EVALUATION OF OCCUPANT PROTECTION DURING THE CRASH PHASE CONSIDERING PRE-CRASH SAFETY SYSTEMS – RESULTS FROM THE EC-FUNDED PROJECT ASSESS

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ABSTRACT

Research Question/Objective
Since integrated safety systems combine active and passive safety elements in one safety system, it is necessary to define new procedures to evaluate vehicle safety from the overall system point of view. The main goal of the ASSESS project is to develop harmonized and standardized assessment procedures for collision mitigation and avoidance systems.

Methods and Data Sources
In ASSESS, procedures are developed for: driver behaviour evaluation, pre-crash system performance evaluation, crash performance evaluation, socio-economic assessment.

This paper will concentrate on the activities related to the crash evaluation. The objective is to perform simulations, sled tests and crash tests in order to understand the influence of the activation of the pre-crash systems on the occupants' injuries during the crash phase. When a traffic accident is unavoidable, pre-crash systems work on various safety devices in order to improve the vehicle occupants' protection. Braking assistance and adaptive restraint systems are the main pre-crash systems whose effect on the occupants' protection will be described in this paper.

Results
The results will be a description of the effect of the activation of the pre-crash systems on the crash phase. Additionally, a set of recommendations for future methodology developments will be delivered.
Furthermore, a first approach to the study of the effect of the pre-crash systems activation on the occupants' protection when the impact is unavoidable will be presented. This effect will be quantified using the biomechanical values obtained from the simulation and testing activities and their related injury risks. Simulation and testing activities will consider the following scenarios:

- No activation of any pre-crash system
- Activation of one or a combination of several pre-crash systems

In this way, differences in the results obtained from different scenarios will show the effect of each pre-crash system separately during the crash phase.

Discussion and Limitations
The set of activities developed in this research project is limited by the fact that with the given resources only a limited number of vehicle models could be investigated. In addition, there are also limitations related to the injury risk curves and the passive safety tools currently on the market.

Conclusion and Relevance to session submitted
The paper will present a complete analysis of the effect of pre-crash systems during the crash phase when the impact is unavoidable. Details, limitations and first application experience based on a few examples will be discussed.

Currently, there is not any regulation, assessment program, or other similar official procedure able to assess pre-crash systems during the crash phase. This project comprises phases of traffic accidents which have been historically analysed separately, and aims to evaluate them taking into account their interrelationship. ASSESS is one of the first European projects which deals in depth with the concept of integrated safety, defining methodologies to analyse vehicle safety from a global point of view.

INTRODUCTION

Background

The overall purpose of the ASSESS project is to develop a relevant and standardized set of test and assessment methods and associated tools for integrated vehicle safety systems with the focus on currently on-the-market pre-crash sensing systems. In order to achieve this objective, methodologies and procedures have been developed for driver behaviour evaluation (WP3) and pre-crash system performance evaluation (WP4). WP5 was in charge of defining a methodology in order to assess pre-crash safety systems activation during the crash phase.

Injury risk curves were going to be the base of the methodology to evaluate the pre-crash systems activation during the crash phase. The idea was to draw injury risk curves relating the impact speed to the probability of injuries for the vehicle occupants. Specifically, it was planned to use two injury risk curves per biomechanical value: one considering the activation of improved restraint systems and the other one without considering it. The performance of simulation activities, sled tests and crash tests was going to be used in order to draw those curves. Figure 1 shows an example of the curves to be used in WP5.

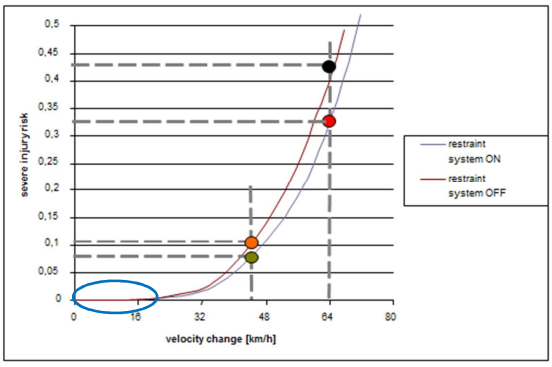


Figure 1. Generic injury risk curve (no real data)

The black point represents the reference test. If the impact occurs at the same speed but with the activation of improved restraint systems, the new injury risk is represented by the red point. On the other hand, if improved restraint systems are not activated but there is an impact speed reduction due to a pre-brake action, the orange point represents the new injury risk value. Finally, if both improved restraint systems and pre-brake action are activated, it is the green point which represents the injury risk level.

After performing the first simulation activities, it was detected that almost all biomechanical values had a related injury risk below 1% (AIS≥3, according to Mertz and Eppinger sources). This meant that all the coloured points explained in the paragraph above would be in the blue circle represented in Figure 1. Only chest deflection had a related injury risk over 1%.

