IMPROVEMENT OF A MATHEMATICAL MODEL TO STUDY PEDESTRIAN SAFETY

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BACKGROUND

The mathematical model MVMA III D from Calspan was get by CITROEN to study in three dimensions the behaviour of a car occupant in frontal impact. In this case, however, it appeared that the two dimensional model developed by CITROEN was easier to use and brought so good results as the three dimensional Calspan program.

In the frame of an experimental study of the behaviour of a pedestrian impacted by a car, CITROEN together with the ONSER and the medical University of Marseille are reconstructing pedestrian collisions on cadavers and ONSER 50 dummies (ref. 1). It has been also interesting to use mathematical modelling in order to spare real tests for studying the influence of various parameters. When looking at the first results, it may be seen that the third dimension is essential to simulate this type of impact, especially when the car hits the subject laterally (the subject does not move only in a single plane). For this reason, it was decided to use the CALSPAN program but modified for pedestrian impact. From another point of view, as the ONSER 50 dummy was used in real impacts, it was important to introduce in the program the ONSER 50 characteristics, in place of those of the American dummy. Before using the model in an operational way, it was necessary, first to introduce the new impact data and secondly to validate the results obtained in comparison with those gained from real impacts. This part of the work is presented in this paper.

I - GENERAL DESCRIPTION OF THE MODEL

1) Inputs

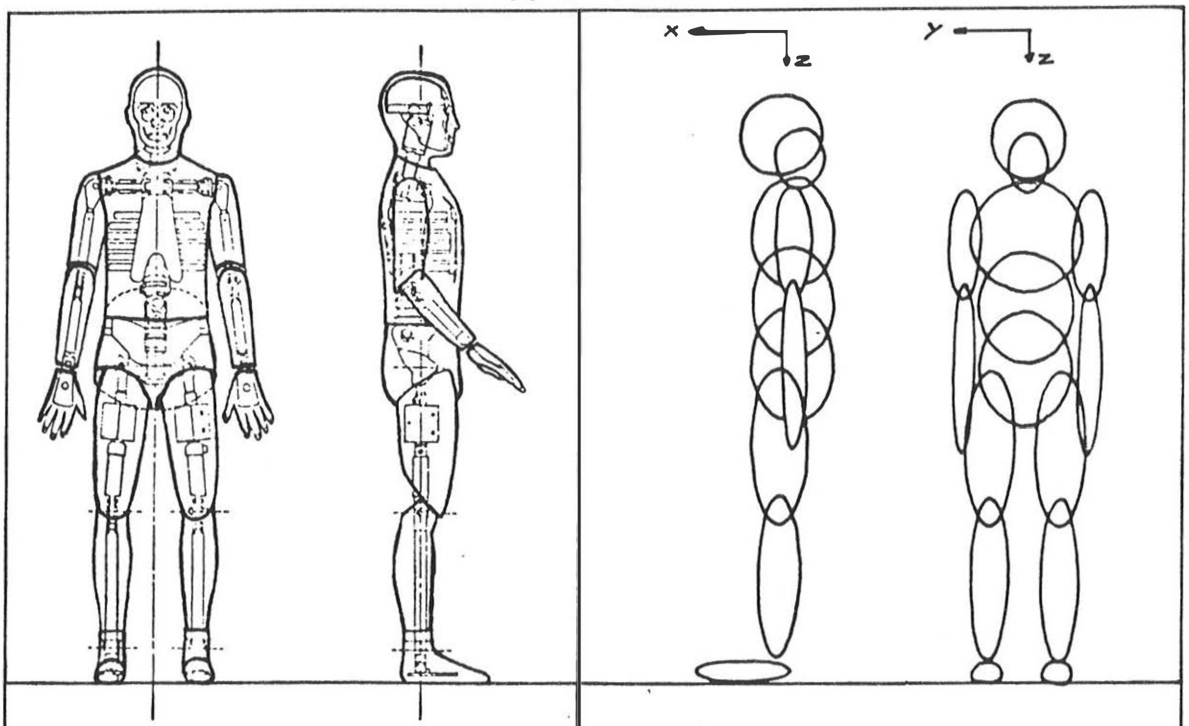
The modelized elements are : the dummy, the car and the kinematics.

