MATHEMATICAL MODELLING OF THE AUTOMOBILE OCCUPANT

INTRODUCTION OF THE OCCUPANT ENVIRONMENT

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INTRODUCTION

For the preliminary design it is no always possible, without measured data, to use a very sophisticated mathematical model. To deal with this lack of data, one after uses a simpler model. This, usually makes it possible to quickly go through a problem, with a good enough precision, if the parameters entered in the computer program are not too far away from physical reality.

The aim of this paper is to show how we solved the problem of acquiring data for a two dimensional model which simulates the behaviour of the automobile occupant during a frontal impact.

The outline of this study is the following :

I. - Description of the model   II - Data acquisition   III - Test simulation

I. - DESCRIPTION OF THE MODEL

It is a two dimensional model, with 11 independant degrees of freedom. The occupant is sitting in the vehicule, he is restrained by a three - point safety belt

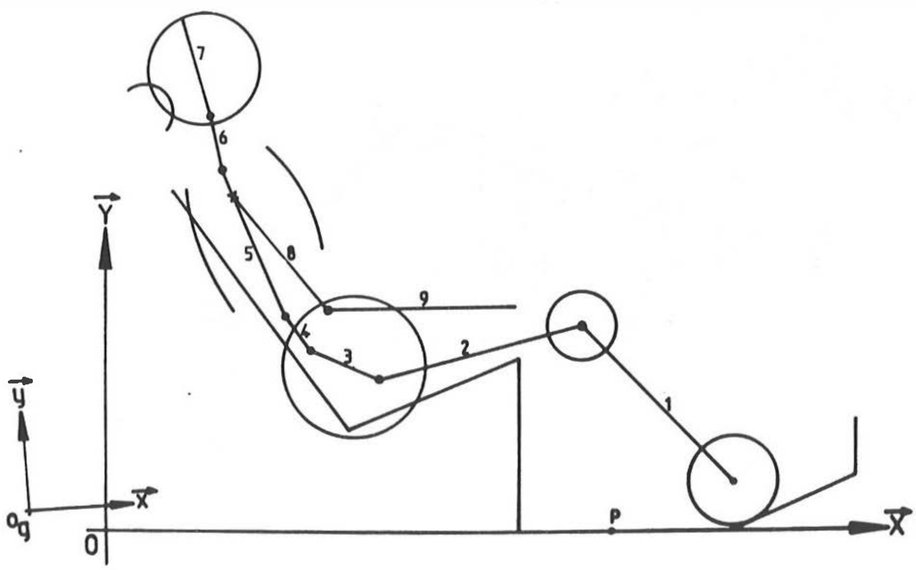


Figure 1 : Diagram of the Model

I.1 - Scheme

The occupant is modelled through an anthropomorphic dummy. He is built of 9 rigid segments, each has its mass and its inertia. They represent (Fig. 1) :

1 - legs	2 - thighs	3 - pelvis
4 - lower torso	5 - upper torso	6 - neck
7 - head	8 - arms	9 - forearms

Arcs are associated to these segments, to delimit the volume of the dummy. Contacts with seat and passenger compartment may thus be introduced.

The segments are connected by joints to one another. Elastic stops with great stiffness, limit their motion.

We assume that, in each joint, there are three non linear resistant torques :

1 - An elastic torque, function of the relative position of the jointed segments

2 - A viscous damping torque, function of the relative rotation speed of the segments

3 - A Coulomb damping torque

I.2 - Modelling of the Contacts

Contacts are modelled by non-linear spring and dashpot (Fig. 2)

