PRAKIMOD : PEUGEOT/RENAULT ACCIDENTS KINEMATICS MODEL

THEORY, VALIDATION AND APPLICATIONS

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ABSTRACT

The mathematical model of the man involved in accidents, PRAKIMOD, (**P**eugeot/**R**enault **A**ccidents **KI**nematics **MOD**el), developed by LPB-APR, is an extrapolation of the MVMA-2D model produced by HSRI before 1973.

The principal of the model is the mathematical representation of the man by a complex two-dimensional rheological system exposed to impacts over a period of time. The software is written in FORTRAN IV and at the present moment works on IBM 3090 hardware.

It was initially designed for the simulation of frontal impacts, and was then extended to the configuration of the pedestrian struck by a vehicle. We also possess TRAJ/PROF software which allows us to analyze the front end of an automobile on a database of 250 types of impacts.
At the present moment, the model is tested in frontal impact for several types of restraint systems ; it is possible to simulate the classical three-point seat belt as well as certain types of passive restraints : several examples will be presented.

The simulation of lateral impacts is also one of the priority lines of research we are working on.

Among the most interesting applications we carry out, are the study of the influence of bumper height and protrusion on pedestrian kinematics and impact severity and the design of an optimum passive restraint system before crash testing of a new model begins, which is the aim of mathematical model.

I - INTRODUCTION

Near the end of 1973, the Peugeot S.A./Renault Association acquired from the former HSRI (now UMTRI) the very first version of a new mathematical model : MVMA-2D (1).

This model was subsequently developed to meet our own needs so that in 1980, as the work done on it was so advanced, its differentiation in relation to the initial model warranted a special designation. It is now well known as PRAKIMOD, which means "**P**eugeot/**R**enault **A**ccidents **KI**nematics **MOD**el" (2).

After describing the main principles of PRAKIMOD, this paper shows how, from theorical data set improved through validations, we benefit of practical informations just before crash test performance on the three axes of application developed by LPB-APR, that are frontal collision, pedestrian to car collision and side impact.

II - DESCRIPTION OF PRAKIMOD

PRAKIMOD is a two dimensional model. The human body is represented by a skeleton with eight rigid body segments interconnected by seven joints in frontal and pedestrian to car collision and limited to five rigid body segments interconnected by four joints in side impact configuration (figures 1 to 3). The length, mass, moment of inertia and the location of the center of gravity are given for each body segment.

Thus, the accident victim model has respectively 10 degrees of freedom (two in translation and eight in rotation) in the two first configurations and 7 degrees of freedom (two in translation and five in rotation) in the last configuration, which are the following : the horizontal position (X) and the vertical position (Z) of an arbitrary point of the dummy (the top of the head) and the angles formed by each of the respectively eight and five body segments with the horizontal.

These ten (seven) degrees of freedom of movement correspond to the ten (seven) generalized coordinates Xi (i = 1, ..., 10 or 7) which define the position of the dummy in space at any moment. For each simulated instant these ten (seven) coordinates are modified by integration of the speed and acceleration values.

The acceleration is calculated using Lagrange's equation :

$$\frac{d}{dt}\left(\frac{\delta T}{\delta \dot{q}i}\right) - \frac{\delta T}{\delta qi} = Qi \qquad (i = 1, \ldots, 10 \text{ or } 7)$$

where qi designates one of the ten (seven) generalized coordinates (X head, Z head, 1, 2, ... 8 or 5 of the body segments), T designates the kinetic energy of the dummy and Qi the generalized force applied to coordinate qi. This generalized force integrates the effects of weight forces, the joint torques, any restraint force and contact forces between the dummy and the vehicle.

III - DETERMINATION OF AN OPTIMUM PASSIVE RESTRAINT SYSTEM BEFORE CRASH TESTS

III - 1. MISCELLANEOUS ENVIRONMENTS

At the present, the system retaining the dummy in the passenger compartment can be defined with sufficient precision thanks to a choice of highly varied options (figures 5 to 7). Although the restraint system configurations corresponding to existing fixtures have been developed step by step for the mathematical model, we have no validations for the totality of simulations for the systems.

Given the desire to use the mathematical simulation concretely before the first vehicle crash tests, our efforts were devoted to validation of the model for the more usual configurations, i.e. three anchoring point roller belt, and more recently, passive safety belt with two anchorages and a knee plate.

III - 2. VALIDATION

Validation of a mathematical model always leads to the following problems :

- Use real tests in which the dummy follows an essentially plane kinematics.
- Avail of sufficient real tests differing from each other by variation of a few elements at a time, so as to be able to determine the exact effect of each of these parameters.

Concretely, for our passive restraint system simulation validation tasks, we used 5 real tests combining the conditions mentioned above.

The variable parameters during these 5 tests were :

- position of the bottom anchoring point of the shoulder belt (movement of 50 mm),
- mechanical characteristics of the knee plate (stiffness ranging from single to double),
- violence of impact.

In general, the simulations obtained for the 5 tests provide results of a rather faithful level and synchronism as far as events are concerned, with respect to those recorded during real tests (set n° 1).

However, in spite of a recent redefinition of the Hybrid II dummy, it has proved impossible to correctly simulate the behaviour of the dummy, especially insofar as head trajectories are concerned (Set n° 2). First of all, this can be explained by the capacity of the Hybrid II neck to take on "S"-shaped geometries (due to its design and production : extendible rubber cylinder). Secondly, and in the present state of modelization of the Hybrid II dummy, the "head-neck" assembly forms a single piece and has only one degree of freedom, which is insufficient to describe the complex behaviour of the Hybrid II neck.

The use of the Hybrid III, in the future, with a better mechanically structured neck than that of the Hybrid II, will doubtlessly enable simulation and modelization closer to the reality of the tests and the technological choices used.

Consequently, we are developing a modelization complement for the Hybrid III dummy, for PRAKIMOD, having a supplementary articulation with respect to the modelization of the Hybrid II dummy (11 degrees of freedom).

This will, of course, enable us to disassociate the present "head-neck" assembly and, due to this, simulate the behaviour of the dummy's head more faithfully. Also, and without considering the intrinsic characteristics of the Hybrid III dummy, this model will be more finely defined at face level, to more accurately determine eventual head-steering wheel interactions during an impact (figure 4).

III - 3. APPLICATION

Within the framework of passivation of a restraint system for a new vehicle, we have decided to exploit our frontal impact mathematical model so as to optimize a system under study in a clearly defined configuration. In fact, this is the most exhaustive application that one could demand from a mathematical model (3) which requires that a correctly validated simulation be available, given that this will be exploited subsequently in a predictive manner with respect to tests, basing ourselves on a limited quantity of informations (types of dummy, environment, restraint systems, impact violence, etc.) without having performed a preliminary experimental test.

In order to optimize the performances of our passive restraint system under study, we have varied the following parameters :

- position of the top lateral anchorage,
- position of the center anchorage,
- stiffness of the knee plate,
- seat position.

(The deceleration law 0° is identical in all cases).

The main criteria which were chosen to discriminate between these various configurations were HIC, the number of head-steering-wheel contacts (speed and location of impact), the force in the femurs and the fall at the end of the seat.

After 21 simulations corresponding to significant configurations (various combinations of parameters used above) with respect to solutions applicable to series production in terms of technical feasibility, comfort and cost, the mathematical model has highlighted six solutions of combinations leading to acceptable values in terms of the safety criteria mentioned above.

On the basis of these results, six crash tests have been planned taking into account the first results, thus preventing the useless and costly destruction of the study vehicle, and leading to solutions unacceptable for safety.

Of course, in the present state of development, it is necessary to relativize a tool of this type, knowing that the mathematical model is an excellent qualitative trend indicator, but the quantitative values obtained for a 2D model must be viewed with a certain amount of reservation. The main advantage of this model is the precious aid that it provides in understanding physical phenomena or principles which occur during the real tests, in which these phenomena cannot be highlighted.

IV - STUDY OF INFLUENCE OF TWO CAR'S FRONT FACE ON PEDESTRIAN KINEMATICS

IV - 1. VALIDATION OF THE MODEL IN PEDESTRIAN COLLISIONS

The model was validated by comparing the simulations supplied by it with experimental dummy collisions, using different automobile models and different speeds.

Validation was carried out on experimental tests made with an adult dummy of 50th percentile, whose legs were more or less bent, to simulate adult victims of differents heights.

Set n° 3 shows the similarity between the trajectories obtained during the experimental tests and those obtained with PRAKIMOD, where the input data set are defined for each collision according to the same method, i.e. most of the data are common to all the simulations and the remainder are determined automatically, according to a limited number of parameters characterizing the vehicle profile and the test conditions.

