INFLUENCE OF THE DRIVER'S POSTURE ON THE SAFETY BELT RESTRAINT DURING FRONTAL CRASH SIMULATIONS

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It is admitted that the conditions of crash simulations in the frame of compliance tests are too perfect. The present trend is to approximate more closely to the reality, mostly in the view of the "whole-vehicle performance-based test".It is therefore important to specify the simulation conditions which most affect occupant protection. Among the conditions taken into consideration, there is the seating position of the occupant.

The aim of this study was to describe some more realistic driver's postures in light cars and to evaluate their influence on the safety belt restraint efficiency in frontal crashes. On a first stage, this paper presents the survey conducted on a drivers sample whose postures have been examined after driving. Then a dynamic tests series simulated with a dummy will be detailled in order to analyse the influence of parameters such as seat and restraint characteristics,pelvis orientation, body joints stiffness, body segments modelisation.

I. STUDY OF THE DRIVER'S POSTURE

I.1. Conditions required

If we consider the position of a subject in a car on the one hand, and if we try to re-create it in a simulated surroundings on the other hand, it is not rare to find out notable differences. Therefore it is important to examine the position of the occupant in the real car compartment, which has been done in this study but firstly with the restriction to the case the sole driver. Indeed his posture presents an ergonomic aspect which does not exist for the passengers. We noticed, during a preliminary experiment, that it was necessary to make subjects drive before the measurement of their position. Indeed this position becomes stable only after the achievement of different gestures necessary for driving.

These different imperatives have conducted us to give up a radiographic technique as that used by NYQUIST (1) and HOLT (2). Therefore we used two types of experiments aiming to know the subject's position :

- firstly, in their OWN vehicle
- secondly, in a SAME vehicle

I.2. Driver's posture in their own car

The aim of this manipulation was to know the position of lap belt with regard to the subject's pelvis after a short drive. The technic itself is identical with the one established by Traffic Accident Research Unit (Australia) and described by HOLT (2) and HERBERT (3).

Two consecutive photographs of the lower part of the subject's body in driving position are taken. On the first photograph the driver is wearing his belt. On the second one, the belt is taken off, and the locations of the left iliac crest and of the trochanter major are pointed out by the operator's indexes.The manipulation is completed by measuring some parameters such as seat back angle, seat forward motion, length of webbing stored in the retractor and "pelvis angle". This last angle is measured with a rigid plate which is held by the driver himself against his iliac crests and his pubic crest. The geometrical characteristics of the pelvis restraint are determined from the set of photographs and from the different measurements. The definition of these parameters are shown on figure 1.

Ten subject's positions have been determined. Two of them have been tested two times.

The different results are collected in the figure 1. It is to be noted that the determination of the left antero-superior iliac crest is a relatively easy operation, but the trochanter major is more difficult to be located, particularly for some subjects in seating position. The method used to determine the pelvic reference line was quite constraining for the subjects ; some of them did not succeed in finding the three contact points between the rigid plate and the pelvis bone.

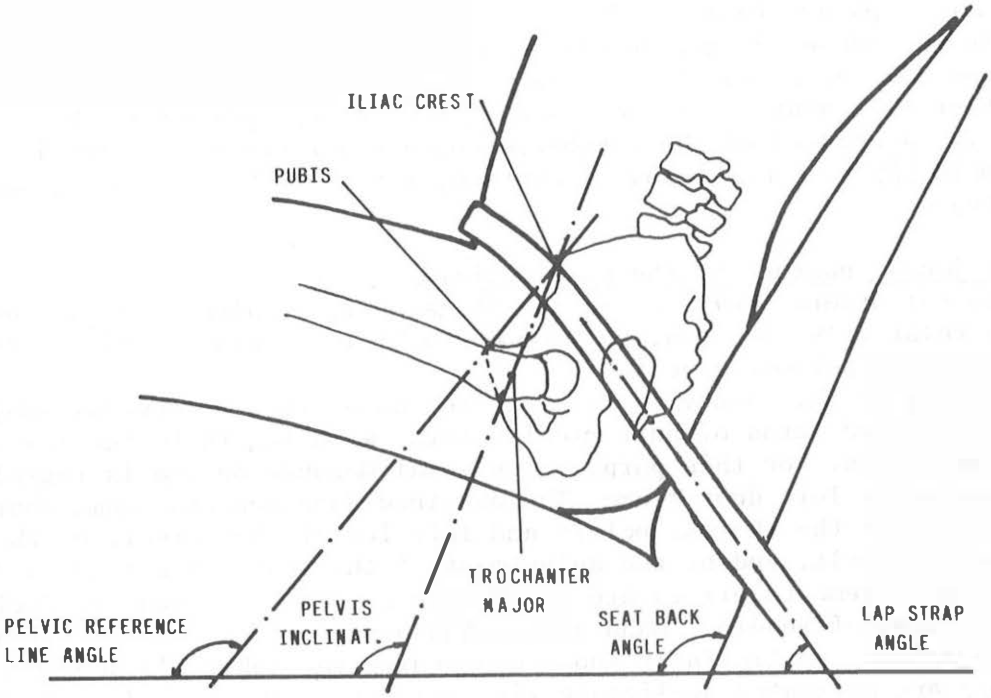
The next table indicates the extreme and mean values of the differents parameters.

