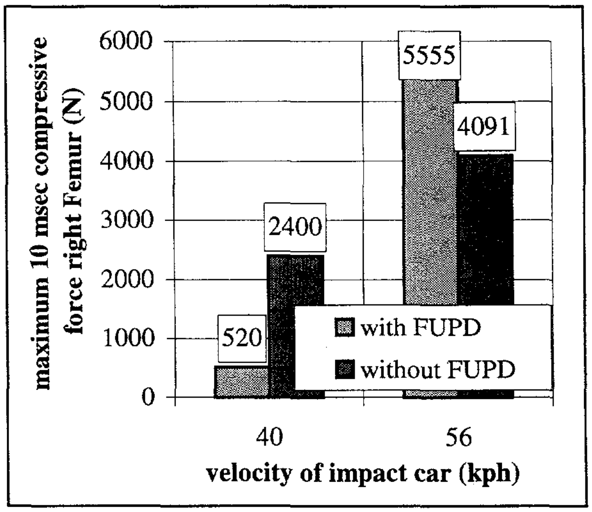

**Figure 13. Influence of the presence of FUPD and of the impact velocity on the maximum 10 msec compressive force right femur**

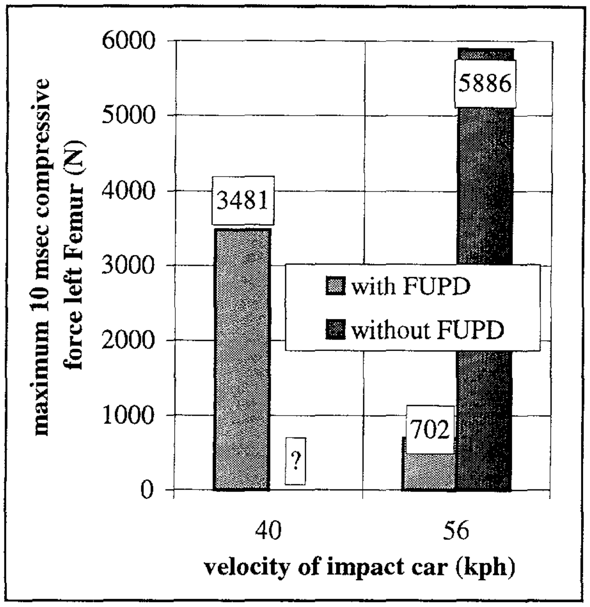

**Figure 14. Influence of the presence of FUPD and of the impact velocity on the maximum 10 msec compressive force left femur**

We recall that the limit for the maximum compressive force for tibias is 8 kN.