. The dummy is represented by 14 rigid segments surrounded with contact ellipsoids connected to each other by 15 joints, the elastic and viscous characteristics of which may be adjusted for pitch and roll but not for yaw. The initial position of the dummy is given by the coordinates of the pelvis center of gravity and by the angles of pitch, roll and yaw for each segment.

The characteristics included in the Calspan program were those of a sitting SIERRA 292/050 dummy.

. The vehicle is represented through maximum 20 planes, 8 belts and 5 air bags. For pedestrian use, belts and air bags are suppressed.

FIGURE N° I



—ONSER DUMMY— —MODELISED DUMMY—

For each plane, the list of possible coming in contact ellipsoids is being precised (5 at the maximum) so as the functions defining the characteristics of the contact (load, deflection, friction). These functions are determined through specific tests (impactor against bonnet, and so on...).

. The movement of the vehicle is defined by initial position and speed and an acceleration-time curve.

The dummy gets the given initial speed but not the accelerations (only through its contacts with the vehicle). In the case of a pedestrian impact, the initial speed value will be 0. The increasing of the vehicle speed will be obtained by a high initial acceleration before hitting the dummy. In order that no dummy movement occurs, the plane defining the road (considered as vehicle property) will be considered without rubbing.

2) Outputs

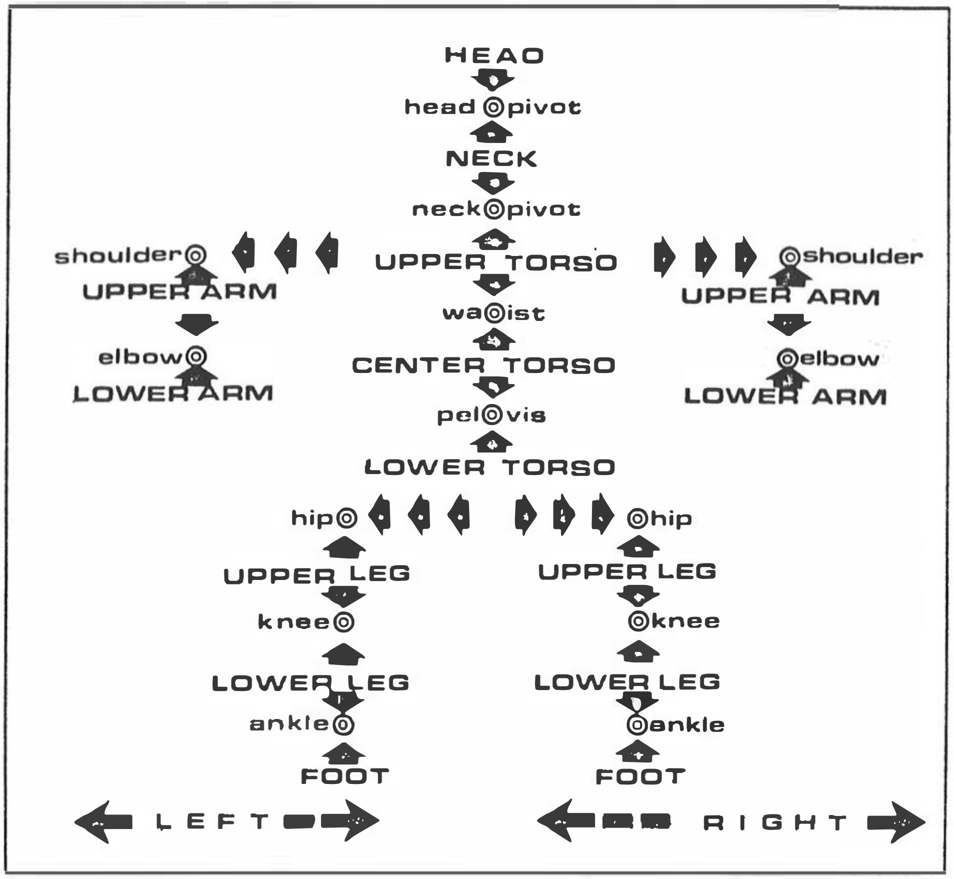
When the impact duration has been defined, we may get in function of the time, the accelerations, speeds, linear and angular displacements of each segment so as the characteristics of articulations, the contact points locations and the contact loads.

