PROCEDURE TO ASSESS SUBMARINING IN FRONTAL IMPACT

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ABSTRACT

This study addresses the submarining issue left in frontal impacts today in the passenger cars, and proposes a methodology to assess it. The first part briefly describes the submarining phenomenon that consists of a sliding of the lap belt above iliac spine due to either bad safety belt geometry or poor coupling of the occupant to the car. This mechanism results in severe abdominal injuries (mesanterin laceration, severe hemoperitoneum, perforation,…). Some recent accident data coming from LAB (Laboratoire d'Accidentologie et de Biomécanique) are also presented in order to highlight the increasing importance of this phenomenon as the compartment intrusion is reduced, the knee support area is eliminated in order to avoid other injuries and the use of the seat belt is generalized in passenger car rear seats. The second part explains the reasons why, despite of evidence review, this phenomenon is not taken into account today, neither by the regulations nor by the ratings. The HIII dummy, widely used for safety assessment, integrates a very stiff lumbar spine. This feature prevents the pelvis rotation and consequently submarining. Therefore, other widely used dummies currently available are considered in this study in order to identify a more biofidelic behavior enabling the pelvis rotation and therefore detection of submarining phenomenon. In the third part, a full procedure based on a sled test and involving these suitable dummies is proposed. Associated criteria that could be used to assess the performance of a given restraint system are also described. The procedure is applied to vehicles with or without submarining countermeasures and the results are validated using the feedback on real accident data from the LAB. The results confirm the efficiency of the countermeasures and validate the assessment procedure.

INTRODUCTION

European official data from the European Road Safety Observatory (ERSO, www.erso.com) shows that Road traffic accidents in 2004 in the Member States of the European Union lead to about 47.000 fatalities and more than 1.8 million people injured. Coming back to the data in France provided by ONISR (Observatoire National Interministériel de la Sécurité Routière) in 2004, 5232 fatalities and 17435 seriously injured people have been observed. 3186 persons died in passenger cars. Frontal impacts represent 47% of killed and 69% of seriously injured people in passenger cars. The distribution is 1290 fatalities in front seats and 143 fatalities in rear seats. Recent progress in passive safety, coming from both regulation enforcement and consumers ratings allowed to solve most of the lethal issues in frontal impact which were :

-intrusion (steering wheel, firewall, footwell,…), decreased with well-designed absorbing structure

-head contact with steering wheel, avoided with frontal airbags

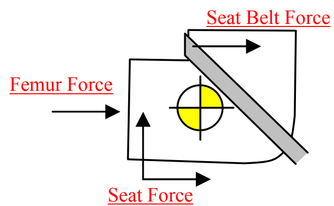
-chest injuries, reduced with belt load limiters

The aim of this paper is to highlight that abdominal injuries frequently occur in frontal crash today, either in front seat but especially in rear seats. Studies regarding abdominal injuries in the U.S. are already available in the literature. [1, 2, 3]. The first part includes a review of real accident data provided by the accident database of LAB, Laboratoire d'Accidentologie et de Biomécanique. The distribution of lethal injuries is shown in order to compare the well-known head and chest injuries with the abdominal ones. In the second part, an explanation is given on the fact that it is highly unlikely to detect submarining issue with the current procedures, either in regulations or in existing ratings, due to the use of the HIII dummy. An alternative test setup is proposed, allowing to observe the submarining phenomenon in a laboratory test. Several dummies and restraint systems are studied, to finally to propose a complete procedure to assess the performance of a given restraint system. This part is also showing that efficient countermeasures exist in recent vehicles. Finally, the third part is a review of real accident data provided by the LAB on recent Renault cars fitted with suitable countermeasures. Injury data have been collected on these vehicles and they are compared with the data presented in the first part, in order to estimate the effectiveness of the countermeasures and to show that it is possible to solve this issue.

WHAT IS SUBMARING?

The submarining phenomenon consists in the sliding of the lap belt above iliac spine due and loading the soft abdominal tissues.

Submarining happens when the restraining forces acting on the pelvis are not in equilibrium during the deceleration of the vehicle and induce its rotation. These forces come from the seat belt, the seat and the dashboard. The seat belt may produce submarining when its positioning due to the anchorage geometry tends the belt to displace upwards on the abdomen. The lack of restraint of force from the seat generates submarining as it is unable to compensate the rotation induced by the seat belt restraint above the pelvis centre of gravity.



ACCIDENT DATA

To act all the developments carried out by Renault in term of safety, the LAB, Laboratoire d'Accidentologie et de Biomécanique, is in charge of performing for Renault in-depth analysis of real accidents occurring on French roads. In-depth crash investigations have been carrying out at LAB since 1970. There are actually two kinds of investigations. The first one concerns secondary safety. The goal is to understand the injury mechanisms in real-world crashes in order to improve occupant safety in cars by the means of protection devices or car structure. Almost all car manufacturers all over the world and even public research institutes have been carrying out that kind of study for decades. Specially trained accidentologists collect relevant information about types and violence of impacts, car deformations and occupant injuries and feed it into a corresponding database. They don't need to go on the scene of the crash. Information is collected by accidentologists a few days or a few weeks after the crash at hospitals and at wreck garages. This methodology leads to a wide range of researches estimating risk curves or evaluating the effectiveness of on-board protection devices.