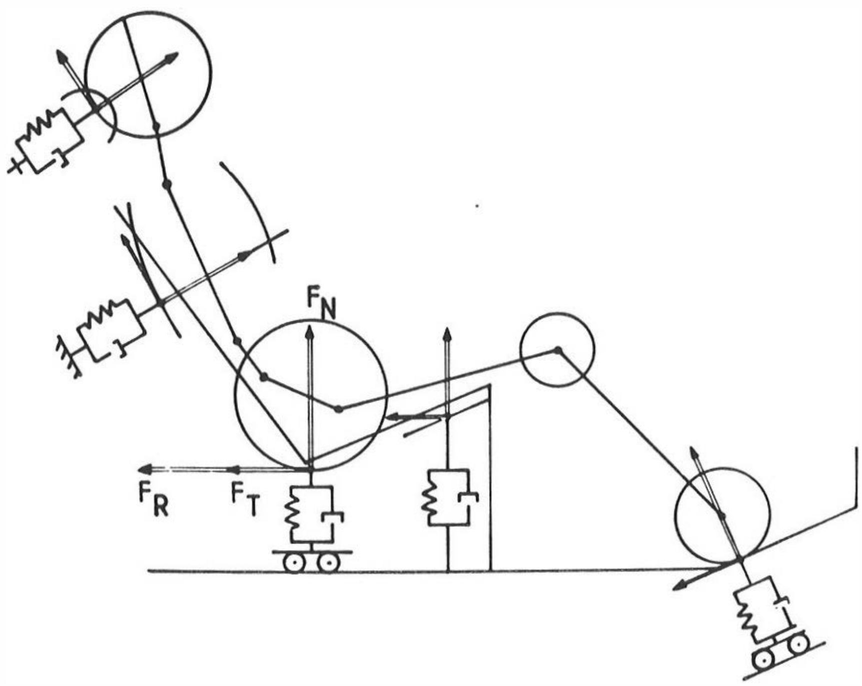


Figure 2 : Forces of Contact

Forces applied on dummy are function of :

1 - local crushing at contact point

2 - speed of the crushing

3 - friction between dummy and passenger compartment

Elastic and damping forces are normal to the dummy. Friction forces, proportional to normal forces are tangential and opposed to slipping speed.

Two spring and dashpot elements, perpendicular to the vehicle floor represent the lower part of the seat. The first, in front of the seat is fixed. The second, behind, moves with the dummy. When the dummy moves forward in its seat, we add a withholding force F_R, proportional to the normal force F_N, to the rear friction force F_T.

I.3 - Modelling of a Three-Point Safety Belt

Figure 3(a) is a front view of a dummy held by a three-point safety belt. We assume that the belt is made of 3 parts : a shoulder belt O_1B_1 an inner side - strap O_2B_1 and an outer side-strap O_3B_2. These straps hold the dummy's chest in A and hip-bones in B_1 and B_2 . We represented the belt, in the model-plane by three non-linear springs : shoulder belt O'_1 A, inner side-strap O'_2 B' and outer side-strap O'_3 B' (Fig. 3 b)

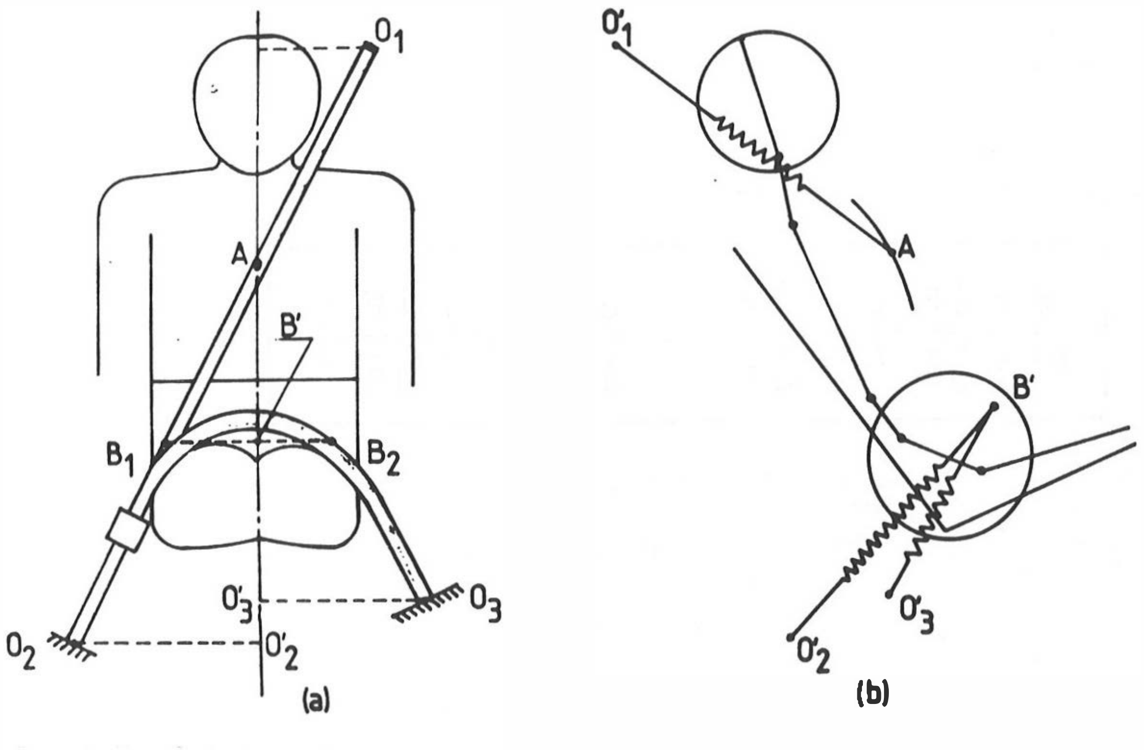


Figure 3 : Diagram of a 3 - Point Belt

I.4 - Hysteresis

Let OLN be the elongation versus force curve of a belt when loaded (Fig. 4).