Parameter	Unit	min value	MEAN VALUE	max value
Pelvis inclination	°/H	92	107	118
Pelvic reference line angle	°/H	135	143	156
Femur angle	°/H	6	20	26
Lap strap angle	°/H	47	54	66
Pelvis depth	mm	99	110	124
Seat back angle	°/H	106	111	116
Stored belt length in retractor	mm	520	759	930

Some values are very close to the ones found out by HOLT (2), more particularly the pelvis inclination. In contrary to HOLT, no relationship can be found between one of the parameters and the seat back angle. As a matter of fact, the seats occupied by our subjects were different and the seat back angle mean value is only given as an indication. As concerns the pelvic reference line angle, three subjects are distinguishable from the others two of them presenting a "honest paunch". In the same way these most corpulent subjects appear to have the least vertical seat back.

It is well known that the lap strap must not pass over the iliac crests and penetrate into the abdomen during a crash, to avoid serious lesions. The potential danger sustained by the occupants has been estimated for the sole restraint of the pelvis, by considering the respective position of the lap belt and the pelvis.

So, among the 12 observations, it can be judged that 4 cases are acceptable, i.e the webbing is below the iliac crest, 4 cases are hardly acceptable



Subject	Sex	Mass (kg)	Stature (cm)	Pelvic Inclin.(°/H)	Pelvis Ref. Line (°/H)	Lap Strap Angle(°/H)
1	M	66	174	103	145	47
2	F	51	162	110	142	57
3	M	82	170	118	135	31 *
4	M	68	174	103	146	51
5	M	76	178	116	143	58
6	M	67	172	114	148	66
7	M	78	172	95	156	57
8	M	63	172	-	135	52
9 A	F	50	165	(97)	140	52
9 B	F	50	165	92	147	51
10 A	M	80	169	117	140	48 *
10 B	M	80	169	102	142	52 *

* Strap pinched in the seat adjustment handle

Fig. 1 : Posture parameters for drivers in their own car

and the last cases are really bad. It is difficult to put these results in relation to the subjects' morphology because of the differences in driving surroundings and car seats. But, it is noticed that the the 4 occupants with the best restraint of the pelvis have the longest pelvis depth.

Finally, 4 drivers can be estimated correctly restrained, that is 33% of the sample ;it is a really low percentage, for the cars are common and not very old types.

I.3. Subjects' posture in the same vehicle

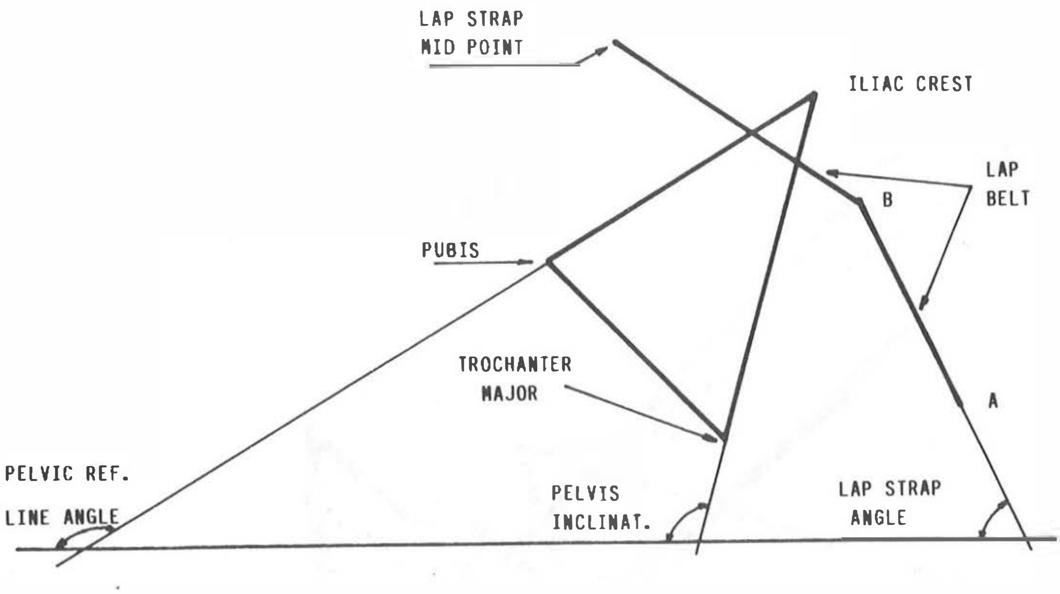
The volunteers' position is investigated in a Talbot 1307 Limousine which is a relatively spacious, very common vehicle in France. The restraint is a three points automatic belt.

The aim of this study is to evaluate the posture of several subjects by noting the coordinates of anatomical points, with regard to the reference of the vehicle axis. For this purpose a special measure device is rigidly fixed to the front left door frame. The obtained data concern some characteristic points of the thorax, pelvis and left leg of the driver, of the shoulder and lap belt, and of the adjustment of the seat. (See figures 2 and 4). The measurements errors are due to two causes : the measure device itself (precision of reading, manufacture and position) and the localization of measured points, particularly those concerning the subject's anatomy. The first errors are estimated negligible with respect to the second ones. The largest error is related to the palpation of the trochanter major (± 5 mm). The posture of 11 drivers has been studied ; 8 of them have already been observed in their own car.