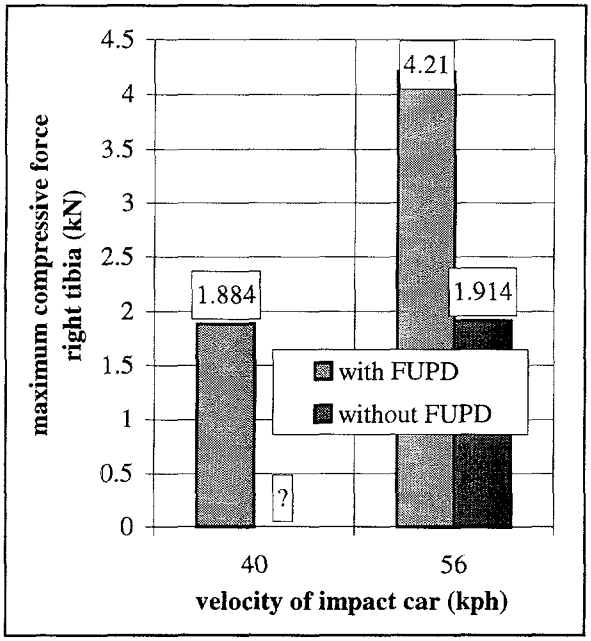

**Figure 15. Influence of the presence of FUPD and of the impact velocity on the maximum compressive force right tibia**

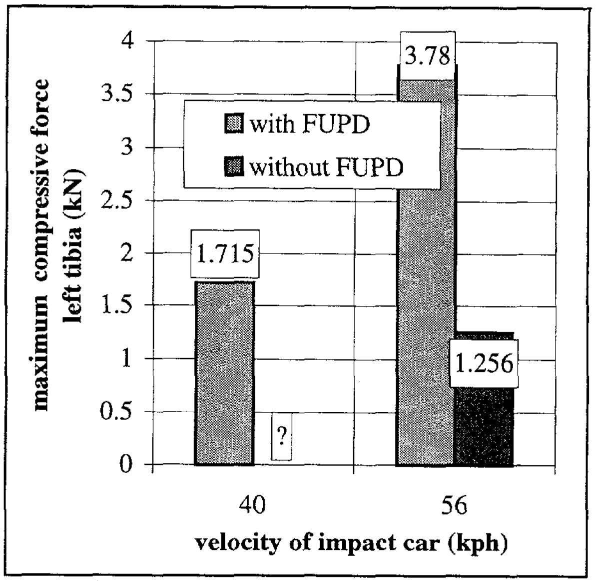

**Figure 16. Influence of the presence of FUPD and of the impact velocity on the maximum compressive force left tibia**

We can see in figure 13 to 16 that the limits for femurs and tibias are far to be reached.

**Influence of the overlap**

As we have mentionned before, all the results we will analyse in this part are relative to crash tests between small car and truck with FUPD. The presentation of the results is the same as for the study of the influence of FUPD.

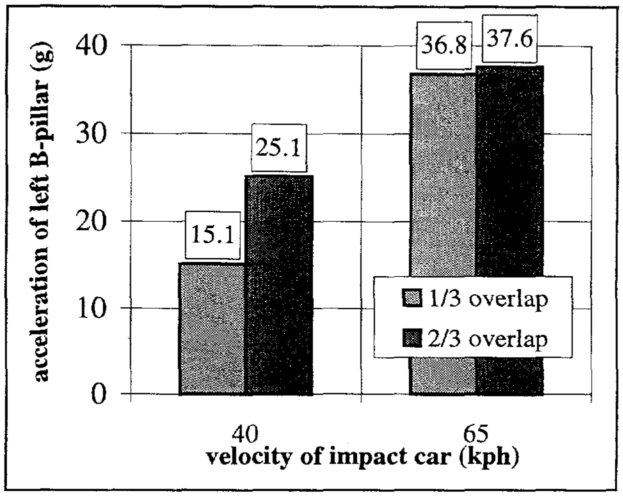

**Figure 17. Influence of the overlap and of the impact velocity on the acceleration of the left B-pillar**

We can see that the acceleration of the left B-pillar at 65 kph for 1/3 overlap is really close to the acceleration for 2/3 overlap. On the contrary, for the lower left external windshield corner displacement the two values are really different (the magnitude for 1/3 overlap is about twice the magnitude for 2/3 overlap).

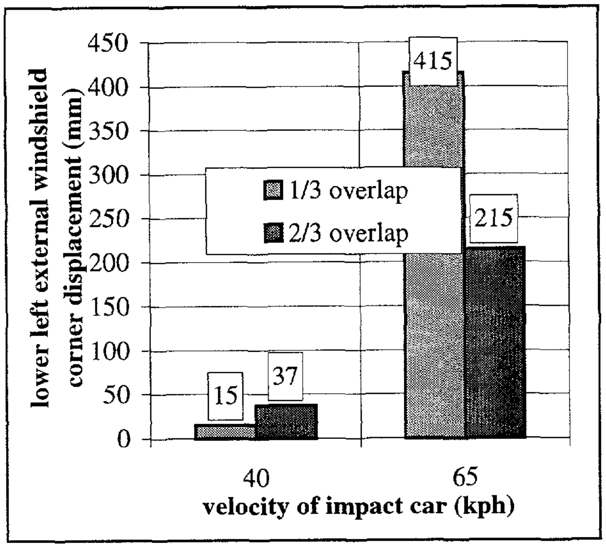

**Figure 18. Influence of the overlap and of the impact velocity on the lower left external windshield corner displacement**

Once again, we can see in figures 19 and 20 that the evolution for the vertical steering-wheel displacement is the complete opposite of the evolution of the longitudinal steering-wheel displacement.