In view of this, the objective of the WP5 of the ASSESS project as well as the activities to be performed were redefined. The new objective of WP5 was to perform a set of simulations, sled tests and crash tests in order to better understand the effect of the pre-crash systems activation during the crash phase. In addition, limitations of the currently on-the-market passive safety tools to satisfy this objective were going to be highlighted.

Activities performed

Below is a list of the activities performed in the WP5 of the ASSESS project in order to achieve the aforementioned objective.

- Braking manoeuvres
- Simulation activities by using MADYMO
- Simulation activities by using LS-DYNA
- Sled tests
- Full Frontal Impact test
- Offset Deformable Barrier Impact Tests

All these activities were performed to analyse the effect during the crash phase of the activation of the two main pre-crash safety systems currently on the market, which are:

- Improved restraint systems (pre-pretensioner)
- Pre-brake action

The activities listed above, which were performed considering the activation or not of the two main pre-crash safety systems, are described in the following section.

ACTIVITIES PERFORMED

Braking manoeuvres

The pre-brake action of a vehicle when an imminent accident is detected reduces the impact speed decreasing, consequently, the amount of energy transmitted to the vehicle occupants. This is obviously positive, but the pre-brake action has also a negative effect on the occupants of the vehicle: the deceleration pulse generated by the braking action provokes a forward movement of the vehicle occupants. This out-of-position complicates the work of the restraint systems of the vehicle since they are designed for a standard driving position.

In order to better understand this effect, several braking manoeuvres were performed with a Daimler S-Class. Three volunteers similar to a HIII 50%ile dummy were seated in position 3 of the car, and the displacement of their head, neck and

shoulder during the braking action was measured by using tracking tools. The repeatability of the braking action was guaranteed by a braking robot, which performed two kinds of manoeuvres: full brake with pre-safe system activation and full brake without activating it. Figure 2 shows the range of displacements (in mm) obtained per body part, considering all volunteers, and separating them depending on the activation or not of the pre-safe system.

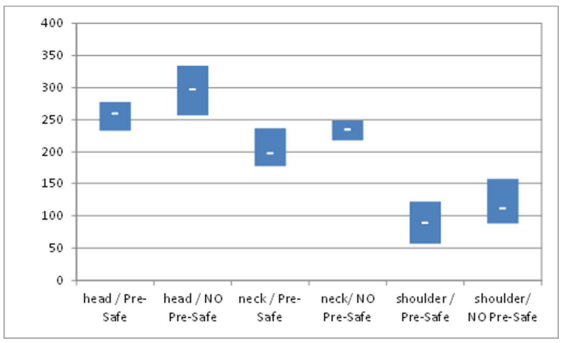


Figure 2. Generic injury risk curve (no real data).

In addition to quantifying the displacement of each body part, Figure 2 shows that the forward motion of the vehicle occupants is reduced when the pre-safe system is activated. In this case, the pre-safe system included a pre-pretensioner and anti-submarining mechanisms.

Simulation activities by using MADYMO

A complete set of simulation activities was performed by using MADYMO. These activities can be separated into two main groups:

Pre-crash phase These simulations were focused on the braking phase (before the impact). Multibody human body models (HBM) were used to analyse the forward motion of the vehicle occupants due to the braking action. Simulations were performed with a Citröen C3 model and using the two pulses shown in Figure 3.

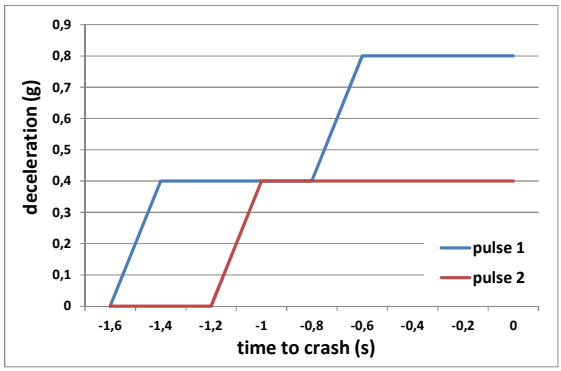


Figure 3. Deceleration pulses used to perform the braking phase simulations.

The abovementioned simulations were conducted considering not only the two pulse represented in Figure 3, but also the activation or not of the Active Control Retractor (ACR). Find in Table 1 the displacements resulting from these pre-crash phase simulations.

Table 1
Occupants' displacement

DRIVER	Pulse1		Pulse2	
Displ. in mm	ACR	No ACR	ACR	No ACR
Head	-192	-192	-37	-101
Thorax	-123	-137	-14	-108
Pelvis	+19	-60	+49	-18

PASSENGER	Pulse1		Pulse2	
Displ. in mm	ACR	No ACR	ACR	No ACR
Head	-179	-236	-44.8	-178.1
Thorax	-121.3	-173.3	-26	-138.1
Pelvis	-8	-53.5	-0.9	-24.57

Similarly to the braking manoeuvres, also in this case a reduction of the forward displacement of the vehicle occupants is detected when the improved restraint systems (in this case, ACR) are activated.

