DEVELOPMENT AND USE OF A MATHEMATICAL MODEL SIMULATING A TRAFFIC ACCIDENT VICTIM

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One of the aims of this paper is to highlight a philosophy for employing mathematical models. The other aim is to present some results obtained in the field of utilization of the MVMA-APR mathematical model drawn from three studies on particular problems shown in the appendices:

- two studies on pedestrian configuration,
- and one in head-on collision configuration with a passenger restrained by a shoulder belt and a knee bar.

HSRI DESIGNED IN 1973 A TWO-DIMENSION, eight-mass mathematical model, called "MVMA-2D". The Peugeot-Renault Association was able to acquire it, and developed it for their account. The programme was initially developed and used in the "occupant" configuration (head-on collision), and also in the "pedestrian" con figuration. Finally, the model was extended to the "side collision" configuration.

One should not be surprised that certain improvements made to the model since it was designed converge, if a comparison is made between the work conducted at the University of Michigan (1) (2) (3), and our own results. The APR modifications were priority oriented by the need for a modelization of human behaviour in collision configurations where the experiment was critical and the theory little known.

I - THE FIELD OF APPLICATION OF MATHEMATICAL MODELS (M.M)

Four types of applications of mathematical models can be distinguished, each requiring special precautions and an increasing degree of validation, in the following order :

a) Help in understanding the phenomena - The user, after defining the simulated collision data himself, has at his disposal a set of results which is a perfectly logical sequence of a cause and effect chain. Even though the result may not be perfectly realistic as certain aspects of reality are roughly simulated or neglected, everything that happens can be explained and this explanation is accessible, either in the model conception, or in the simulation results or data. In particular, all accelerations of the victim's body segments can be explained by the forces generated in contacts, by the centrifugal effect of rotation, by the articulation couples, etc. All these couples and forces can in turn be explained by the position and velocity of the dummy with relation to the vehicle at any moment in time. A mathematical model can therefore be an excellent teaching instrument, provided that it functions well, that the schematization it implies does not distort reality too much, that the results are fairly complete (forces, velocities, acceleration crumpling, couples, etc.) and is stated in a clear and "readable" manner. The user should also make the effort to find the explanations to all the questions that may present themselves.

b) Calculating physically unmeasurable parameters - When conducting experimental tests, it is easy to measure accelerations. Movements, forces and couples are more difficult (at least for some). For each extra measurement, there is a corresponding extra cost (cost of sensor or measuring instrument, fixture, recording, dismantling, analysis, calculations, etc.)
As for some quantities such as kinetic energy, amount of movement, crushing energy, they are impossible to measure. On the other hand, as the results supplied by a mathematical model are pure products of calculation, all variable functions are accessible or can be calculated. The user has far too much to choose from, and the outputs are generally controlled by a series of selector switches.
Should the user really need a particular function which is missing from the designed list of outputs, it is always possible for the calculation and the printout of this function's values to be added to the model (Cf. list of variables added as further output).
A mathematical model (M.M.) can therefore serve to complete measurements made in experimental testing: the mathematical model data should therefore be adjusted so as to make the results of the simulation coincide with the known and measured results of experimental testing (trajectories, accelerations, etc.) As soon as the results coincide satisfactorily, any particular function can be calculated (see example in Appendix 2: calculating energy distribution -passive belt). Such a use of M.M. can also be envisaged for accident reconstructions.
The conditions for using a M.M. in this manner are as follows:
- a sufficient number of results should be had on the reference test or the accident to be reconstructed (trajectories, impact points, levels of acceleration, etc.) so that reproducing the known results will ensure that the unknown results and data are reproduced. Example: knowing the coordinates of the impact point of a pedestrian's head on a vehicle will not suffice to correctly simulate the accident if all the other parameters are not known (size of pedestrian, vehicle velocity at moment of impact, etc.)
  On the other hand, knowing the size of the pedestrian can enable the impact velocity to be evaluated using simulations in which the vehicle velocity will be gradually increased or decreased until the right impact location is found.

In other words, the more reliable data the user has at his disposal, the less risk there is of the effects of certain errors on the input data being cancelled and consequently being hidden from him because of the effects of other errors.
- The model should ensure sufficient quality of simulation so that the user may reproduce quite accurately the results of a test.
- Finally, the user should take pains and call on his intuition in order to define the most relevant set of input data. His task will be made easier if he has sets of data approaching the configuration he wishes to simulate.

c) Study of the influence of a parameter - This is what M.M. are usually used for. The technique consists, firstly, in finalizing a set of reference data enabling a simulation to be produced which is considered realistic and representative of a collision the user is interested in, and then in changing the values of certain input parameters the influence of which is to be studied, with the others keeping their reference values. The results are then compared with the reference results, thus enabling the influence of the input data, the value of which has changed, to be quantified taking the results as a basis (maximum rates of acceleration, severity indices, trajectory amplitude, forces sustained, etc.) See appended examples: "Study of the influence of bumper position on the kinematics of a pedestrian's head when pedestrian is struck", "Study of the influence of several dummy parameters on its propensity to submarine". The condition for a mathematical model to be used in such a manner is that the model be close enough to reality for us to rely on the sense and amount of output result variations. The model and set of reference data should therefore be validated for at least one configuration close to that being simulated.

d) Directly predicting test results -, even if there are no experimental data in similar conditions. This is the most ambitious manner of using a M.M. It consists in predicting, with just one simulation, the trajectories and impact velocities with accuracy, and the levels of acceleration and severity indices less accurately in the case of collision, based on a limited amount of synthetic information (anthropometric data of victim, impact velocity, shape of vehicle deceleration curve in a head-on collision, approximate position of victim, etc.)
We are presently working in this direction on simulating pedestrian collisions, and the results obtained enable us to be reasonably confident. The condition for such a use is:
- to split up the input parameters into two categories: those for which the average and common values can be frozen for all the tests; those for which the value should be accurately determined for each particular configuration.
- Assign standard values to the parameters of the first category.
- Validate the model with the thus-defined data over a relatively high number of experimental collisions as different as possible.

II - REFLECTIONS ON THE NOTION OF VALIDATING

Validation is never acquired absolutely. At a certain stage in development of the model, we have a state of validation which is limited to:
- certain configurations (e.g. a model can be validated for the occupant and badly validated for a pedestrian, or well validated for 3-point belts and badly validated for different passive belts);
- certain fields of variation of input parameters (e.g. for pedestrian: large vehicles, low vehicles, small and tall pedestrians, low, average and high speeds, particular shape of vehicle front).
- Certain output parameters (e.g. a good quality of trajectory simulation will be obtained more easily than the acceleration levels on impact).

These restrictions will depend on the degree of accuracy required by the user on the parameters he is interested in. They will also depend on the data for feeding the model as much as on the model itself: if the values of certain input data can be readily determined by measurement, others are difficult to be determined experimentally.