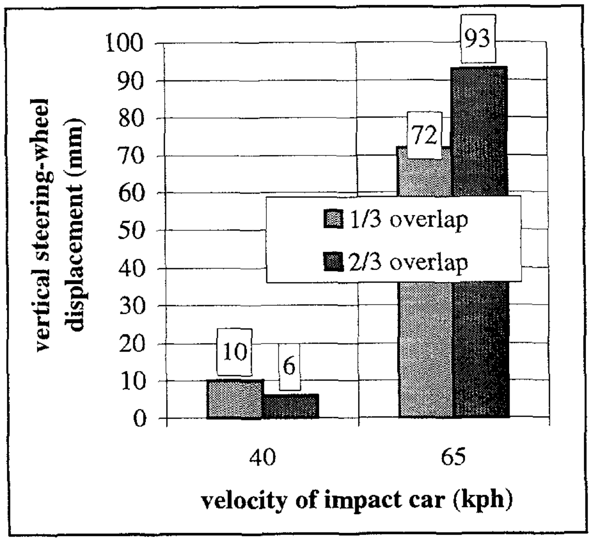

**Figure 19. Influence of the overlap and of the impact velocity on the vertical steering-wheel displacement**

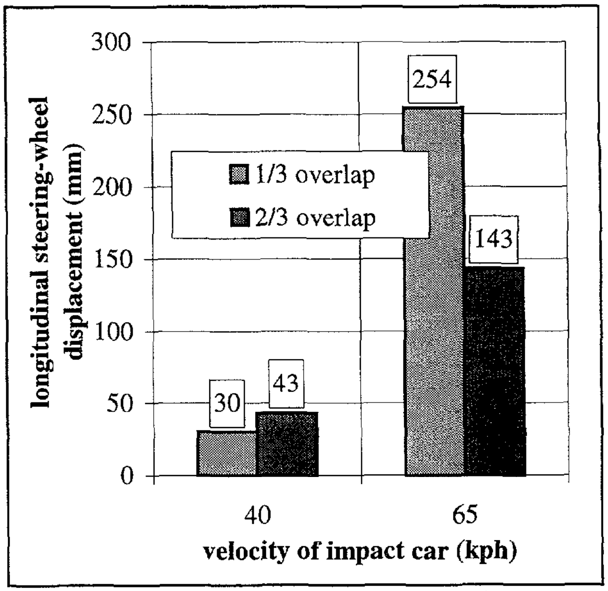

**Figure 20. Influence of the overlap and of the impact velocity on the longitudinal steering-wheel displacement**

As we can see in figure 21, the driver HIC is greater than the limit for 2/3 overlap at 65 kph.

But, in opposition to the first study (the influence of FUPD) the evolution of the driver HIC is not the same as the evolution of the acceleration of the left B-pillar and of the maximum 3 msec chest acceleration (see figure 17 and 22). These two characteristics have the same evolution in this case also.

