SIMULATION OF THE HUMAN BEHAVIOUR IN LATERAL IMPACT

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INTRODUCTION

In order to evaluate lateral protection provided for the occupants of vehicles according to the Composite Test Procedure , it is necessary to have a mathematical modelization of the occupant. Due to the lack of a sufficiently human-like test dummy (1-2-3), this model must be made from data related to the dynamic behaviour of the human being under lateral impact.
In the absence of sufficient data characterising the stiffness and the viscous effect of each part of the body , the European Automobile Manufacturers Association has undertaken a programme of cadaver tests to acquire the data required for modelization of the human being, integrating the role of the arm and the shoulder.
5 static tests with 2 cadavers and 17 dynamic impactor tests with 5 cadavers have been carried out to characterize the lateral responses of the human being.
Two impact model responses were investigated and validated in comparison with the cadaver impactor tests :
- model with arm and shoulder interposed called "passenger arm position."
- model without arm and shoulder interposed called "driver arm position."

EXPERIMENTAL MATERIALS AND METHODS

Static tests

In order to define :
- the combined stiffness of the rib cage and shoulder (KO and K1),
- the stiffness of the thorax (K1), of the arm (K3), and pelvis (K5),

static tests on cadavers, whose anthropometric characteristics were close to 50th percentile male, were carried out (see tests MS 404, MS 402, MS 422 -annex 1).
For these tests, the human being was compressed by means of a rigid flat impactor (240 x 240 mm).
The deflection was measured with a linear potentiometer.
The force applied by the impactor was measured with 3 piezo resistive sensors.
The results in terms of force deflection characteristics are given figure 1.

Dynamic tests

In order to approach :
- the dynamic stiffness of the arm and pelvis,
- the viscous component of the thorax,
- the effective mass of the pelvis, the arm , the ribs and the thorax

17 dynamic impactor tests were carried out with 5 cadavers.
The test matrix is shown below :

	IMPACT VELOCITY (m/s)		
TEST CONDITIONS	4.4	6.7	9.3
Impact on pelvis (whole subject)	393-1 * 393-2 * 394	393-3 * 396-2	395-2
Impact on pelvis (subject without thorax)	393-5 * 394-5	393-6 * 396-5 406-1	394-6
Impact on thorax (without arm and shoulder interposed)	393-4 *		
Impact on thorax **(with arm and shoulder interposed)	394-2	396-1	395-1
Impact on thorax (with shoulder but without arm interposed)		406-2	

* For the cadaver MS 393 (tests 1 to 6) the impactor shape was a 15 cm diameter disc with edges rounded. The other cadaver tests were conducted with a square plate (240 x 240 mm) impactor.

** Impact on thorax with arm and shoulder interposed means a position where the upper arm is virtually parallel to the spine and to the outside surface of the thorax, with the upper arm resting on the surface of the thorax.

Each impact configuration has been performed for 3 values of impact velocity and the averages are given below.

4.4 m/s (x = 4.38 m/s	SD = 0.18	n = 7)
6.7 m/s (x = 6.61 m/s	SD = 0.10	n = 7)
9.3 m/s (x = 9.41 m/s	SD = 0.33	n = 3)

For the pelvis tests several impacts were conducted on the same subject : tests on the whole subject and test on pelvis alone, without trunk.
After the test on the whole subject and before the test on the pelvis alone, X-rays were taken in order to verify the absence of pelvic fracture or femur fracture.
Pelvis impacts were conducted with the impactor approximately centred on the great trochanter. Taking into account the dimensions of the square plate, the center of the plate was approximately 35 mm above the center of the great trochanter.

Selection, preparation

The unembalmed cadavers used for static and dynamic tests were provided through the Department of Anatomy of "Faculté des St Pères" in Paris. They had an average age of 60 years and average body weight of 72 kg; anthropometric characteristics are given in annex 2.

Instrumentation

The instrumentation used for thorax and pelvis impacts is described in annex 2.
In order to measure the transversal rib accelerations, transducer mounts are directly bound on the ribs.
The other transducer mounts (spine, arm, sacrum, sternum) are screwed into the bones.
With the aim of determining the time of contact, a net is plastered onto the impacted area and a second onto the impactor.
For the tests on the pelvis alone, only the impactor acceleration and the triaxial acceleration on the sacrum are measured.

Deflection response

A specific device was developed by the laboratory. The instantaneous deflection, in the transversal axis of the thorax, is measured by means of a linear potentiometer (ranges 150 mm) with a mobile rod through the thorax between the 6th and 7th ribs. The mobile rod is sewn to the skin and the potentiometer is fixed on a rigid device screwed on the spine between T4 and T7 levels.
The mobile rod is centred on the middle axis of the impactor.The mobile mass was 250 grams.

Necropsy

The rib bone condition factor (4) was evaluated for each subject. This value is given in annex 2 with the anthropometric data.
A synthesis of the lesions observed at autopsy is given in annex 2.

CONSTRUCTION OF THE MODEL

In a previous study (5-6) APR had already presented an approach by mathematical modelization of the dynamic behaviour of the human being under lateral impact.
The model of the thorax had been validated on the basis of ISO DP 9790 N°3 - reference data and Viano raw data (7). With respect to the VIANO tests, the response of this model in terms of force, deflection and Viscous .Criterion. was within the dispersion of the cadavers test results.
At this stage of development the mass located at the periphery of the thorax was near 0.Moreover the constant values of spring and damper were determined by a heuristic approach.
On the basis of the complementary test programme presented in this paper we have refined this model in order to take into account the role of the skin , the arm and the shoulder.
Two possibilities of impact response model were investigated :

"Driver arm position" means a position of the upper arm that would result from placing the hands of a normally seated driver on the steering wheel rim, in a "ten to two" position, so as to completely expose the thorax.

"Passenger arm position" means a position where the upper arm is virtually parallel to the spine and to the outside surface of the thorax, with the upper arm resting on the surface of the thorax ; so in this configuration the upper arm and shoulder are interposed with the thorax.

MODEL SIMULATING THE "DRIVER ARM POSITION"

The approach which seemed the most satisfactory is given annex 3. This is in accordance with the work of Hung Hsu Chen (8) and Langdon (9).

Calculation of the effective mass of the thorax

The thorax effective mass can be calculated by dividing the impulse of the impactor by the variation of the transverse velocity measured on the spine (T4). The mass was calculated at the time where T4 and impactor velocity are identical. At this time the pelvis acceleration is neglectable and thus the effect of the thorax/pelvis coupling is obviated.

For new APR data the results are given in the table 1.

With the exception of the subject MS 396.1 which had a total weight of 90 kg we observed :

- that the effective mass of the thorax does not vary in the range of the subject total weight between 64 kg and 77 kg,
- that the thorax effective mass does not vary as a function of the impact velocity,
- that the thorax effective mass does not vary according to the test conditions (with or without arm and shoulder interposed).

On the basis of our sample a standard thorax effective mass of 24.4 kg is proposed.

ROBBINS (10) proposed for the 50th percentile male (76.5 kg) a mass of 25.09 kg , of which 22.87 kg for the thorax and 2.22 kg for the abdomen.