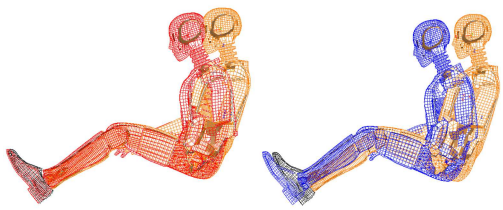


Figure 4. After braking position of the Hybrid III dummy in LS-Dyna simulations "with ACR" (left) and "without ACR" (right) activation.

However, to analyse in detail the results above it is necessary to take into account that these simulations were conditioned by some limitations, namely:

- Seat models only correlated for crash (not for pre-crash scenarios).
- Unknown level of the seat belt correlation.
- Correlation level of the HBM partially known.

Crash phase This group comprises those simulations which focused on the analysis of the injuries suffered by the vehicle occupants during the impact. According to the WP objective, these activities were performed considering the activation or not of the pre-pretensioner and pre-brake action.

Also in this set of activities a Citröen C3 model was used, but in this case it was virtually crashed

against a deformable barrier according to the Euro NCAP frontal impact configuration. The occupant model used was the HIII Multibody model (muscles not strained). Impacts at 65, 56 and 40 km/h were simulated in order to reproduce the speed reduction generated by the pre-brake action. Additionally, all those impacts at different speeds were simulated with and without ACR activation and considering or not the "after braking" occupant' position obtained in the pre-crash simulations. In this way, the effect of the pre-pretensioner and the pre-brake action were going to be evaluated separately. Table 2 summarizes the configuration of the simulation activities comprised in the crash phase.

Table 2
Crash phase simulation activities plan

Impact speed	After braking positioning	Pre-pretensioner
64 km/h	no	no
56 km/h	no	no
40 km/h	no	no
64 km/h	yes	no
56 km/h	yes	no
40 km/h	yes	no
64 km/h	yes	yes
56 km/h	yes	yes
40 km/h	yes	yes

In line with the initial objective of the WP5 of the ASSESS project, the biomechanical values resulting from these simulation activities were related to their injury risks AIS≥3, according to Mertz and Eppinger sources. At this point, it was observed that all biomechanical values except chest deflection had a related injury risk below 1%.

The blue circle in Figure 5 shows the zone of the graph were almost all biomechanical values are situated.

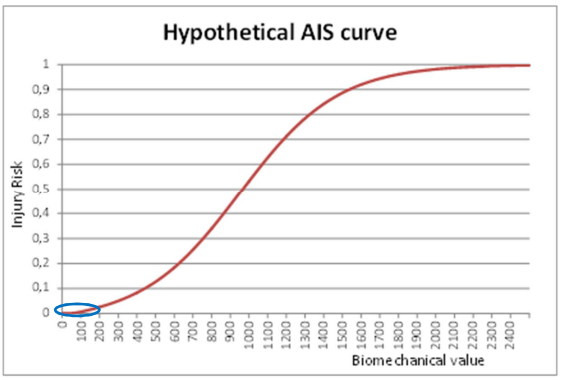


Figure 5. Hypothetical injury risk curve.

As explained in the introduction, in view of these results it was decided to change the WP5 objective in benefit of the better understanding of the effect of the pre-crash systems activation during the crash phase, without considering the definition a methodology based on the injury risk curves.

Simulation activities by using LS-DYNA

The simulations conducted by using LS-DYNA were focused only on the crash phase. In this case a vehicle buck model of a Mercedes E-Class was used, and the occupants were represented by Hybrid III 50% finite-element models . These activities were conducted focusing only on the passenger side (position 3) and considering the activation or not of the pre-brake action and pre-pretensioner. Similarly to the MADYMO simulations, the pre-brake effect was represented by crash tests at different impact speeds, all of them in a full frontal impact against rigid barrier configuration. The "after braking" position was taken from the HBM MADYMO pre-crash phase simulations explained in the previous section, by applying the displacements shown in Table 1 on the nominal position, (see Figure 4).

Four different configurations were simulated. First of all, the basic configuration, which is a full frontal impact at 56 km/h with the occupant in the standard position. Secondly, another full frontal impact with the dummy model in the standard position, but this time at 40 km/h. Then, a full frontal impact at 40 km/h considering the after braking occupant position without pre-pretensioner activation. Finally, the same impact at 40 km/h but considering the after braking occupant position with pre-pretensioner activation.

Figure 6 compares the biomechanical results obtained from the different variants of the simulations conducted.

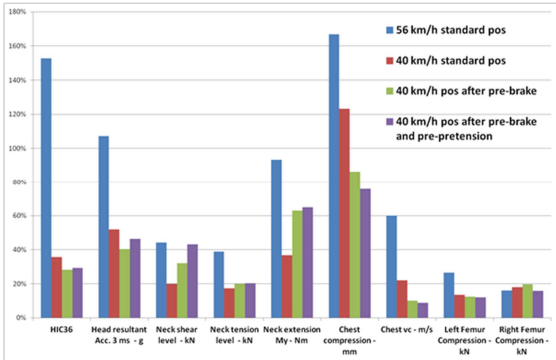


Figure 6. Biomechanical values resulting from each of the impact variants simulated.

