The influence of passive safety systems on head injuries suffered by the vehicle's driver

Oana V. Oţăt, Nicolae Dumitru, and Victor Oţăt

Abstract - The present research paper underpins a thorough comparative study aiming to determine the influence of the active security systems upon the injuries suffered at the collision moment. Hence, a series of statistical data on road accidents casuistry have been analysed in order to establish the type of impact to be investigated and the particular human body region mostly exposed to severe injuries. By means of Virtual Crash software we simulated a frontal-type collision of a vehicle against a rigid wall, at a speed of 50 km/h. The kinematic parameters obtained following this simulation have been further applied in a numerical modelling of four distinct situations, using this time the LS-DYNA software package. Throughout the undertaken study, we have considered those situations in which the vehicle's driver is restrained with a seat belt while the vehicle has been provided with an airbag system. Aiming to underpin a comparative analysis, we have also investigated those situations in which the driver is not secured with the retaining system and the vehicle is not equipped with an airbag.

Keywords— passive safety, frontal impact, dummy kinematics, head injury criteria.

I. INTRODUCTION

The ever increasing necessity for road transportation development, both for freight and for passenger transport, in the context of a road infrastructure that has not undergone much change in the last decades, has led to an increased density of flow traffic. Admittedly, the main negative effect of road congestion is the steady growth of the number of accidents, particularly those with serious consequences.

In order to reduce both the number of traffic overcrowdings as well as the injuries' severity, in case of an accident, among the most actual solutions adopted by vehicle manufacturers was a large-scale implementation of active and passive safety systems in order to increase their effectiveness. Thus, the airbag system is a well-known example of passive safety systems, already integrated in the mass production, and closely related to the seat belt, the widely acknowledged safety system element, which has been the subject matter of a series of recent research studies within this field of investigation.

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A close and critical reading of mainstream literature indicates that a series of scientific research studies analyses the casuistry occurrence of traffic accidents, as well as the type and the severity of the injuries suffered by of the occupants of the vehicle.

An essential research study on the analysis of the driver's kinematic behavior is indicated in [1], aiming at quantifying the whole-body kinematic response of the post mortem human surrogates (PMHS) tested in the same frontal impact condition. Within this research study the three-dimensional displacement corridors development has been introduced in order to quantify the whole-body kinematic response of restrained PMHS for a frontal impact conducted in a controlled laboratory environment.

In terms of development and optimization of the active safety systems, K. Preston White et al. describe in [2] recent enhancements of a software which enables the use of vehicle and occupant simulation models in order to determine the design and the restraint systems meant to increase the occupant impact protection, being also applied to establish the optimal design of a passenger vehicle involved in frontal collisions.

A method to develop injury prediction algorithms by statistical analysis of numerical crash reconstructions using dummy models is presented in [3]. The normal or out of position of the occupants correlated with the operating mode of the airbag system leads to a further research topic.

In [4] Louden indicates, how the air bags are affecting the occupants (Hybrid III 3-year-old, 6-year-old and SID-IIs - 5th percentile adult female side impact dummy) in different OOP test modes for all rows in the vehicle. In [5] some recommended procedures are envisaged in order to evaluate the occupant injury risk due to side airbags deploying. An overview of the actual status with regard to the simulation methods for the deployment process of an airbag is provided in [6], a research paper entitled *On the simulation of out-of-position load cases with the ale-method*. By means of the case-control study of real-world crashed vehicles conducted in [8], the reduction in number of head, face, chest and neck injuries in airbag-equipped vehicles is being highlighted, although the numbers of upper extremity injuries increased.

According to [7], frontal impacts have been defined as follows: non-rollover and principal direction of force (DOF1)

= 11, 12, or 1 o'clock positions or DOF1 = 10 or 2 o'clock positions with the crash damage forward of the A-pillar.

The salient regulations in force, which establish the prerequisites of vehicle testing in frontal impact simulations, are the Federal Motor Vehicle Safety Standards (FMVSS208) and the ECE (UN Economic Commission for Europe).