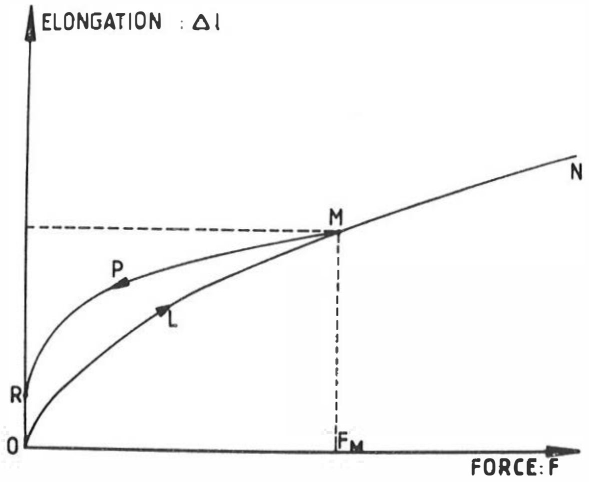


Figure 4 : Hysteresis of the Belt

When unloading, curve MPR (starting from any point M) is different from OLN. For a zero force, the belt keeps a plastic-elongation OR, function of the force F_M in M.

To take this hysteresis into account, we assume that MPR is a second degree curve, tangent to the vertical axis. The program determines the curve equation from F_M and OR.

I.5 - Setting up Equations

We use Lagrange's formula to set up equations :

$$\boxed{\frac{d}{dt}\left(\frac{\partial E}{\partial \dot{q}_i}\right) - \frac{\partial E}{\partial q_i} = \frac{\partial P}{\partial \dot{q}_i} - P\left(\frac{\partial F}{\partial \dot{q}_i}\right)}$$

- t = time
- E = total kinetic energy of the dummy
- q_i = generalized coordinate
- P = power dissipated by forces applied to dummy
- F = all forces applied to dummy

Motion is referred to a fixed set of axes $(Og \mid \vec{x}, \vec{y})$. In these axes, vehicle motion is given by accelerations in 2 points O and P (Fig. 1).

Dummy's displacements are computed in a set of axes $(O \mid \vec{X}, \vec{Y})$ linked to the vehicle.

II - DATA ACQUISITION

Dummy's characteristics : dimensions, centers of gravity position, masses, inertias, stiffnesses, dampings and joint frictions, have been carefully measured at the beginning of the program. This paper shows how we introduce occupant's environment, so we assume that characteristics are known.

We also assume that initial position is known. We easely get it by photographing in profile a dummy with sighting marks glued on to show the articulations

II.1 - Seat Stiffness Measurement

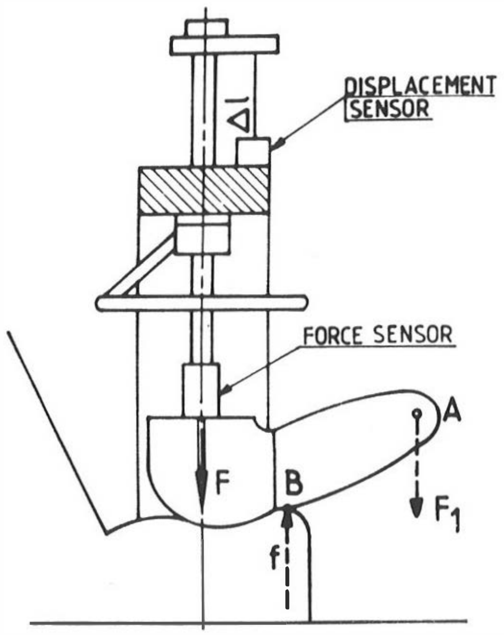
Seat characteristics are measured statically with dummy elements. To get global contact elasticity, we use the dummy that will undergo tests.

II.1.a - Cushion crushing

Seat is fixed by its slide bars to a rigid frame, in same position as in vehicle.

Force F is applied in middle of seat, through a dummy reduced to lower parts (pelvis and thighs).

We record F, function of dummy displacement (Fig. 5).