From these results it is possible to affirm that the impact speed reduction due to the pre-brake action diminishes substantially most of the biomechanical values, mainly the ones related with the head and chest. On the other hand, the out-of-position

generated by the pre-brake action worsens the biomechanical values related to the neck. The combination of pre-brake with pre-pretensioner changes the neck loads marginally.

Sled tests

Six sled tests were conducted using a Mercedes E-Class buck. Also in this case a full frontal impact against rigid barrier configuration was considered, making it possible to compare these results with the ones obtained from the LS-DYNA simulations. Similarly to the LS-DYNA simulation activities, also in this case the tests focused on the co-driver side. Only Speed reduction due to the braking action was studied also for the driver side.

In line with the activities described above and with the objective of the WP5 of the ASSESS project, sled tests plan was defined in order to analyse the effect of the pre-brake action and pre-pretensioner activation separately. Table 3 below shows the sled tests plan.

Table 3
Sled testing plan

V	Intention	Km/h	Driver	Pass.
1	Reference	50	50%	50%
2	Influence pre brake	50	--	50%
3	Pre- pretensioner (ACR)	50	--	50%
4	Reference	40	50%	50%
5	Influence pre brake	40	--	50%
6	Pre- pretensioner (ACR)	40	--	50%

According to the experience from several pre-braking tests in real cars with humans and dummies, the forward motion of the HIII dummy does not reliably represent the forward movement of a human during a braking manoeuvre. According to the paper 11-207-O presented by Daimler in the ESV Conference in 2011, this unreliability can be partially solved by introducing a piece of foam between the dummy chest and the seat belt. Since the pre-braking phase can physically not be reproduced on the sled, this foam has been not installed to perform these sled tests. However, in order to represent the influence of the pre-brake action, the initial position of the dummy has been taken from the abovementioned paper.

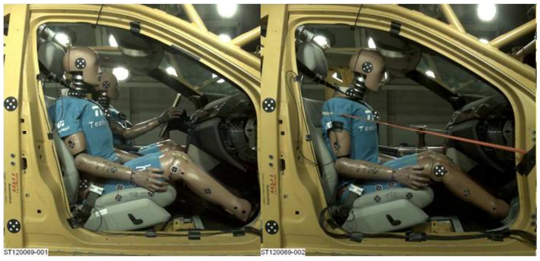


Figure 7. Initial position of the dummy in the sled tests considering or not the forward movement due to the braking action.

In real scenarios pre-pretensioners are activated approximately at the same time as the pre-braking actions, so the dummy forward movement has not started yet. In order to represent this situation in the sled tests performed, the dummy was positioned in its nominal position and, ~2.5s before staring the test, the pre-pretensioner was triggered. This pre-pretensioning supposed a maximum belt force of ~190N.

Figure 8 and Figure 9 below show the results for both driver and co-driver occupant positions according to the test plan shown in Table 3 and the abovementioned considerations.

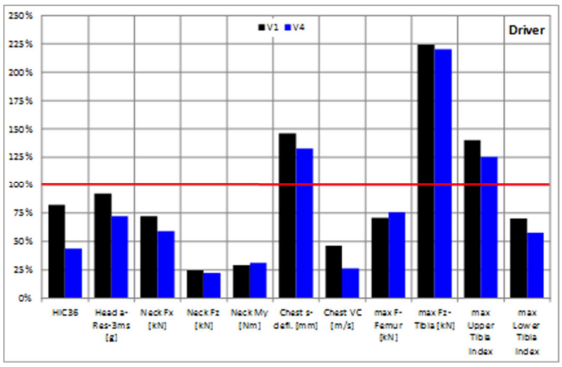


Figure 8. Dummy values for driver side compared to the Euro NCAP higher performance limits, V1 (50km/h, black) vs. V4 (40km/h, blue)

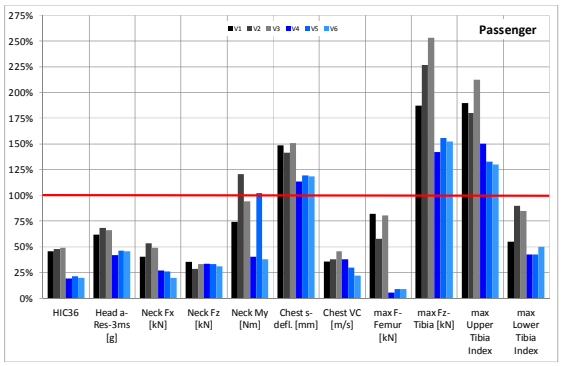


Figure 9. Dummy values for passenger side compared to the Euro NCAP higher performance limits, V1-V3 (50 km/h grey) vs. V4-V6 (40 km/h blue)

Similarly to the conclusions obtained from the LS-DYNA simulations, also in this case a clear benefit is observed due to the impact speed reduction for all the biomechanical values. Again, the forward motion of the dummy due to the braking action has a negative effect on the neck injuries (mainly in the My, in this case). In this case, an undesired early interaction between the dummy head and the deploying airbag was observed, which could explain this negative effect of the pre-brake action on the neck injuries. When the pre-pretensioner activation is considered, this occupant forward motion is reduced, minimizing the abovementioned undesired interaction and diminishing, consequently, the negative effect on the neck injuries.