According to the USA FMVSS 208 and the CMVSS 208 Canada, frontal impact testing shall be conducted at a vehicle velocity of 48 km / h, with a rigid barrier and a 100% overlapping. However, according to the European regulations ECE / 96/79, [8] the front velocity on frontal impact shall be between 48.3 km / h and 53.1 km / h.

II. ROAD ACCIDENTS STATISTICS

In order to establish the type of collision that generates serious injury and even the death of a vehicle occupant, a statistical assessment of road traffic accidents has been carried out. Thus, for this study the following criteria have been taken into consideration: the type of collision, the human body parts exposed to the most severe injuries as well as the type of the driver.

Prior to this case study, in order to determine the most vulnerable road user, statistical data on road accidents have been thoroughly analysed. This study was divided into four main categories, as follows:

2.1. The identification of the type of transport with the highest rate of fatalities caused by road accidents:

Figure 1 [9] indicates a comparison of the male and female fatality distribution by road user type for four age groups. Accordingly, it can be observed that regardless age and sex classification, most of the victims are the occupants of vehicles, at the rate of over 40% in all cases.

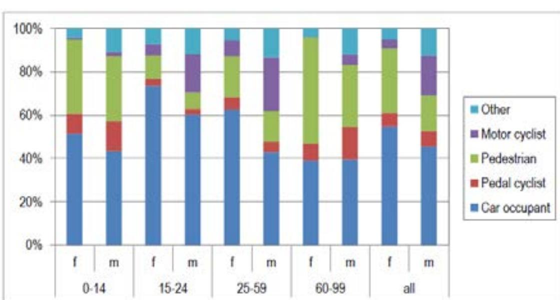

Fig.1. Distribution of fatalities by road user type [9]

2.2. Type of vehicle occupant: Male vs. female

In order to select the most appropriate type of dummy that will be used within this case study, we have first analysed the statistical data in Figure 2. As shown in Figure 2, the highest death rate is registered among male vehicle drivers, i.e. 35% of all fatalities recorded.

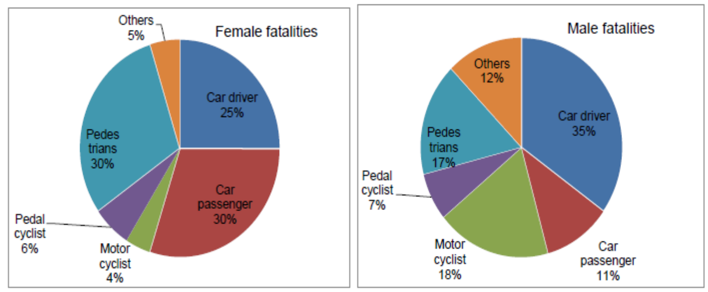

Fig.2. Distribution of male and female fatalities by means of transport [9]

2.3. Type of car occupant: passenger *vs*. driver

Figure 3 [9] indicated the proportion of fatalities by road user type on three types of road. Thus, regardless of the road type, vehicles' rivers have been reported as the most frequently encountered road traffic victims.

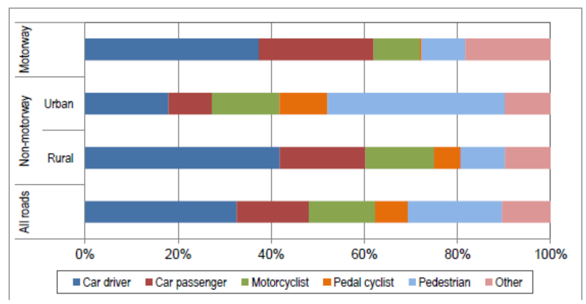

Fig.3. Distribution of fatalities by road user type [9]

2.4. Injured body part

Figure 4 [9] illustrates the distribution of the injured body parts with various road user types. As indicated below, the ratio of head injuries as well as the ratio of neck and throat injuries is most frequently recorded among car occupants, presumably linked to the incidence of whip-lash.