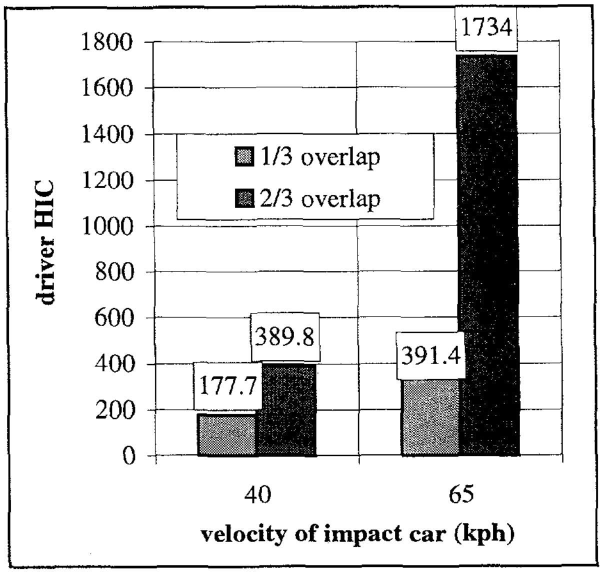

**Figure 21. Influence of the overlap and of the impact velocity on the driver HIC**

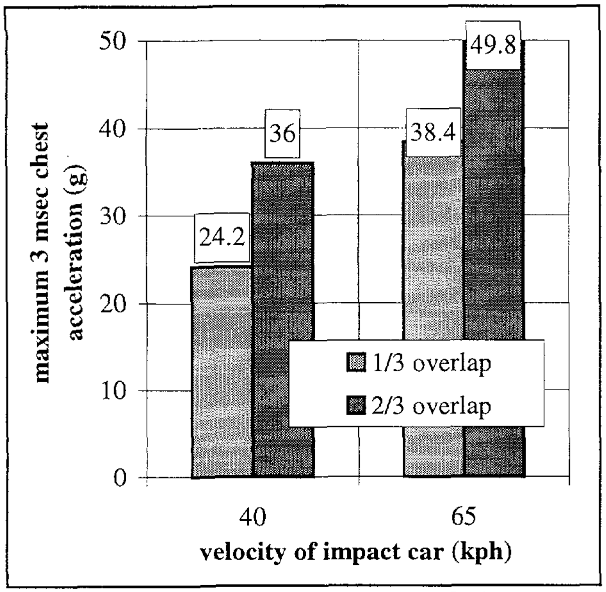

**Figure 22. Influence of the overlap and of the impact velocity on the maximum 3 msec chest acceleration**

On figures 23 to 26, we can see the evolution of the characteristics relative to femurs and tibias. In this study too, these values are far from the biomechanical limits.