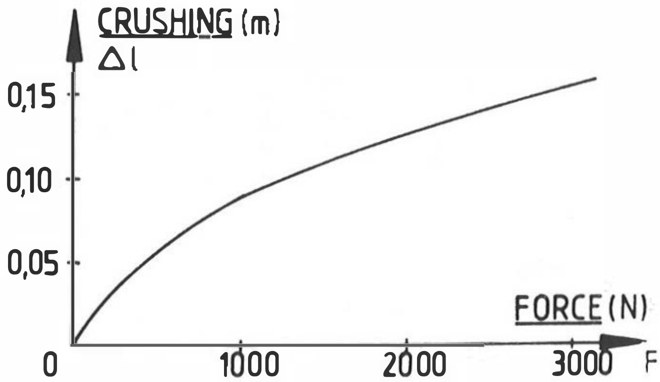


Figure 5 : Cushion Crushing

II.1.b - Elasticity at Seat Front

Force applied to dummy at seat front is small , for thigh rotation towards the bottom is limited, no only by foot resting on vehicle floor, but also because dummies used are sitting dummies.

To measure stiffness in that area, we use the same set-up (Fig. 5). We take off force F and apply vertical force F_1 in A, after tying knees together with a skewer. Force f in B is computed from lever arms. For small displacements, we get an almost linear stiffness around 2 000 N/m.

II.1.c - Horizontal withholding force

Seat is fixed in vehicle position on a horizontally guided carriage (Fig. 6).

Reduced to its lower part (pelvis and thighs) dummy is placed in the rear of the seat. It is vertically pushed in seat, till seat reaction R_1 reaches 500 N. Seat is then pulled back. We record pull F_2 and variation of R_1 function of displacement Δl_2 .

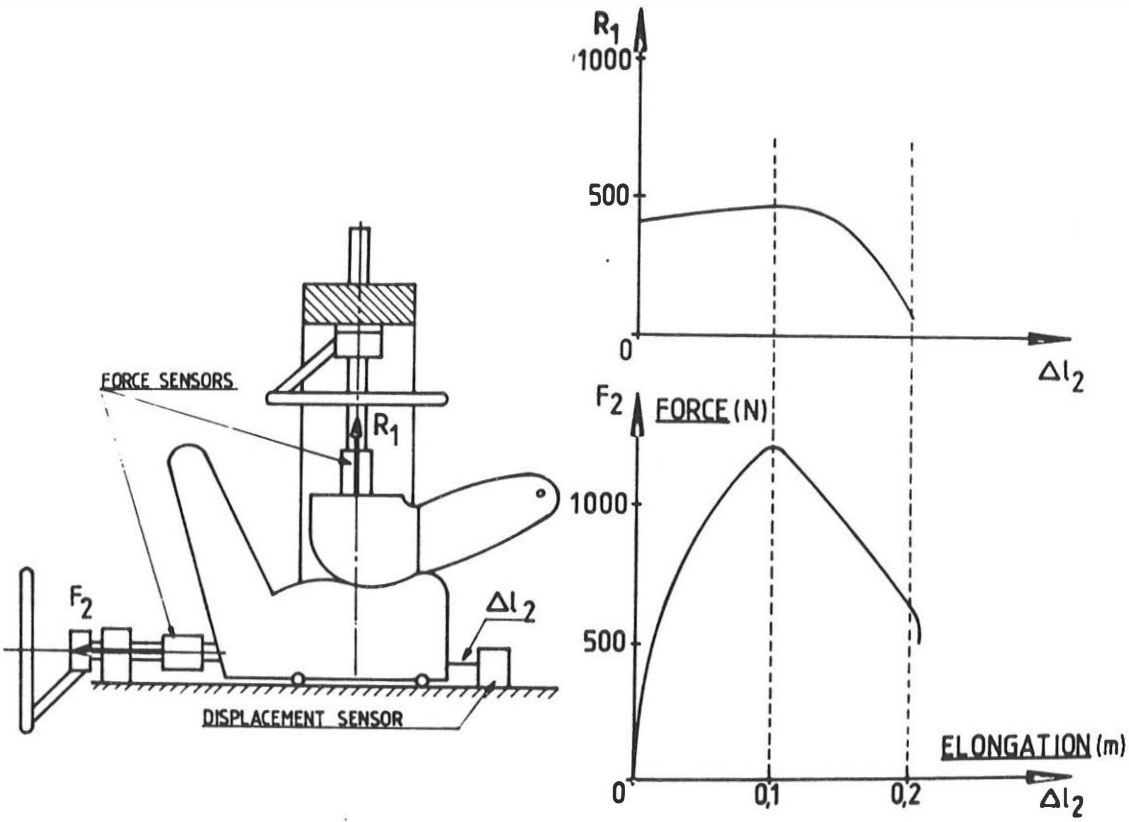


Figure 6 : Horizontal Withholding Force

II.1.d - Seat back elasticity

Seat is fixed by its slide bars to a rigid iron angle so that seat back be horizontal. Dummy, reduced to its higher parts (pelvis and torso) is placed inside and held by a strap (Fig. 7).