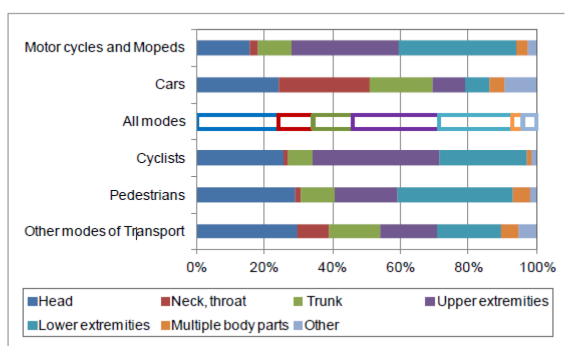

Fig.4. Body part injured by mode of transport [9]

Based on the above-indicated statistical analysis, it has been established that the highest amount of injuries and fatalities caused by road accidents was recorded among male car drivers. The most commonly affected body part due to road accidents is the upper part of the human body, i.e. the head, neck and thorax regions.

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III. DUMMY POSITIONING

3.1 The dummy-type used

In line with the above illustrated statistics, the study of the influence of passive safety systems in a frontal crash test shall be performed on a Hybrid III dummy-type - 50th percentile male, which was placed on the driver's seat.

Figure 5 indicates the geometry of the Hybrid III-type dummy to be used throughout the proposed study.

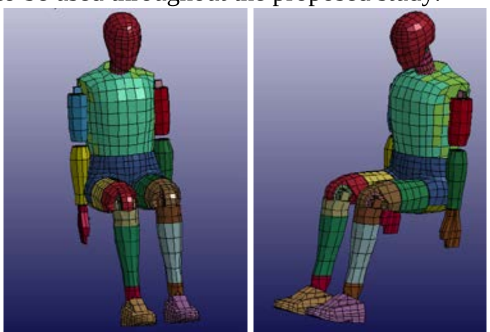

Fig.5. Hybrid III – 50th percentile male

3.2 Dummy positioning

The following step in implementing the numerical simulations of the driver's kinematic and dynamic behavior during frontal impacts consisted in the design of the seat-steering wheel-dashboard assembly. Once this assembly was designed, the dummy was also positioned.

The normal position of the dummy was considered and the percentile male Hybrid III dummy - WAS Placed 50th in the centered position in relation to thorax- 50th was placed in a thorax- centered position in relation to the steering wheel, at a distance of 350 mm.

The joints of the upper and lower limb(s) of the dummy were positioned as indicated below, in relation to the global coordinating system:

- the full arm up down joint was set at an angle of -40˚
- the elbow joint at an angle of -70˚
- the hands were placed on the wheel at an angle of -10˚
- the knee joint was set at an angle of -40˚
- the foot joint was set at an angle of -3˚
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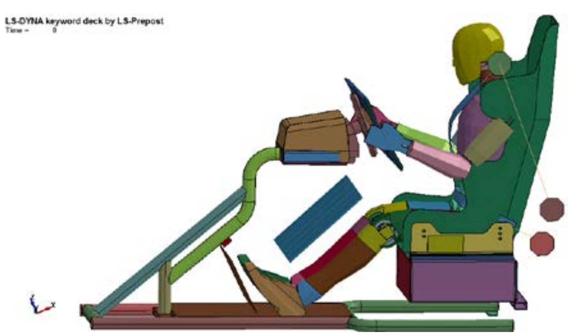

Fig.6. Normal position belted dummy

IV. PASSIVE SAFETY SYSTEMS

The present research study aims therefore to provide a comparative analysis with regard to the influence of the passive safety systems upon the behavior and the injuries caused to the vehicle driver in the head region during a frontal collision.

In addition, it is necessary to define and to fix the seat belt at the level of the dummy's body components. The contact between the seat belt and the dummy is of a node – area type, and it has been defined in the dummy's torso and pelvis region, as shown in Figure 7.

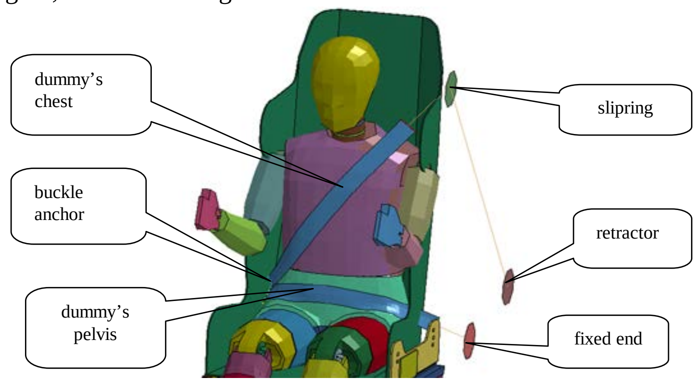

Fig.7. Seatbelt fitting

The second passive safety system that has been defined during the simulation was the airbag, positioned on the steering wheel assembly.