Study of the pelvis restraint

The pelvis seen in profile plane (i.e in the plane XZ of the car) can be schematized by a triangle, the apexes being the iliac crest, the "pubis" point and the trochanter major (fig. 2). Our pelvic triangle differs from the triangle described by NYQUIST (1) who utilizes the H-point (the center of the head of the femur) defined by X-ray examination, instead of the trochanter major. The pelvic reference line angle is calculated from the coordinates gathering which is a different procedure from the preceeding one. So the main parameters are collected on figure 2. The following extreme and mean values are interesting to comment :

Parameter	Unit	min value	MEAN VALUE	max value
Pelvis inclination	°/H	93	102	111
Pelvic reference line angle	°/H	139	148	161
Femur angle	°/H	15	20.5	27
Lap strap angle	°/H	52	59	69
Pelvis depth	mm	91	107	136
Pelvic reference line length	mm	74	91	113
Seat forward motion	mm	10	50.5	87
Seat back angle	°/H	103	110	118
Stored belt length	mm	520	650	700



Subject	Sex	Mass (kg)	Stature (cm)	Pelvic Inclin(°/H)	Pelvic Ref. Line (°/H)	Lap Strap Angle (°/H)
1	F	52	162	103	142	59
2	F	50	164	98	139	56
3	M	80	169	103	161	61
4	M	64	170	108	145	60
5	M	67	170	100	145	57
6	M	65	172	93	146	55
7	M	67	172	107	158	63
8	M	83	172	103	155	52
9	M	67	174	111	150	60
10	M	75	178	94	146	61
11	M	70	187	104	143	69
H II	M	74	(175)	90	137	57

Fig. 2 : Pelvis posture for drivers in the Talbot 1307 car

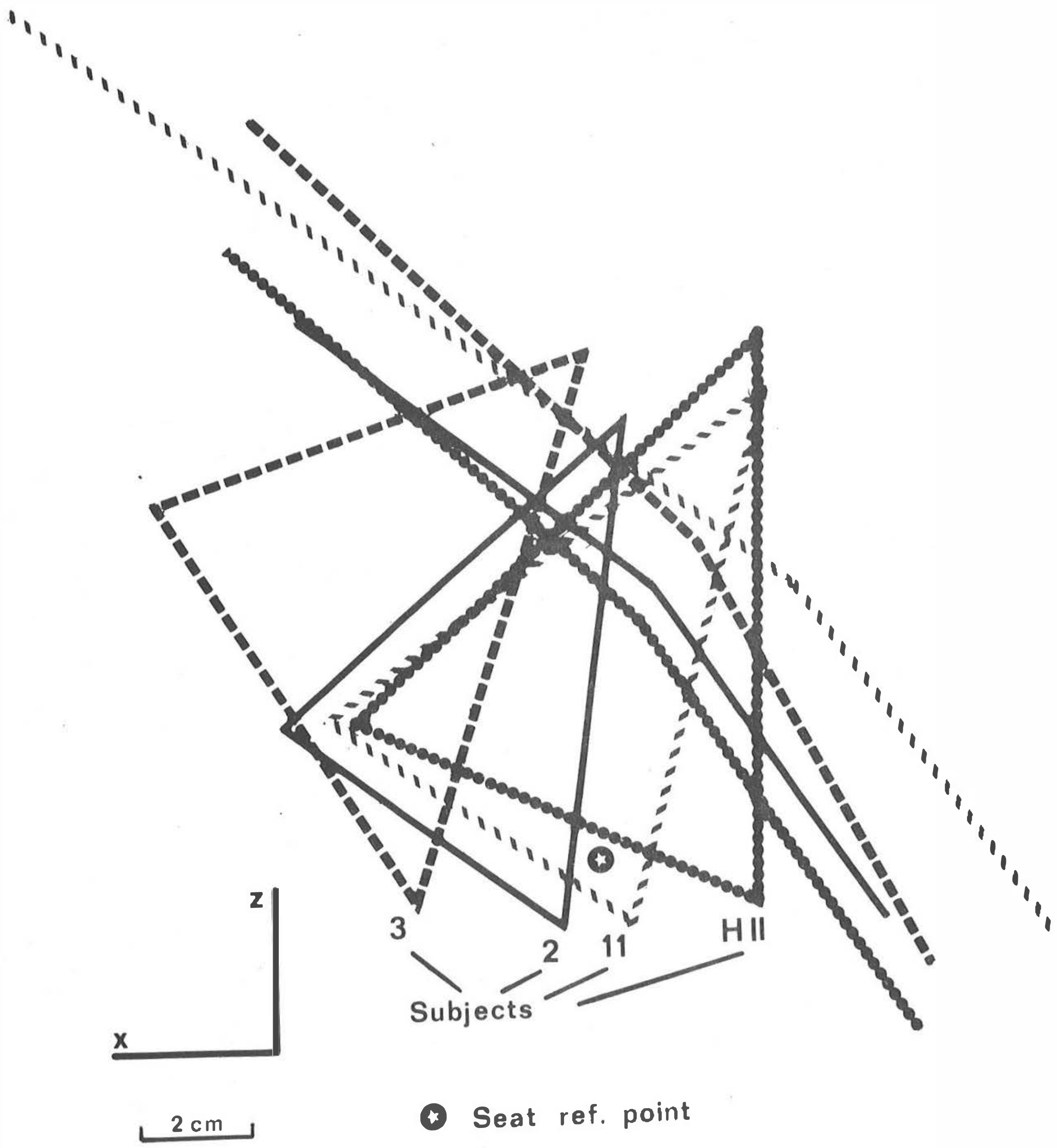


Fig. 3 : Pelvic triangle and lap strap positions in the 1307 car seat.