In addition, are drawn : the trajectories of three points (head, hip, knee) so as frontal and side views of the dummy at constant time intervals.

II - INTRODUCTION OF THE ONSER 50 CHARACTERISTICS

The modification of these characteristics has been made according to the "structural shape" of the dummy which was included in the program (14 volumes, 15 joints), each volume, however, being adjusted to the proper characteristics of the ONSER 50 dummy (different locations of joints, for instance the shoulder). Measurements of segments and joints (list in fig.2) have been made in the same conditions as for the American dummy (ref. 2).

FIGURE N° 2



1) The segments

They are defined by their weight, their moment of inertia according to the axis x, y, z of the segment coordinate system (symmetry axis of the ellipsoïd), the dimensions of the semi-axis of ellipsoïd and the position of the center of ellipsoïd in function of the center of gravity location.

The following measurements were made to obtain segment characteristics :

- the weight
- location of the center of gravity
- location of joints
- moment of inertia.

The three first measurements (weight, center of gravity and joints) were obtained by classical methods.

The contact ellipsoïds are defined from the drawings of the dummy in rest and movement positions.

The moments of inertia are obtained experimentally by the torsion pendulum method as follows :

$$I = K\,(P2 + P1)\,(P2 - P1)$$

I : moment of inertia
K : torsion constant of the steel rod (measured or computed)
P1 : period of not loaded pendulum
P2 : period of loaded pendulum

The signification of used symbols will be found in Figure 3 ; the results of measurements may be seen in table 4.