Force F_3 is applied to torso, through a perfectly rigid block that fits dummy's shape. We record F_3 function of displacement Δl_3.

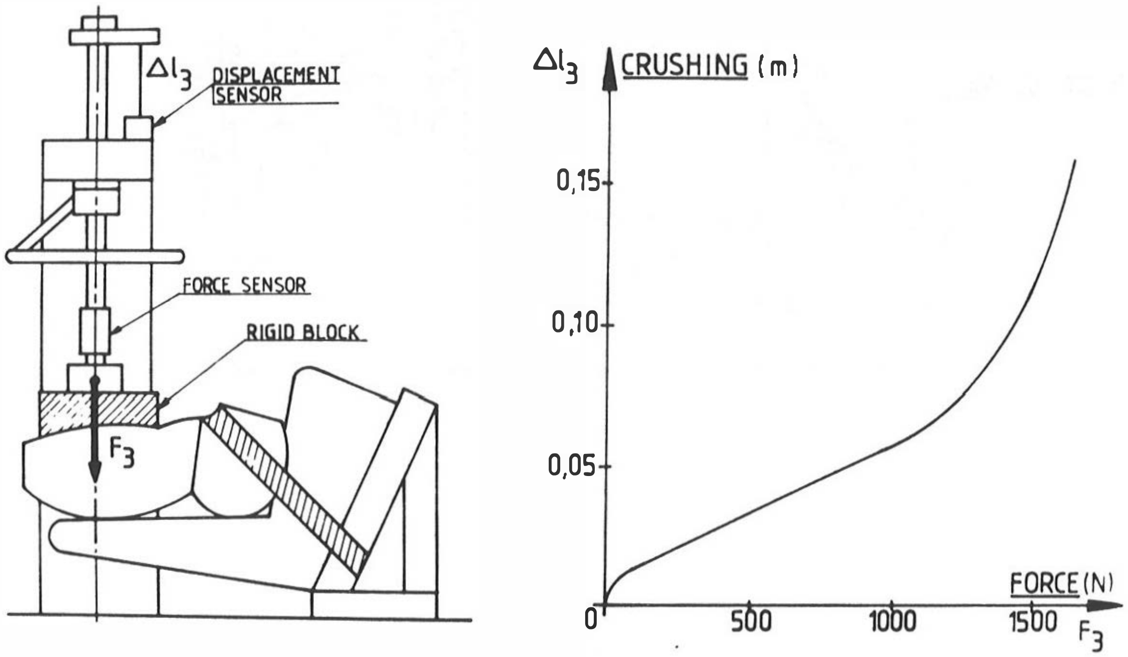


Figure 7 : Seat Back Elasticity

II.2 - Three-Point Belt Stiffness Measurement

As for seat, to get significant measurements, we must use dummy. Its flexibility in effect is far from small, when applied forces are taken into account.

Dummy, reduced to torso and pelvis is suspended with a rocking lever, to an eight ton press moving platform. It is positionned with regard to a vertical plane that represents vehicle floor (Fig. 8).

Anchorage points are simulated by rigid iron angles fastened to press fixed frame.

Force P is applied by successive steps through two rigid blocks that fit dummy's back and bottom.

We record forces F_4 , F_5 and F_6 at anchorage points and displacements of points A" and B" located above A and B' in dummy's back and in middle plane. We compute stiffness of modelled belts O'_1 A, O'_2 B' and O'_3 B' (Fig. 3).