The vehicles profiles in these figures are not the real profiles used for the model, but stylized profiles corresponding to real vehicle shapes. The pedestrian silhouettes are those that were actually used for the model.

The head trajectories obtained with PRAKIMOD and those obtained during experimental tests without any accident during performance are in a very good agreement, taking account of experimental scatter. The aimed objective was the validation of PRAKIMOD in pedestrian configuration, for the simulation of head trajectories, user's work being facilitated by a simplified classification of the input data. This objective has been reached. Other experimental tests of car-to-pedestrian collisions, performed later on, notably with experimental safety vehicles Peugeot VLS 104 and Renault EPURE, confirmed the accuracy of the head trajectory provided by PRAKIMOD. So, one can reasonably think, now that the validation has been carried out, to be accurately able to simulate any type of pedestrian collisions, at least inside the field of speeds simulated during the validation.

IV - 2. COMPUTER METHOD FOR RATING A PROFILE

No method based on experiments is convenient for evaluating globally the potential risk of a given vehicle for the whole population of pedestrians at risk, which encompasses the smallest children and the tallest adults simultaneously, when a large range of impact speeds has to be considered.

Mathematical models are also inadequate, due to the large number of runs required for obtaining the probability of impact on each section of the front end profile. So we developed a mathematical method for defining the head trajectories yielded by experimental simulations or by a validated mathematical model. We present then a computer program that simultaneously uses this method and statistical data concerning real accidents. The output of this program is a distribution of the impact probabilities for a given profile. The head impact velocities can be utilized for weighing the results.

IV - 3. SYSTEM OF EQUATIONS OF THE TRAJECTORY OF THE HEAD : TRAJ PROGRAM

The tests with which we validated PRAKIMOD in the context of car-pedestrian collisions involved the use of vehicles of various sizes and shapes traveling at a wide range of velocities - from 16 to 48 Km/h. We investigated a mathematical form of CG kinematics of the head obtained by means of PRAKIMOD, for 24 simulations consisting of those performed during the phase of validation of the model and the complemen- tarty simulations with 6 year-old pedestrians or pedestrians with a height between that of a 6 year-old and a 50th percentile adult (4).

The form selected consists of 8 terms adjusted by least squares for each coordinate :

$$\frac{\rho}{Ro} = 1 + A_{1,1}\, t^2 + A_{1,2} t^3$$

$$\Theta = \frac{\pi}{2} - \frac{Vot}{Ro} + A_{2,1} t^2 + A_{2,2} t^3$$

where the constants A (2 per coordinates X, Z or ρ ,Θ) are functions of V, Ro and G

$$A_{i,1} = B_{i,1,1} \frac{V^2}{Ro^2} + B_{i,1,2} \frac{G}{Ro}$$

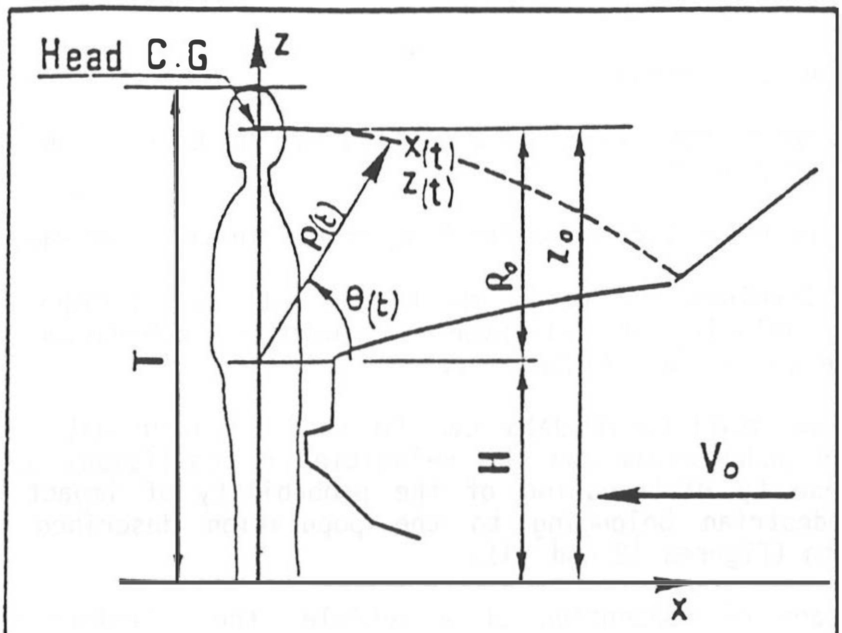
$$A_{i,2} = B_{i,1,2} \frac{V^3}{Ro^3} + B_{i,2,2} \frac{V}{Ro} \times \frac{G}{Ro}$$

the constants B (4 per coordinates) are functions of Ro and H

$$B_{i,j,k} = C_{i,j,k,1,} + C_{i,j,k,2} \frac{Ro}{H}$$

and the constants (8 per coordinates) are determined by a least squares method on the basis of the coordinates of CG of the head with a time interval of 10 ms from the output data of the 24 PRAKIMOD simulations.

The description of the movement by polar coordinates generally gives better results than the description by means of cartesian (rectangular) coordinates for all the shapes tested (as far as pole is placed at the anterior edge of the hood).



Rectangular and polar coordinates frames.

Most of the original trajectories are well fitted by these equations (figure 8), except for those that involved vehicles with a high and angular hood edge (figure 9). This demonstrates that the present form of the equations is not optimal. They can certainly be improved while retaining the general principle of a statistical, nonlinear model for all of the trajectories used in the input data.

IV - 4. APPLICATION : THE PROGRAM PROF FOR THE DETERMINATION OF THE SITES AND VELOCITIES OF IMPACT BETWEEN THE PEDESTRIAN'S HEAD AND ANY VEHICLE PROFILE

These new equations can be used by the PROF program simulating the "bombardment" of the front profile of any vehicle by spheres with a given radius simulating the heads of pedestrians. The kinematics of the center of these spheres are controlled by the equations, in which the coefficients have been determined by the TRAJ program and which involve the height of the pedestrian, the projection of the bumper bar, the height of the anterior edge of the hood, the initial velocity of the vehicle, and the time.

The immediate typical applications for use with the PROF program are :

A - Determination of the site and velocity of head/vehicle impact for a particular impact characterized by :

- a vehicle profile,
- a height of the pedestrian,
- a velocity of collision (figure 10),

B - The same operation for :

- a given vehicle profile,
- a series of pedestrian heights defined by the user at the beginning of the program,
- a series of velocities of collision defined in the same way.

The program determines the head impacts for all sets (height of the pedestrian and velocity of collision) obtained by combination of the elements of the two series (figure 11).

C - The computerized statistical data can be used as input data for the heights of the pedestrians and the velocities of collision, so as to attribute a density distribution of the probability of impact of the head of a pedestrian belonging to the population described by the statistical data (figures 12 and 13).

At the stage of conception of a vehicle, the attention of the constructor's research department can, therefore, be drawn to the zones with the highest risk of impact to make them less stiff.

IV - 5. VALIDATION OF THE TRAJ AND PROF PROGRAMS

A validation of these programs has been attempted by using them to determine the site and velocity of head/vehicle impact in cases of collision between another car, which characteristics were not included in determination of the equations, and a 50th percentile adult in the middle zone of the front of the vehicle at a velocity of 40 km/h. Figure 14 shows the impact obtained :

- by the PROF program (using the coefficients previously determined by TRAJ),
- by mathematical simulation by means of PRAKIMOD,
- in five experimental collisions with dummies.

The site and the velocity of impact predicted by PROF were within the scatter of the values obtained by PRAKIMOD and by the experimental tests.

This attempted validation can be considered to be successful.

IV - 6. CONCLUSION

In this model, the neck is reduced to a simple articulation. The simplicity of this model of the neck does not prevent good simulation of the kinematics of the head up until head/vehicle impact, but it does not allow good simulation of the behavior of the head and neck unit during the head/vehicle impact if the trunk exerts a force in the axis of the neck.

Using the currently developed new version of PRAKIMOD with one more segment, we shall expect to avoid those drawbacks.

Following a more detailed validation and, if necessary, an improvement in the statistical model used, the TRAJ and PROF programs described in this paper may constitute a very reliable computerized tool to determine the zones of a vehicle at greatest risk of impact with the head of a pedestrian.

V - LATERAL IMPACT

Initially developed for the pedestrian impact, then used for frontal impact with a wide variety of restraining systems, PRAKIMOD has been the subject of special developments for the lateral impact configuration. In spite of the existence of this since 1980, no attempt at validation was made due to the lack of an adequate dummy.

However, since the availability of the EUROSID dummy, and due to performance of the first lateral impacts with this dummy, it is possible and necessary to avail of a tool enabling us to better interpret the phenomena which occur, and which are difficult to highlight during a complex real test.