FIGURE N° 3

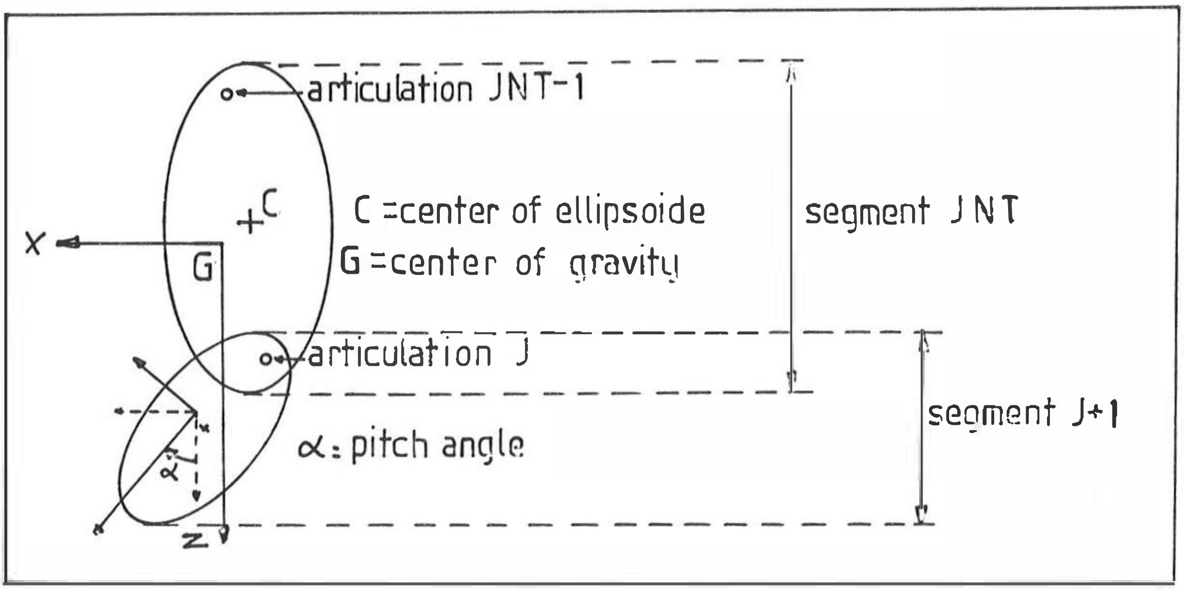


FIGURE Nº 4

CRASH VICTIM ONSER 50 15 SEGMENTS 14 JOINTS

I	SEGMENT SYM	PLOT	WEIGHT (LBS.)	SEGMENT MOMENT OF INERTIA (LB-SEC**2-IN) X	Y	Z	SEGMENT CONTACT ELLIPSOID SEMIAXES (IN) X	Y	Z	CENTER (IN) X	Y	Z
1	LT	5	32.735	1.17800	0.57300	0.97700	4.72	5.31	6.49	0.0	0.0	0.98
2	CT	4	7.392	0.06600	0.06000	0.02400	4.72	5.51	6.30	0.0	0.0	-1.97
3	UT	3	33.013	2.28800	1.99100	1.19000	4.72	6.30	6.30	0.0	0.0	-0.39
4	N	2	5.090	0.07800	0.07800	0.00900	2.75	2.36	3.34	-1.57	0.0	0.79
5	H	1	8.007	0.22200	0.18200	0.16400	4.53	4.13	4.52	0.0	0.0	1.38
6	RUL	6	23.090	0.93900	0.92800	0.13000	3.25	2.85	8.76	0.0	0.0	0.88
7	RLL	7	6.583	0.31800	0.32000	0.01300	2.26	2.13	9.25	0.0	0.0	0.39
8	RF	8	2.753	0.03400	0.03300	0.01200	1.22	1.77	5.22	0.0	0.0	1.87
9	LUL	9	23.090	0.93900	0.92800	0.13000	3.25	2.85	8.76	0.0	0.0	0.88
10	LLL	A	6.583	0.31800	0.32000	0.01300	2.26	2.13	9.25	0.0	0.0	0.39
11	LF	B	2.753	0.03400	0.03300	0.01200	1.22	1.77	5.22	0.0	0.0	1.87
12	RUA	C	6.691	0.14900	0.14600	0.01600	2.07	1.87	6.30	0.0	0.0	0.79
13	RLA	D	3.523	0.20600	0.20600	0.00700	1.18	1.28	9.64	0.0	0.0	1.57
14	LUA	E	6.691	0.14900	0.14600	0.01600	2.07	1.87	6.30	0.0	0.0	0.79
15	LLA	F	3.523	0.20600	0.20600	0.00700	1.18	1.28	9.64	0.0	0.0	1.57

J	JOINT SYM	PLOT	JNT	PIN	LOCATION(IN) - SEG(JNT) X	Y	Z	LOCATION(IN) - SEG(J+1) X	Y	Z	CENTER OF SYMMETRY (DEG) YAW	PITCH	ROLL
1	P	P	1	0	0.0	0.0	-1.61	0.0	0.0	2.42	0.0	5.00	0.0
2	W	O	2	0	0.0	0.0	-2.42	0.0	0.0	7.16	0.0	40.00	0.0
3	NP	N	3	0	0.0	0.0	-5.27	-0.83	0.0	4.33	0.0	10.00	0.0
4	HP	M	4	0	0.59	0.0	-3.15	0.0	0.0	0.08	0.0	10.00	0.0
5	RH	Q	1	0	1.57	3.97	2.12	0.0	0.0	-7.12	0.0	40.00	-5.00
6	RK	R	6	1	0.0	0.0	8.78	0.0	0.0	-6.50	0.0	-65.00	0.0
7	RA	S	7	0	0.0	0.0	8.66	2.32	0.0	-2.16	0.0	80.00	0.0
8	LH	T	1	0	1.57	-3.97	2.12	0.0	0.0	-7.12	0.0	40.00	5.00
9	LK	U	9	1	0.0	0.0	8.78	0.0	0.0	-6.50	0.0	-65.00	0.0
10	LA	V	10	0	0.0	0.0	8.66	2.32	0.0	-2.16	0.0	80.00	0.0
11	RS	W	3	0	0.0	7.10	-4.09	0.0	0.0	-3.94	0.0	50.00	-10.00
12	RE	X	12	1	0.0	0.0	6.69	0.0	0.0	-6.50	0.0	65.00	0.0
13	LS	Y	3	0	0.0	-7.10	-4.09	0.0	0.0	-3.94	0.0	50.00	10.00
14	LE	Z	14	1	0.0	0.0	6.69	0.0	0.0	-6.50	0.0	65.00	0.0

TABLE 4 : RESULTS OF MEASUREMENTS

2) The joints

They are defined by the location of their axis or the center of rotation (see before), the mean location and from this point, the extreme positions (joint stops), the elastic and viscous torques in flexion (movement in the longitudinal plane) and torsion (movement in the transversal plane). Other parameters as energy dissipation coefficient, viscous coefficient, Coulomb coefficient so as full friction angular velocity which corresponds to the speed the level at which the Coulomb coefficient is fully used, are added to the main data.