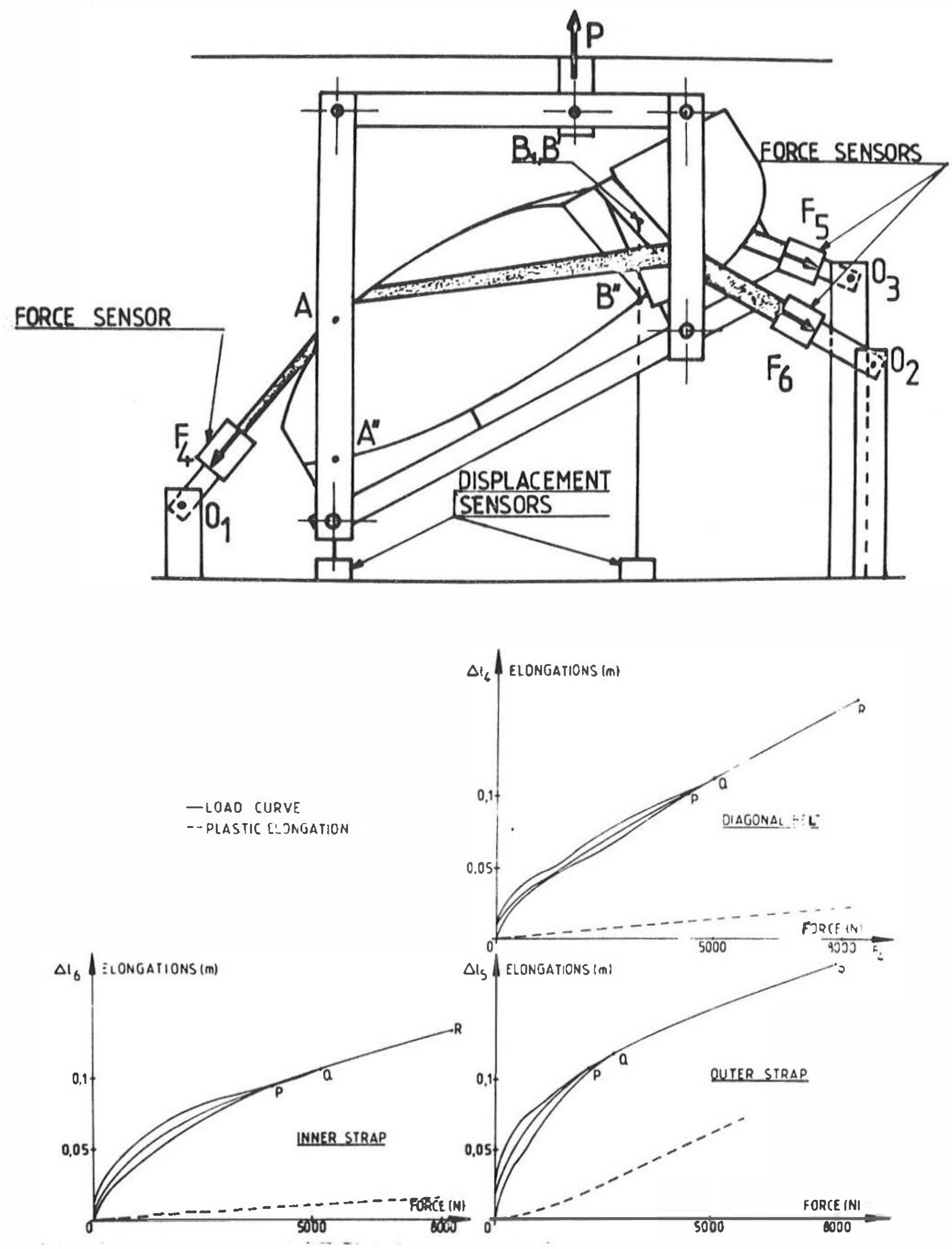


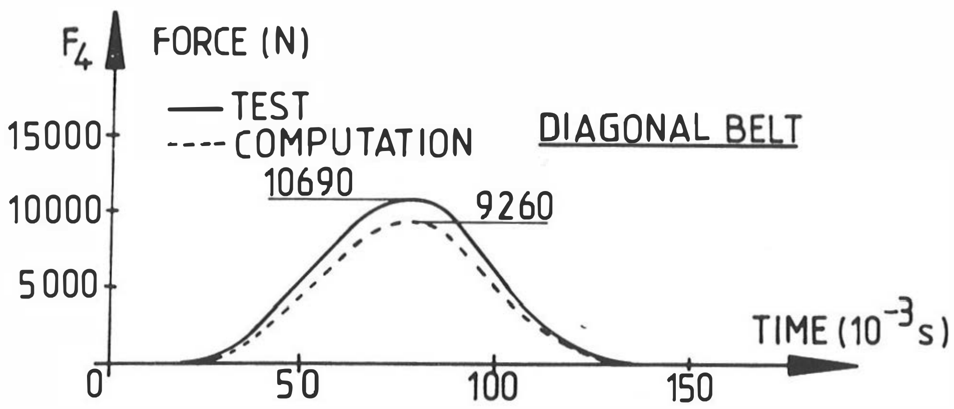
Figure 8 : 3-Point Belt Stiffness

By slowly coming back to P = 0, after each force step, we determine belt plastic elongation variation function of applied load (Fig. 4, 8).