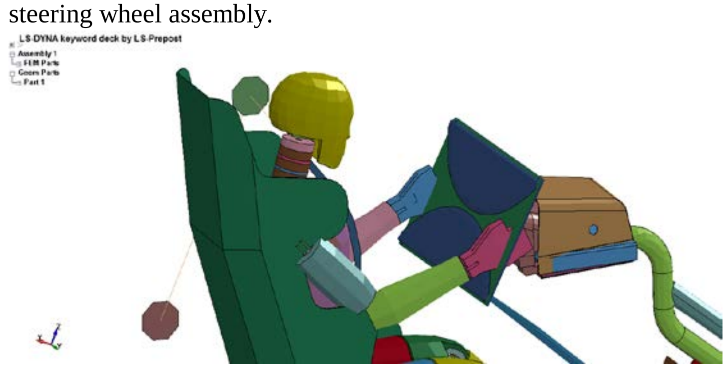

Fig.8. Airbag positioning

The airbag inflator follows the curve for mass flow rate, indicated in Figure 9.

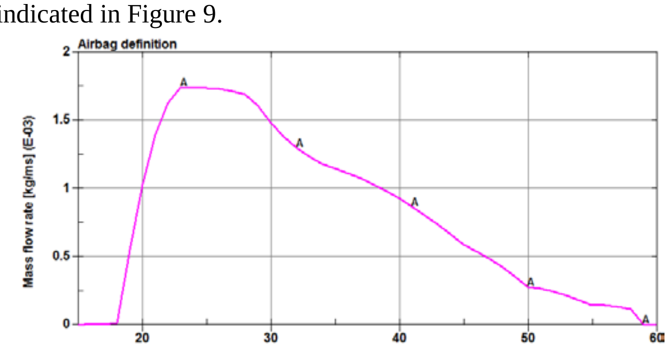

Fig.9. Airbag inflator

V. Collision Type and Prescribed Motion

In order to determine the motion curve of the vehicle during the pre-crash, crash and post-crash phase and to determine the kinematic parameters required for the dynamic impact analysis, a frontal-type collision simulation was obtained by means of the software Virtual Crash.

Thus, a frontal impact between a mid-size sedan vehicle and a rigid wall has been considered, where the main force direction (PDoF) has been oriented in a 12 o'clock position and a 100% overlapping degree.

The initial vehicle velocity during the pre-crash phase has been set at 50 km / h.

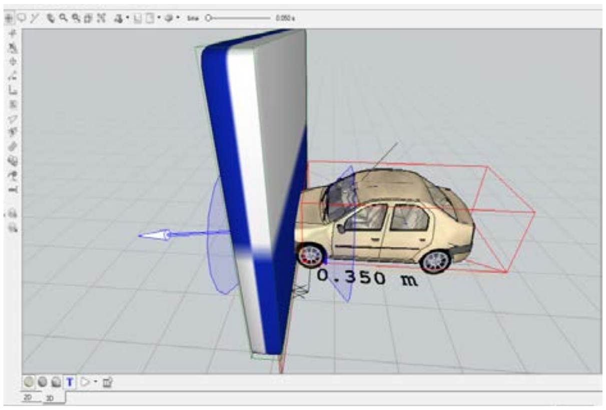

Fig.10. Frontal collision between a vehicle and a rigid wall in Virtual Crash

According to the velocity diagram in relation to time, the highest velocity variation was obtained within a time interval of 110 ms, during which the velocity rate ranged from the 0 [mm/ms] baseline and reached the maximum value vmax = 13,686 [mm/ms] at the final moment of tf=110 ms.

Based on the simulation performed by means of Virtual Crash we have established the velocity time variation diagram, as a prerequisite for the simulation used by the LS-DYNA software package as indicated in Figure 11.