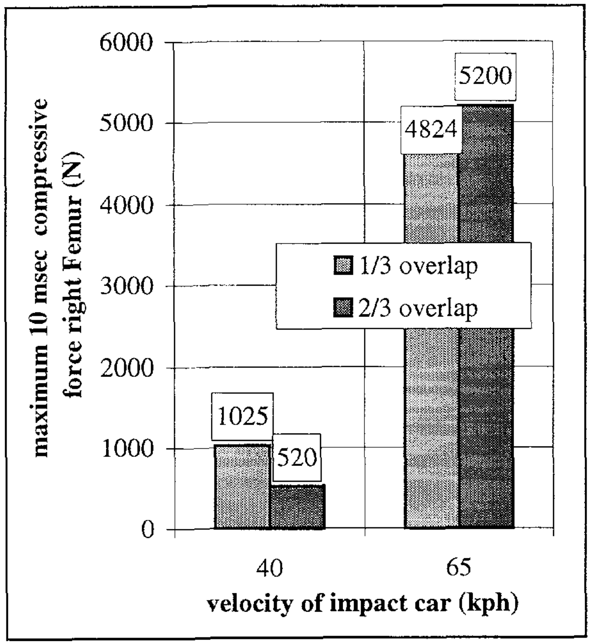

**Figure 23. Influence of the overlap and of the impact velocity on the maximum 10 msec compressive force right femur**

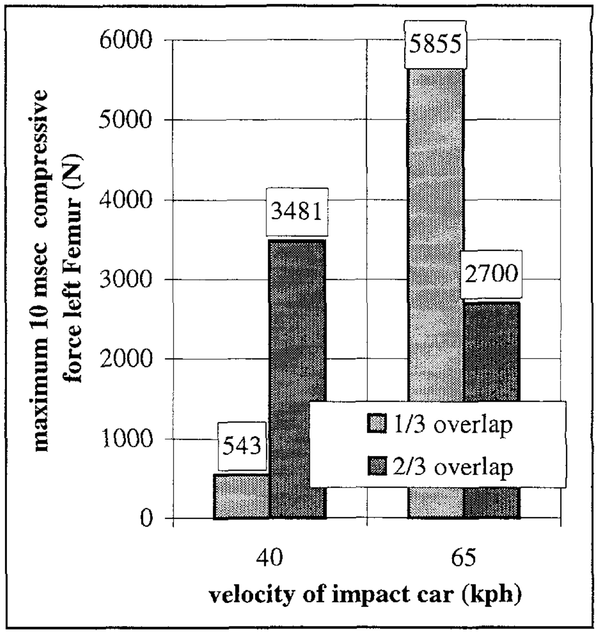

**Figure 24. Influence of the overlap and of the impact velocity on the maximum 10 msec compressive force left femur**

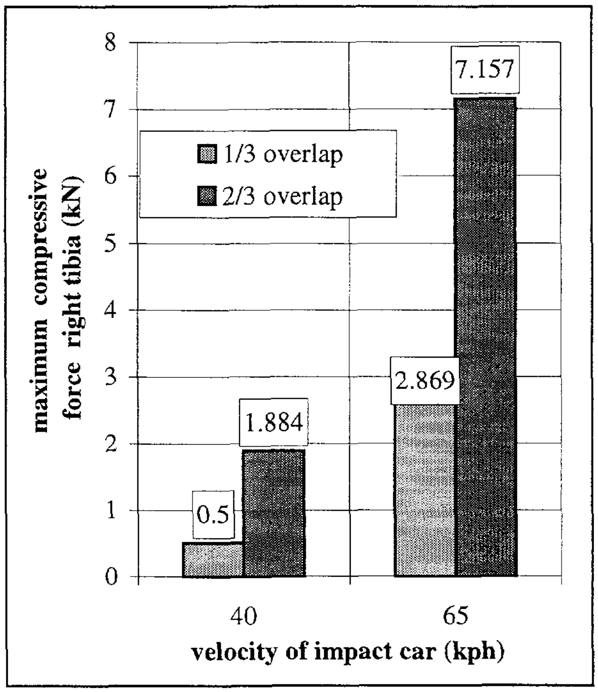

**Figure 25. Influence of the overlap and of the impact velocity on the maximum compressive force right tibia**

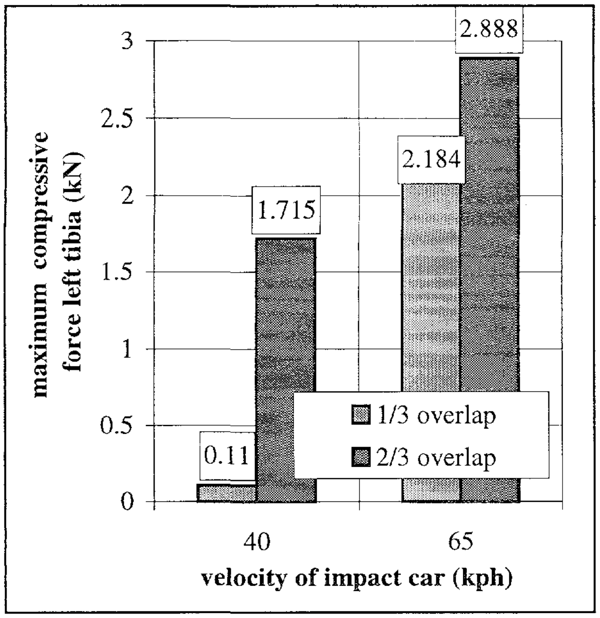

**Figure 26. Influence of the overlap and of the impact velocity on the maximum compressive force left tibia**

## DISCUSSION AND CONCLUSION

The analysis of the results of 13 car to truck frontal impact tests allows to evaluate the influence of the front underrun protection device (FUPD) for different speeds and offset values.

Most of the characteristics we have studied are increasing with impact velocity for any configuration (presence or not of FUPD, 1/3 and 2/3 overlap), except for 4 cases. These cases show that impact velocity is not the only parameter that have to be taken into account in order to study the FUPD.

The FUPD controls the deformation of car limiting the intrusion ; but this increases the deceleration of the car and then provides higher biomechanical criteria values, compared to cases without FUPD. Nevertheless, these values are below or very close to protection criteria limits ; this means that for closing speed up to 65 kph it is possible to assess the protection in car-to-truck frontal collision when the geometrical compatibility.is guaranted by the FUPD

The influence of the intrusion on injury risk would probably appear more clearly at higher speeds.

After completion of the program, it will be possible to recommend some relevant characteristics for an energy-absorbing front underrun protection device.

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## ACKNOWLEDGEMENTS

This research started under the responsability of Jean Bloch who left INRETS in January 1998.
The authors want to thank him as well as the whole technical team of the LBSU laboratory.