Our first approach consisted in a 2D modelization of the EUROSID dummy. This was modelized into 5 segments interconnected by 4 articulations. We disassembled the dummies into subassemblies corresponding to the modelization segments, so as to determine the weight, center of gravity and inertia for each, together with the form coefficients.

The forms given to this dummy consist of 14 deformable ellipses : 1 head, 1 neck, 1 shoulder, 3 for the thorax, 1 abdomen, 2 for the buttocks, 2 for the ischion and 2 for iliac crests.

The dummy is the only system studied in the modelization. The struck vehicle is represented by a transverse section passing through point R. The environment is defined by two types of regions :

- the passenger compartment, consisting of the non-deformed parts of the vehicle struck by the struck vehicle, or the MBD on impact :
  - . side opposite shock,
  - . roof,
  - . opposite floor,

- the struck side, and therefore the deformed side, is defined tabularly with time :
  - . door,
  - . center pillar
  - . seat,
  - . padding.

These regions conserve their mechanical properties with time, if necessary.

At the present, the initial results with this simulation have become available at the same time that the first tests have been performed using the EUROSID dummy. As of now, we can state that the model offers realistic and promising results without, however, being validated. The limit of these models is constituted by the fact that it does not integrate a second mathematical model (a model of deformation of the impacted side structures of the struck vehicle with respect to time).

Essentially, the interest consists in detailed knowledge of the side wall-dummy interactions in time, together with corporal deflections caused (without omitting all the criteria provided by the model) during the various contacts.

In its most recent lateral shock configuration, PRAKIMOD is a highly interesting instrument of study due to the richness with which the dummy/striking forehead is described, and is much more descriptive than a linear model. In these terms, it may be a non-negligible aid for the development of a mathematical model used for future regulation concerning lateral impact.

VI - REFERENCES

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(2) D. Lestrelin, F. Brun-Cassan, A. Fayon, C. Tarrière, F. Castan,
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(3) D. Lestrelin, A. Fayon, C. Tarrière, Laboratoire de Physiologie et de Biomécanique PSA/Renault, La Garenne-Colombes (France),
"Development and use of a mathematical model simulating a traffic accident victim",

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"Mathematical evaluation of the head impact risk on a given part of a vehicle, as regards pedestrians", SAE Paper 830059.

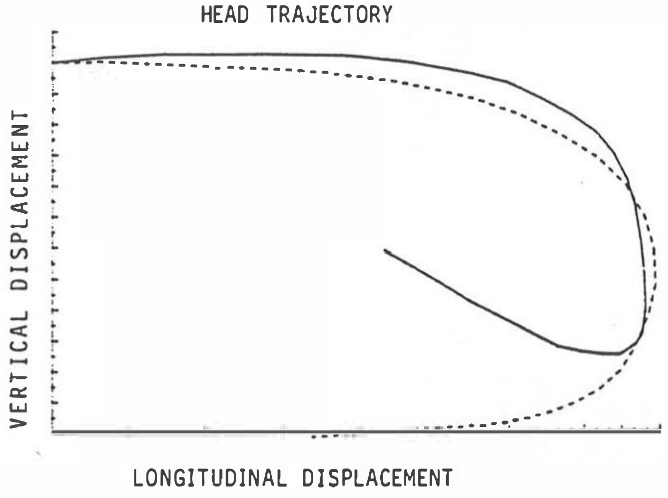
COMPARISON OF TRAJECTORIES

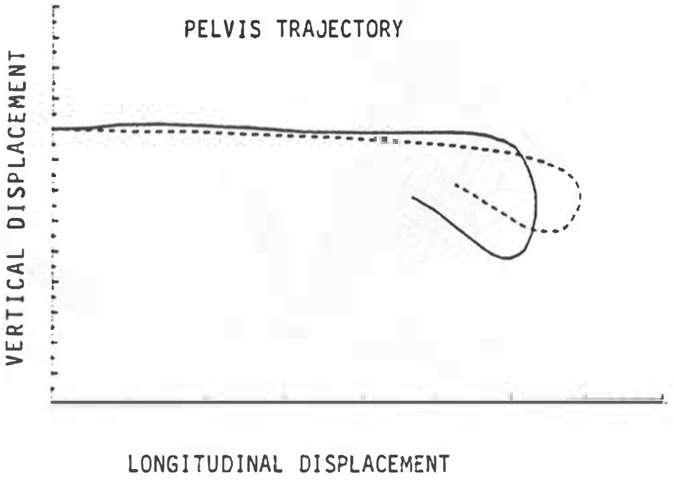
TEST B (Set 1a)

Trajectories are compared :

- at head C.of.G for the HEAD.
- at H point for PELVIS.

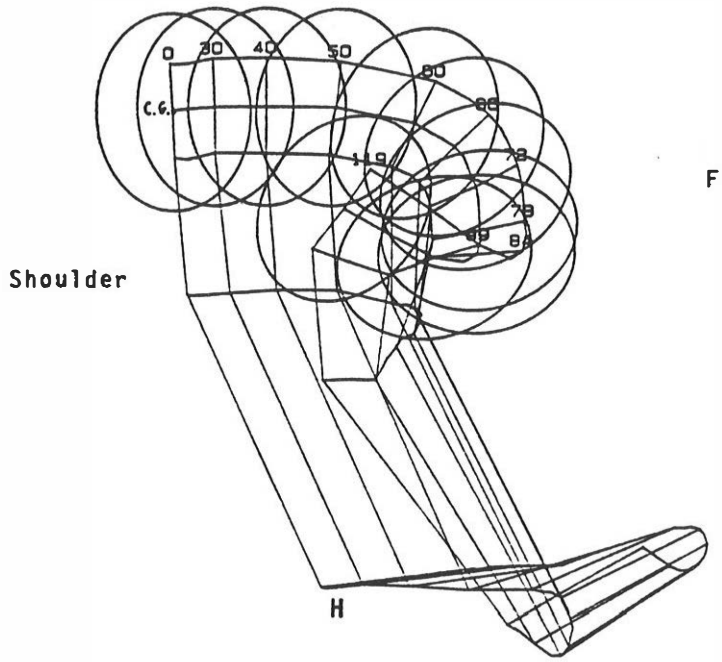
——— Test results.
----- Mathematical simulation.