Full frontal impact test

After performing several simulations and sled tests considering a full frontal impact test configuration, a full scale impact test was performed in similar conditions.

A full frontal impact test was performed with a Mercedes E-Class taking into account the effect of its own pre-safe safety systems. Daimler provided the information of a standard Full Frontal impact test at 50km/h. By performing another full frontal impact test, but activating the pre-safe systems of the vehicle, the benefit coming from these systems should be analyzed. In this way, the vehicle was accelerated by a hard brake action in order to impact at a speed close to 40km/h. Due to the braking action improved restraint systems were automatically activated . Figure 10 represents the configuration of the test performed.

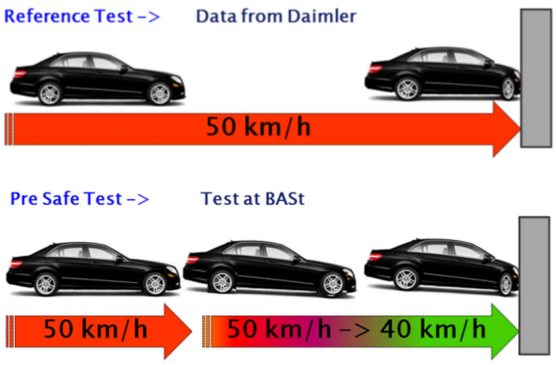


Figure 10. Schema of the full frontal test performed

The braking action was activated by using a robot which was attached to the braking pedal. This method guarantees the use of the braking system of the vehicle and, therefore, the achievement of a realistic deceleration pulse. Since the aim of this test was not the detection of an imminent impact, the improved restraint systems of the vehicle were activated by using an external trigger, which was situated at a specific distance from the impact point.

In order to make the forward movement of the dummies more comparable to a human during the braking phase, a piece of foam was situated between the seatbelt and the dummy chest according to the paper 11-207-O presented by Daimler in the ESV Conference in 2011.

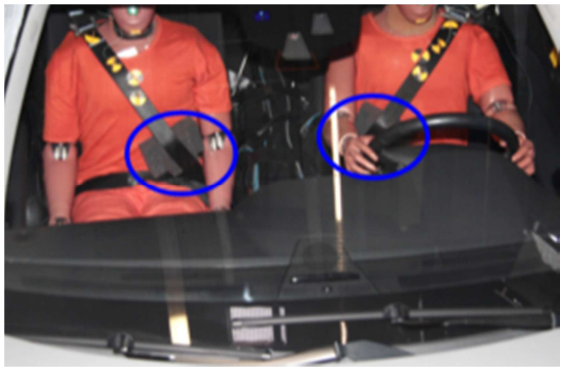


Figure 11. Picture of the foam installed between the seatbelt and the dummy chest.

After performing the full scale test at 40 km/h, the deformation of the structures during the impact were compared. Figure 12 shows that the impact speed reduction clearly diminishes the deformation of the frontal structure of the vehicle during the impact.

Figure 12. Comparison between the deformation of the structure in the reference test (left) and the test at reduced impact speed (right).

Comparing now the greatest penetration of the dummy head in the airbag (around 100ms after t0), a greater safety margin in the reduced speed scenario can be clearly observed, since the dummy remains further away from the steering wheel (see Figure 13).

Figure 13. Comparison of the penetration of the dummy head in the airbag at 100ms.

The abovementioned safety margin opens the door to an optimization of the restraint systems of the vehicle, for example, allowing a greater forward displacement of the dummy which could reduce the chest biomechanical values.

Regarding the biomechanical values, a clear benefit is observed when comparing both tests. The impact speed reduction due to the pre-brake action together with the activation of the improved restraint systems has a substantial positive effect on both driver and co-driver occupants. All biomechanical values of the co-driver dummy are reduced (see Figure 15). On the driver side, only the neck moment in Y direction (My) is not reduced.

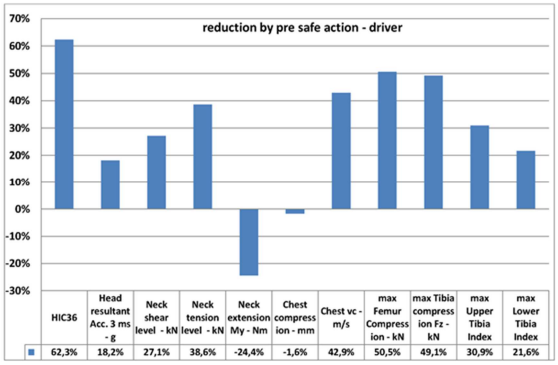


Figure 14. Reduction of the biomechanical values when pre-safe systems are activated. Driver side.