Thus, a model is progressively validated as new collisions are simulated, certain parts of the model are improved upon, and experience we have on data makes progress.

III - WORK CARRIED OUT ON THE MODEL

III - 1.- Quality of simulation.-

For an equivalent utilization cost, the advantages of a model increase with the quality of simulation it affords. This justifies efforts being made on the model when it appears that such and such a modification, whether it be pin-point or fundamental, will enable a considerable improvement of the model behaviour to be hoped for in a precise situation or in all cases. This is always reasonable when the intended modification is based on a more thorough analysis of the phenomena. On this score, at least three parts of the model have been improved upon in particular.

Belt system in head-on collision - Step by step, we have developed a belt system with options enabling different configurations to be simulated realistically. These options are :

- 3-point belt with buckle and sliding belts, or independent lap and shoulder belts, or both types of 2-point belts;
- adherence or slip with rubbing at thorax, buckle and pelvis levels,
- simulation of the belt between top anchor point and reel, with or without rubbing at return loop,
- simulation of belt tightening in reel,
- uniform distribution of belt stretching over whole length of belt, or local deformation in a load limiter,
- possibility of anticipated tensioning of belt by a time-controlled retractor.
- possibility of cancelling belt-thorax ties in order to keep good belt geometry.

Articulations - The friction couple model and the stop couple model have been modified providing more realistic "dummy" behaviour and better stability of the step-by-step integrations of programme. Muscular reactions couples have been added as option to simulate the victims of real accidents.

Angle problems in vehicle contact surfaces - This delicate problem of generating realistic contact forces when impacting sharp edges, which is important for pedestrians, has been dealt with by distinguishing between two types of contact areas with different "behaviours":"bent sheet metal" types of region (bumper, front nose panel, bonnet, windscreen, etc.) and regions the shape of which limits a full volume (padding, soft-nose, etc.)

This modelization gives satisfaction, although it can still be improved upon.

III - 2.- Improving usability.-

When the model becomes easier to use and when the results become more "meaningful", the users will use the model more readily, lose less time by using it, and draw more information from it.

This justifies the efforts made on the following detailed main points:

Reliability of operation - Execution ending abnormally for reasons other than data errors have become very rare. "Safety devices" have been added. Even if there is a problem, the results already obtained are printed out and plotted due to the programme being divided into independent stages (simulation, calculation of indices, printing out of results and plotting of curves, simulation display).

Simplifying data - Certain data which are difficult to determine have been replaced by automatic calculations.

Further printout outputs - Outputs have been added to those already existing. They are destined either to help in understanding the simulation sequence, or in completing simulation results.

Calculating severity indices - Calculating and printing out indices in an independent stage from simulating has been conducted with great care. Besides calculating the severity indices on components A-P and S-I, and on the resultants of head and thorax accelerations, calculating the time during which the specified acceleration thresholds of 0 to 200 g are exceeded in steps of 1 g, for head, thorax and pelvis accelerations, can be made. The resulting levels of acceleration exceeded for 3 ms are calculated for the head, thorax and pelvis. A very performing HIC calculation has been designed. Its execution time does not increase with the square of the number of points, but approximately with the square root of the number. Furthermore, it automatically calculates the HIC corresponding to each sufficiently isolated and pronounced peak (e.g. pedestrian impacts with vehicle and ground).

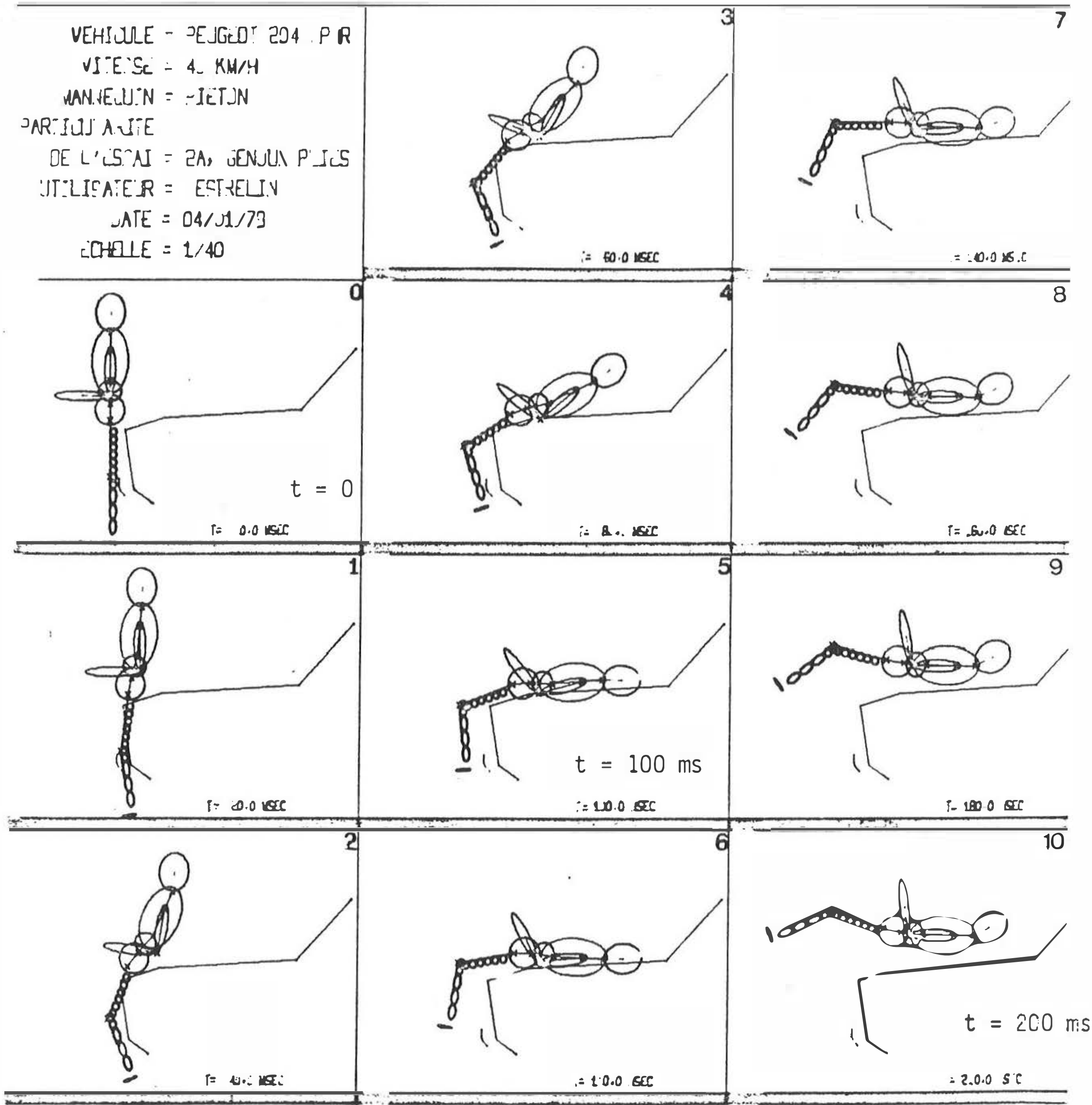
Displaying kinematics - The victim is drawn by a plotter in his environment (vehicle profile, occupant belt if any, the ground for pedestrian), at the scale required by user, in a reference frame related to the vehicle or to the ground with the sequences being separated or superimposed (see figure 1). The plot can be made automatically at the same time as the simulation immediately after the results have been printed out. The user can, furthermore, obtain data on cards at output which can be stored in the archives, thus enabling him to have other displays in other conditions (other scales, offboard datum instead of separate, etc.) To compare the trajectories of two tests, the users can make displays on a transparent support and superimpose them or have them plotted on the same sheet with different lines. These displays are extremely useful in understanding the phenomena arising during a simulated collision, and in interpreting the results.