The second one deals with primary safety. French car manufacturers started this activity in the early nineties, when it appeared that secondary safety would necessarily have limits and that there was a need for crash avoidance as well as a need for occupant protection. The challenge in this field is to understand the crash process, purpose new functions for active safety systems, and eventually to evaluate the effectiveness of new safety devices or avoidance systems on any kind of motorized vehicles.

In any case, agreements are signed with the French ministry of Justice to allow that kind of technical work on crashes apart from judicial process involving drivers at fault. Investigations are exclusively technical and are carried out for research purposes only.

In France, three institutes are presently carrying out that kind of in depth investigations with regards to primary safety concerns: the National Research Institute for Transport and Safety (INRETS) and The European Center for Safety Studies and Risk Analysis (CEESAR) with LAB (Laboratoire d'Accidentologie, de Biomécanique et d'étude du comportement humain).

As for secondary safety oriented investigations, LAB has identified two study designs. The first design aims at getting a representative sample of impacts and impact violence of cars involved in a road crash in France. For this purpose, all crashes involving a passenger car with at least one occupant injured are investigated in a restricted sample area in the West of Paris. About 200 cars and their occupant injuries are examined in-depth every year. The sample rate is relatively small as about 90 000 passenger cars are involved in injury crashes every year in France.

The second design aims at evaluating the effectiveness of protection systems supplied in newer cars. 150 cars involved in (mostly) severe crashes are chased all over the country each year. The only selection criterion is that the car must be a newer one, mostly Renault and PSA cars, equipped with the most recent safety devices.

The collection of the information about crashed cars takes about one and a half hour in the garage. Complementary collection is made afterwards at the hospital with the authorization of the medical doctors and the patients. Most of the data is then coded and filled in a special database. Information that cannot be coded is conserved in original dockets along with photos and sketches.

The two teams at CEESAR and LAB have investigated about 14 000 passenger cars, i.e. 25 000 occupants and 65 000 injuries since 1970, which makes this database one of the most important one in Europe.

This database allows not only to detect the remaining issues left in the real world like abdominal injuries we detail below, but also to check the real efficiency of the countermeasures fitted in the modern vehicles [4], once enough accidents involving these new cars have been studied. LAB investigation method has already been described in details in previous paper [5].

To highlight the submarining issue in frontal impacts, a first sample S1 of the following accidents coming from the LAB database have been considered :

- vehicles from LAB database with a first registration year between 1990 and 2000
- frontal impact (+/- 30°), with a dashboard intrusion limited to 250mm. Indeed, above this value, fatalities are resulting from intrusion problems – these case usually match with old vehicles and cannot be solved thanks to restraint systems
- EES above or equal to 40km/h
- age above 9 years old, since below this, children must be sitting in Child Restraint System
- front passengers on one hand, and rear passengers on the other hand
- injuries on head, chest and abdomen are investigated, in the AIS3+ severity range. If the injury features on head and chest are well-known, abdominal ones can be found on peritoneum, mesentery, large bowels, abdominal big vessels… Injuries can be of different severity, from bruise to laceration and perforation.

Front seats occupants

The sample obtained from the request involves 1260 occupants, among which 74 fatalities and 380 AIS3+ injured occupants. Fatality and AIS3+ risk (ρ_i) can be calculated as follows :

$$\rho_1 = Fatality - risk = \frac{number - of - fatalities}{n}$$

$$\rho_2 = AIS3 + risk = \frac{number - of - AIS3 + occupants}{n}$$

where n is the number of involved occupants

confidence interval is [ρ-2σ ; ρ+2σ], where σ is the standard deviation :

$$\sigma = \sqrt{\frac{\rho(1-\rho)}{n}}$$

Table 1 presents, for front seats occupants, fatality and ASI3+ risk of the considered sample, as well as the confidence interval for each risk

Involved occupants	1260	Risk	Confidence interval
Fatalities	74	6%	$[5\% - 7\%]_{95\%}$
AIS3+ injured occupants	380	30%	$[28\% - 33\%]_{95\%}$

Table 1 : Fatality and AIS3+ risks for front seats occupants of sample S1

It is now important to understand from where these injuries come from. We can go deeper by analyzing in this same sample what are the injuries on head, chest and abdomen, which are the current lethal body areas. Concerning fatalities, most of these cases are not followed by an autopsy that could help precisely to find the origin of the death. Nevertheless, an autopsy has been performed on one third of fatalities, providing the distribution of injuries between head, chest and abdomen. We assume that the remaining cases without autopsy have the same injury distribution. For injured occupants, injury distribution is known from the hospital report recorded by LAB.