Figure 8 shows belt characteristic curves for three force steps. For the program, we use lower curve O, PQR when loaded and curve OS when plastic elongation occurs.

III - TEST SIMULATION

As much as possible, before using the model, we try to reproduce a test. Although it is not compulsory, it allows us to adapt some parameters (particularly damping coefficients) and thus improve computation. When it cannot be done we use coefficients from a preceding computation. That is what we have done to simulate a catapult test (Fig. 9 to 12).



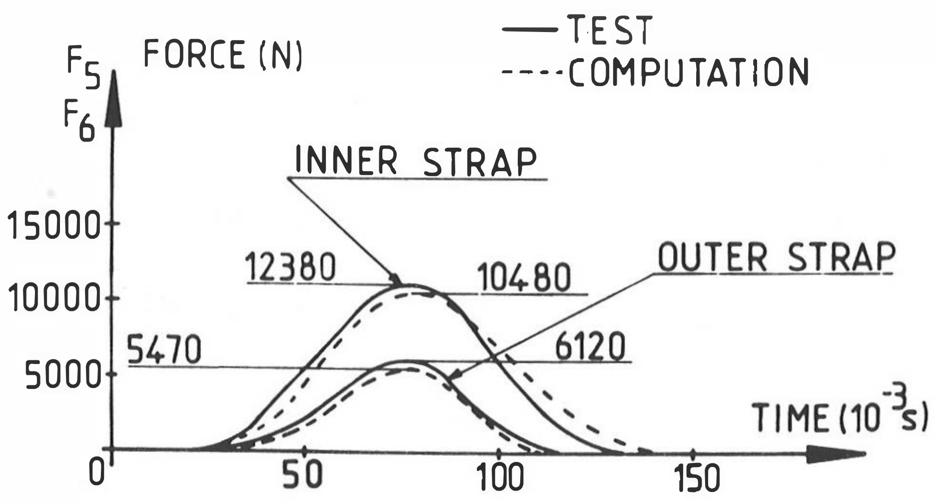


Figure 9 : Forces at Anchorage Points

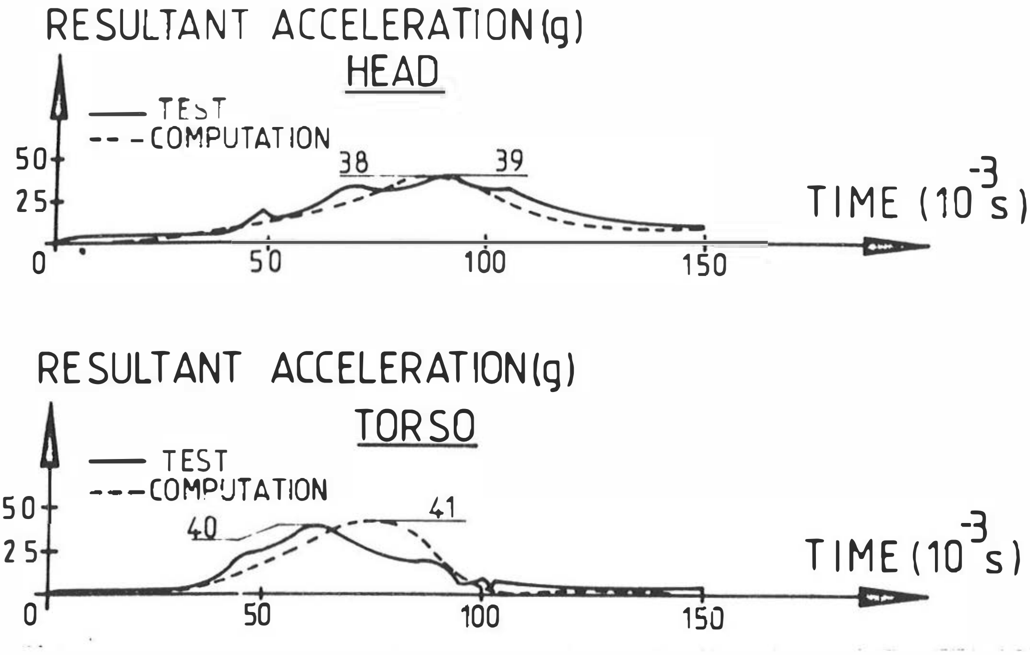


Figure 10 : Head and Torso Resultant Accelerations

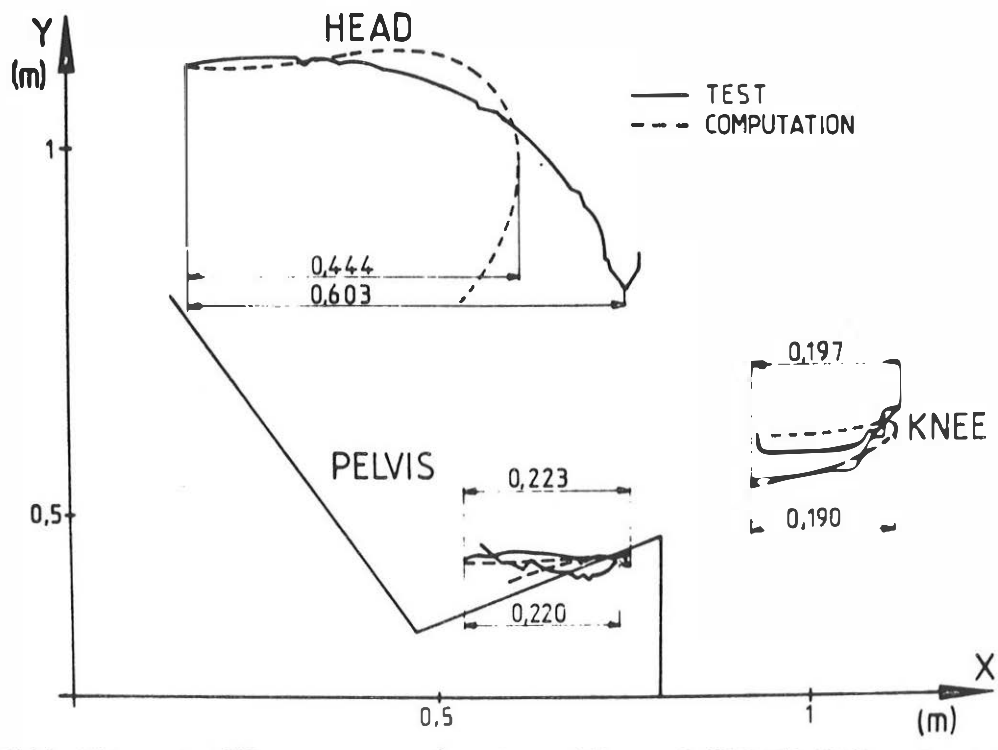


Figure 11 : Head, Pelvis and Knee Displacements

Let us analyse these simulation results.

- Simulation gives forces, at anchorage points, inferior to measured forces and out of phase by 15 to 20 m/S. We see two possible reasons :

  1 - Stiffness of belts having been measured statically, it is normal to find larger dynamic forces.

  2 - Belts may have been very tightly strapped during test (slight pre-constraint).

  To get larger forces, we could eventually take higher damping coefficients for belts.

- Head and torso accelerations match test's. Note that torso acceleration goes out of phase identically with forces in shoulder belt.