Display and check of initial conditions prior to calculating - The set of data can be tested prior to carrying out the simulation using a programme that traces the dummy, the vehicle and, if required, the belt, in the initial collision position at 1/5 scale, and can also show up certain anomalies in the set of data.

Plotting of output curves - All the results it is possible to print out at output can be selectively plotted on a variable number of sheets. On each sheet, the user can have all the variable he wishes traced out as ordinates depending on the same parameter as the abscissa, which may be time, but also any other parameter, taken from a same category or different categories, in order to compare the shape of the curves, highlight any dephasing or synchronisms, determine graphically equivalent masses, trace trajectories of ellipse/vehicle contact points, effort/deformation curves, etc.

IV - INTERACTIONS BETWEEN DEVELOPING AND EXPLOITING THE MODEL

It goes without saying that working on the programme will improve the quality of the results obtained by users. For example, the increasing similarity which is obtained in occupant configuration in a head-on collision between the mathematical simulations and experimental reference tests can be explained on the one hand by greater data experience, and on the other by successive impro-



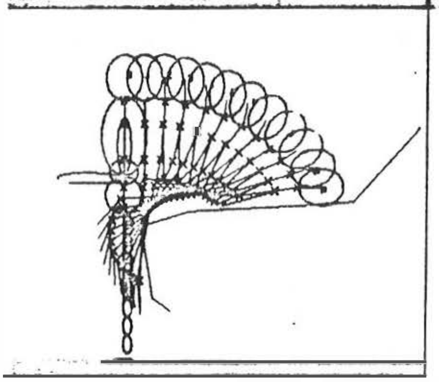


Fig. 1 : Example of kinematic display
- separated sequences (above)
- superimposed sequences (opposite)

vements made to the programme, notably to the belt model. But it should be stressed that, conversely, not only is the exploitation of all the models vital in order to highlight operating problems and test programme modifications - the tests, although necessary, will not suffice - but it is also very useful for showing up a utility hierarchy among all the improvements it would be tempting to programme. It enables therefore the person in charge of improving the programme to carry out the most useful work in priority.

CONCLUSION

The results developed in the appendices will not be recalled; it is rather a question of taking stock of the use made of MVMA/APR.

After several years of practice with a relatively complex mathematical model, it appeared that results which could be verified only with difficulty in experiments, could be obtained using the M.M. Does this mean that the proportion of research work conducted using models will increase indefinitely to the detriment of research work conducted experimentally ? No answer can be given to this question for the choice of either approach will depend on the permanent adaptation work which is necessary both for the models and full-size accident simulations. The models need simulation quality, experiments need repetitivity. It can however be remarked that any extending of the domain accessible to the model means conducting validation tests and that the test results have repercussions on the model input data and pose questions relating to the latter.

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APPENDIX I

STUDY OF THE INFLUENCE OF BUMPER POSITION ON THE KINEMATICS OF A STRUCK-PEDESTRIAN'S HEAD. (April 1977)

Question : Will a bumper, designed to reduce the risk of serious knee injury to a struck pedestrian, due to its position lower than the kneecap, increase the risk of fatal head injury because of the increase in head/véhicule impact velocity or of a less favourable location of the impact point ?

1 - Simulation data.

Pedestrian : 50 percentile, upright
Impact speed : 32 km/hr (20 mph)
Vehicule : two profiles were used :

. a low streamlined profile (that of the Citroen GS)
. a "square" profile (that of the Opel Kadett model 66, type B)

Bumper : The same for both vehicles (shape, strength)

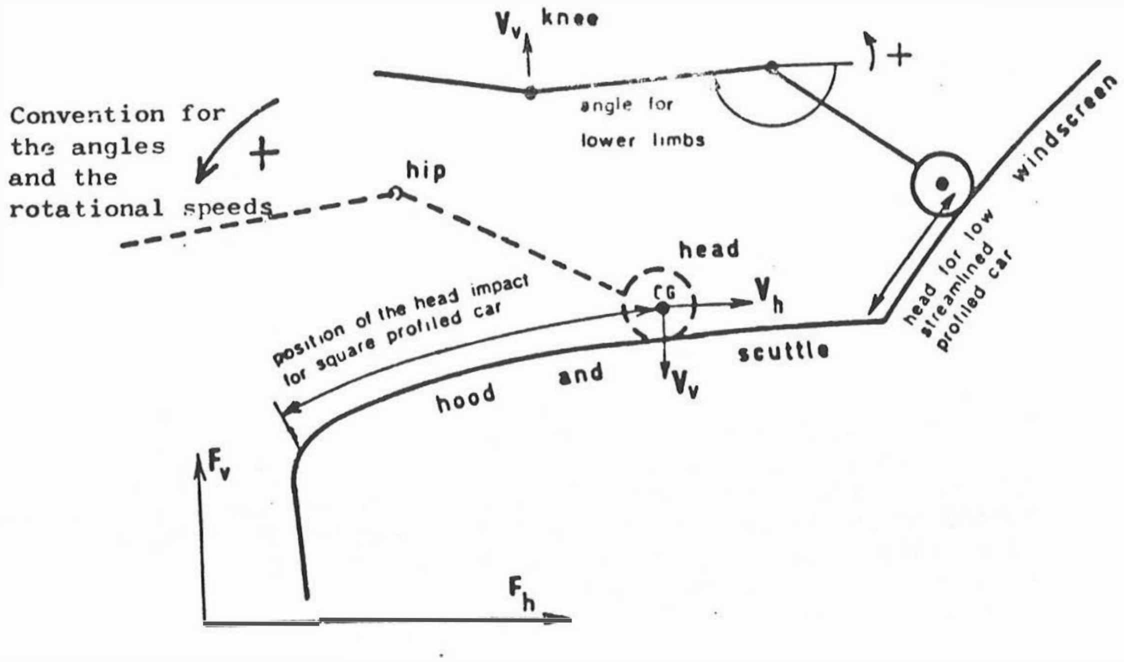
Only the height (h) and overhang (d) with relation to front end of the vehicle vary and are defined in fig. 2.
In this paper, the position d = 0 is called "normal", and d ≠ 0 is called "projection".