TABLE 1 :COMPUTATION OF THE THORAX EFFECTIVE MASS - IMPACTOR TESTS ON THE THORAX AT 90° ANGLE (M = 23.4 KG - 240 X 240 MM)

Test N°	Impact configuration	Subject mass (Kg)	Impact velocity (m/s)	Thorax effective mass (Kg)	Impactor shape (mm)
MS 393-4	without arm and shoulder interposed	67	4.47	24	disc O 150
MS 394-2 MS 395-1 MS 396-1	with arm and shoulder interposed	64 77 90	4.41 9.63 6.66	24.9 24 34	square plate 240 x 240
MS 406-1	only shoulder interposed	70	6.71	24.7	

Determination of the dynamic behaviour of the skin covering the ribs (k2)

The force deflection characteristics of the skin covering the ribs was obtained on the basis of free fall tests with rigid thorax shape (figure 1) covered by a sample of skin and ribs taken from a cadaver.The specimen of skin was cut off between the 4th and 8th ribs in the middle of the right side of the thorax (Dimensions:0.22m x 0.13m - Thickness: 0.02m - Mass :0.708 kg).

The dynamic behaviour of the skin is shown in figure 1.

The value proposed by PRASAD (11) for the skin element was 320 000 N/m.

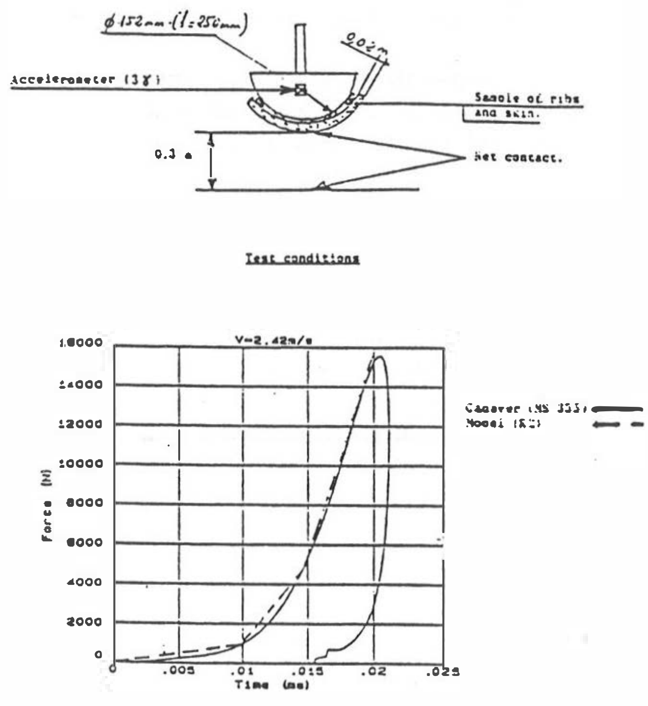


FIGURE 1 : CADAVER SKIN CHARACTERISTICS

Characterisation of the skin behaviour and the rib mobile mass

On the basis of our sample of skin and ribs a density of 1223 kg/m3 was calculated.

For an impactor shape of diameter 150 mm a minimum moving mass corresponding to a projected impactor surface can be deduced : the value obtained is 0.45 kg and is similar to the value given by Viano (12).

In the same conditions, with frontal loading of the thorax ,LOBDELL (13) calculates the mobile mass in movement as being 0.32 kg. PRASAD (11) proposed a rib mass value of 0.25 kg.

Determination of the damping (C1) between the ribs and the spine

For the same half chest deflection value, the force linked to the damping can be obtained by subtracting from the impactor load (cadaver test MS 393-4) the force obtained in static test (cadaver test MS 422) (see figure 2)

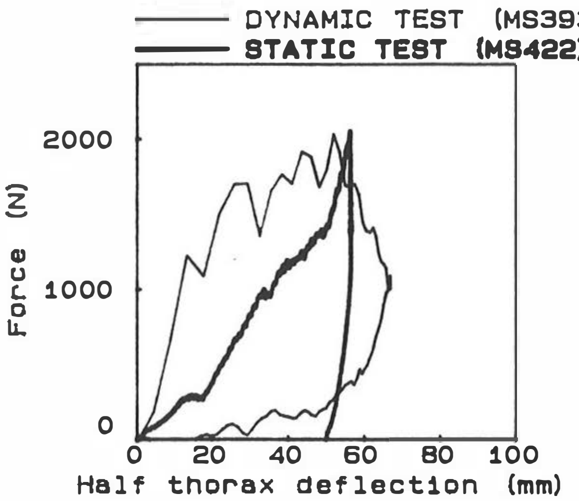


FIGURE 2 :
FORCE-DEFLECTION CHARACTERISTICS
STATIC AND DYNAMIC TESTS

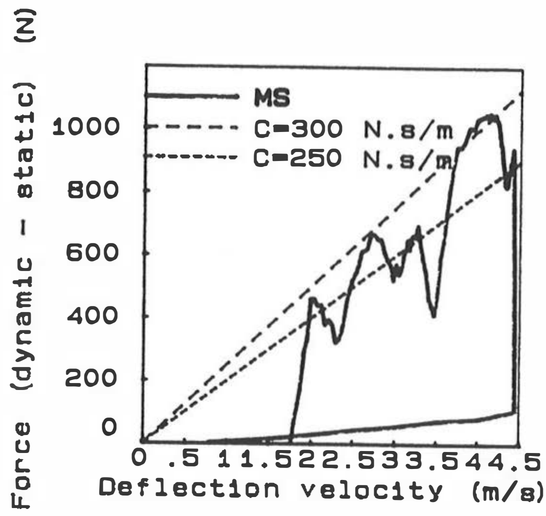


FIGURE 3 :
DAMPER CHARACTERISTICS IN MS 393-4
CADAVER TEST

The approach of calculation of viscous damping without mass (C1) is made by calculating the ratio "force linked to the damping / deflection velocity" (figure 3).

A damping constant of 250 N.s/m is chosen.The value proposed by PRASAD (11) was 300 N.s/m

MODEL SIMULATING THE "PASSENGER ARM POSITION".

In this configuration the upper arm and shoulder are interposed with the thorax.

The simplified approach which seemed the most satisfactory is given in annex 3.

Calculation of the thorax effective mass and moving effective mass

According to the anthropometric study conducted by Mc. Conville (14) and the values proposed by Robbins (10), the total weight of the arm is 3.85 kg.

This value is calculated from volume multiplied by density of the segment ; the result is corrected to take into account the mass of the 50th percentile male.

By addition with the rib mass (0.45 kg) determined before (see driver model) we obtain a total arm and rib mass of 4.3 kg.

During the autopsy of cadaver MS.394 (see anthopometry in annex 2) we isolated the skin and half rib cage with the arm ; the total weight obtained was 4.226 kg .

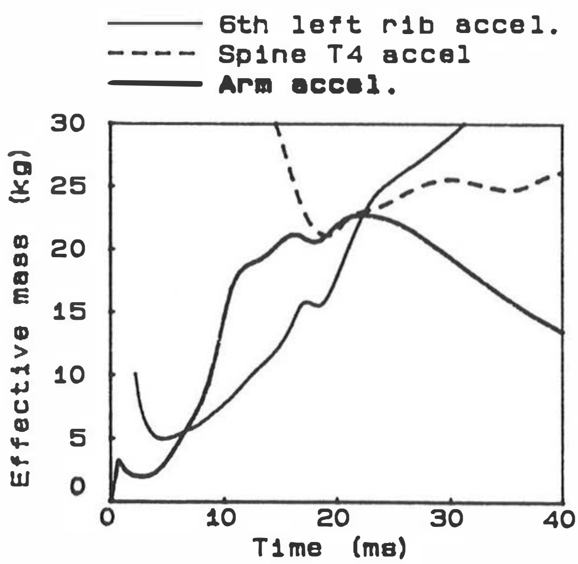


FIGURE 4 :EFFECTIVE MASS (MS 395-1)

In order to evaluate the effective moving mass we calculated the ratio impulse/variation velocity for the ribs and for the arm (see figure 4).
On the basis of cadaver test MS.395-1, which is close to the 50th percentile male, we observe on figure 4 that when the arm and rib mass are joined the effective mass is 5.5 kg. For the model a moving mass between 4.3 kg and 5.5 kg is proposed. At the time when the arm, the ribs and the spine meet, the total effective mass of the thorax is nearly 24 kg ; therefore a spine mass of 20 kg is proposed for the model.