Table 2 presents the AIS3+ severity risk per lethal body region and their respective confidence interval

Body region	Head	Chest	Abdomen
Severity risk AIS3+ in a given body region	4%	16%	7%
Confidence interval	$[3\% - 5\%]_{95\%}$	$[14\% - 18\%]_{95\%}$	$[6\% - 9\%]_{95\%}$

Table 2 : Distribution in body regions of AIS3+ risks for front seats occupants of sample S2

Comments for front passengers :

- the main risk is the chest, typically ribs & sternum fracture due to the seat belt load. This kind of injury is well known and the effective solution is to fit the belts with load limiters allowing direct load reduction on chest.
- abdominal injuries are identified as the second risk coming after the chest, as a lethal issue
- if we consider the occupants with at least one AIS3+ injury (380 occupants), we observe that 90 occupants have suffered from at least one abdominal injury, eg 24% of seriously injured occupants have an abdominal injury..
- to illustrate this, we have detailed examples of real accidents studied by the LAB. The picture 1 and 2 illustrate one example where the driver has suffered an AIS4 to the abdomen, the precise injury being a severe hemoperitoneum and a mesenterin laceration. Due to a bad coupling of the pelvis with the seat, the seatbelt has passed over the iliac bones and entered the soft abdominal tissues, losing the pelvis load path. This is a typical injury pattern that can be observed when either lap belt anchorages are too high, or the seat and seat belt do not provide enough pelvis coupling

Figure 1 : seat after accident

Figure 2 : collapse of the seatbase structure

Rear seats occupants

The sample obtained from the request involves 146 occupants, among which 21 fatalities and 55 AIS3+ injured occupants. Fatality and AIS3+ risk (ρ_i), and their respective confidence are presented in table 3.

Involved occupants	146	Risk	Confidence interval
Fatalities	21	14%	[9% - 20%]$_{95\%}$
AIS3+ injured occupants	55	38%	[30% - 46%]$_{95\%}$

Table 3 : Fatality and AIS3+ risks for rear seats occupants of sample S1

Body region	Head	Chest	Abdomen
Severity risk AIS3+ in a given body region	2%	14%	23%
Confidence interval	[0% - 4%]$_{95\%}$	[9% - 20%]$_{95\%}$	[16% - 30%]$_{95\%}$

Table 4 : Distribution in body regions of AIS3+ risks for rear seats occupants of sample S1

Comments for rear occupants :

- the most important risk for rear occupants is on the abdomen
- the fatality risk for rear occupants is 2.5 times more important than the front occupants one (6% to 14%)
- Abdomen AIS3+ severity risk is much more important than chest one
- if we consider the occupants with at least one AIS3+ injury (55 occupants), we observe that 33 occupants have suffered from at least one abdominal injury, eg 60% of seriously injured occupants have an abdominal injury.

PROCEDURE TO ASSESS THE RESTRAINT SYSTEM PERFORMANCE FOR SUBMARINING ISSUE

Why the issue is not highlighted today ?

The anthropometric device currently used in crashworthiness is the HIII dummy. One particular feature is its very stiff lumbar spine that does not allow high pelvis rotation. It is assumed that it is that pelvis rotation which is at the origin of the upward movement of the lapbelt in the abdominal tissues.

To show that current test protocol cannot highlight this issue, we have conducted some tests involving restraint systems of cars where submarining issue has been observed in accident data. The test setup consists of a sled test simulating a full lap impact of the considered car at 56km/h, with only the seat and the belts system, including buckle pretensionner. The figure 3 details the test setup, where the driver airbag is not fitted, and to reduce the chest forward movement, the 4kN load limiter usually fitted on Renault cars is replaced by a 6kN one. The first test is performed with the current HIII dummy. In addition to its current instrumentation, a sensor is located in the pelvis to measure the rotation around the y axis and the lab belt is equipped with a force sensor.

Figure 3 : Test setup

Figure 4 shows the dummy position at 78ms, matching with the maximum forward pelvis movement. The lap belt is still stuck onto the pelvis and it never tried to escape from the pelvis, continuously maintaining the occupant without any aggression to the abdomen. This fact is also visible on the lap belt trace (figure 5), where no collapse is visible on the curve. It is assumed that if the lap belt enters the soft HIII abdomen, the load would decrease heavily.