Generally speaking, no clear relationship can be found between the different data of the pelvic triangle and the subjects' stature or weight. It appears only that the heavier the driver is, the more important the pelvic reference line inclination tends to be. Moreover the two women of our sample have the most vertical pelvic reference line inclination. Further more they have the smallest seat back angle, that had been observed in their own vehicle.

HOLT (2) found a relationship between the pelvis inclination and the seat back angle with subjects on a wooden seat. As for us, we cannot detect this relationship, but we find that the pelvic reference line angle depends on the seat back angle. The more vertical is the seat, the more vertical is the pelvic reference (smaller angle). Two subjects diverge from the average ; one has the highest stature, the other has the most important embonpoint.

The positions of pelvic triangles are given on figure 3 for three subjects. Two of them (n° 3 and 11) have the most extreme position in the sample which can be compared to the seat reference point, defined with the three dimensional H point machine following the SAE procedure.

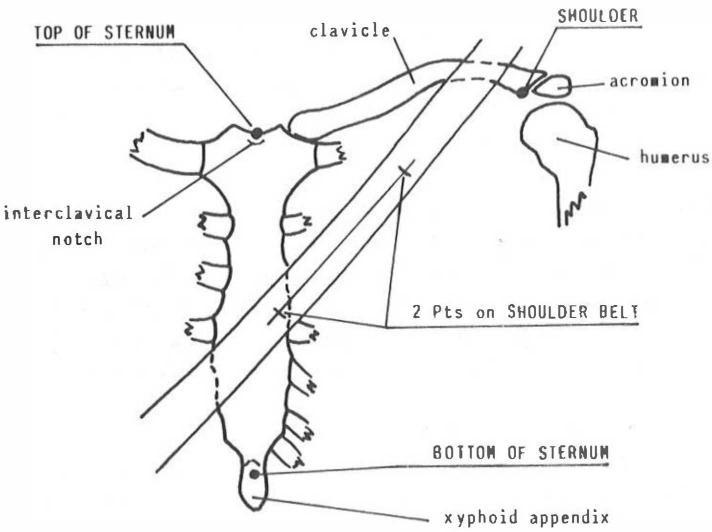
The variation of the lap strap angle is very small if we take into account the diversity of seat adjustments and subjects' morphologies. No direct relationship can be found between the lap strap angle and the seat forward motion on the one hand, or the importance of abdomen on the other hand.

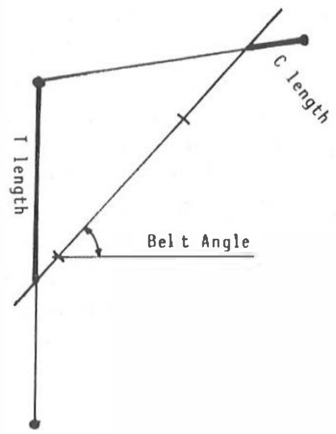
Finally, the restraint of the pelvis appears more favourable than in the first observation. As a matter of fact, in the 1307 Talbot, there is no subject with the lap belt over the iliac crest. Only four cases show a location of the belt relatively near the iliac crest. On the other hand, with the use of this method which allows us to obtain accurate coordinates, the lap belt position can neither be connected with the subject's anatomy nor with the seat adjustment.

Study of the thorax restraint

The thorax restraint can be described in the YZ plane (transversal) by the parameters shown on figure 4 which give good informations on the geometry of the sash belt relative to the thorax. In the longitudinal plane XZ, the sternum and torso line angles are the only measured parameters. So the further on table indicates the extreme and mean values of these parameters.

Parameter	Unit	min value	MEAN VALUE	max value
Calculated sternum angle	°/V	14	25	37
"Torso Line" angle	°/V	14	20	25
Seat back angle	°/V	13	20	29
Distance C : Belt center line/ clavicle extremity	mm	9	38	75
Distance T : Belt center line/ top of the sternum	mm	65	92	164
Shoulder belt angle	°/H	33	40	45





Subject	Sex	Mass kg	Stature cm	C mm	T mm	Belt angle °/H	Torso line Angle °/H
1	F	52	162	62	72	42	113
2	F	50	164	46	110	41.5	109
3	M	80	169	47	69	37.5	115
4	M	64	170	-	90	40.5	108
5	M	67	170	44	94	41.5	110
6	M	65	172	75	73	42	104
7	M	67	172	33	103	43	114
8	M	83	172	54	65	36	110
9	M	67	174	31	99	38	112
10	M	75	178	9	70	33	111
11	M	70	187	16	164	45.5	110
H II	M	74	(175)	60	79	41	117