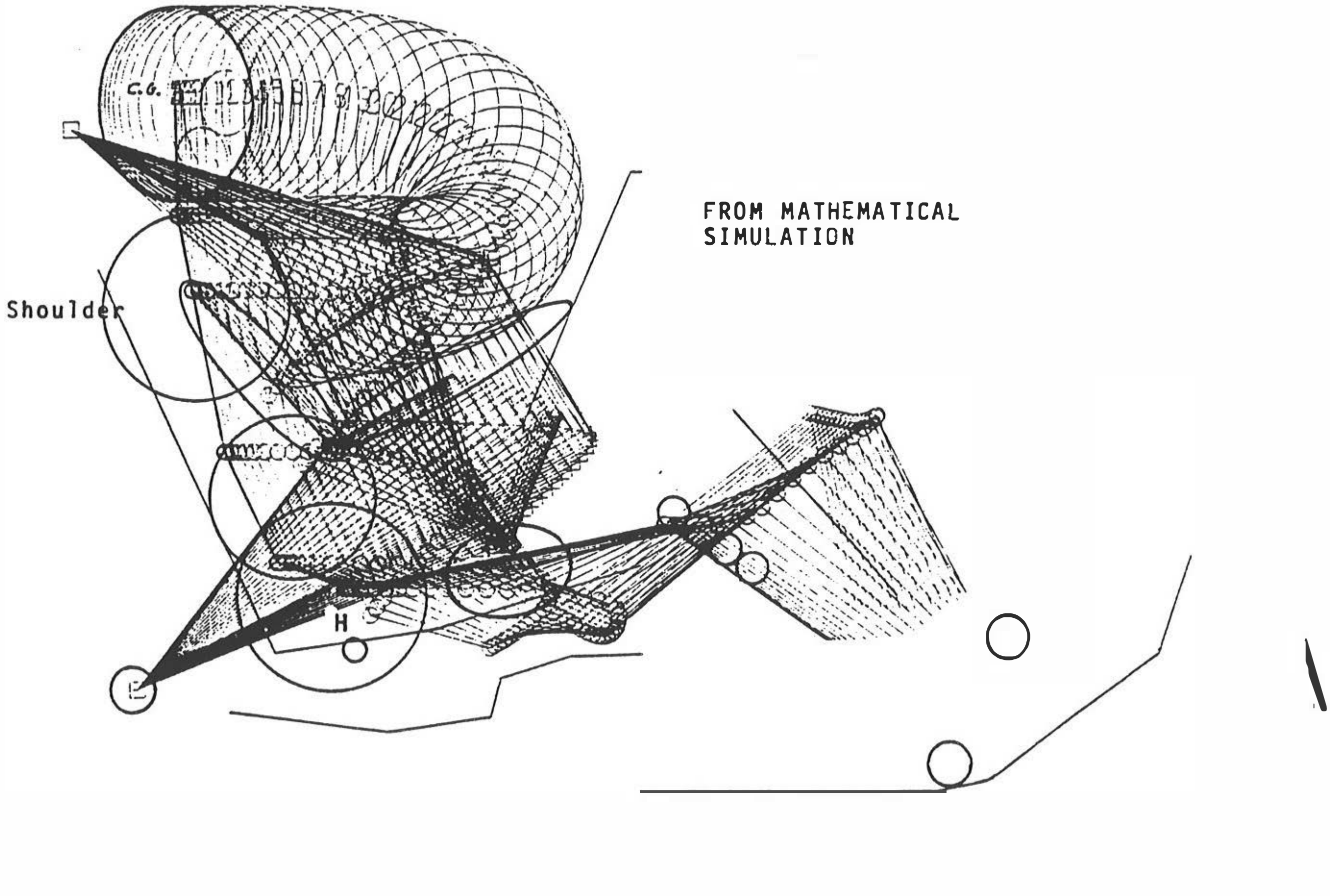


COMPARISON OF KINEMATICS

TEST B (Set 1b)



FROM FILM ANALYSIS

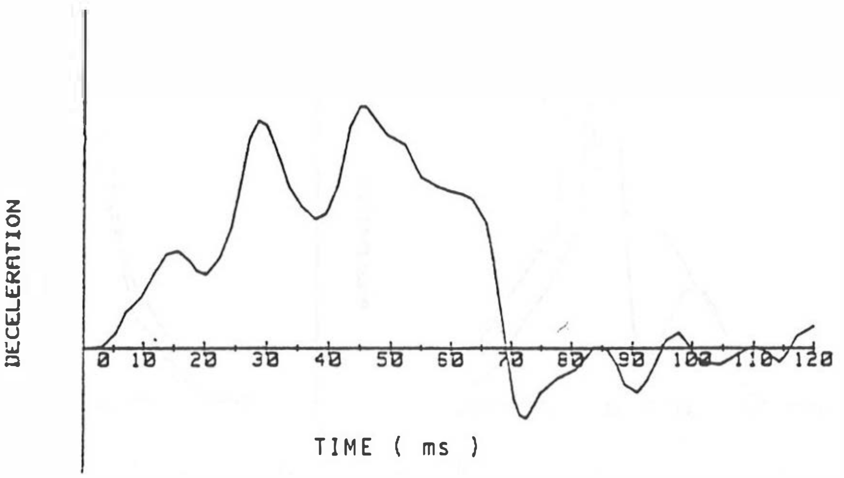


FROM MATHEMATICAL SIMULATION

COMPARISON OF ACCELERATION CURVES

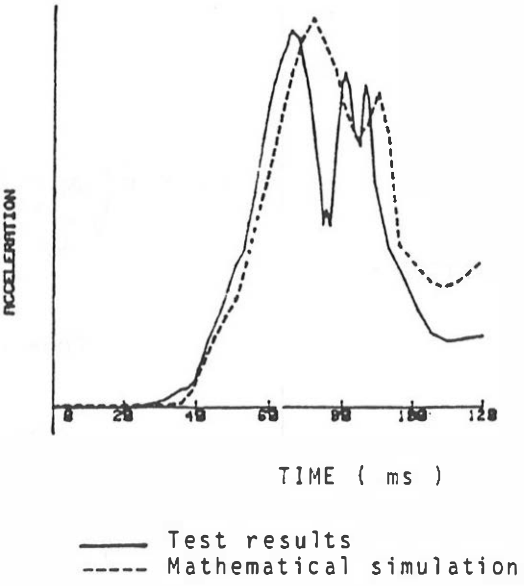
TEST B (Set 1c)

VEHICLE DECELERATION



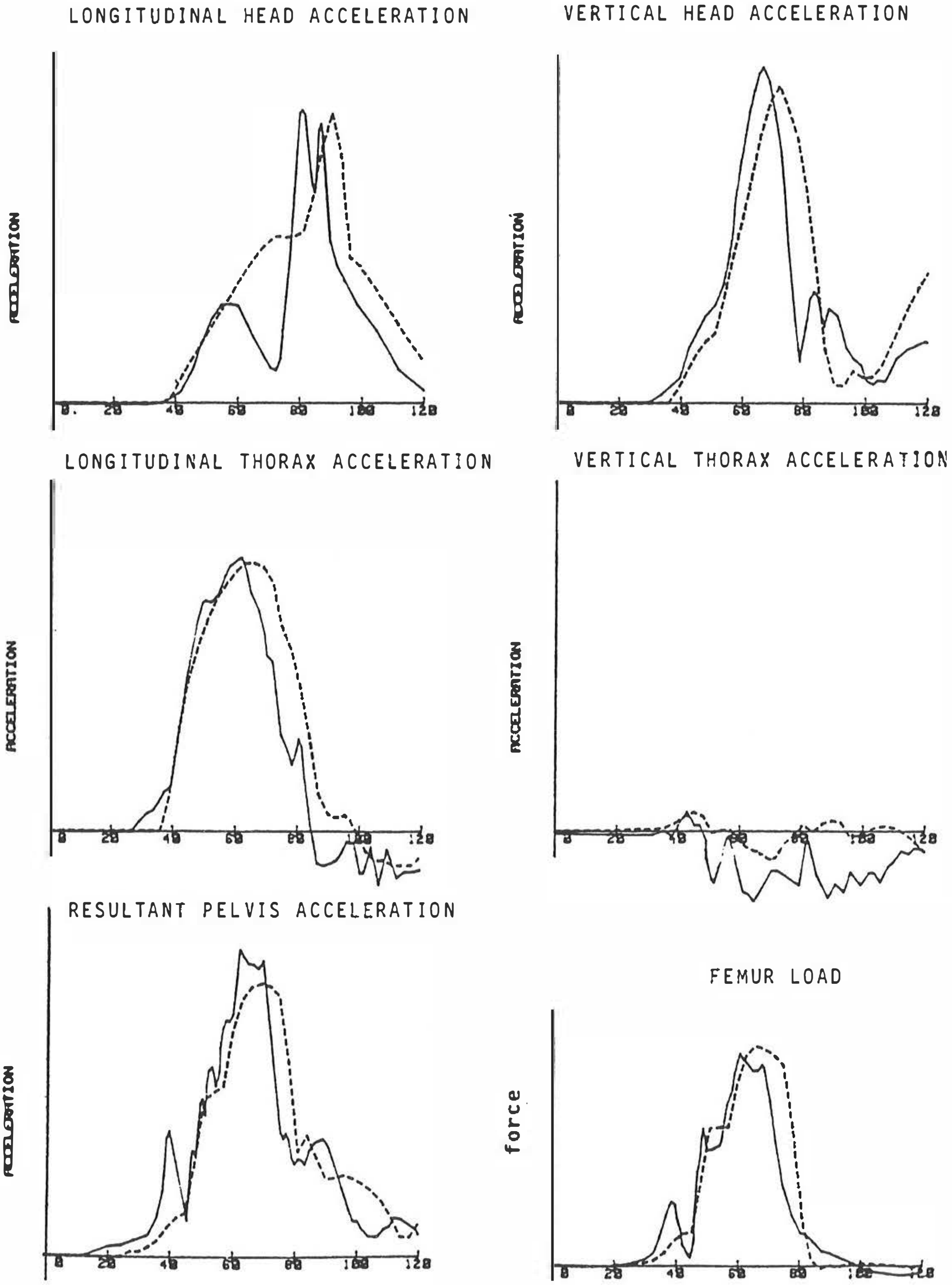
RESULTS OF SIMULATION

RESULTANT HEAD ACCELERATION



COMPONENTS OF ACCELERATIONS AND FEMUR LOAD

TEST B (Set 1d)



Time in ms on X - axis

COMPARISON OF TRAJECTORIES

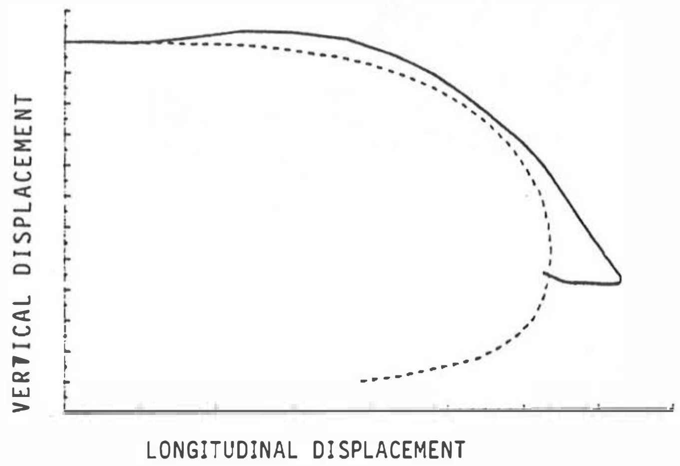
TEST A (Set 2a)