2 - Discussion on data.

2.1 - The impact velocity chosen is that at which fatal pedestrian accidents appear.
2.2 - Position of vehicle body is that obtained with the reference load but with no braking.
2.3 - Bumper height in the simulation means the height of front top edge of bumper (see fig. 2).
These heights are for rather low bumpers with the relation to the average height, and especially so with relation to recent models; but as we have made no corrections for the variation in body position due to braking (which happens in most cases prior to impacting), the chosen heights should be close to the average.

3 - Results.

3.1 - Velocity of centre of gravity of head upon impact (see table 2)
It increases as the bumper is lowered;
It also increases as bumper projects more.
3.2 - Head S.I. (see table 3)
The S.I. was calculated, but the values obtained show that it is not a valid criterion for rating bumper heights, for it depends too much on the shape and characteristics of the bodywork where head impact takes place for a general conclusion to be drawn. On the other hand, the maximum velocity of head along its trajectory would have been interesting to have, but it wasn't yet calculated when the study was conducted.



Angle convention for the rotation of the lower limbs
and the torso of the dummy

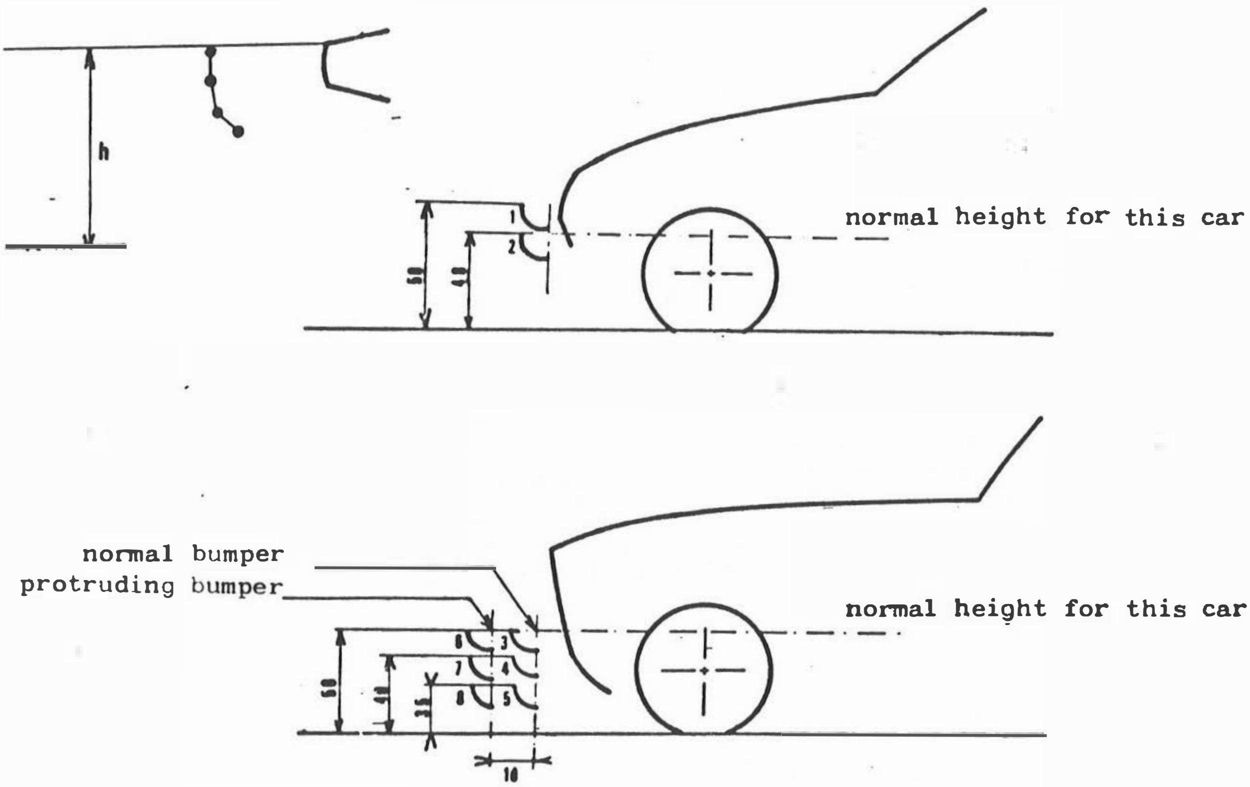


Fig. 2 The eight compared configurations
for bumper adjustement

3.3 - Maximum bumper force.

It varies very little and increases slightly with bumper height. At a given height, the maximum force is greater for the square profile with a non-projecting bumper than for the low streamlined profile, and also greater for the square profile with a projecting bumper than for the square profile with a non-projecting bumper. The maximum force applied by the bumper is interesting from the biomechanical point of view inasmuch as it is in direct ratio with the local injuries sustained.

The 2nd. effect of the force applied by the bumper to the lower members is to throw them forward and make them turn. The values which best characterize, according to us, the repercussion of the kinematics are the horizontal et vertical components of the dummy momentum imparted by the bumper. We included this calculation in the programme after this study, which showed up the need for it.

3.4 - Rotation of lower members and torso

recorded at 200 ms, consequently after the head-torso/vehicle impacts. Generally speaking, dummy rotation in direction of vehicle (see fig.3) is greater and quicker(from 1 to 2 rad/s at 200 ms), and the legs are higher if the bumper is 40 cm above the ground instead of 50 cm.

Is the whole body turning and the legs rising a favourable or unfavourable factor for the pedestrian (effect of head/ground impact) ? A conclusion cannot be easily drawn, for, on the one hand, these rotations are probably exagerated in all these simulations (too-elastic contact components in the data), and on the other hand, the subsequent kinematics of the pedestrian are largely conditioned by the torso/bonnet contacts which occur during the long phase preceding the fall to the ground when the pedestrian bears more or less the bonnet.

3.5 - Locating the head/vehicle impact

Impact points move very little (from 0 to 3 cm) and do not always go in the same direction when bumper height is modified.