Determination of the dynamic behaviour of the arm and skin covering the ribs (K3)

The dynamic load is obtained by multiplying at each instant the impactor acceleration by its mass : 23.4 kg.
The deflection of the arm is calculated by double integration of the difference between impactor acceleration and impacted rib acceleration (R6). As presented in figure 5 the loading part of the dynamic behaviour of the arm and skin can be simulated by a constant value of 160000 N/m for a deflection value less than 0.06 m.
From 0.06 m a second slope of 320000 N/m is proposed on the basis of the static compression test with isolated arm (see annex); this value corresponds to the hone characteristics.

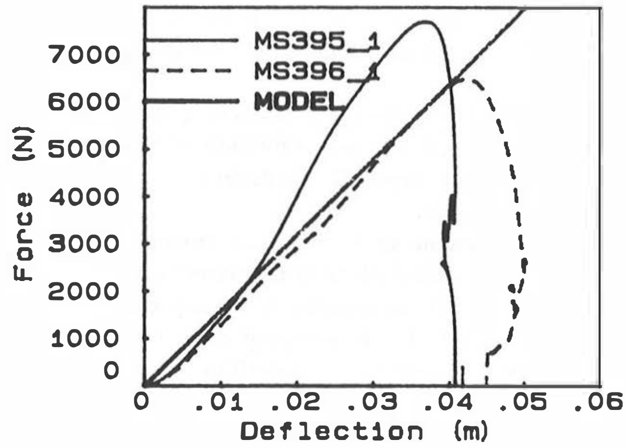
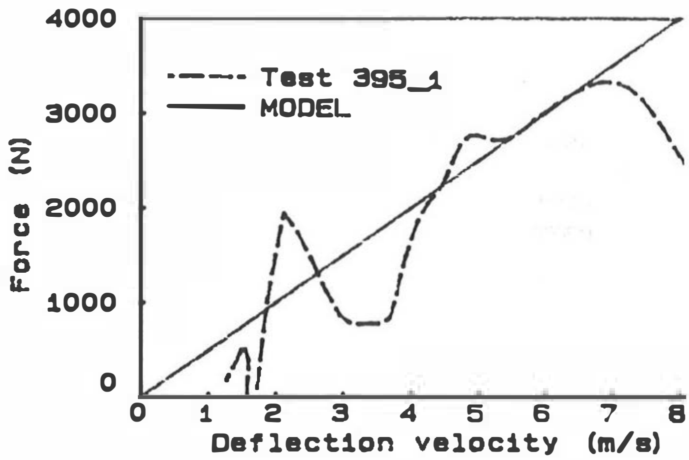


FIGURE 5 :
ARM DYNAMIC STIFFNESS

Determination of the damping (CO) between the spine and the combined arm and ribs masses

For the same half chest deflection value the force linked to the damping can be obtained by subtracting from the force applied between spine and ribs the force obtained in static test (figure 6).
On the basis of impactor test MS.395-1 with arm and shoulder interposed the force applied on the thorax can be approximated by subtracting from the impactor load the force due to the cumulated arm and rib masses.
The force due to the cumulated arm and rib masses is calculated by multiplying the rib acceleration (R6) by the ratio of the impactor force and rib acceleration. This ratio is 4.78 kg corresponding to the time where the impactor load is maximum.
The viscous damping without mass is calculated using the ratio "force/deflection velocity" (figure 7); a constant value of 500 N.s/m is proposed for the mathematical model.



MODEL SIMULATING THE PELVIS/THORAX COUPLING

According to the Composite Test Procedure concept, the coupling must be simulated only by a one dimensional movement.
For each test, the force-deflection characteristics between the pelvis and the thorax was calculated: the applied force is obtained by multiplying the thorax acceleration by its effective mass (24 kg); the relative displacement is obtained by double integration of the spine acceleration (T4) subtracted from the pelvis acceleration.
It is very difficult to calculate the coupling, because of the significant rotation of the spine, for an impact on the pelvis. We chose to model the coupling with a simple spring, to obtain a sufficient maximum level for the acceleration of the spine. A small damper was used to avoid oscillations in the model.

The linear coupling proposed is:
K4 : 25000 N/m
C4 : 200 Ns/m
A better approach could be made by a two degrees of freedom system as proposed by J. HASEWAGA (15).

MODEL SIMULATING THE PELVIS

Calculation of the pelvic effective mass

The effective mass is calculated by dividing the maximum impactor force by the maximum pelvis acceleration. On the basis of tests with pelvis coupled or uncoupled with thorax, an average value of 14.8 kg with a standard deviation of 3.1 kg is calculated; a pelvic mass value of 14 kg is proposed for the model.

Determination of the force/deflection characteristics of the pelvis (K5)

The dynamic load is obtained by multiplying at each instant the impactor acceleration by its mass 23.4 kg. The deflection is obtained with the difference between the double integrations of the impactor acceleration and the pelvis acceleration.
From the dynamic tests, the static stiffness (Ks) is approximated with a linear slope, defined by the point where the dynamic deflection is maximum.
The difference of phase between the impactor force and the deflection requires the use of a damper to simulate this dynamic effect. The damping effect (c) is deduced at the maximum impactor force point. This damper is in series with a simple spring (Kd) to avoid a great initial effort. This spring (Kd) is estimated with the initial slope of the force-deflection curve.
For the model, three constant values are proposed for the elements of connection:

Ks :	static stiffness	35000 N/m
Kd :	dynamic stiffness	300000 N/m
c :	damping coefficient	1800 N/m/s

VALIDATION OF THE DRIVER THORAX MODEL

By analogy with the cadaver test results, the calculation interval for the model was .666 ms and the data were filtered by FIR 100 Hz.
The comparison between cadaver impactor test MS 393-4 (Impactor mass 23.4 kg and V=4.4 m/s) and simulation results is shown figure 8 and table 2.

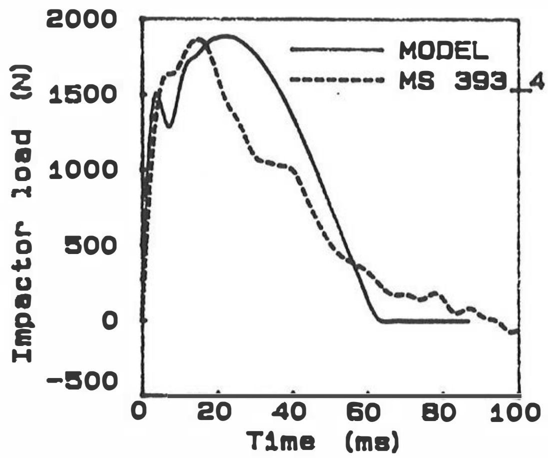


FIGURE 8:
MODEL RESPONSE COMPARED TO CADAVER TEST DATA

TABLE 2 Impactor test on thorax (m= 23.4 kg)

	impactor velocity (m/s)	max. impactor force (N)	Total deflection (mm)
Cadaver MS 393-4	4.4	1870	71
Model	4.4	1879	79

The force deflection response is a biomechanical key and defines the compliance of the thorax under a lateral impact. The response area under the curve represents the energy absorbed by body deformation.