Trajectories are compared :

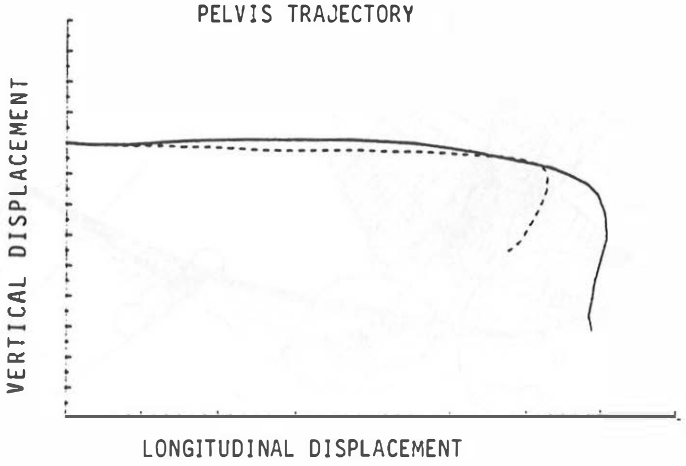
- at head C.of.G for the HEAD.
- at H point for PELVIS.

———— Test results.
----- Mathematical simulation.

HEAD TRAJECTORY

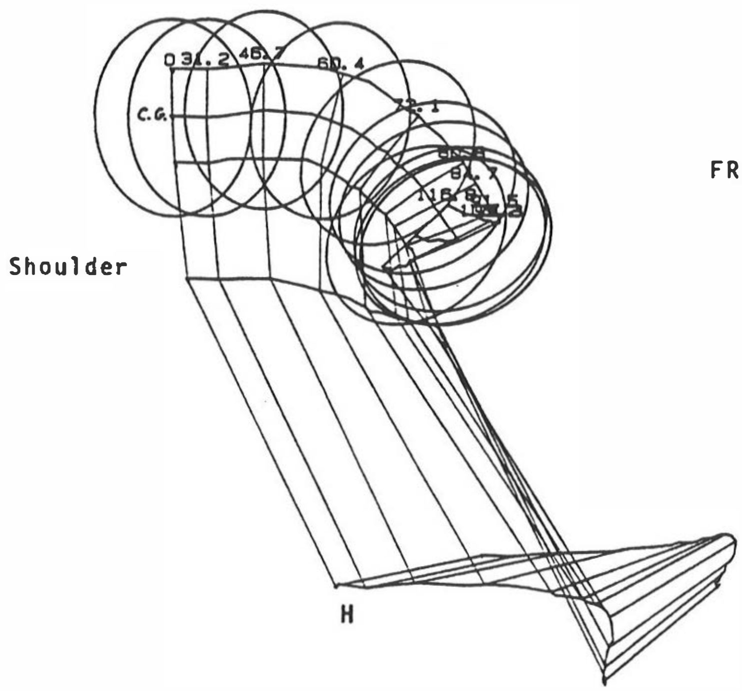


PELVIS TRAJECTORY

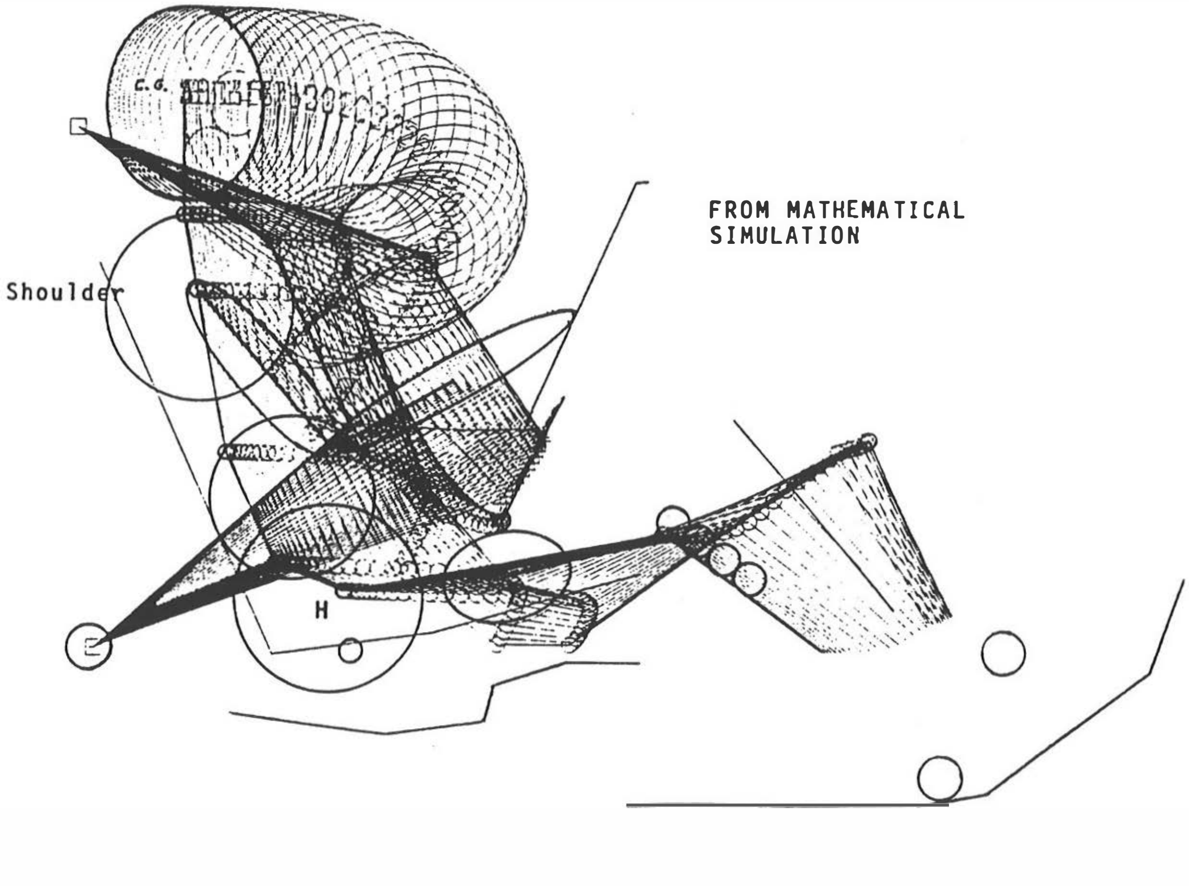


COMPARISON OF KINEMATICS

TEST A (Set 2b)



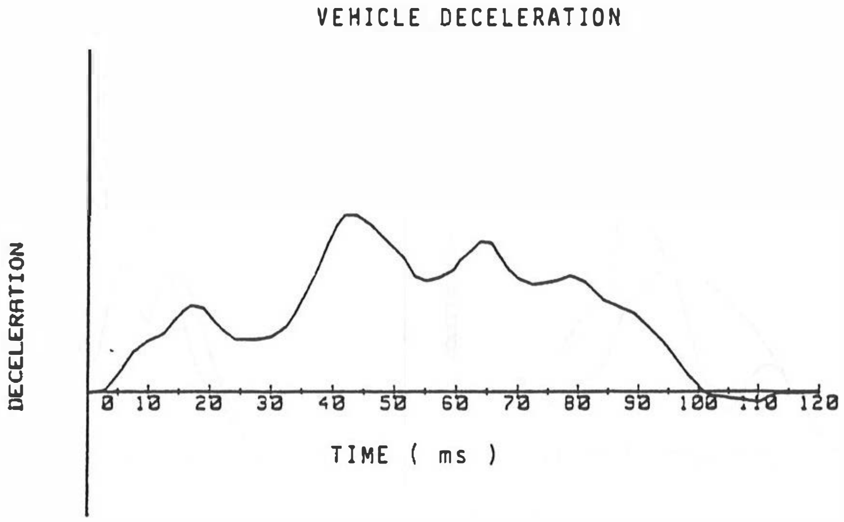
FROM FILM ANALYSIS



FROM MATHEMATICAL SIMULATION

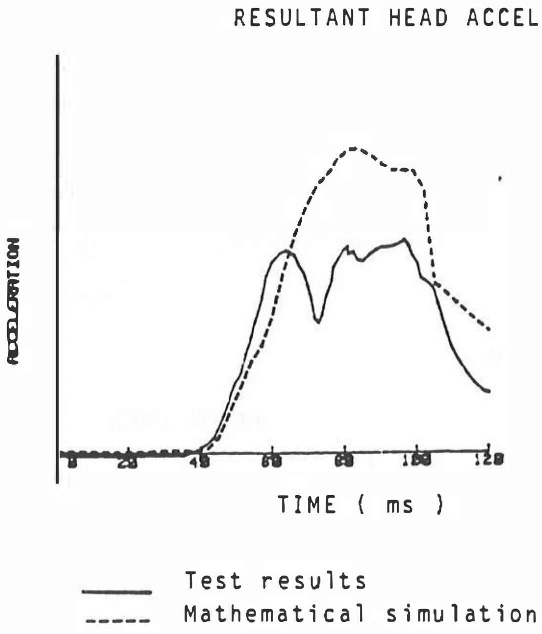
COMPARISON OF ACCELERATION CURVES

TEST A (Set 2c)