Fig. 4 : Thorax posture for drivers in the Talbot 1307 car

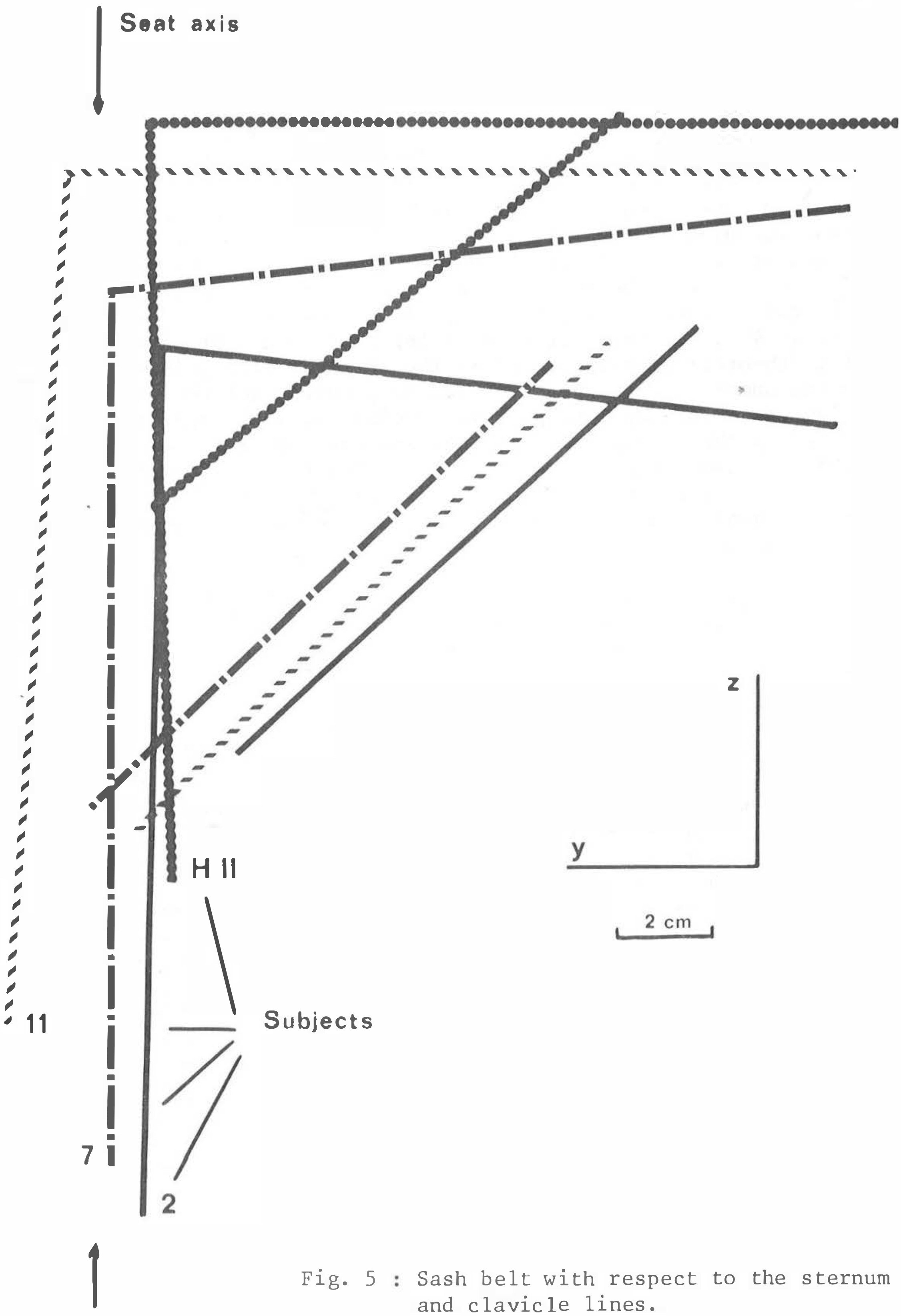


Fig. 5 : Sash belt with respect to the sternum and clavicle lines.

In agreement with HASLEGRAVE (4) we estimate that "the belt should not be liable to slip off the shoulder and should not chafe the subject's neck" for reasons of comfort and safety. So examining the position of the belt relative to the clavicle, two extreme cases correspond to tall subjects (n° 10 and 11) who drive with a seat in rearward location and so have the sash belt very close to the shoulder edge. For the remaining subjects, the belt is located on an average at one third of the clavicle from the shoulder (length ratio comprised between 21 and 54%).

Concerning the crossing of the belt on the sternum (fig. 5), we can notice that the highest crossing refers to the fattest subject, whereas the diagonal strap is nearly on the bottom of the sternum of the tallest one. Eliminating again these two subjects, and comparing the distance T with respect to the sternum length, the range lies between 41% and 61%. The mean value is 49%, i.e the belt crosses the sternum almost on the middle of it. The "theoretical torso line" is the straight line joining the H point to the humerus center of rotation. But, having not the possibility of locating the points by external examination, we shall approximate the "torso line" by the straight line connecting the end of the clavicle to the trochanter major, that corresponds to a 20mm forward translation from the theoretical line. So this torso line is easily measurable.(fig.4).

For our sample, the difference between the torso line angle and the seat back angle never exceeds 4° except for the subject 1.