The elastic torques have been measured in submitting each point (adjusted at a certain torque) to various loads inside its movement area. For each joint, the variation of the applied torque in function of the angle has been drawn. After, it has been calculated a cubic function on all the points obtained. This function may be written under the following form :

$$C = A_0W^3 + A_1W^2 + A_2W$$

where C is the torque and W the angle.

With the help of the classical method, the coefficients of the third, the second and the first degrees have been calculated. The results are found in table 5.

FIGURE Nº 5

JOINT TORQUE CHARACTERISTICS

FLEXURAL SPRING CHARACTERISTICS

JOINT	SPRING COEF. (IN LB/DEG**J) LINEAR (J=1)	QUADRATIC (J=2)	CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
1 P	3.710	-0.119	0.001	1.000	10.000
2 W	3.710	-0.119	0.001	1.000	50.000
3 NP	10.000	0.244	0.000	1.000	20.000
4 HP	10.000	0.244	0.000	1.000	20.000
5 RH	48.750	-9.913	0.049	1.000	60.000
6 RK	2.245	-0.093	0.000	1.000	65.000
7 RA	1.185	-0.002	0.0	1.000	32.500
8 LH	48.750	-9.913	0.049	1.000	60.000
9 LK	2.245	-0.093	0.000	1.000	65.000
10 LA	1.185	-0.002	0.0	1.000	32.500
11 RS	10.000	-29.500	0.096	1.000	105.000
12 RE	3.650	-0.077	0.000	1.000	65.000
13 LS	10.000	-29.500	0.096	1.000	105.000
14 LE	3.650	-0.077	0.000	1.000	65.000

TORSIONAL SPRING CHARACTERISTICS

JOINT	SPRING COEF. (IN LB/DEG**J) LINEAR (J=1)	QUADRATIC (J=2)	CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
1 P	3.080	-0.036	0.000	1.000	10.000
2 W	3.080	-0.036	0.000	1.000	40.000
3 NP	10.000	0.244	0.000	1.000	20.000
4 HP	10.000	0.244	0.000	1.000	20.000
5 RH	15.950	-1.236	0.026	1.000	50.000
6 RK	0.0	0.0	0.0	1.000	0.0
7 RA	0.0	0.0	0.0	1.000	0.0
8 LH	15.950	-1.236	0.026	1.000	50.000
9 LK	0.0	0.0	0.0	1.000	0.0
10 LA	0.0	0.0	0.0	1.000	0.0
11 RS	55.900	1.430	0.008	1.000	65.000
12 RE	0.0	0.0	0.0	1.000	0.0
13 LS	55.900	1.430	0.008	1.000	65.000
14 LE	0.0	0.0	0.0	1.000	0.0

FLEXURAL VISCOUS CHARACTERISTICS

JOINT	VISCOUS COEFFICIENT (IN LB SEC/DEG)	COULOMB FRICTION COEF. (IN LB)	FULL FRICTION ANGULAR VELOCITY (DEG/SEC)	-	-
1 P	98.541	561.00	30.00	0.0	0.0
2 W	15.470	55.40	30.00	0.0	0.0
3 NP	2.000	9.10	30.00	0.0	0.0
4 HP	2.000	9.10	30.00	0.0	0.0
5 RH	5.000	252.40	30.00	0.0	0.0
6 RK	0.064	136.70	30.00	0.0	0.0
7 RA	0.038	21.87	30.00	0.0	0.0
8 LH	0.161	92.20	30.00	0.0	0.0
9 LK	0.064	136.70	30.00	0.0	0.0
10 LA	0.038	21.87	30.00	0.0	0.0
11 RS	0.566	324.00	30.00	0.0	0.0
12 RE	0.078	44.62	30.00	0.0	0.0
13 LS	0.566	324.00	30.00	0.0	0.0
14 LE	0.078	44.62	30.00	0.0	0.0