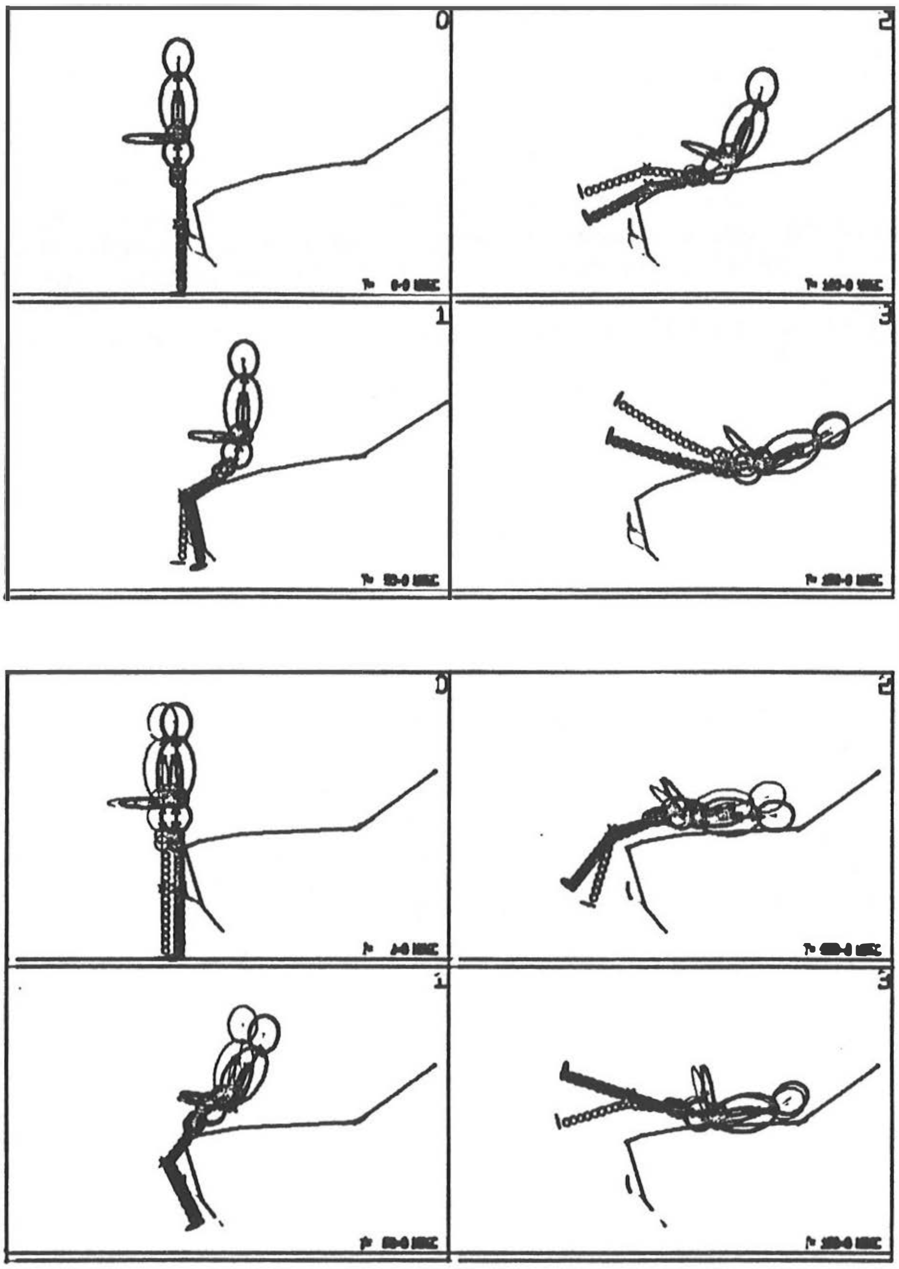
However, a slight tendency for the impact point to move to the front of the vehicle can be detected when the bumper is lowered. Paradoxically, a (slight) backward movement of impact point is observed when bumper projection is increased (only the square profile concerned by this). This can be explained by the fact that the greater angle formed by the tigh bones with the vertical during the time they are in contact with front edge of bonnet tends to induce their slipping backwards.

4 - CONCLUSIONS

4.1 - Influence of bumper height on the head/vehicle impact.

In both profiles studied when the bumper does not project, we obtain, for the head, slightly better results with a bumper at 50 cm than at 40 or 35 cm. The differences in impact velocity are probably amplified by the too great elasticity of the contact components defined in the data. In practice, they might be compensed for by smoothing out the more agressive impact areas, at the same time lowering the bumper.

We can ask ourselves whether the results obtained with the model are valid as far as absorbed energy distribution is concerned. It would appear that as the chronological order and the different load and acceleration levels in the model with relation to the test are complied with (with the previously mentioned reservations), the calculation should convey reality faithfully.



a)

b)

Fig.3 : Influences of a) bumper height
b) bumper protrusion
on pedestrian kinematics.

It should be noted that lowering the bumper makes the bullet car less agressive in side collisions.

4.2 - Influence of bumper projection on head impact severity.

If the S.I. and maximum acceleration of the head are excluded for the reasons stated in § 3.2. page 2, only the head/vehicle impact velocity remains as a possible severity criterion. According to this criterion, no significant difference is observed between both configurations of bumper if it is at 50 cm ("normal" height for the square profile used) However, the advantage falls clearly to the "non-projecting" configuration if the bumper is in the low position (40 or 35 cm).

Remark

Influence of bumper projection on the severity of the femur/leading edge of bonnet impact, as well as bonnet accelerations.

For the three heights in question, the forces generated at femur/leading edge of bonnet impact, as well as the accelerations sustained by the pelvis, are not so high with the projecting bumper than with the non-projecting bumper.

On these two points, the "projecting bumper" configuration is therefore better than the "non-projecting bumper" configuration.

4.3 - Generally speaking, there is no bumper height and projection suitable to all vehicles. These parameters should be optimized as a function of the vehicle profile and the location of the area we most wish to be impacted by the pedestrian's head.

4.4 - The purpose in lowering the bumper is to reduce the severity of injuries to the lower members which, although they are rarely fatal, give rise to concern by theirfrequency and the disability they too often give rise to.

Although at the present time it exists no injury criterion for the lower members of pedestrian dummies MVMA/APR, the mathematical model will enable however knee acceleration as well as femur compression forces as a function of time to be obtained. Knee acceleration could temporarily be used. Furthermore, it would be easy for the knee shearing force to be calculated into the model.

4.5 - It would be useful to simulate other vehicle profiles and velocities in order to verify whether the calculated values develop in the same sense when the height or projection of the bumper is varied.