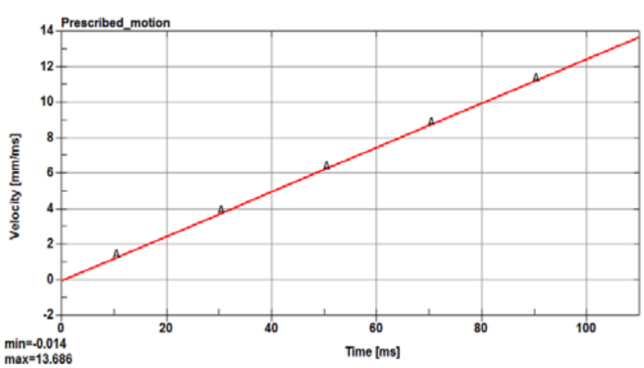

Fig.11. The velocity variation curve for vehicle's movement

VI. The Analysed Situations

In order to establish the major influence on the driver's behavior as well as the most severe injury degree, four different situations concerning the position of the dummy have been analysed during the impact moment, as follows:

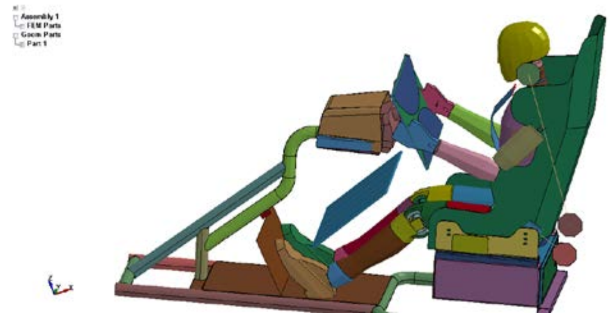

Fig.12. Test A - normal position with seat belt and airbag systems

Fig.13. Test B - normal position with seat belt, without an airbag system

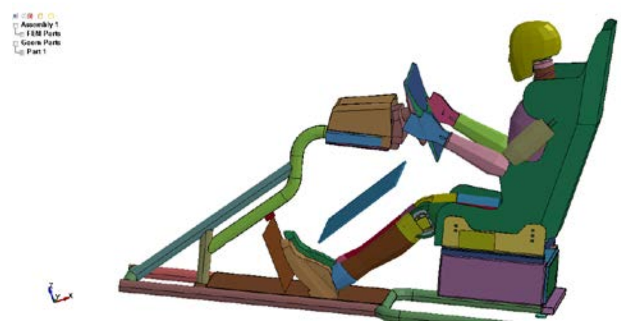

Fig.14. Test C - normal position without seat belt and airbag system

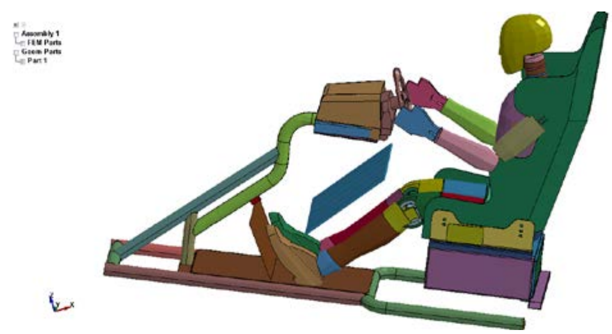

Fig.15. Test D - normal position without seat belt and airbag system

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The analysis carried out in all the above mentioned situations focused on the kinematic and the dynamic behavior of the mechanism.

VII. RESULTS AND DISCUSSION

The assessment of the driver's injury degree in the head region at the moment of the frontal impact can be completed by means of two parameters:

- the head acceleration

According to the FMVSS 208 Regulation, the maximum acceleration in the head region is 80 [g].

- HIC (head injury criteria)

To determine the brain lesions in the head region according to the complex curve of acceleration, we have established as a factor the Head Injury Criteria.

Where t1 and t2 indicate the initial and the time (in seconds) and a (t) is the acceleration resulted (in g), measured in the center of gravity of the head region.