Figure 4 : Test 1 – HIII dummy position when maximum pelvis forward movement is reached

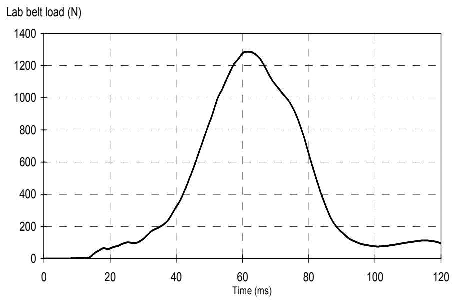


Figure 5 : Test 1 – HIII dummy lab belt force

This laboratory test, involving a given restraint system fitted in current cars, does not represent what happened in real accident data. The submarining phenomenon, supposed to be a movement of the lab belt towards the abdomen is not reproduced in this first test. We have already stressed that the lumbar spine stiffness could be at the origin of this biofidelity problem. We propose to repeat this test with the HII dummy, which was used before the HIII appeared. The HII lumbar spine is much softer than that of the HIII, and then more in line with human being anatomy. Both are compared on figure 6

Figure 6 : HIII (left) and HII (right) lumbar spine

Keeping exactly the same test setup, a second test is performed with a HII dummy. Figure 7-a presents the test at 58ms, where the lap belt is still on the pelvis, and figure 7-b shows the situation 15ms later where the lap belt has clearly left the pelvis to move into the abdomen. Figure 8 present the sequence between 50 and 75ms. This phenomenon is also visible on the figure 9 comparing the lap belt force from the two tests. A strong force breakdown begins at 58 ms, matching with the event seen on the film.

Figure 7-a : Test 2 – HII dummy position at 58ms – lab belt still on the pelvis

Figure 7-b : Test 2 – HII dummy position at 73ms – lab belt in the abdomen

Figure 8 : Test 2 – HII dummy submarining sequence (from 50 to 75 ms)

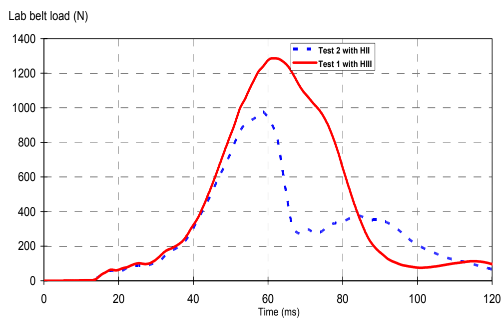


Figure 9 : Test 1&2 - lap belt forces comparison

The pictures comparison of the two tests shows that the pelvis rotation is much higher for the HII dummy, as we assumed from dummy features. This fact is checked after integration of the rotation sensors traces provided during the 2 tests, figure 10. The pelvis rotation obtained with HII raises much quicker and is almost twice more than with HIII, enabling to reproduce submarining.

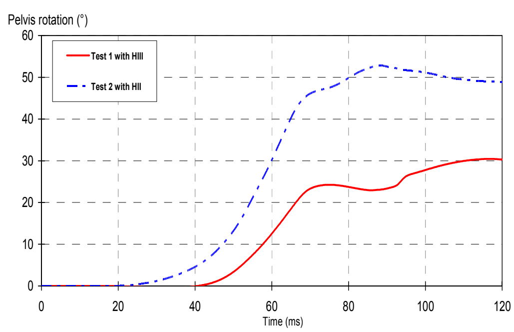


Figure 10 : Test 1&2 – pelvis rotation comparison

Keeping the same setup, the use of HII dummy instead of HIII dummy allows to reproduce the submarining phenomenon observed in real accident data.

Can submarining phenomenon be observed with another dummy than HII ?

HII dummy is barely used today since it was replaced by HIII, now used in all regulations because it is supposed to provide more information on risk in frontal impact. For example, the HII is not fitted with chest deflection sensor that is widely used today to assess risk on thorax. Going further in dummy investigation, on opportunity is to focus on the dummy used in aeronautic field, named HIII-FAA; Actually, this dummy is based on the HIII, the only differences being the lumbar spine, lumbar spine support on pelvis, upper-femur and chest flesh which are those of HII. Indeed, since HII and HIII have the same pelvis, it is easy to switch the lumbar spine. Then, a current HIII dummy, provided the FAA kit, is easily changeable towards a HIII-FAA dummy. The drawback is that current HIII chest sensor must be removed due to HII chest flesh that wraps the lower rib. Nevertheless, it is possible to replace the current sensor by a wire sensor whose data will be studied farther in this study. Figure 11 gives the wire sensor setup.

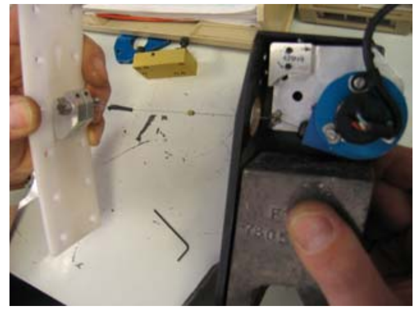


Figure 11 : detailed view of the wire sensor to replace chest deflection rod sensor

The test 3, similar to those performed before with HIII and HII dummy, is carried out with this new HIII-FAA dummy, the conditions being exactly the same. The behaviour of this new dummy is similar to the HII one, where the pelvis rotation is enabled. Figure 12 shows the dummy at around 73ms, where the lap belt is clearly in the abdomen, matching with high pelvis rotation, then reproducing the behaviour observed and expected on the HII. Figure 13 gathers the lap belt loads of the 3 tests, where traces of HII and HIII-FAA are similar, especially with the occurrence of a breakdown in force which is not present in the test involving the HIII. Figure 14 compares the pelvis rotation of the 3 tests. The magnitude of the rotation is similar for HII and HIII-FAA, and much smaller in the HIII case.