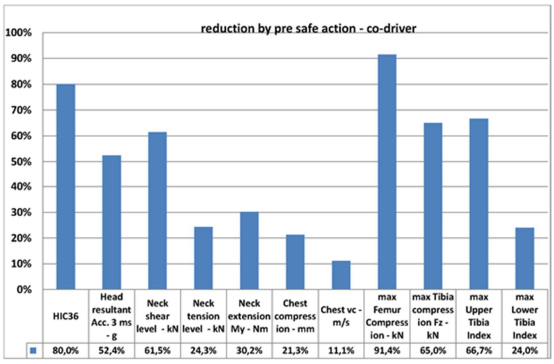


Figure 15. Reduction of the biomechanical values when pre-safe systems are activated. Co-driver side.

ODB impact tests

Two frontal impact tests with a configuration similar to the one defined in the Euro NCAP protocol were performed with a Citröen C3. Considering the official Euro NCAP test as a reference, two additional impacts were performed: one considering only the pre-brake action and another one considering the pre-brake action and the pre-pretensioner activation. In this way, the benefit of the pre-brake action and the pre-pretensioner activation could be evaluated separately.

In the two tests performed the vehicle was accelerated up to 64 km/h and, then, the braking system was activated to generate a deceleration pulse in order to impact at a speed close to 50 km/h.

Figure 16. Reduction of the biomechanical values when pre-safe systems are activated. Co-driver side.

Since the Citröen C3 does no incorporate pre-pretensioners, seatbelts incorporating this function were specially built to perform these tests. These seatbelts were set to the vehicle and controlled by a control box which was activated by an external trigger. In this way, it was possible to activate the pre-pretensioners at the right time.

In this case the braking action was generated by an external braking system able to introduce the suitable oil pressure into the ABS (anti-lock braking system) controller in order to activate the brakes of the vehicle in a natural way.

In a standard crash test, the vehicle is pulled by the propulsion system until 1 meter (approx.) before the impact. This pulling action not only accelerates the vehicle up to a specific speed, but also guides the car in the right direction, minimizing the risk of suffering impact deviations. In this case, since the vehicle need to brake before the impact, the propulsion system cannot guide the vehicle that much. It means that the vehicle will be freely moving during several meters, which increases the risk of impact deviations. In order to guarantee an offset within the limits specified in the Euro NCAP protocol, a specific guidance system was designed (see Figure 17). The aim of this system was to guide the car during the braking phase as close as

possible to the impact barrier, but without jeopardize the free dynamic of the vehicle after the first contact time.

Figure 17. Photo of the test car, the test barrier and the guidance rollers.

Similarly to the full frontal crash, also in this case one piece of foam was situated between each seatbelt and each dummy chest according to the paper 11-207-O presented by Daimler in the ESV Conference in 2011.

Before start analyzing the tests results, it is interesting to mention that one of the main lessons learned in this part of the ASSESS project is the necessity of a better understanding of the dummy forward movement during the braking phase. Besides the two crash tests with pre-brake action, additional braking tests (without impact) were performed, and noticeable differences on the dummies forward motion were detected. Remarkable differences were also found when comparing the braking pulses, which are probably related with the differences between dummies' forward movement.

Figure 18 compares the deceleration pulses of the two crash tests with pre-brake action performed. Although their final value is similar (around 0.8g) there is a noticeable difference between the deceleration gradients to reach this 0.8g. This is a point to be better analyzed in future studies.

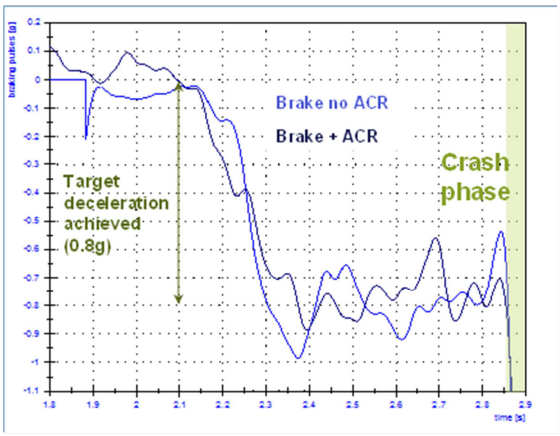


Figure 18. Comparison of the braking pulse of the two crash tests with pre-brake activation.

Regarding the dummies forward motion during the braking phase, it is possible to affirm that the slight forward movement observed during the pre-brake action when the pre-pretensioner is not activated disappears when the pre-pretensioner is activated.