TABLE I - HEIGHT OF BUMPERS-RESULTS OF THE MATHEMATICAL MODEL

	Low stream-lined profile		Square profile			Square profile protruding bumpers		
Height	50 cm	40 cm	50 cm	40 cm	30 cm	50 cm	40 cm	35 cm
Max. force on bumpers (N) :								
. Max. Fx	15200	14700	16100	15700	15600	16400	16000	15800
. Max Fz	2000	3600	2100	4100	4100	2300	4200	4200
. Max. resultant	15300	15100	16300	16200	16100	16600	16500	16400
	Windshield		Bonnet or scuttle					
Head impact- Area :								
. Localization (see fig.)	24,1	21,9	102,1	101,9	100,5	102,4	103,8	101,0
. Time	150	145	120	120	120	135	130	130
Velocity of head C.G. at head/vehicle impact (m/s) :								
. Vx	8,29	8,52	4,06	3,79	3,74	3,36	4,73	3,88
. Vz	7,87	8,60	10,08	10,63	10,98	10,43	11,41	11,87
. Resultant	11,43	12,11	10,87	11,29	11,60	10,96	12,35	12,49
γ Max (g) :								
. Head	90	93	121	118	111	117	133	117
. Thorax	57	58	58	59	61	61	67	67
. Pelvis	24	24	65	57	52	48	40	44
Severity index :								
. Head	1071	1313	1419	1517	1476	1421	1977	1764
. Thorax	326	363	326	354	418	350	454	493
Lower limbs-t = 200 ms :								
. Leg angle (°)	-218	-234	-215	-229	-237	-180	-227	-239
. Thigh angle (°)	-214	-233	-210	-225	-232	-197	-224	-237
. Leg rotational velocity(rd/s)	-6,53	-8,20	-10,8	-12,7	-12,1	-15,7	-12,3	-12,3
. Height/ground - Knees	107	124	116	128	133	109	132	138
Pelvis	83	91	95	98	100	97	103	103
. Vertical knee velocity (m/s)	3,15	3,42	3,80	3,56	3,68	2,32	3,75	3,92
Rotational speed of the torso t = 200 ms : Thorax	5,52	4,57	2,34	2,53	1,62	4,01	2,08	1,12
Pelvis	3,75	2,53	4,22	4,29	3,47	6,27	3,98	2,09

TABLE 2 - VELOCITY OF THE CENTER OF GRAVITY OF THE HEAD AT IMPACT

It increases when the bumper is lowered:

Profile	Height of the bumper (cm)	Velocity of the head (c.d.g.) m/s	%
Low streamlined	40/50	12.1/11.4	+ 5.9
Square(bumper no protruding)	40/50	11.3/10.9	+ 3.7
	35/40	11.6/11.3	+ 2.8
	35/50	11.6/10.9	+ 6.7
Square (protruding bumper)	40/50	12.3/11.0	+ 12.7
	35/40	12.5/12.3	+ 1.2
	35/50	12.5/11.0	+ 14.0

It increases too when the bumper is protruding :

VELOCITY OF THE CENTER OF GRAVITY OF THE HEAD

Height of the Bumper	Square profile with protruding bumper	Square profile with bumper no protruding	%
50 cm	11.0	10.9	+ 0.8
40 cm	12.3	11.3	+ 9.4
35 cm	12.5	11.6	+ 7.7

TABLE 3 - S.I. FOR THE HEAD.

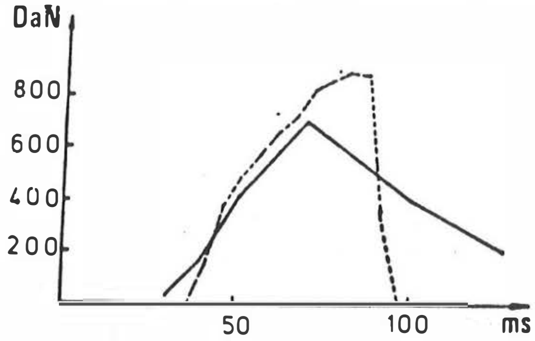
It increases when the bumper is lowered from 50 to 40 cm.

Profile	Height of the bumper (cm)	S.I. Head	%
Low streamlined	40/50	1313/1071	+ 22.6
Square (bumper no protruding)	40/50	1515/1419	+ 6.9
Square (protruding bumper)	40/50	1977/1421	+ 39.1

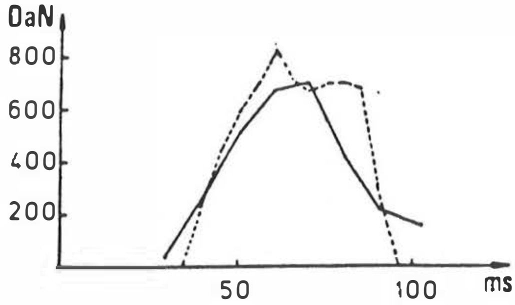
It decreases for the two configurations where 35cm was tested, when the bumper is still lowered from 40 to 35cm.

Profile	Height of the bumper (cm)	S.I. Head	%
Square (bumper no protruding)	35/40	1476/1517	- 2.7
	35/50	1476/1419	+ 4.0
Square (protruding bumper)	35/40	1764/1977	-10.8
	35/50	1764/1421	+24.1

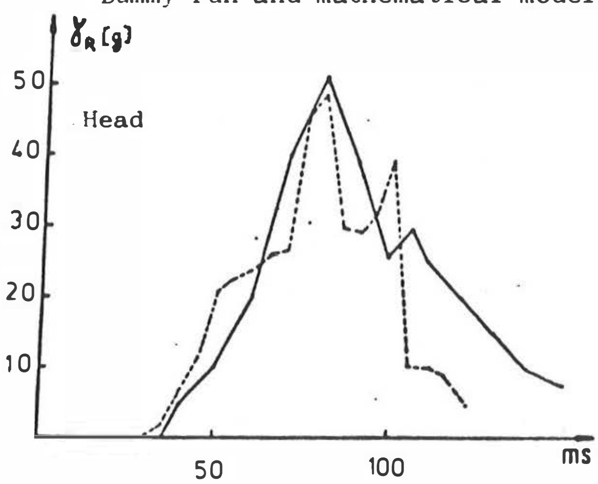
Upper shoulder-Restraint force

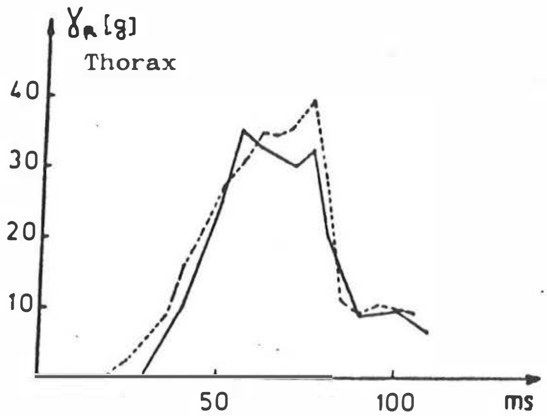


Lower torso belt-Restraint force



Head and thoracic accelerations
Dummy run and mathematical model compared





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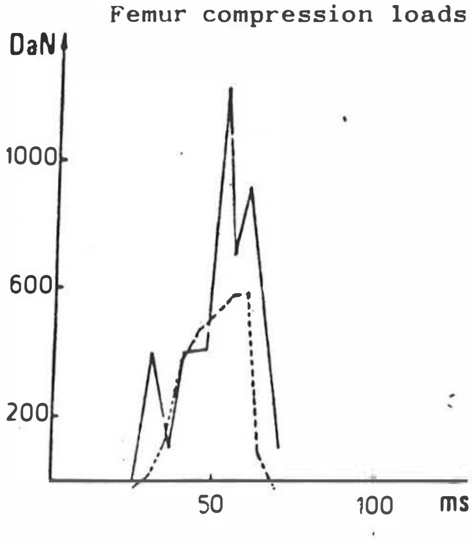

——— Dummy run
– – – – Model

Fig:4,5 et 6

A P P E N D I X II

EXAMPLE OF RESULTS FROM MVMA / APR MODEL.