1.4. Posture of an HYBRID II dummy in the 1307 Talbot limousine

With the object of making a comparative study of the posture between the dummy and the human subject, the 50th percentile male HYBRID II has been placed in the 1307 Talbot limousine. The process for noting the position is the same that this used for human subjects, except that here a special device is used to know the different parameters of the pelvic triangle, for which the H point replaces the trochanter major. The Figures 3 and 5 show the pelvic triangle and thorax positions of the dummy.

Comparing the positions of HYBRID II with these of our subjects, it is noticeable that the thorax of the dummy is higher and that its pelvis goes deeper in the seat. Moreover the H-point of HYBRID II is about 3 to 4 cm behind the seat reference point.

Concerning the pelvis, we can notice several differences. The pelvis reference line angle is lower than the least of the values found among the human subjects. The distance between the iliac crest and the lap belt centre line is really superior to the highest of the subjects values.

With regard to the thorax, the angle of the shoulder belt projection in a YZ plane is 41° with respect to the horizontal line ; this value is situated in the middle of the values range for human subjects. Still it can be noted that the position of the shoulder belt is nearly in the middle of the clavicle : 44% for the HYBRID II instead of 37% among the sample drivers. As a matter of fact, as it is shown on the figure 5 the dummy, which is more rigid than a human being having the same height, is about 3 cm higher than this one.

To sum up, this comparison let us ascertain that the HYBRID II dummy is in better restraint conditions than a human subject of the same height.

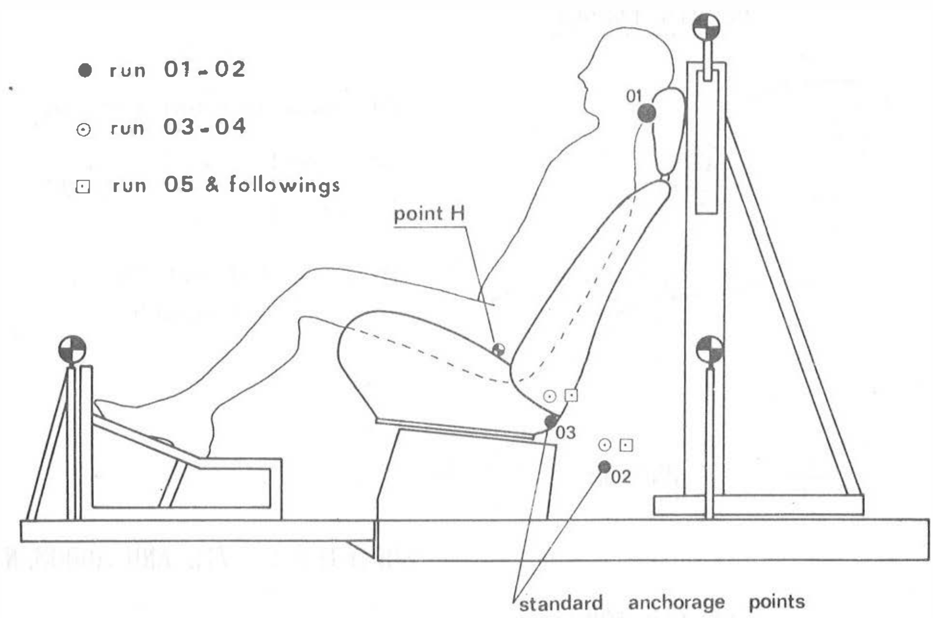
II.INFLUENCE OF SOME POSTURE PARAMETERS ON THE OCCUPANT KINEMATICS

After considering the results obtained from the preceeding investigations on the driver's posture, two kinds of parameters have been chosen in the aim of studying their influence on the occupant kinematics during a frontal crash simulation. The first ones are related to the vehicle environment : belt adjustment, pelvis position on the seat, seat stiffness and anchorage points positions. The second ones concern the body modelisation : pelvis and abdomen characteristics, joints stiffness.

The influence of these factors has been analysed through a dynamic sled test series with special emphasis on the pelvis behaviour and risks of submarining with a three point belt.

II.1. Description of the tests

On the ONSER sled are installed the seat of a vehicle (new for each test), the HYBRID II Dummy (carefully positionned) and the anchorage points of the manually adjusted belt (50 mm width, 13% elongation under 10 kN). No front structure is simulated.



The test velocity varied between 49 and 50 km/h ; the sled is stopped with a deceleration pulse simulating that of a light vehicle against a barrier, which corresponds to a level of about 20 G. The recordings of the head, thorax, pelvis acceleration and of the belt tensile loads at the lower anchorage points (O2, O3) are complemented by cinematographic analyses resulting from an adequate targetting of the pelvis and the femurs. The submarining phenomenon is judged with the two techniques now available and experienced by other laboratories. Load transducers are implanted on each side of the dummy pelvis : the CIC is inserted at the upper extremity of the iliac crest and submarining is detected when the signal fall time is less than 5 ms (DEJEAMMES- 5). The CAPR is fixed on the iliac wedge behind the crest and submarining is dangerous when the load is too high (> 800 N, limit value on discussion) LEUNG (6).