- Hip and knee displacements match test's. But head displacement is much smaller. We cannot remedy this last flaw, inherent to a plane model. During a real crash, dummy's whole top part rotates around diagonal belt, so head displacement is larger.

CONCLUSION

We shall conclude this brief study by saying that, with a very simple mathematical model, it is often possible to make a good simulation, if you respect certain rules :

- Model simplicity should not lead to neglecting program necessary data acquisition

- Measurements must be significant. That is why we have used dummy, whose flexibility cannot be overlooked, and a complete three-point belt, rather than a single strap like is usually done.

- Measurements must be adapted to computation method. That is what lead us, for the belts, to measuring displacements in dummy's middle plane and corresponding efforts at anchorage points.

We shall present in another paper, examples of utilisation of our mathematical model (4).

BIBLIOGRAPHY :

1 - D.H. ROBBINS, R.O. BENNETT, A.W. HENKE and N.N. ALEM : Predictions of Mathematical Models Compared with Impact Sled Test Results Using Anthropometric Dummies.

2 - R.R. Mc HENRY and K.N. NAAB : Computer Simulation of the Crash Victim - A Validation Study.

3 - J.A. BARTZ : A Three Dimensional Computer Simulation of a Motor Vehicle Crash Victim.

4 - F. MECHLING, C. TISSERON, M. DEJEAMMES and F. MARTIN : Mathematical Modelling of the Automobile Occupant - Use and Limitation of the Model.