Question : Where does the kinetic energy go of a passenger restrained by a belt and knee stop in a head-on collision ?

The simulated test is for a passenger dummy in a R.5. body on a sled at 50 km/hr. The results of the test and model are compared (Fig. 4, 5, 6).

- Head and thorax accelerations are similar.
- The femur loads are higher in the test: the knee stop characteristics are different (Knee bar on rigid fixture in test, modelized load/deformation curve not so steep).
- The lower shoulder belt forces are comparable.
- The upper shoulder belt forces are higher and have a different shape. It is a problem related to dummy rotation and slipping away at the end of collision in the real test : the shape of the upper shoulder belt force recorded in the model is close to the tests with no slip of the belt over the shoulder. The simulation of belt passage over the thorax (two predetermined points) can be questioned.

Based on this modelized test, the distribution of dummy kinetic energy during the collision was calculated. In the following tables one will find :

- The dummy energy which goes into structure (front unit), broken down depending on the forces acting on the dummy and which bring about dissipation in the structure.
- The dummy energy which is absorbed by the different passenger compartment parts (belt + anchor points + seat, knee bar, floor), and by the dummy joints.

This energy has been divided into two time phases of 0 to 70 ms (end of the body Y , but slight movement of the dummy remains), and 70 to 150 ms.

The modelized thorax in the calculation is rigid.

DUMMY ENERGY ABSORBED BY FRONT UNIT

t(ms)	Seat	Floor	Knee stop	Belt	Total
0-70	375	681	1220	698	2974
70-150	5	10	9	108	132
0-150	380	691	1229	806	3106

DUMMY ENERGY ABSORBED IN PASSENGER COMPARTMENT

Deformations

t(ms)	Seat	Floor	Knee stop	Belt + fixations	Total
0-70	247	158	726	1503	2634
70-150	52	0	79	235	366
0-150	299	158	805	1738	3000

Frictions and dummy joints

t(ms)	Seat	Floor	Knee stop	Belt	Joints	Total
0-70	164	42	40	40	210	496
70-150	6	1	26	96	512	641
0-150	170	43	66	136	722	1137

Kinetic energy of dummy is 7222 J at 0 ms
1161 J at 70 ms
88 J at 150 ms

which gives the following variations : 0- 70 ms : - 6061 J
70-150 ms : - 1073 J
0-150 ms : - 7134 J

Taking account of the reservations made on the quality of simulation, the following remarks can be made concerning the distribution of dummy energy during the collision :

- the 7 kJ for the dummy are split up into 3 kJ for the front unit and 4 kJ in the impact and various frictions in the passenger cell. These 4 kJ are divided into 3 kJ for deformation (impacts) and 1 kJ for friction (dummy/passenger cell and shoulder belt + dummy joints).
- The knee bar absorbs less energy than it transmits to the front unit (871 as against 1229 J). Its layout in the passenger cell affords good ride-down. 29% of dummy energy is transmitted in the knee bar forces (17% in front unit + 12% by knee bar deformation).
  It would seem, however, that the energy dissipated in the knee bar is greater in the test than in the simulation. This could be due to the characteristics of the knee bar defined as data in the model (cf. § 1/, maximum upper femur load on test/model).
- The "shoulder belt + anchor point" system absorbs more energy than it transmits to the front unit (1874 as against 806 J). Most of the energy absorbed by the belt is during the deceleration phase of the vehicle (0 - 70 ms). In the case under examination, 30% of the energy coupled with the force acting through the belt is transmitted to the front unit. 37% of dummy energy goes through the belt loads (26% in the belt + 11% in front unit).
- the seat absorbs a not inconsiderable amount of dummy energy (469 J) and transmits another quantity (380 J) to the front unit. In all, 11% of the energy absorbed goes through the forces applied to the seat, whence the importance of seat fixing to floor.
- besides the energy absorbed by the dummy's joints and by belt friction, most of the energy is absorbed during the deceleration phase of the vehicle.

APPENDIX III

EXAMPLE OF UTILIZATION OF THE MVMA/APR MODEL :

Comparison of various solutions usable for reconstructing real-life accidents od pedestrians with a 50-percentile dummy to simulate a smaller and/or lighter victim.

When a car collides with a pedestrian, the size (and to a lesser extent, the weight) of the pedestrian is of noticeable effect on the head impact location, and consequently on the injuries.

It would therefore appear indispensable when reconstructing accidents using the 50-percentile dummy, to modify the size of the dummy (or at least its height with relation to the vehicle) to ensure that it corresponds with that of the victim. To do this, several solutions are possible and were simulated by the MVMA/APR model. The problem of the weight is considered later.

1 - SIMULATED SOLUTIONS.

In an initial series, the authors have striven to simulate an accident which occured between a Peugeot 204 and a female 10 centimetres less in height than the 50-percentile male, and of about the same weight.

The six solutions modelled are as follows :

1.1 - Modified dummy

Test 1-A : Reduction in the lengh of the legs and tighs of 5 cm, resulting in an overall reduction in height of 10 cm.
Reduction in the inertia moments and masses, proportional to the reductions in lengh, in the parts concerned.

Test 1-B : Same modification to the lengh, but with the masses and inertia moments of the lower limbs restored to their initial values, i.e. those of the 50-percentile dummy.

Test 1-C : Shortening of the legs and tighs by only 2.5 centimetres, but combined with 5 centimetres on the lower lumbar of the trunk, consequently amounting to 10 centimetres in all. The masses and inertia moments are again kept to the initial values.

1.2 - Relative position between modified dummy and vehicle.

Test 2-A : Lower limbes bent, lowering the trunk and head by 10 centimetres.

Test 2-B : Dummy with legs straight, while raising the vehicle (by changing its seating) by 10 centimetres.

Test 2-C : A compromise between test 2-A and test 2-B : slight bending of the legs (height of head reduced by 5 centimetres only), while at the same time raising the vehicle by 5 centimetres.

2 - INPUT DATA TO MATHEMATICAL MODEL.

The vehicle profile used was that of a Peugeot 204 along the centre-line of the headlamps, just as in the real-life accident.