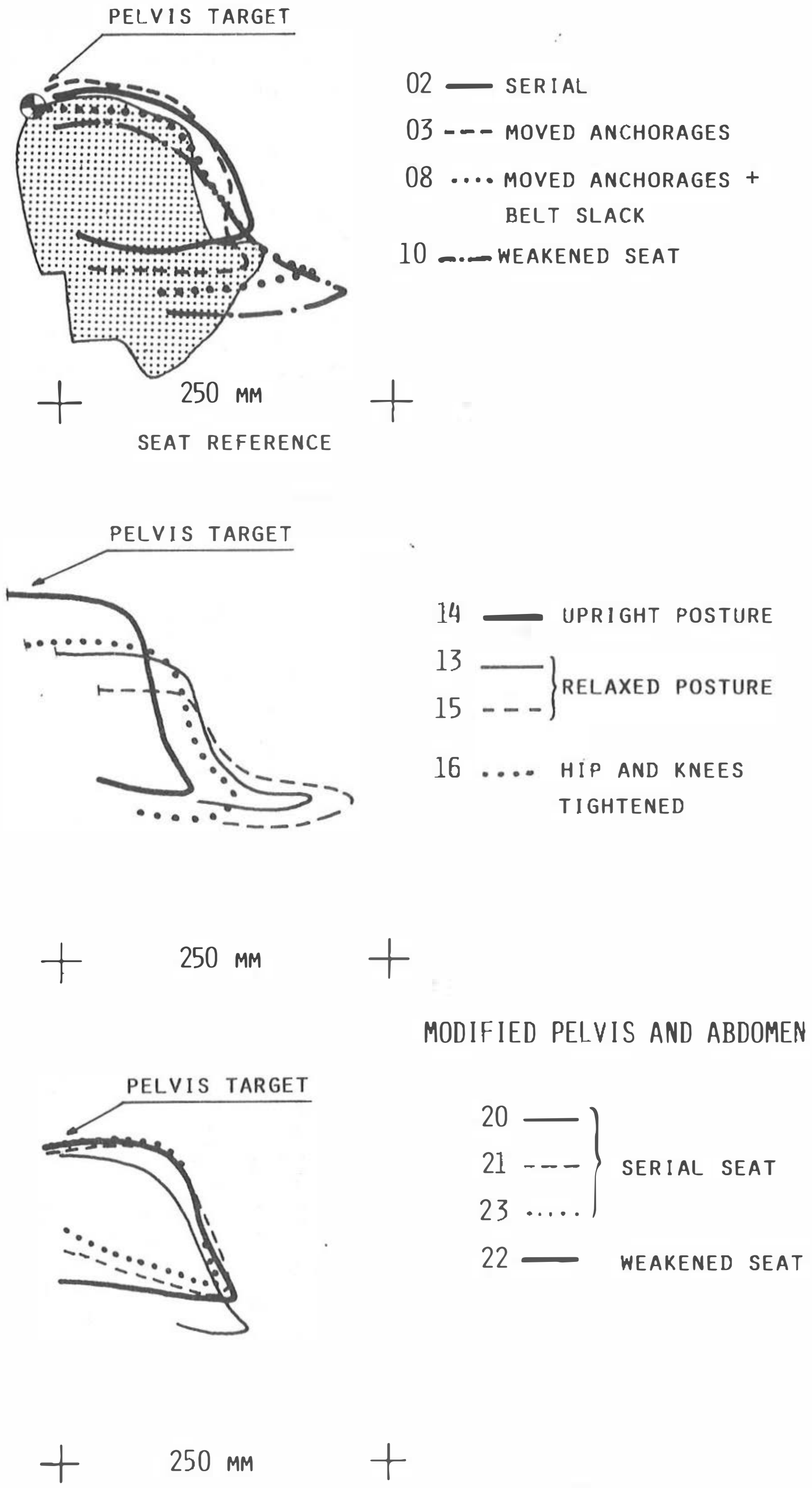


Fig. 6 : Pelvis trajectories for different dummy postures and modelisations.

II.2 Influence of vehicle environment

The first test configuration is that a French car with the seat in middle position. It has been successively modified in a way increasing the submarining risks : moving the lower belt anchorages upwards and backwards (the lap belt becomes more horizontal), loosening the belt adjustment and weakening the seat cushion frame. The runs conditions are as follows :

Run	Lower anch. (mm)	Belt slack(mm) lap	sash	Seat
01-02	serial	25	0	serial
03	Z + 50	25	0	serial
04	Z + 50	30	30	serial
05 to 08	X,Z + 50	30	30	serial
09-10	X,Z + 50	30	30	weak

These modifications affects the pelvis trajectories and consequently the overall kinematics. During runs 01-02 considered as the reference, no submarining phenomenon is visible on the films nor from the pelvis load traces. The effect of the upward movement of the lower anchorage points is an increased displacement mainly in Z direction and an increased rotation of the pelvis during the restraint (run 03). The combination of anchorage points modification and belt slack has a much more clear influence. The pelvis motion is given on figure 6 on the site of the outer anchorage O_3. The tendancy expressed earlier is confirmed and it can be concluded from the film as well as from the CIC and CAPR transducers that submarining occured in runs 05-07-08. Run 06 is a borderline case. The dummy experiences as compared to the first runs, a decreased head horizontal displacement and an increased vertical displacement.

The weakened seat cushion amplifies the submarining phenomenon as seen on figure 6. It must be noted that the left CAPR load does not reflect the exact importance of submarining as in fact it has been so great that the lap strap came over this transducer penetrating further more in the abdomen (run10)

The important role of the seat on the safety belt restraint is now taken into account by the designers. ADOMEIT (7), STATES (8) and SVENSSON (9) have indicated that a stiffer seat cushion could diminish the head criterion by diminishing the risk of submarining. LUNDELL (10) has applied the same concept for the improvement of rear safety belts.