Figure 12 : Test 3 – HIII-FAA dummy position at 73ms – lab belt in the abdomen

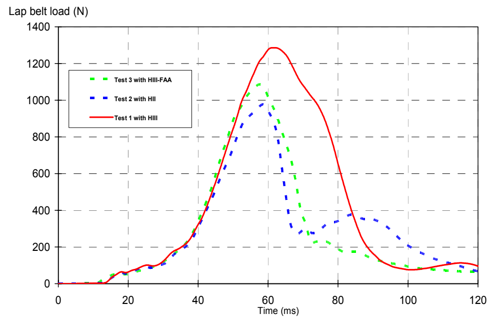


Figure 13 : Test 1, 2&3 - lap belt forces comparison

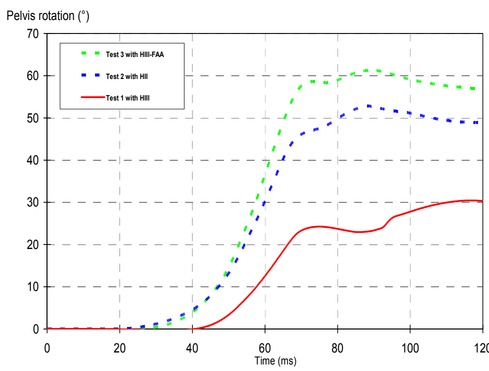


Figure 14 : Test 1, 2&3 – pelvis rotation comparison

A summary of the 3 previous tests is proposed in the table 6. 3 criteria are indicated :

- Did a lap belt load breakdown occurs during the test ?
- Is submarining visible on the film ?
- What is the maximum pelvis rotation ? Note that we considered the maximum pelvis rotation during the time the pelvis is still moving forward. Indeed, the rotation can continue to increase during the dummy rebound, when the pelvis begins to move rearward. But, after that, there is no more risk of submarining. Then the maximum pelvis rotation must be considered during the pelvis forward movement time range.

	Test #	Dummy involved	Lab belt load breakdown	Submarining on the film	Pelvis rotation (°)
Restraint system #1	1	HIII	NO	NO	30
	2	HII	YES	YES	53
	3	HIII-FAA	YES	YES	60

Table 6 : Summary of the first 3 tests with a given restraint system #1

It is now proven that the current HIII-50th is not able to detect submarining phenomenon, whereas HII and HIII-FAA does it. Especially, the most important thing is to enable the pelvis rotation which is the good indicator of the submarining risk. The lab belt load breakdown and the visual signal on the film are only consequences.

ASSESSMENT OF DIFFERENT RESTRAINT SYSTEMS WITH THE PROPOSED PROCEDURE

We now proposed to involve 2 other restraint systems, in order to highlight that this procedure can assess the performance of submarining countermeasures. Restraint system #2 is composed of a single pretension system (belt retractor), like restraint system #1 (with pyrotechnic buckle), but with a more recent seat, stiffer and including an anti-submarining steel ramp on the seat base. Restraint system #3 is the same as #2 but with a double pretension (belt retractor and pelvis pretensioner). Better results are expected with these 2 restraint systems compared to #1. Table 7 present the results for the 3 restraint systems, involving the 3 dummies. Table 8 presents the same results, but showing for each dummy, the results for every restraint system

	Test #	Dummy involved	Lab belt load breakdown	Submarining on the film	Pelvis rotation (°)
Restraint system #1	1	HIII	NO	NO	30
	2	HII	YES	YES	53
	3	HIII-FAA	YES	YES	60
Restraint system #2	4	HIII	NO	NO	17
	5	HII	NO	NO	31
	6	HIII-FAA	NO	NO	35
Restraint system #3	7	HIII	NO	NO	12
	8	HII	NO	NO	25
	9	HIII-FAA	NO	NO	30

Table 7 : Summary of the 9 tests with results relative to restraint systems

	Test #	Restraint system #	Lab belt load breakdown	Submarining on the film	Pelvis rotation (°)
HIII	1	1	NO	NO	30
	4	2	NO	NO	17
	7	3	NO	NO	12
HII	2	1	YES	YES	53
	5	2	NO	NO	31
	8	3	NO	NO	25
HIII-FAA	3	1	YES	YES	60
	6	2	NO	NO	35
	9	3	NO	NO	30

Table 8 : Summary of the 9 tests with results relative to dummies

From this new set of tests, we can deduce that HIII dummy never highlight submarining phenomenon in term of visual and lap belt load signals. We can observe that even if the pelvis rotation is less important than that got with HII and HIII-FAA, the magnitude of this rotation obtained for the 3 different restraint systems is different and vary from 12 to 30°. It would mean that the only way to assess submarining risk with this dummy is through pelvis rotation.