VEHICLE DECELERATION

RESULTS OF SIMULATION

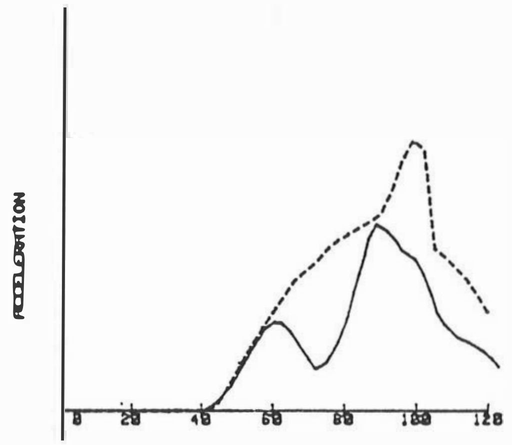


RESULTANT HEAD ACCELERATION

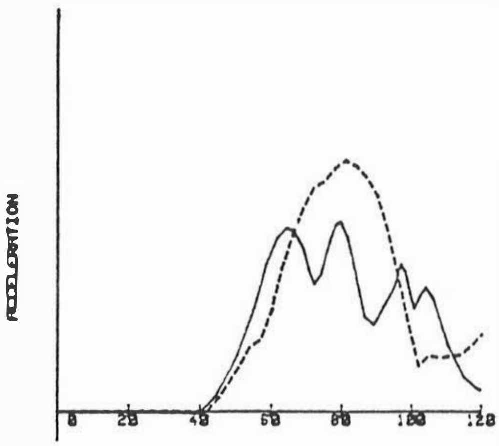
COMPONENTS OF ACCELERATIONS AND FEMUR LOAD

TEST A (Set 2d)