The comparison between the energy absorbed in the cadaver test and the simulation is given in figure 9.

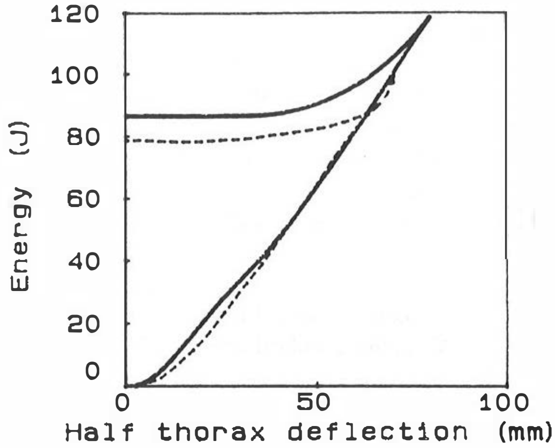


FIGURE 9 :
ENERGY ABSORBED BY THE THORAX
COMPARISON BETWEEN CADAVER AND MODEL RESPONSES

Simulation of VIANO cadaver tests (7)

In the 33 rd Stapp Car Crash Conference, VIANO presented the results of fourteen unembalmed cadavers which were subjected to forty four blunt lateral impacts on thorax, abdomen and pelvis with a 15 cm flat 23.4 kg pendulum in range of 3.6 m/s to 10.2 m/s impact velocity.

The specimen, impacted on the left or right side, was rotated 30° and the center of pendulum impact on the thorax was aligned with the xiphoid process. Abdominal impact was aligned 7.5 cm below the xiphoid.

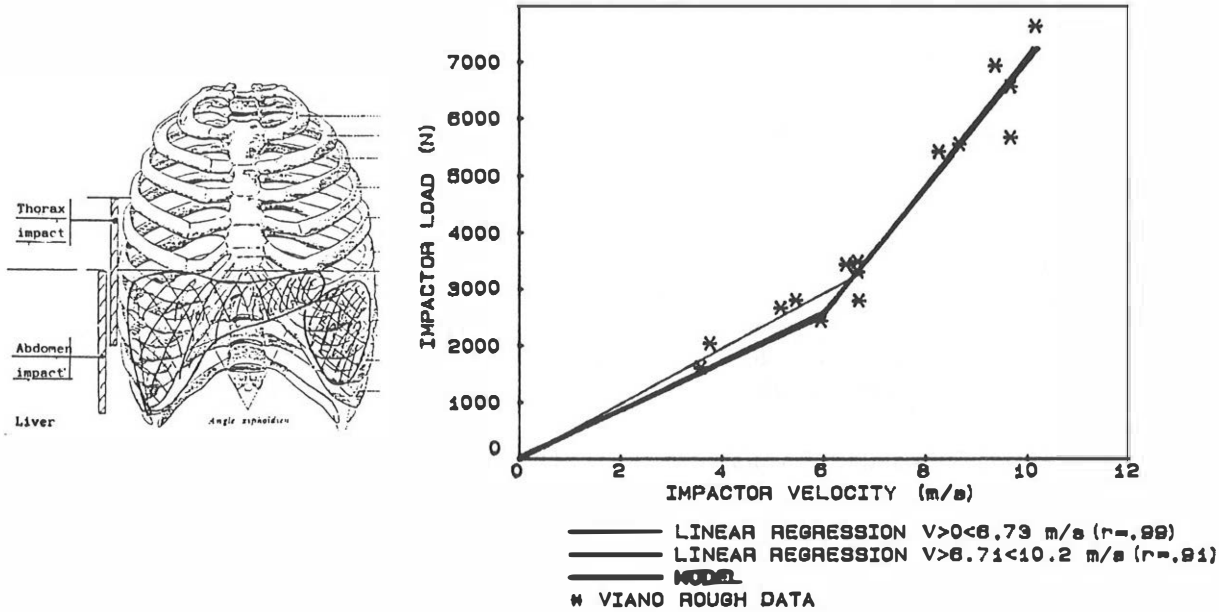


FIGURE 10
FORCE VERSUS IMPACT VELOCITY IN VIANO CADAVER TESTS
COMPARISON WITH MODEL RESPONSES

Figure 10 shows the original force/impact velocity response (filtered FIR 100) for each impact on the thorax compared with the response given by mathematical model.

Using a linear regression between force and impactor velocity as shown in Figure 10, Viano data were reanalysed in order to rescale the cadaver raw response to a common impact speed. The best relationship is obtained by dividing the Viano test sample into two sub-samples:

the first one corresponds to tests with impactor velocity from 3.6 m/s to 6.73 m/s, the second one to tests with impactor velocity from 6.71 m/s to 10.2 m/s.

As illustrated, we can conclude that the dynamic thorax behaviour can be approached by two different slopes ; the statistic model and the mathematical model give similar results.

In order to compare the force-time response given by a group of cadaver data it is possible to rescale to a standard impact speed the tests with a low variation. Three groups are determined (figure 11A,B,C)

At each instant, the rescaled impactor load is given by :

$F' = Vs / Vc * F$ where :

F ' is the rescaled force.

Vs is the standard impactor speed.

Vc is the test impactor speed.

F is the test impactor load.

In this procedure the time is not affected. The rescaled impactor load compared with the model is given for each impact velocity group in figure 11A,B,C.

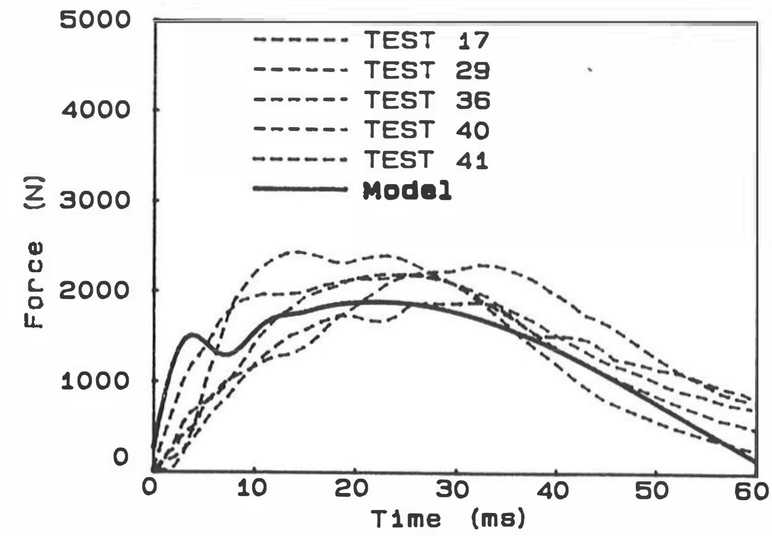
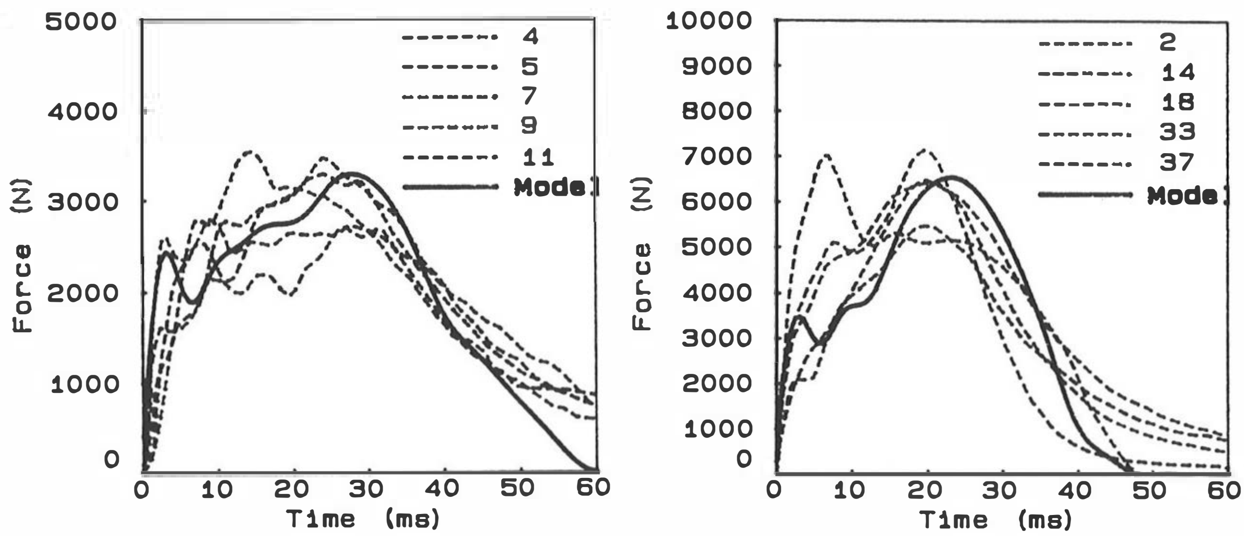