In this series of simulations, a particular rigidity was not given to the scuttle area. Thus, the rigidity of the bonnet was used up to the windscreen. The head accelerations, the severity index (SI) and the (HIC) depend therefore only on the speed of the head at impact against the vehicle.

The attitude of the vehicle was that of the unbraked vehicled carrying a standard reference load. The reason for this is that during the reconstruction, it was designed to brake the vehicle only at first impact, in order better to control the height of the nose of the bonnet on impact.

Two other cases were considered in order to act as references, namely :

- Test 0, with the 50-percentile dummy in the normal position.
- Test 0a, with an homothetic dummy reduced as to be 10 cm shorter, and with the same mass.

3 - RESULTS (see table 4, appended)

All the tests with the trunk at its initial lengh (i.e. all tests except 1-C) result in an impact point from 83 to 87.5 centimetres from the nose of the bonnet, as against 110 with the normal 50-percentile dummy (test 0), i.e. a mean shift of about 25 centimetres.

Test 1-C should be compared to test 0a, since in both cases the trunk was shortened, and in order to have the same head height, the pelvis occupied a higher position with relation to the vehicle. Since the edge of the bonnet strikes the dummy lower compared to its centre of gravity and at the hip of the dummy, the trunk rotates more slowly, the dummy moves further towards the rear. The speed with which the head strikes the bonnet is lower and the point of impact further back. (The reader may be reminded that the scuttle at this point has the same rigidity as the bonnet, so one cannot conclude that the impact is any less severe in cases 1-C or 0a, than in the other cases.)

Apart from case 1-C, the results are fairly similar.

Configuration 2-A (dummy with legs bent) being the easiest to carry out using concerned test facilities, seems to be preferable, when the 50-percentile male dummy must be used to reconstruct a real-life pedestrian accident, the victim of which is slightly shorter in height for the same weight.

4 - CONFIRMATION BY MEANS OF CATAPULT TESTS

A test with a dummy was made in configuration 2-A. The results are very similar to those obtained by the mathematical model. In particular, the point of impact is the same to within 1 centimetre (see table of results).

A second test was made, with the dummy raised by 4 centimetres (still with the legs bent), in order to approximate more closely to the actual conditions of the accident, in which the driver stated that he had braked before impact, which would thus dip the nose of the vehicle. In this case, the head struck the scuttle instead of the true accident.

This test was simulated in the case 2-A-b, where a scuttle replaced the section of bonnet at the bottom of the windscreen. Here again, the results are highly similar.

TABLE 4 - COMPARED RESULTS OF COMPUTER AND DUMMY RUNS

Test n°	CONFIGURATIONS	HEAD g's	PEAK time (ms)	S.I.	H.I.C.	D cm (*)	THORAX g's (**)	PEAK time	HIP g's	PEAK time	HEAD/CAR SPEED at impact m/s (***)
COMPUTED											
0	50% dummy	115	125	1572	1228	110	56	130	94	15	11.66
0a	Homothetic dummy 1.65 tall	77	120	1023	804	96	53	120	107	10	10.99
1a	Shorter legs - lower weights	122	102.5	1445	1042	87.5	59	105	112	10	12.25
1b	Shorter legs - 50% weights	125	102.5	1496	1055	87	60	105	117	10	12.19
1c	Lumbar spine and legs reduced	77	117.5	1028	803	95	51	115	102	15	11.35
2a	Flexed legs	119	100	1433	1057	87	54	105	113	10	12.41
2b	Raised vehicle	123	97.5	1532	1133	83	58	100	110	15	13.04
2c	Intermediate between 2a and 2b	121	97.5	1476	1076	84	57	100	113	10	12.95
2Aa	Flexed legs, z - 5 cm only	99	122.5	1235	992	104.5	57	125	104	15	11.83
2Ab	Flexed legs - 6 cm; realistic scuttle	152	120	2317	1817	102.6	79	120	.105	15	11.66
1Da	Like 1c + lower weights	125	117.5	1508	1135	95	67.5	115	100	15	10.94
1Db	Like 1Da; one side without lower arm	126	117.5	1542	1172	95	66	115	100	15	11.25
1Dc	Like 1Da; one side without upper limbs	126	117.5	1477	1112	93.7	63	115	101	15	10.65
1Dd	Like 1Da; both sides without upper limbs	123	117.5	1449	1065	91.5	68	115	104	15	10.63
2a, dummy	2a parameters - test with dummy	122	110	-	-	86	27	125	102	18	-
2Ab, dummy	2Ab parameters - test with dummy	186	113	2424	1615	98	30.5	120	83	13	-

* D = distance from head impact point to the front edge of the bonnet.
** Thoracic are too high according to mathematical model. Chest stiffness has to be reduced in modeling
*** Car speed : 11.11 m/s (40 km/h)

5 - OTHER CONFIGURATIONS SIMULATED.

A series of four simulations was conducted, derived from the 1-C case, but with the masses and moments of inertia of the lower limbs and lower thorax modified in proportion to the length. In addition, all or part of the upper members were withdrawn in these four tests, these modifications being easy to carry out on a reference dummy. The purpose was to approximate the 50% male dummy to a subject shorter by 10 cm and slightly lighter, with fairly harmonious distribution of the weights.

These four simulations are :

- 1-D-a : Same dimensions and configurations than in 1-C but with the masses and moments of inertia of the legs and lower thorax reduced in proportion to their lengths. Total weight : 72.1 kg instead of 74.9 kg for the 50% dummy.
- 1-D-b : As for 1-D-a, with one forearm eliminated. Total weight : 69.7 kg.
- 1-D-c : As for 1-D-a, with one upper limb eliminated. Total weight:67.1 kg.
- 1-D-d : As for 1-D-a, with both upper limbs eliminated. Total weight : 62.2 kg.

The rigidity of the scuttle is again equal to that of the bonnet.

The results approximate to those of test 1-C as regards the position of the head-to-bonnet impact point and the HIC.

It is merely to be observed that the head-to-bonnet impact point moves slightly toward the front of the vehicle, as the upper limbs are eliminated. This can be explained by the fact that the lower inertia of the upper part of the dummy cuts down the shift towards the rear.

6 - CONCLUSIONS

6.1 - Real-life accidents to pedestrians the height of which is shorter, though fairly closed to that of the 50% male dummy, can be constructed satisfactorily by such a dummy, provided the height of the top of the head be brought to coincide with the height of the pedestrian involved, simply by bending its legs.

6.2 - If only the head impact location is desired, it would not appear necessary to adjust the weight to that of the victim, since this weight has but little effect on the trajectory. This conclusion does not apply if comparable values of the HIC are desired.

6.3 - This applies at least to pedestrians of normal corpulence and for a vehicle profile comparable to that of the Peugeot 204. A similar study will be necessary to confirm these results for different profiles.

6.4. - The practical limit to the method, i.e. the maximum distance the dummy can be lowered without introducung unacceptable errors, must also be discovered.