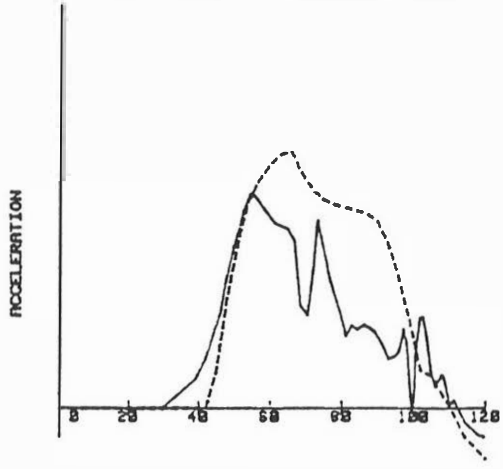
LONGITUDINAL HEAD ACCELERATION



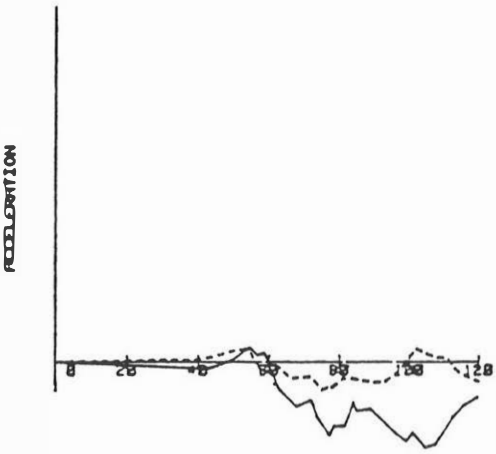
VERTICAL HEAD ACCELERATION



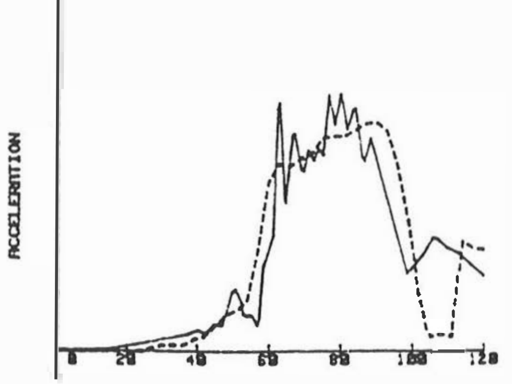
LONGITUDINAL THORAX ACCELERATION



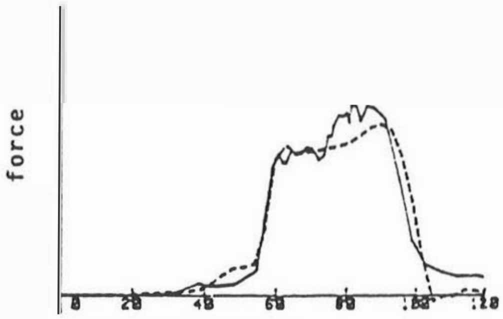
VERTICAL THORAX ACCELERATION



RESULTANT PELVIS ACCELERATION

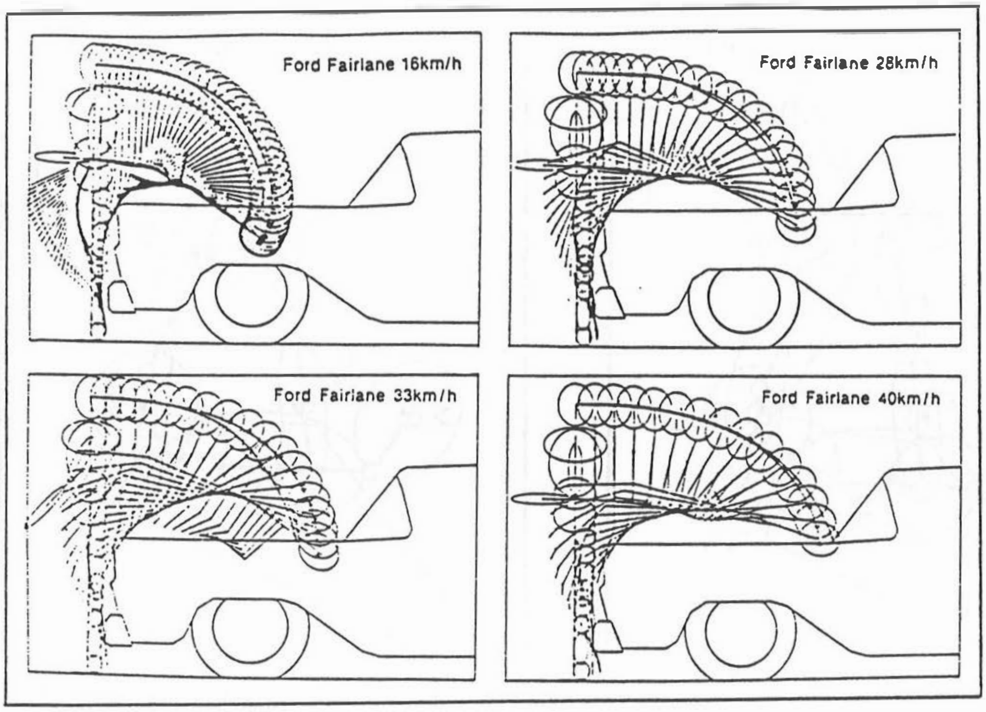


FEMUR LOAD

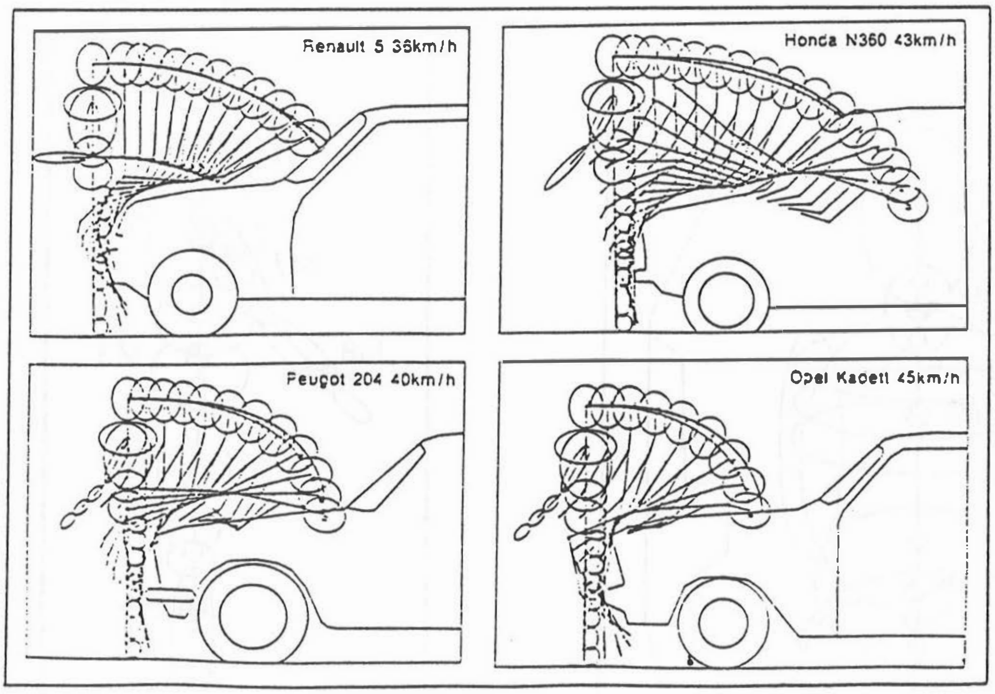


Time in ms on X - axis

Set n° 3



Validation of PRAKIMOD on a series of collisions with the same vehicle, at different speeds.



Validation of PRAKIMOD on a series of collisions with vehicles of different shapes.

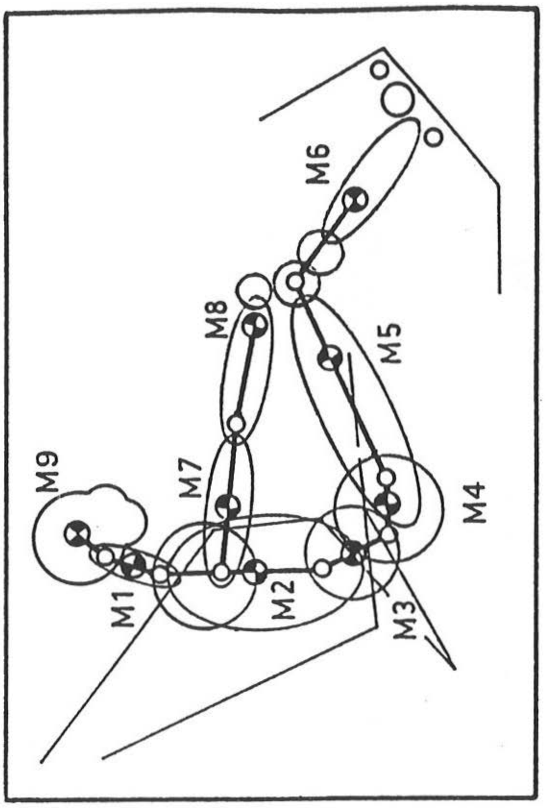


fig 4

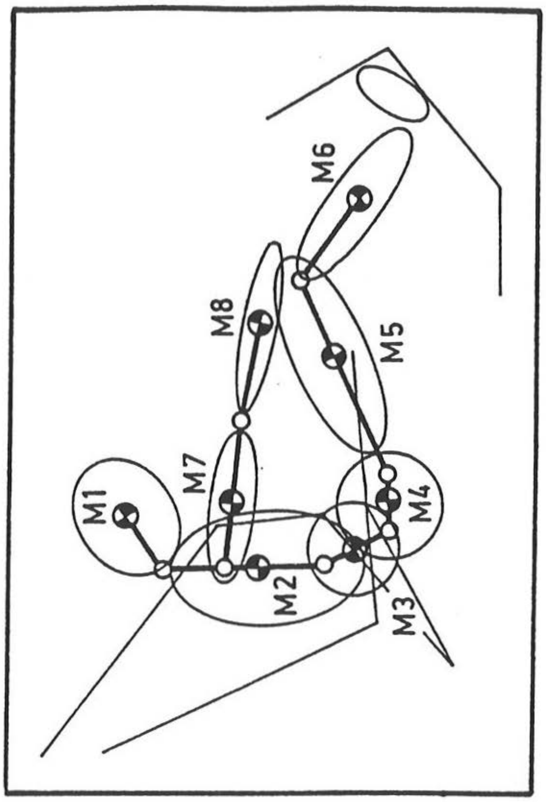


fig 3

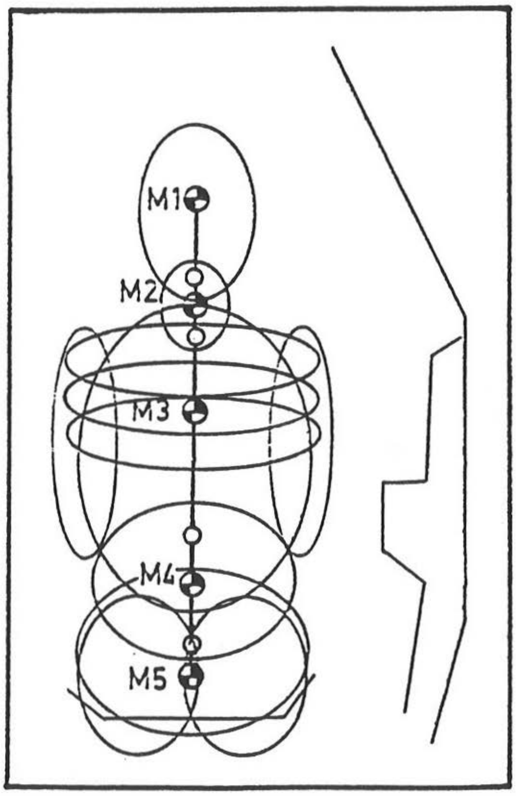


fig 1

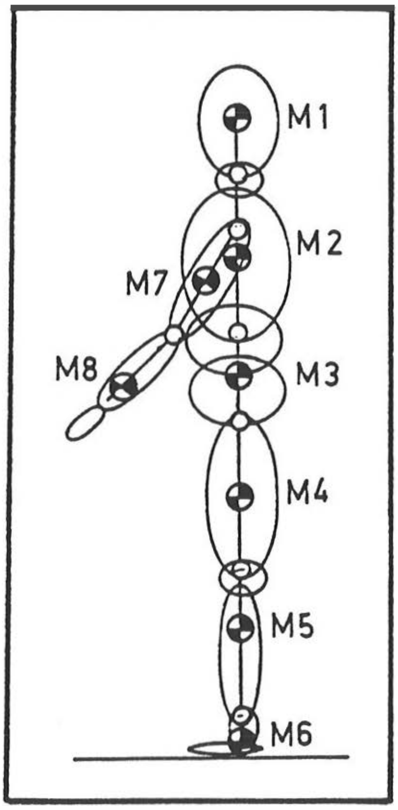


fig 2

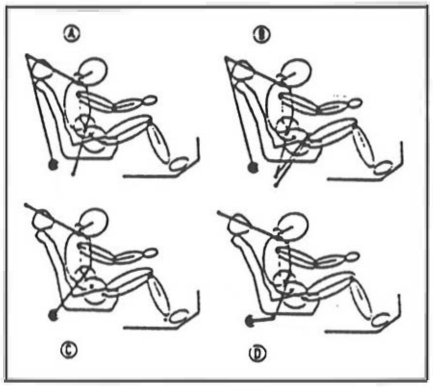


Figure 5 Simulation of safety belt retractor with different examples of retractor position and of a possible web-guide.

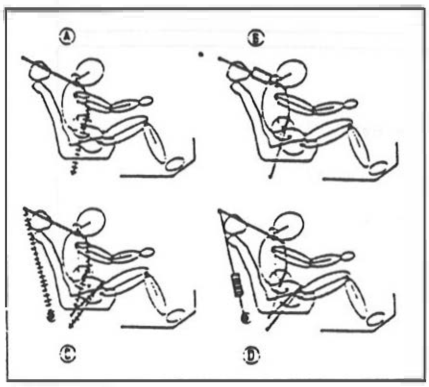


Figure 6 Distribution of the deformation of the belt: a) and c): uniform distribution of the deformation on the whole length of the belt; b) and d): localization of the deformation in a load limiting device.