Figure 11 A -TESTS BETWEEN 3.6 M/S AND 5.5 M/S



TESTS BETWEEN 5.99 M/S AND 6.73 M/S

TESTS BETWEEN 8.3 M/S AND 10.2 M/S

FIGURE 11 B ET 11 C

COMPARISON BETWEEN THE RESPONSE GIVEN BY THE MODEL AND THOSE GIVEN BY THE VIANO CADAVER TESTS (7) RESCALED TO A STANDARD IMPACT SPEED

VIANO has also shown that there are similar levels of force and deflection for each impact severity on thorax or abdomen, so he has established a combined response of the torso compliance.

As shown in figure 12 the model simulates the torso behaviour of the cadavers.

These impactor cadaver tests on the thorax (from 4.4 m/s to 9.6 m/s) cannot be simulated with the actual dummies which have a mechanical thorax deflection of less than 80 mm. The minimum value required for the test at 4.4 m/s is 80 mm. In order to simulate these tests a mechanical thorax deflection device operating from 0 to 150 mm should be necessary.

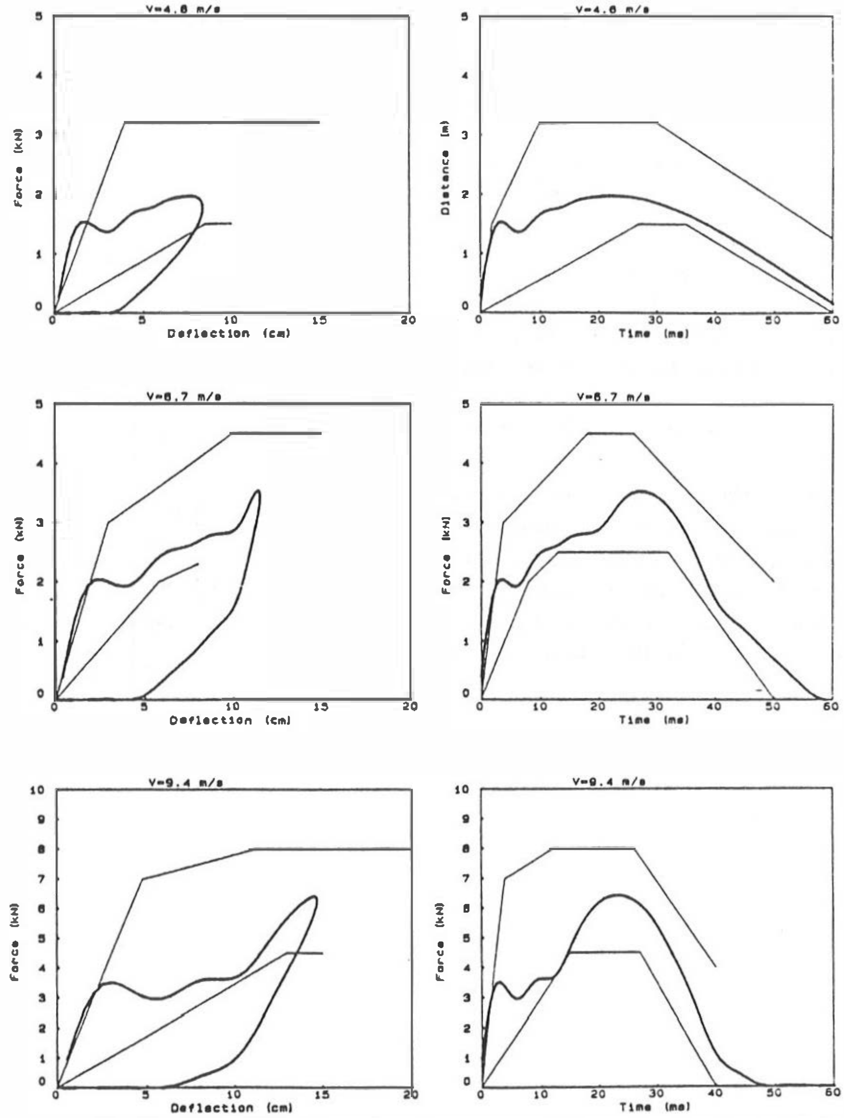


FIGURE 12 : VIANO corridors (1) for force-deflection and force-time responses for merged data on the blunt lateral impact of the chest and abdomen at three severities
Cadaver data compared with the model.

VALIDATION OF THE PASSENGER THORAX MODEL

Validation against the requirements of documents ISO/DTR 9790-3 (17)

The biofidelity of the thorax model can be evaluated against the requirements of documents ISO/DTR 9790-3 The lateral impact test configuration of the University of Heidelberg for rigid impact in sled test configuration can be simulated with the"passenger model". The comparison with ISO corridors (17) is given in figures 13a and 13b respectively for 6.7 m/s and 8.9 m/s..

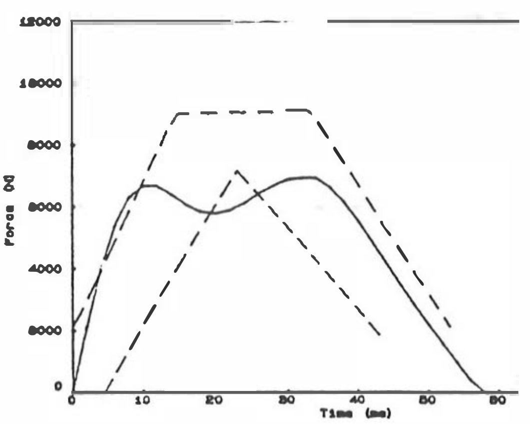


FIGURE 13A-:HEIDELBERG TESTS(V=6.7 M/S)

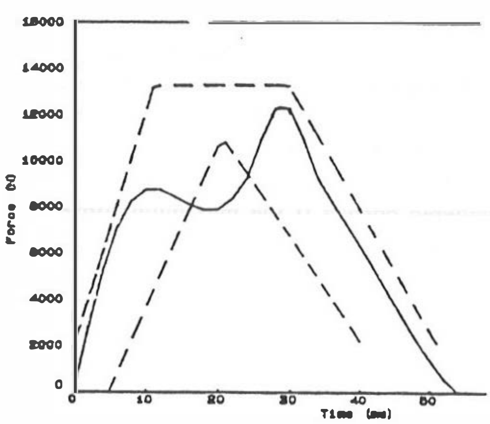


FIGURE 13B -HEIDELBERG TESTS(V=8.9 M/S)

Simulation of new APR cadaver tests MS 394 - 395 - 396

On the basis of impactor test conditions, presented previously, the comparison between the response given by the "passenger model" with those of the cadavers is illustrated in figure 14.