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

According to FMVSS 208 and CMVSS 208 Regulations in case of frontal, the maximal values of HIC, compatible with the driver's survival are as follows:

HIC 15 (throughout a 15 ms interval) < 700

HIC 36 (throughout a 36 interval ms) < 1000

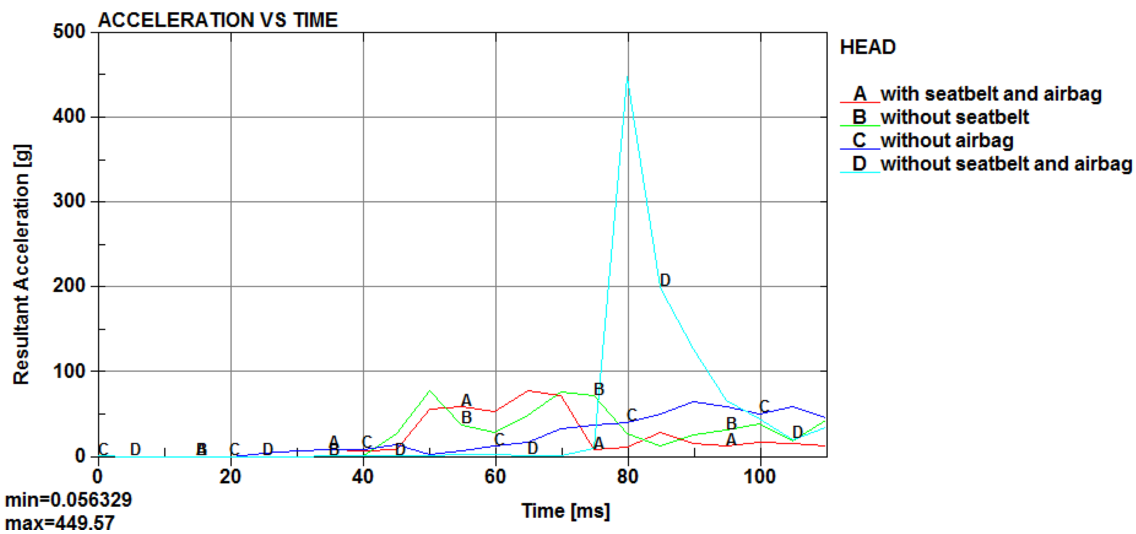

Fig.16. Head acceleration

According to the variation of acceleration over time, as in Figure 16, we have registered that the acceleration highest value in the head region is recorded in situation D, i.e. the driver's normal position without restraint and airbag system.

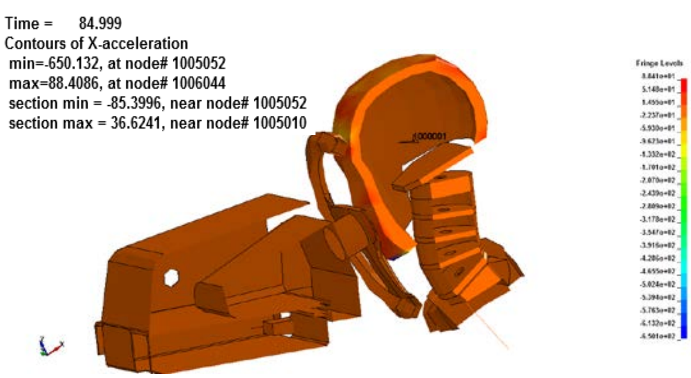

Fig.17. Contours of head acceleration – test D

As indicated in Table 1, the lowest acceleration value in the head region was registered in that situation when the driver is restrained by a seatbelt while a frontal airbag system is missing, i.e. test C. In this situation the maximum value of the acceleration recorded does not exceed the limit of 80 g, which is compatible with the driver's survival. During the simulation, we could notice that due to the restraint system, the dummy's head moves longitudinally, according to the X axis direction, though it does not get in contact with the steering wheel, while the missing airbag prevents any impact in the head region of the dummy. Also in this situation, the maximum recorded acceleration value does not exceed the acceleration limit, thus the injuries suffered are compatible with the driver's as well.