Regarding HII and HIII-FAA results, they are very close, especially in term of visual signal on the film and lap belt load breakdown. One difference appears: the pelvis rotation for HII seems always lower than that of HIII-FAA. We assumed that the reason comes from abdomen flesh : HIII-FAA is equipped with the current HIII abdomen, which is smaller than that of HII. Then, the bigger HII abdomen tends to prevent the pelvis rotation more than the HIII one. Anyway, the lumbar spine stiffness is overwhelming in this pelvis rotation.

Figure 15 presents a graph with the pelvis rotation obtained for the 9 tests

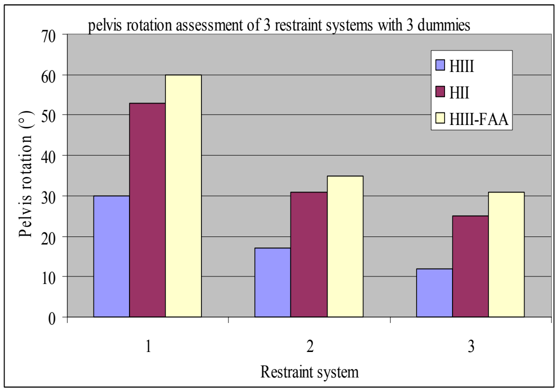


Figure 15 : pelvis rotation comparison for the 9 tests

For restraint system #1, the proposed procedure makes the link between what has been observed in real accident data and what can be highlighted in the laboratory. The laboratory test can now confirmed that this restraint system present a submarining risk in real life.

Concerning restraint system #2 and #3, no lap belt breakdown occurs and there is no visual signal on the film. The only difference is on pelvis rotation, which is 5° more important for restraint system #2 whatever the considered dummy is. One can assume that the submarining risk is higher for restraint system #2 in real life. The last part of this document will study the effectiveness of restraint system #3 since this system is really fitted in vehicles. Nevertheless, restraint system #2 matches actually with system #3 where the second pretension has been removed, and it is not fitted on real vehicles. Then its effectiveness in real world cannot be calculated.

As a partial conclusion, when a given restraint system is submitted to the previous procedure and presents the following results :

- Visible overpassing of the lap belt above the pelvis, through the film
- Lap belt load breakdown during the test
- Pelvis rotation above [55°] with HII dummy and above [60°] with HIII-FAA dummy

  → We can state that submarining risk in real life is high

- No visible overpassing of the lap belt above the pelvis, through the film
- No lap belt load breakdown during the test
- Pelvis rotation below [25°] with HII dummy and below [30°] with HIII-FAA dummy

  → We can state that submarining risk in real life is low

This last assertion needs to be confirmed with the third part of this document, where effectiveness of restraint systems #3 is studied.

Is this procedure repeatable?

All the tests already performed have been repeated and we provide those concerning restraint systems #2 as an example (tests 10 to 12). Table 9 presents the results, where no difference can be observed on neither pelvis rotation values nor lab belt load breakdown & visual signal on films.

	Test #	Dummy involved	Lab belt load breakdown	Submarining on the film	Pelvis rotation (°)
Restraint system #2	4	HIII	NO	NO	17
	10	HIII	NO	NO	18
	5	HII	NO	NO	31
	11	HII	NO	NO	30
	6	HIII-FAA	NO	NO	35
	12	HIII-FAA	NO	NO	35

Table 9 : Tests repeatability

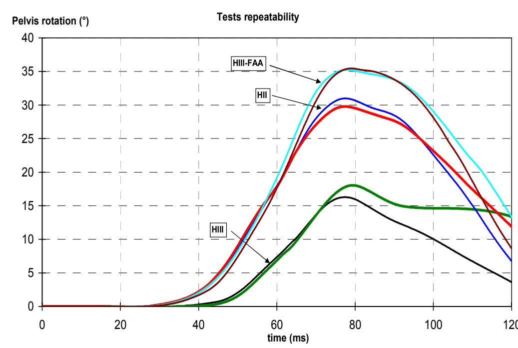


Figure 16 : Test repeatability for all dummies with restraint system #2

The previous tests are a good indication to show that the procedure is repeatable

Chest deflection

It has been mentioned that the current chest deflection sensor used in HIII dummy should be removed when using HIII-FAA, and that a wire sensor has been added in this dummy. It is now interesting to check if the data provided by the wire sensor in the HIII-FAA give similar results to those obtained with the normalized rod pot in the HIII. Table 10 presents the different values obtained regarding restraint system #3. Moreover, test #7 (involving HII) and test #9 (involving HIII-FAA) have been repeated (test #13 and #14). Figure 17 shows the chest deflection curves for the 4 tests.