VALIDATION OF THE PELVIS MODEL

By analogy with the human being tests results, filtered with the FIR 100 filter, the calculation interval was 0.625 ms. The results of the modelization are not post-filtered.

On the basis of 10 dynamic impactor tests presented in this paper, combined with 13 dynamic impactor tests presented by VIANO (7), a linear regression between maximum impactor load (rough data) and impactor velocity has been performed (r=0,93) :

$$\text{Force} = 126.704 * \text{velocity} - 85.5514$$

Figure 15 shows that the force results given by the model are in the 95 % confidence limits for the mean response at a given value of velocity.

Table 3 shows the comparison between the maximum values predicted by the model and those observed in the tests on the uncoupled pelvis.

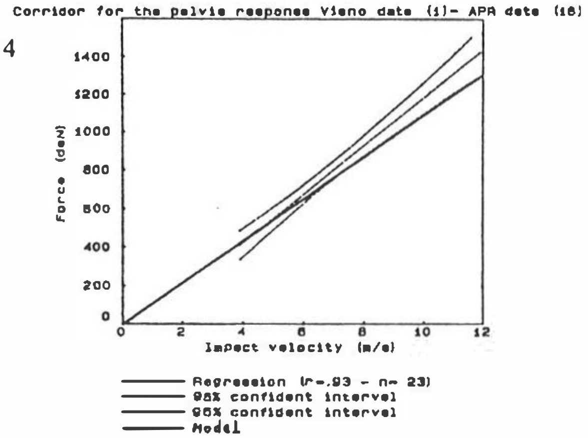


FIGURE 15 :
FORCE-VELOCITY CORRIDOR RESPONSE BASED ON VIANO (1) AND APR DATA (16) COMPARED TO THE MODEL

TABLE 3 : Simulation of tests on uncoupled pelvis.

TEST N°	IMPACT VELOCITY (m/s)	FORCE (daN)	PELVIS ACC. (g)	PELVIS DEFLECTION (m)
394/5	4.0	360	27.3	0.033
model	4.0	429	31.2	0.024
396/5	6.5	719	73.1	0.057
model	6.5	698	50.8	0.039
394/6	9.0	1210	85.7	0.059
model	9.0	966	70.3	0.054

Validation of the pelvis model according to ISO/DP9750-4

The responses of 22 unembalmed cadavers submitted to lateral impact on the great trochanter was investigated. A relationship between the impact speed and the maximum standardised force is determined on the basis of rigid impactor tests (M = 17.3 kg).When the shock applied occurs at a speed of between 6 and 10 m/s, the response is considered correct if the maximum force of the impacting device is within the corridor. The model response is inside the corridor response, as shown in figure 16.

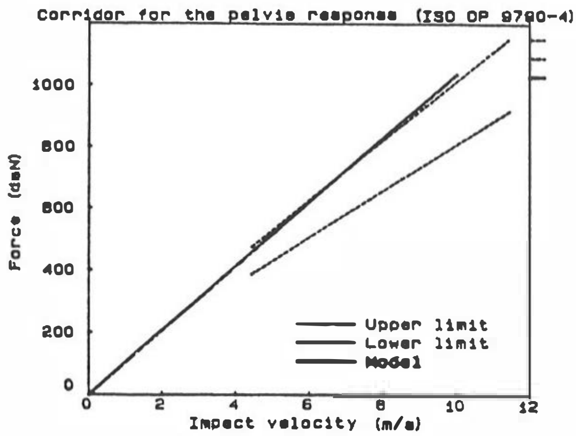


FIGURE 16 :PELVIC MODEL RESPONSE COMPARED TO ISO REFERENCE DATA (ISO/DP97 50-4)