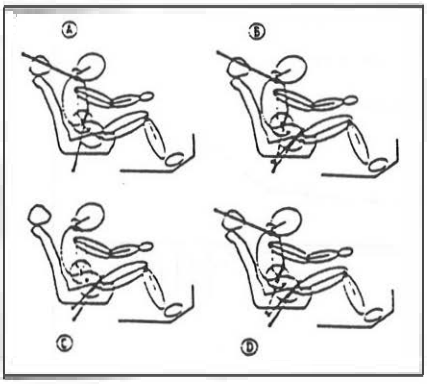


Figure 7 Some examples of belt configurations simulated by PRAKIMOD:

a) shoulder belt only
b) three-point belt
c) lap-belt only
d) lap belt and shoulder belt independent.

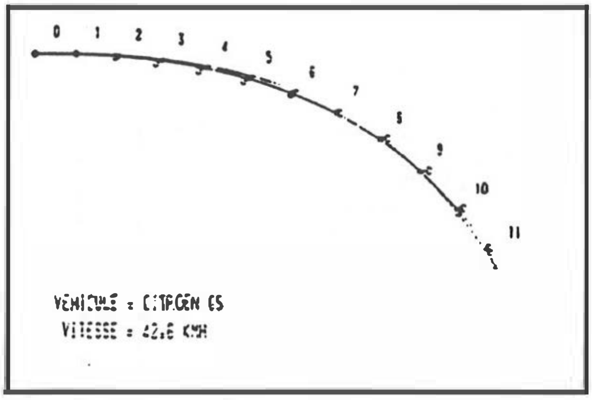


Figure 8 **Example of good adjustment of the trajectory by the TRAJ equations**

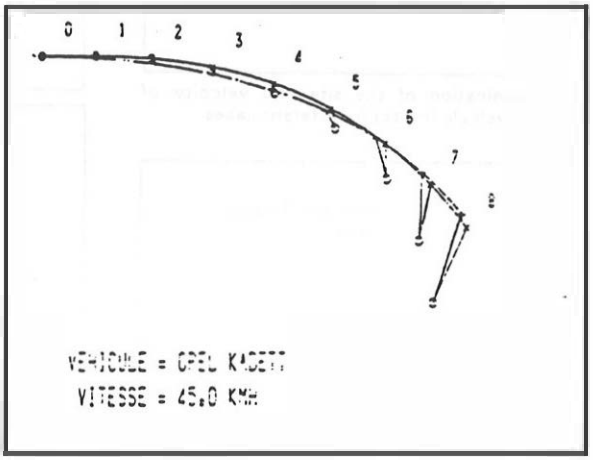


Figure 9 **Example of poor adjustment of the trajectory by the TRAJ equations**

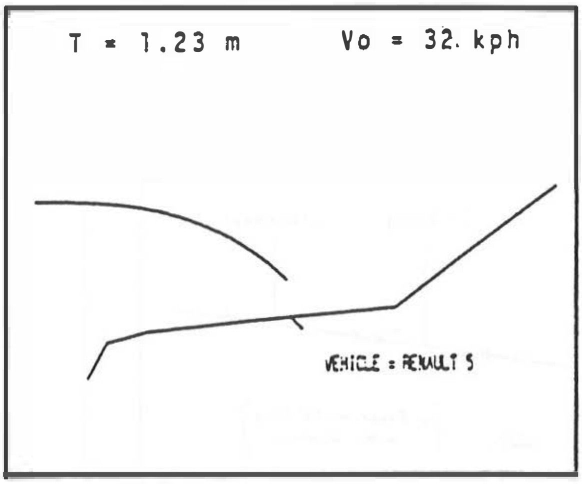


Figure 10 **PROF output examples—determination of the site and velocity of head/vehicle impact in different cases**

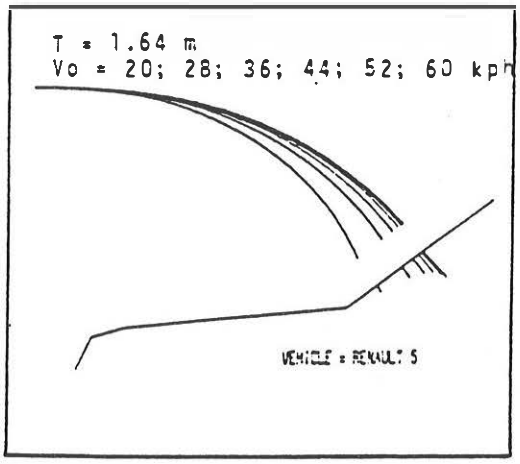


Figure 11 Determination of the site and velocity of head/vehicle impact in different cases

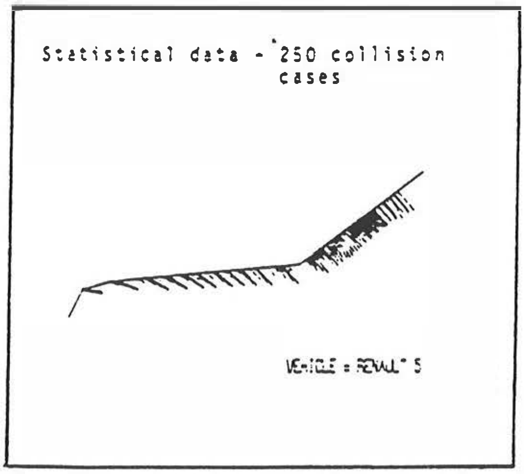


Figure12 Determination of the site and velocity of head/vehicle impact in different cases

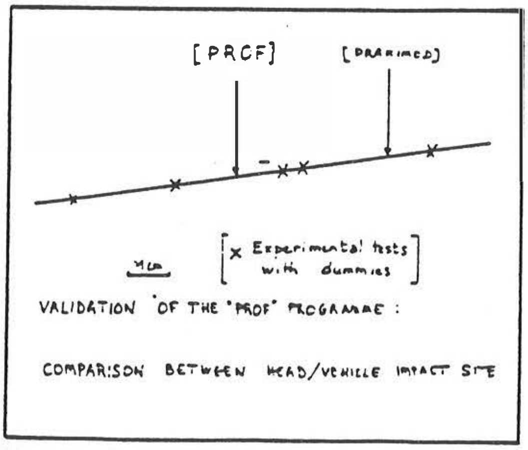


Figure14 Comparison between head/vehicle impact site

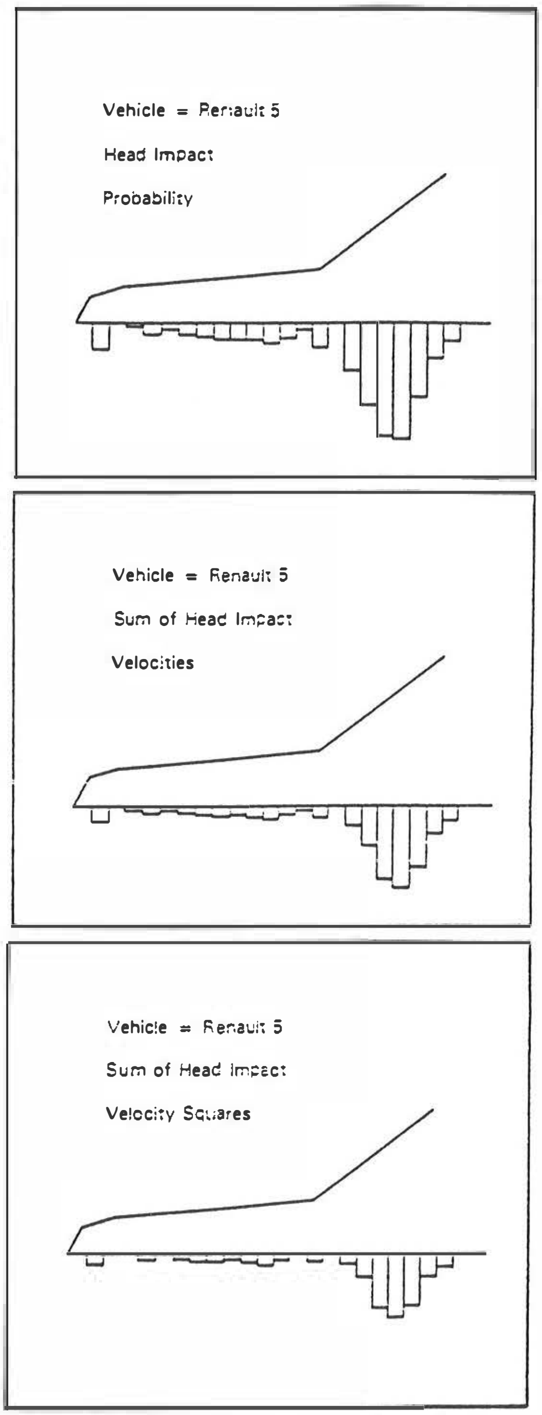


Figure 13 Weighting of the results shown on Figure 12 by the impact velocity