	Test #	Dummy involved	Chest deflection (mm)
Restraint system #3	7	HIII	32
	13	HIII	30,3
	9	HIII-FAA	31
	14	HIII-FAA	32,4

Table 10 : Chest deflection obtained with HIII&current rod pot sensor and with HIII-FAA&wire sensor

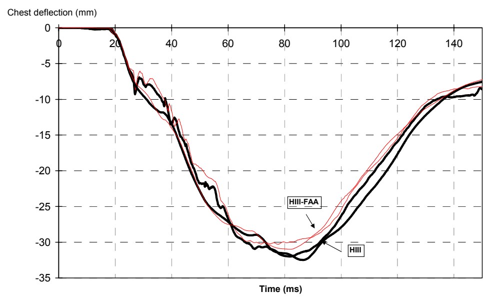


Figure 17 : Chest deflection curves got with HIII and HIII-FAA for restraint systems #3

The values are very similar and present low variation. It shows the ability of the replacing wire sensor to assess the chest risk at the same level as the current chest deflection sensor.

ACCIDENT DATA : FEEDBACK ON RECENT CARS

As submarining issue seems to be an important issue in real world accidents, especially for rear seats occupants but also for front ones, countermeasures have been developed on Renault recent cars, thanks to the procedure detailed before. A second sample S2 is considered from LAB database. It takes into account the same request as in sample S1 except that only the recent Renault cars are considered, e.g. vehicles equipped with submarining countermeasures, including antisubmarining ramp, suitable belt anchorages geometry and double pretension (for front seats) or single pretension (for rear seats). This advanced restraint system has been fitted in Laguna II for the first time in 2001 and then on most of the vehicles range. The sample obtained from the request leads to 157 front occupants (including 3 fatalities and 25 AIS3+ injured occupants) and 11 rear occupants (no fatality and 1 AIS3+ injured occupant). Fatality risk, AIS3+ risk and AIS3+ per body region risk (ρ_i), and their respective confidence interval are calculated and compared with those of sample 1 in table 11&12 (front seats occupants), and 13&14 (rear occupants).

SAMPLE 1 :

Involved occupants	1260	Risk	Confidence interval
Fatalities	74	6%	[5% - 7%]$_{95\%}$
AIS3+ injured occupants	380	30%	[28% - 33%]$_{95\%}$

SAMPLE 2 :

Involved occupants	157	Risk	Confidence interval
Fatalities	3	2%	[0% - 4%]$_{95\%}$
AIS3+ injured occupants	25	16%	[10% - 22%]$_{95\%}$

Table 11 : Fatality and AIS3+ risks for front seats occupants of sample S2 compared with S1

SAMPLE 1 :

Body region	Head	Chest	Abdomen
Severity risk AIS3+ in a given body region	4%	16%	7%
Confidence interval	[3% - 5%]$_{95\%}$	[14% - 18%]$_{95\%}$	[6% - 9%]$_{95\%}$

SAMPLE 2 :

Body region	Head	Chest	Abdomen
Severity risk AIS3+ in a given body region	3%	9%	3%
Confidence interval	[0% - 6%]$_{95\%}$	[4% - 13%]$_{95\%}$	[0% - 5%]$_{95\%}$

Table 12 : Distribution in body regions of AIS3+ risks for front seats occupants of sample S2, compared with S1

SAMPLE 1 :

Involved occupants	146	Risk	Confidence interval
Fatalities	21	14%	[9% - 20%]$_{95\%}$
AIS3+ injured occupants	55	38%	[30% - 46%]$_{95\%}$

SAMPLE 2 :

Involved occupants	11	Risk
Fatalities	0	0%
AIS3+ injured occupants	1	9%

Table 13 : Fatality and AIS3+ risks for rear seats occupants of second sample S2 compared with S1

SAMPLE 1 :

Body region	Head	Chest	Abdomen
Severity risk AIS3+ in a given body region	2%	14%	23%
Confidence interval	[0% - 4%]$_{95\%}$	[9% - 20%]$_{95\%}$	[16% - 30%]$_{95\%}$

SAMPLE 2 :

Body region	Head	Chest	Abdomen
Severity risk AIS3+ in a given body region	0%	9%	9%

Table 14 : Distribution in body regions of AIS3+ risks for rear seats occupants of sample S2, compared with S1

Comments on this cars fitted with submarining countermeasures :

- Front seats : the global fatality and AIS3+ risks are decreased respective to the first set. The main differences are on chest and especially abdomen injuries which are lower in this second set of cars. This reveals the efficiency on one hand of 4kN load limiter that allows to decrease chest load and then chest injury which confirms previous studies [6, 7] and on the other hand of submarining countermeasures fitted in these vehicles. Figure 18 shows the antisubmarining ramp in a seat after a real accident. The double pretension fitted in this car has produced a good coupling of the pelvis that was caught and restrained by the deformable ramp.