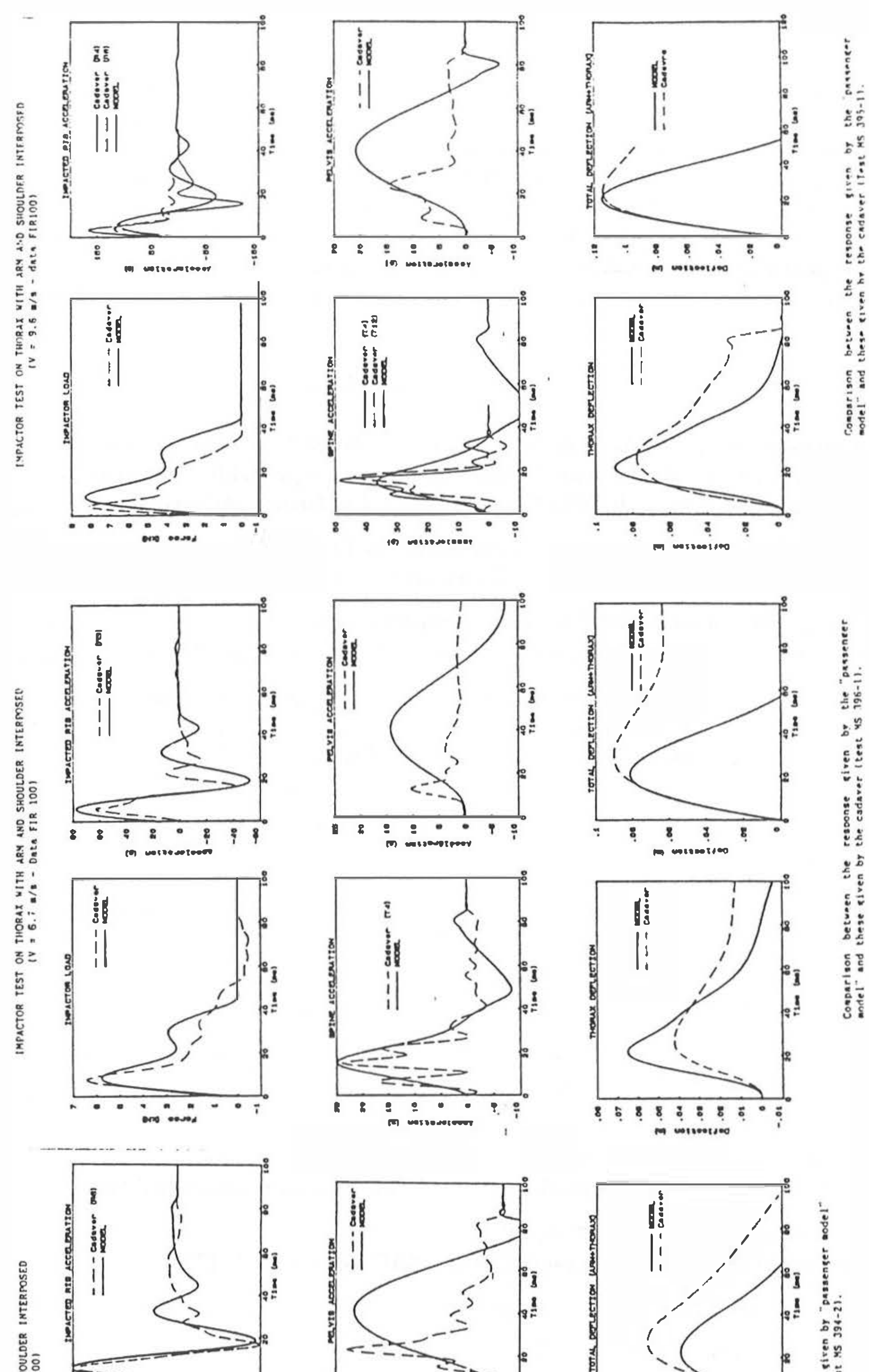


FIGURE 14:
COMPARISON BETWEEN THE RESPONSES GIVEN BY "PASSENGER MODEL" AND THOSE GIVEN BY THE CADAVERS

CONCLUSIONS

On the basis of static and dynamic cadavers tests on the lateral parts of the body, a mathematical human being impact model , with or without arm and shoulder interposed , was developed and was shown to be capable of simulating the impact response given in the literature.
Nevertheless , a complementary test program with cadaver is necessary to improve the mathematical model response included in the C.T.P. procedure.
Concerning the coupling between thorax and pelvis and taking into account the spine rotation ,a better modelling approach could be obtained by two dimensional approach.
The model and the data from cadavers given in this report could be used as a tool in the design of an impact dummy.

REFERENCES

1. "Comparative Evaluation of the Biofidelity of EUROSID and SID Side Impact Dummies", F. Bendjellal et al., Laboratory of Physiology and Biomechanics Associated with Peugeot SA/Renault, 32th Stapp Car Crash Conference, Atlanta (Georgia), Paper n° 881717.

2. "Biofidelity of the European Side Impact Dummy EUROSID",E.G. Janssen et al., TNO Road institute, 32th Stapp Car Crash Conference,Atlanta (Georgia), Paper n° 881716.

3 "Comparison of the EUROSID and SID impact responses to the response corridors of the international standarts organization Annette L. Irwin et al General Motors corp.paper SAE 890604

4. "Proposal for a thorax tolerance level in side impacts based on 62 tests performed with cadavers having known bone condition",J. Sacreste et al., Laboratoire de Physiologie et de Biomécanique Peugeot SA/Renault, 26rd Stapp Car Crash Conference (821157), Michigan 1982.

5 . "Modelisation mathématique du comportement de l'être humain en choc latéral",Rapport interne. F Chamouard - Février 1989 - Laboratoire d'Accidentologie et de Biomécanique Peugeot SA/Renault 132 rue des Suisses 92000 Nanterre France.

6. "Approach by mathematical modelization of the human behaviour in lateral impact",Proceeding of Institution of Mechanical Engineers of London. F. Chamouard - April 1989.

7 "Biomechanical responses and injuries in blunt lateral impact D.C.", Viano - G.M. research labs- 33 rd Stapp Car Conference - October 1990.

8. "Computer simulation and evaluation of the effect of padding on the thorax in lateral impact", Hung-Hsu Chen and D.A. Guenther, Ohio State University, 32th Stapp Car Crash Conference, Atlanta (Georgia), Paper n° 881722.

9. "Modelling the lateral impact of the thorax in car side impact accidents", M. Langdon, 10th International Technical Conference on Experimental Safety Vehicles.

10 "Seated posture of vehicle occupants", Robbins et al. - 27 th Stapp car conference SAE paper n° 831617.

11. ISO/TC22/SC12/WG6 N°293, May 1989

12. "Biomechanics of chest and abdomen for lateral impact (progress report)" Viano GM- ISO/TC22/SC/WG5 n° 202 - June 1988.

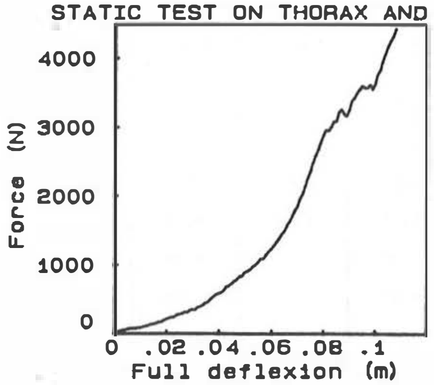
13. "Impact response of the human thorax " I.E. Lobdell et al., Research publication GMR 1282, October 2.3.1972, General Motors Corporation, Waren Michigan.

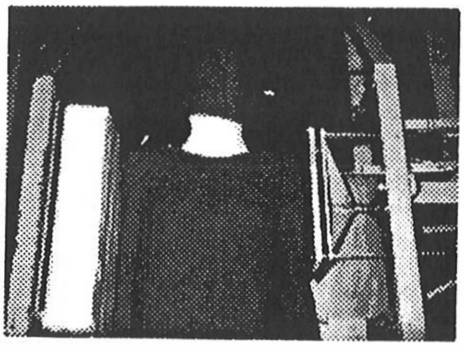
14. "Anthropometric relationship of body and segment moments of inertia",Mc Conville et al., Aerospace Medical Research Laboratory, December 1980, AFAMRL-TR-80-119.

15 Side Impact Simulation analysis using an improved occupant model J. Hasewaga et al. Toyota Motor Corporation Proceeding of the 12th E.S.V. conference- May 29 - Goteborg Sweden 1989.

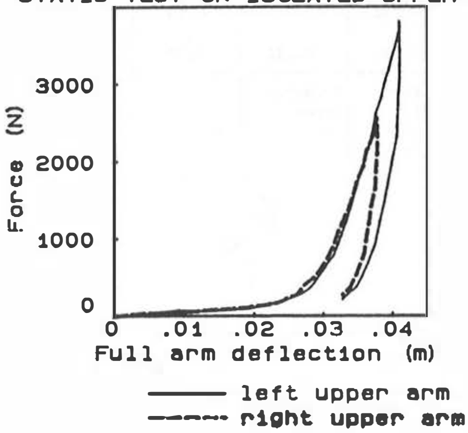
17. ISO, "Road Vehicles Anthropomorphie Side Impact Dummy Lateral Thoracic Impact Response Requirements to assess the Biofidelity of the dummy" Draft proposal ISO/DTR 9790.