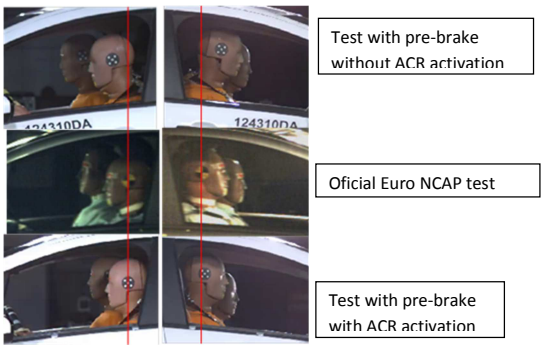


Figure 19. Dummy forward movement during the braking phase.

Starting now with the crash phase analysis, the first issue to be highlighted is the reduction of the deceleration pulse during the impact (see Figure 20). This pulse reduction is obviously beneficial not only for the structure integrity, but also for the occupants' injuries mitigation.

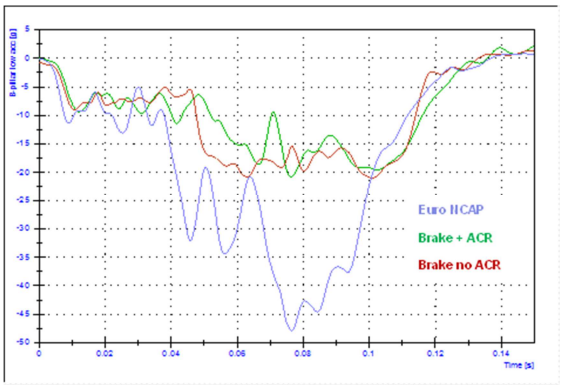


Figure 20. Crash pulses of the three ODB impact tests (reference test in blue, tests with pre-brake action in green and red).

Similarly to the full frontal crash test, the reduction of the impact speed had a direct effect on the structure deformation during the impact. Figure 21 shows a comparison between the maximum deformation of the structure in the reference test and one of the tests performed with pre-brake action.

Figure 21. Comparison between the deformation of the structure in the reference test (left) and one of the tests at reduced impact speed (right).

Focusing on the interaction between the dummies' heads and the airbag deployments, also in this case an important safety margin is observed for the tests with a reduced impact speed. The impact energy reduction diminishes the amount of energy required to restraint the dummies, so the vehicle's restraint systems can be optimized.

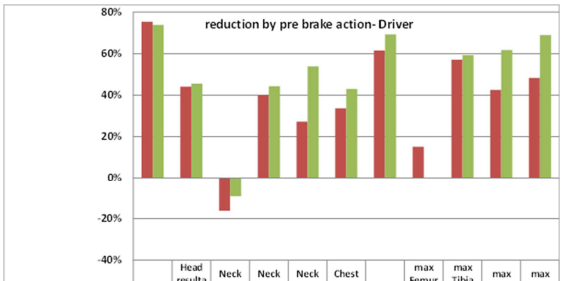
Figure 22. Head penetration into the airbag, driver side. Reference test on the left, test at reduced speed on the right.

An interesting effect was detected on the co-driver side when observing the interaction between the dummy head and the airbag. Comparing the two tests at reduced speed (with and without pre-pretensioner activation), a better dummy positioning (pre-pretensioner activation) together with the impact energy reduction due to the braking action worsens the interaction between the dummy head and the airbag (see Figure 23). This is a clear example of the necessity of adapting the vehicle restraint systems to the new energy level.

Figure 23. Head penetration into the airbag, Passenger side. Test with pre-pretensioner on the top, test without pre-pretensioner on the bottom.

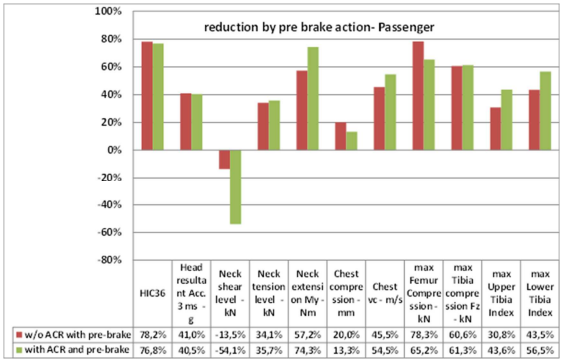
Regarding the biomechanical values, the results and their related conclusions are similar to the ones obtained in the activities described above. The benefit on the occupants' injuries due to the impact speed reduction is clearly observed in both driver and co-driver sides. However, the forward motion of the dummies generates an increment on the neck injuries (neck shear level, in this case). The pre-pretensioner activation mitigates this effect on the driver side. In contrast, the neck injuries on the passenger side are higher when the pre-pretensioner is activated. This last counterintuitive effect is explained by the phenomenon shown in Figure 23.

With respect to the other biomechanical values and comparing only the two tests at reduced speed, almost all of them are reduced on the driver side when the pre-pretensioner is activated. On the co-driver side this positive effect is also appreciated, but to a lesser extent.