Figure 18 : front seat after real accident – pelvis impact on anti-submarining ramp

- Rear seats : The sample is too small to draw some conclusions, but the trend seems good, since no fatality has been observed yet, and the AIS3+ risk has been observed on only 1 occupant among 11. More data will be obtained in the future to validate this conclusion. Figure 19 presents a rear seat steel ramp after a real impact. The steel part is deformed highlighting that the pelvis was restrained, the pretension having taken the belt gap and stuck the occupant pelvis on the seat.

Figure 19 : rear seat after real accident – pelvis impact on anti-submarining ramp

DISCUSSION

- Accident data presented in the first part for cars with a first registration between 1990 and 2000 reveal that submarining phenomenon is at the origin of many fatalities and serious injuries in frontal impact, not only for front seats but also and especially for rear seats. The problem is due to a low performance of restraint systems in coupling the occupant pelvis, the consequence being an escape of the lap belt from the pelvis bones, and a loading of this lap belt in the abdominal soft tissues, causing rapidly serious injuries or fatalities.
- The importance of this issue comes from the difficulty to observe the problem with the current dummy used in frontal impact on one hand, and from the fact that no regulation or rating (except NCAP made by China by CATARC) is dealing with rear occupant seats on the other hand.
- For front seats, the main risk is still coming from chest, the second one being abdominal injuries.
- For rear seat, submarining phenomenon is the overwhelming priority and abdominal injuries are much more frequent than chest injuries. Only considering frontal impact fatalities, the AIS3+ risk is higher when belted than unbelted. It has been stressed already in other publications (Lamielle – AAAM 2006). The trend in recent vehicle is to decrease the passenger compartment intrusion. If the consequences are extremely positive in reducing head&chest contact to steering wheel, in lowering legs injuries due to intrusion,…it also leads to have stiffer cars and then stronger deceleration pulse. For rear seats, if one considers that the restraint device is not changed, a more severe pulse will lead to a higher abdominal risk for rear occupants. Then, if nothing is done in this area, it is expected that this phenomenon will be more and more observed in the real world.
- Coming back to the laboratory, we have explained why this issue cannot be observed today with the current HIII dummy and we propose an alternative with either the former HII dummy or HIII-FAA dummy, whose the main feature is to have a softer lumbar spine with a behaviour more in line with that of human being. These 2 ATD's show the submarining phenomenon observed in real accident data, especially through the pelvis rotation and the lap belt load breakdown. The procedure has been applied to different restraint systems whose the performance are checked in the real world. A good correlation is obtained since a poor (or good) restraint system in the real world is also assessed poor (or good) by the proposed procedure.
- The countermeasures fitted in recent Renault vehicles seem very effective. For front and rear seats, the need for load limiter is confirmed to avoid chest injuries. Load limiters are fitted in the analyzed cars, on front (4kN) and rear (6kN) seats. Data indicate a risk decreasing respective to vehicles of the 90's which were not systematically fitted with this device.
- For front and rear seats, abdominal risk is also decreased showing that the countermeasures fitted in the set of recent cars are effective, even if more data on rear seats are needed to draw conclusions . It also shows that the proposed procedure provides a good assessment of the risk.

REFERENCES

[1] Huelke D., Mackay G. & Morris A. Intrabdominal injuries associated with lap shoulder belt usage. Proc., S.A.E. Conf., S.A.E. Paper 930639; 1993.

[2] Elhagediab A. & Rouhana S. Patterns of abdominal injury in frontal automotive crashes. 16th ESV Conference, Windsor Canada, 98-Sl-W-26; 1998.

[3] Yoganandan N., Pintar F., Generalli A. & al. Patterns of abdominal injuries in frontal and side impacts. 44th Annual Proceedings Association for the Advancement of Automotive Medicine, Chicago, Illinois, 44:17-36; 2000.

[4] Huere J.F., Forêt-Bruno J.Y., Faverjon, G., Le Coz J.Y., Airbag efficiency in frontal real world accidents, 18 th ESV Conference, Amsterdam, June 2001, Paper number: 2001-S1-O-193

[5] Faverjon G. Méthodologie des enquêtes sur les accidents réels. Le concours médical 107-30, pp2834-2839; 1985.

[6] Foret-Bruno JY., Trosseille X., Page Y. & al. Comparison of thoracic injury risk in frontal car crashes for occupant retrained without belt load limiters and those restrained with 6kN and 4kN belt load limiters. Proc.45th Stapp, p375; 2001.

[7] Forêt-Bruno J.Y., Trosseille X., Le Coz J.Y., Bendjellal F., Steyer C., Phalempin T., Villeforceix D., Dandres P., Got C., Thoracic injury risk in frontal car crashes with occupant restrained with belt load limiter, SAE paper 98S-4, 1998.

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