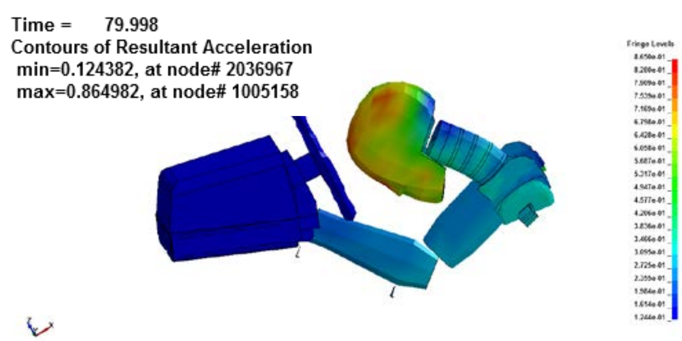

Fig.18. Contours of head acceleration – test C

The close values of the acceleration in the dummy's head region obtained in A (with restraint and airbag system) and in B (without restraint system, but with an airbag system), indicate that the degree of injury is primarily influenced by the existence of the frontal airbag system. Thus, in B, that at the impact moment, the entire body, having not been retained by the seat belt, moves freely not only in the head region, subsequently indicating lower acceleration values in the head region.

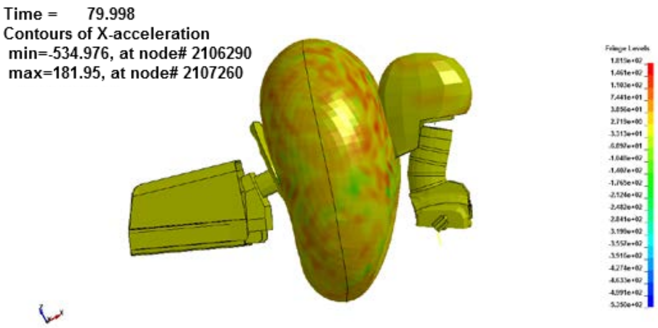

Fig.19. Contours of head acceleration – test B

The results obtained following the analysis of the above-illustrated situations are indicated in Table 1.

Table 1 – Resultant acceleration and HIC

Parameter / Nr. test	Max resultant acceleration [g]	HIC 36
Test A	79	714
Test B	70	600
Test C	64	626
Test D	449	1566

Comparing the values obtained in the situation where the driver has not been restrained with a seat belt and the vehicle has not been equipped with an airbag system, we have drown the conclusion that the maximum values as established by the CMVSS 208 and FMVSS 208 regulations are outdated . Thus, in situation D, the driver's injuries degree in the head region is not compatible with the driver's survival.

Figure 20 indicates the acceleration variation and the head injury criteria for the situations when the driver is secured by a restraint system and the vehicle is equipped with an airbag system.

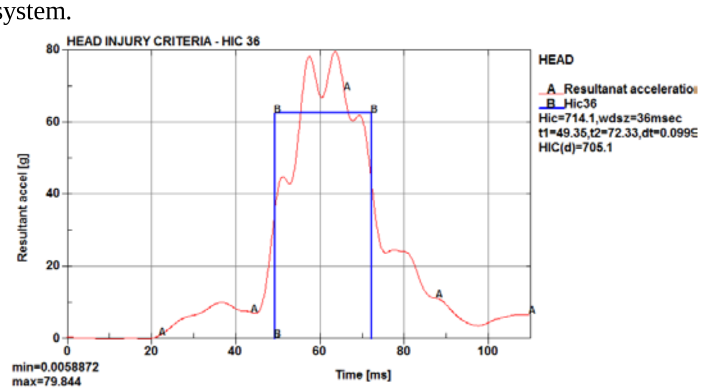

Fig.20. Head injury criteria – test A

VII. Conclusion

To put in a nutshell, according to the results obtained following the analysis of the above-mentioned situations, during a frontal collision against a rigid wall at a speed of 50 km/h, the passive safety systems point out a considerable influence upon the driver's degree of injury.

The most severe injuries are to be registered in such situations when the driver is not secured by a retention system and the vehicle is not provided with an airbag system.

The influence of at least one passive safety system (be it a retention seat belt system or an airbag system) triggers acceleration values and head injury criteria which are situated below the maximum limit established according to crash tests regulations.

Acknowledgment

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