STATIC TEST ON THORAX AND ARM

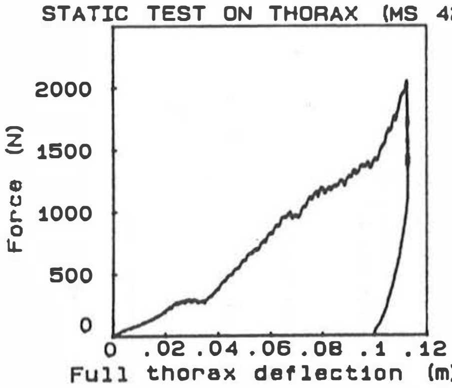




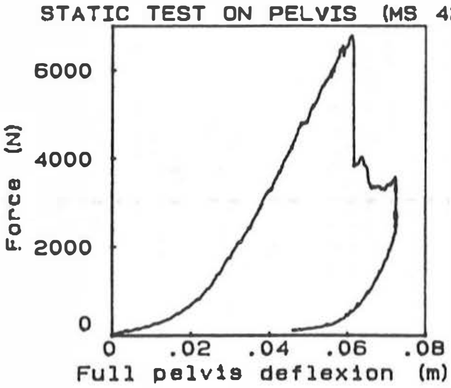
STATIC TEST ON ISOLATED UPPER ARM



STATIC TEST ON THORAX (MS 422)



STATIC TEST ON PELVIS (MS 422)

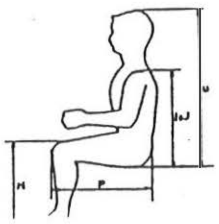


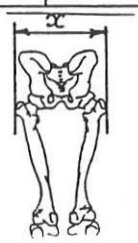
Force versus deflection obtained in static tests compression

ANNEX 2

Subjects anthropometry

Cadaver N°	MS 393	MS 394	MS 395	MS 396	MS 402	MS 404	MS 406	MS 422
Age	69	66	50	58	55		57	65
Sex	1	1	1	1	1	1	1	1
Weight (kg)	67	64	77	90	83	60	70	70
Stature (m)	1,65	1,64	1,85	1,83	1,71	1,65	1,70	1,70
U (m)	0,91	0,87	0,98	0,95	0,92		0,95	
I + J (m)	0,67	0,64	0,70	0,74	0,67		0,70	
P (m)	0,52	0,56	0,60	0,65	0,56		0,45	
M (m)	0,51	0,49	0,59	0,60	0,54		0,53	
Chest breadth (m)	0,33	0,285	0,33	0,36	0,33	0,250	0,35	0,310
Chest depth (m)	0,23	0,195	0,22	0,30	0,235		0,23	
(x) pelvis breadth (m)	0,315	0,320	0,330	0,360	0,350	0,285	0,32	0,340
CAUSE OF DEATH	heart attack		Myocardial infarction	Myocardial infarction	heart attack	Pulmonary edema		Cerebral contusion
BONE CONDITION FACTOR	- 0,3	- 0,6	0,3	0,8	- 0,9		0,8	0,3





<== Synthesis of cadavers injuries

	M.S. N°	Type of impact	Injuries
DYNAMIC TESTS	393-1	Pelvis impact (V = 4.47 m/s)	No fracture
	392-2	Pelvis impact (V = 4.47 m/s)	No fracture
	393-3	Pelvis impact (V = 6.59 m/s)	No fracture
	393-4	Thorax impact (V = 4.46 m/s)	6 rib fractures - no other iojury
	393-5	Pelvis impact (V = 4.46 m/s) (subject without trunk)	No fracture
	393-6	Pelvis impact (V = 6.5 m/s) (subject without trunk)	Fracture of the great trochanter
	394-1	Pelvis impact (V= 4.48 m/s)	No fracture
	394-2	Thorax impact (V = 4.41 m/s) (with arms and shoulders interposed)	No fracture - No injury
	394-5	Pelvis impact (V = 3.96 m/s) (subject without trunk)	No fracture
	394-6	Pelvis impact (V = 9.04 m/s) (subject without trunk)	Complex fracture of the smaller and greater trochanter and head of the femur
	395-1	Thorax impact (V = 9,63 m/s) (with arms and shoulders interposed)	10 rib fractures (flail chest) - Fracture of the left arm and left clavicula - no lesion.
	395-2	Pelvis impact (V = 9.62 m/s)	Fracture of the great trochanter
	396-1	Thorax impact (V = 6.66 m/s) (with arms and shoulders interposed).	- Fracture of the left arm - 7 rib fractures of the impacted half thorax
	396-2	Pelvis impact (V = 6.68 m/s)	No fracture
	396-5	Pelvis impact (V = 6.46 m/s) (subject without trunk)	No fracture
	406-1	Pelvis impact (V = 6.71 m/s)	No fracture
	406-2	Thorax and shoulder impact without shoulder interposed (V = 6.7 m/s)	11 rib fractures - no lesion
STATIC TESTS	402	Thorax compression with arms and arm interposed)	4 rib fractures
	402	Pelvis compression (I.L.D. tests)	Fracture of the great trochanter
	404	Thorax compression with arms and shoulders interposed	No fracture - no lesion
	422	Thorax compression	3 rib fractures
	422	Pelvis compression	Fracture of the great trochanter

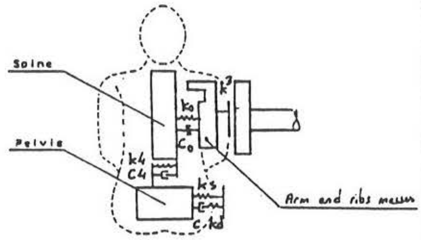
Cadavers instrumentation

ARM	- Acceleration (y) situated at the level of y axis of chest impactor : CFC 600
THORAX	- Acceleration of (R3), (R4), (R6) and (R8) ribs (y), left and right sides ; 8 channels : CFC 1000. - Acceleration of (T1), (T4) and (T12) on spine (x,y,z) ; 9 channels : CFC 1000 - Acceleration of upper and lower sternum (x,y) ; 4 channels : CFC 600. - Chest deflection (y) with APR device ; 1 channel : CFC 600.
PELVIS	- Acceleration of sacrum (x,y,z) ; 3 channels : CFC 1000.
IMPACTOR	- Acceleration (y) ; 1 channel : CFC 1000.
TOTAL	- 27 channels ; Acquisition frequency was be fixed to 5 times the cut-off frequency of filtering.

ANNEX 3

Hunan being model simulating the passenger arm position

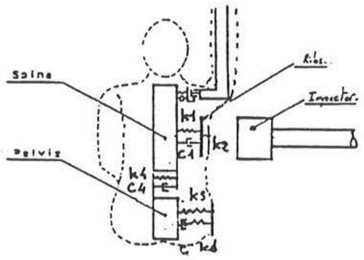
SEGMENT	MASS (kg)
Rib + Arm	4,45
Spine	20
Pelvis	14



CHARACTERISTICS OF THE ARM AND SKIN COVERING THE RIBS (K3)	RIB CAGE (K0)	DASHPOT CONSTANT OF THE RIB CAGE (C0)
Loading or unloading phase K = 160 000 N/m If displacement > .06 m then K = 320 000 N/m	loading or unloading phase (m) | (N/m) 0 | 37500 .025 | 88500 .09 | 400000	Loading or unloading phase C = 500 N.s/m
Coupling between thorax and pelvis (loading or unloading phase) K = 25 000 N/m C = 200 N.s/m	Characteristics of Pelvis : loading or unloading phase KS = 35 000 N/m Kd = 300 000 N/m C = 1 800 N/m/s	

Hunan being model simulating the driver arm position

SEGMENT	MASS (kg)
Rib	0,45
Spine	24
Pelvis	14



SKIN COVERING THE RIBS (K2)	RIB CAGE (K1)	DASHPOT CONSTANT OF RIB CAGE (C1)
Loading phase (m) | (N) 0 | 0 0,01 | 1000 0.015 | 5200 0,02 | 15100 If displacement > 0,02 m then K = 2 000 000 N/m Unloading phase K = 2 000 000 N/m	Loading or unloading (m) | (N) 0 | 0 2250 | 0,09 If displacement > 0,09 m then K = 100 000 N/m	Loading or unloading phase C = 250 N.m/m
	Characteristics of Pelvis : Loading or unloading phase KS = 35 000 N/m Kd = 300 000 N/m C = 1 800 N/m/s	Coupling between thorax and pelvis (loading or unloading phase) K = 25 000 N/m C = 200 N.s/m