II.3. Influence of body modelisation

Among the parameters describing the occupant posture, our interest will concentrate on the pelvis and lower body ones.

The pelvis inclination has been identified as a parameter likely to vary widely from the above survey. Considering the Hybrid II dummy and the seat chosen for this experiment, the pelvis inclination has been measured prior to each test and its value was quite repetitive, that is 144°/Horizontal. A "relaxed" position of the pelvis can be easily obtained without changing the seat nor the dummy adjustments. Only the H point is situated a little forward. The inclination obtained is 154 and 159°/H. But in order to reach an upright position, the seat back must be set right. The inclination is 137°/H.

When comparing the pelvis trajectories (fig. 6) to that of runs 05 to 08, it can be seen that the submarining is more obvious in the relaxed posture and that the lap belt stays under the iliac crests when the pelvis is upright, even with the slight decrease of its inclination (-7°). This appears on the CIC traces (the CAPR were not recorded). Moreover the thorax hardly rotates around the sash belt in case of relaxed posture and submarining.

The stiffness of the knees and hip joints can be modified in order to simulate the possible effect of muscle tone on the body restraint. The part 572 standard prescribes a "joint adjustment to 1 G". All the preceeding runs were performed with this adjustment. Run 16 is undertaken after tightening the joints (10 mN on each hip, 5 mN on each knee). The other test conditions are that of runs 05 to 08. So even from the analysis of only one run, it can be concluded that submarining does not occur when the lower extremities joints are tightened (fig.6). The same tendancy has been highlighted by LEVINE (11) by experimental simulations with human cadavers.

The pelvis and abdomen modelisation must be considered. LEUNG (6) indicated that the simulation of pelvic bone and abdomen was not realistic enough on the part 572 dummy and realised the modification of the Sartorius notch and the abdominal insert. This new pelvis has been tested three times in the same conditions as runs 05 to 08 and one time with a weakened seat as in runs 09 and 10. It appears that the dummy with the modified pelvis does not submarine even on the weakened seat. The loads recorded on the CAPR transducers are very low ($<$400 N) and correspond to a compression through the foam with no direct support of the lap belt. The trajectories of the pelvis (fig. 6) are quite similar in the four tests and comparable to that of the upright pelvis (run 14). In fact, a more detailled examination of the film indicates that the pelvis modification tends to stop the lap belt motion which applies its restraining load directly on the Sartorius notch. It provokes a reduction of submarining risks.

Another parameter of the dummy modelisation is cited as being non realistic on the part 572 HYBRID II : the mass distribution between the tighs and the pelvis. FOSTER (12) and HUBBARD (13) indicated that following the more recent knowledge, a mass of 4.7 kg should be transferred from the tighs to the pelvis. Such a modification is achieved on the HYBRID III dummy made by General Motors. This mass is not distributed but concentrated at the junction of the lumbar spine. So the center of gravity is moved upwards and backwards on this dummy.

CONCLUSION

In view of defining some more realistic occupant situations and modelisations, the survey of the driver's posture has been undertaken by using two procedures : different drivers in their own vehicle and a sample of drivers in a chosen one after a driving period. From the results it appeared difficult to correlate different posture parameters to morphological characteristics. The first survey in various vehicles indicated that the variations of the parameters defining the pelvis and abdomen positions are less important than one would have expected. The main important fact is that the lap strap is often worn with a limit, even dangerous position. From the second survey, while making the needed reservations due to the use of only one vehicle and to a small sample, it appeared that the scatterings of the pelvis orientation are quite important all the more as the possible variation for each subject is not taken into account. On the contrary the lap belt angulation has a small scattering. On another hand, the overall geometrical configuration (belt/squeletton) is less widespread for the thorax than for the pelvis. So the thoracic restraint has been appreciated as favourable.

When comparing these findings to be corresponding situation of the part 572 dummy, it must be emphasized that this modelisation of the human being presents a great overall rigidity which gives a straight and high posture on the seat, a more upright orientation of the pelvis and a H point situated more backwards. And generally speaking, the position of both straps on the dummy should be more efficient for the three point belt restraint.

These data have argued the experimental phase of our study. Technical improvements of the three point belt restraint are possible by special researches on the seat characteristics and anchorage points location. But for there evaluations, the dummy modelisation needs to be more and more realistic. This experimental study has indicated the important influence of the posture on the whole body kinematics. As concerns the submarining phenomenon, it has been identified that the dummy pelvis orientation has a great importance ; a more upright position prevents it from submarining. Moreover the stiffening of knee and hip joints on one hand or the modification of the pelvis frame and abdomen insert proposed by APR on the other hand, act in the same way.

The two stages of this study confirm the great complexity of the occupant's posture in a car seat and its influence on the dynamic body behaviour during a crash. It let us emphasize that it is important to carry on the research of a more realistic model by reference to the precise analysis of the human being posture and the dynamic behaviour of surrogates. In our point of view, for an improvement of the dummy in terms of submarining, parameters such as pelvic frame simulation, weight distribution, lumbar spine geometry should be checked.

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