	HIC36	Head resultant Acc. 3 ms - g	Neck shear level - kN	Neck tension level - kN	Neck extension My - Nm	Chest compression - mm	Chest vc - m/s	max Femur Compression - kN	max Tibia compression Fz - kN	max Upper Tibia Index	max Lower Tibia Index
w/o ACR with pre-brake	75,4%	44,0%	-16,3%	40,0%	27,2%	33,6%	61,5%	15,0%	57,0%	42,6%	48,3%
with ACR and pre-brake	73,9%	45,6%	-9,3%	44,3%	53,8%	43,0%	69,2%	0,0%	59,3%	61,7%	69,0%

Figure 24. Biomechanical values reduction due to the braking action with (green) and without (red) pre-pretensioner activation on the passenger side.



	HIC36	Head resultant Acc. 3 ms - g	Neck shear level - kN	Neck tension level - kN	Neck extension My - Nm	Chest compression - mm	Chest vc - m/s	max Femur Compression - kN	max Tibia compression Fz - kN	max Upper Tibia Index	max Lower Tibia Index
w/o ACR with pre-brake	78,2%	41,0%	-13,5%	34,1%	57,2%	20,0%	45,5%	78,3%	60,6%	30,8%	43,5%
with ACR and pre-brake	76,8%	40,5%	-54,1%	35,7%	74,3%	13,3%	54,5%	65,2%	61,3%	43,6%	56,5%

Figure 25. Biomechanical values reduction due to the braking action with (green) and without (red) pre-pretensioner activation on the passenger side.

INJURY RISK CURVES

At the beginning of this article it was explained that the initial objective of the WP5 of the ASSESS project was to define a methodology based on the injury risk curves in order to evaluate the effect of the pre-crash systems activation during the crash phase. In addition, it has also been explained that this objective was changed after obtaining the first simulation results, since they showed that all biomechanical values (except of chest deflection) had a related injury risk under 1% AIS≥3, according to Mertz and Eppinger sources.

After performing additional simulations, several sled tests and three different full-scale tests, it can be affirmed that the initial suspicions were correct. Hence, the use of the injury risk curves AIS≥3 to evaluate the effect of the pre-crash safety systems on the occupants' injuries during the crash phase when the impact is not avoided is ruled out. The only exception is chest deflection, which has a related injury risk high enough to be evaluated by using the injury risk curves (see Figure 26 below).

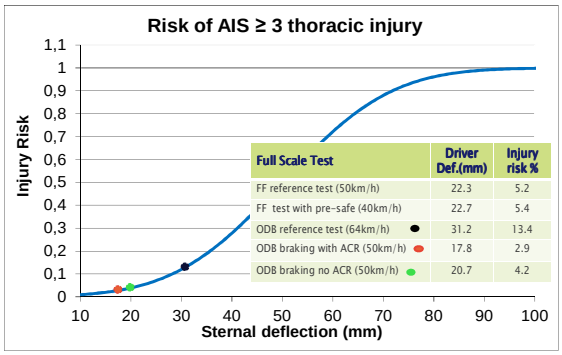


Figure 26. Risk of AIS≥3 thoracic injury.

At this point, two levels of injury risk can be distinguished: on the one hand the AIS≥3 curves, which are available, but only useful for the chest deflection evaluation; on the other hand the AIS<3 curves, which are not available so it is not known if they could be useful to evaluate the biomechanical values.

CONCLUSIONS

In this article several activities have been presented in order to better understand the effect of the activation of pre-crash safety systems on the occupants' injuries during the crash phase. Fortunately, similar conclusions can be drawn from the different activities.

First of all, it is important to highlight the notable benefit obtained from the activation of pre-brake systems,, which has been observed in all the activities conducted. The consequent impact speed reduction diminishes the kinematic energy at the impact time, reducing substantially the energy transmitted to the vehicle occupants and reducing, consequently, the injuries suffered by them. In addition, this energy reduction allows an optimization of the restraint systems in order to minimize even more the injuries on the vehicle occupants'. The impact speed reduction is also beneficial for the structure integrity, since vehicle deformations during the impact have also been diminished.

The effect of the pre-pretensioner also seems to have a positive effect in reducing the occupants' injuries, but to a lesser extent than the pre-brake action. Some differences can be found when comparing the effect of the pre-pretensioner activation on the occupants' injuries during the crash phase depending on the passive safety tool used to analyse it. Probably the sensitivity of the currently on-the-market passive safety tools is not high enough to reliably quantify this benefit.

The new objective of the WP5 of the ASSESS project was not only to better understand the effect of the pre-crash safety systems during the crash phase, but also to detect the limitations to perform a methodology in order to evaluate it. In this field, it is important to highlight the necessity of better understanding the relation between the forward motion of the dummies during the braking phase and the forward movement of a real human under the same circumstances. It is also remarkable that, since biomechanical values have no sense by themselves, more sensitive AIS curves are required in order to relate those biomechanical values with a real human injury. Finally, it is necessary to enhance the reproduction of a repeatable braking pulse in the laboratory.

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