TORSIONAL VISCOUS CHARACTERISTICS

JOINT	VISCOUS COEFFICIENT (IN LB SEC/DEG)	COULOMB FRICTION COEF. (IN LB)	FULL FRICTION ANGULAR VELOCITY (DEG/SEC)	-	-
1 P	115.200	750.00	30.00	0.0	0.0
2 W	10.040	80.20	30.00	0.0	0.0
3 NP	5.500	28.30	30.00	0.0	0.0
4 HP	5.500	28.30	30.00	0.0	0.0
5 RH	4.600	305.00	30.00	0.0	0.0
6 RK	0.0	0.0	30.00	0.0	0.0
7 RA	0.0	0.0	30.00	0.0	0.0
8 LH	0.051	29.50	30.00	0.0	0.0
9 LK	0.0	0.0	30.00	0.0	0.0
10 LA	0.0	0.0	30.00	0.0	0.0
11 RS	0.036	19.96	30.00	0.0	0.0
12 RE	0.0	0.0	30.00	0.0	0.0
13 LS	0.036	19.96	30.00	0.0	0.0
14 LE	0.0	0.0	30.00	0.0	0.0

TABLE 5 : JOINTS CHARACTERISTICS

For the viscous characteristics of the joints, the same assumptions as the ones contained in the Calspan book (ref. 2) have been made, especially concerning the angular speed of 1 rad/sec. On the other hand, the value of the viscous coefficient was chosen of the same value as for the Coulomb coefficient. The results were shown in table 5.

III - RESULTS

As the testing program is always running, we will consider only the results on the ONSER 50 dummy for speeds at 20 and 25 km/hr (5.55 and 5.94 m/s). The testing vehicle is a VISA and the dummy is impacted frontally or laterally.

In these conditions, we will compare the calculated results to the test results only in 4 test situations.

1) Selection of validation criteria

In a first step, we just consider the first part of the impact, that is from the time of the first contact bumper-dummy to the time of the first head contact with the front of the vehicle. The following events (rebound or sliding and falling on the ground) are depending directly from the first impact and it does not present any interest to study them immediately.

In this first part of impact, the main comparison criteria selected are the following : the characteristics of the head-vehicle impact (if existing), the location of impact, the impact speed so as the general kinematics of the dummy. In spite of its importance on the pedestrian state of health after the collision, the acceleration sustained by the head during impact was not selected as comparision criteria, because this acceleration depends only on the impact speed and the characteristics of rigidity given to the impacted surface.

2) Results

Several tests and calculation have been made for each situation. The results are shown in table 6 and some examples of the dummy kinematics are seen in Figure 7.

In spite of some dispersion among the results of real tests, it may be noted, for the calculation, that :

. the head impact against vehicle occurs earlier

. the impact point is located nearer of the front of the vehicle

. the impact speed is slightly lower.

Concerning the general kinematics of the dummy, the calculation reproduces quite well the situations where the pedestrian is frontally impacted.

In side impacts, the dummy movement depends essentially on the initial position of the legs (rotation to the front or the back) and the head impact is strongly influenced by the arm movement and its support on the bonnet. This explains the great differences between the head impact speeds during side impacts at 20 and 25 km/hr.

CONCLUSIONS

The next step will be to examine if the results at 20 and 25 km/hr will be confirmed at higher speeds (real tests are made at 32 and 40 km/hr).

Some parameters may be modified to precise the simulation (joint torque for example). Other parameters that have a strong influence on the dummy kinematics will be more difficult to adjust :

. the movement of the vehicle (speed according to the ground, variation of the vehicle body position)

. the representation of contact ellipsoïds of the vehicle which are necessary schematized.

Although the validation of this program is not made for all impact situations, we could notice that the tridimensional representation and the numerous possibilities of outputs for this program are very interesting in the case of car-pedestrian impacts, this being made therefore with a very heavy manipulation.

REFERENCES

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2) A three dimensional computer simulation of a motor vehicle crash victim
   J. BARTZ - F.E. BUTLER - CALSPAN Corp.
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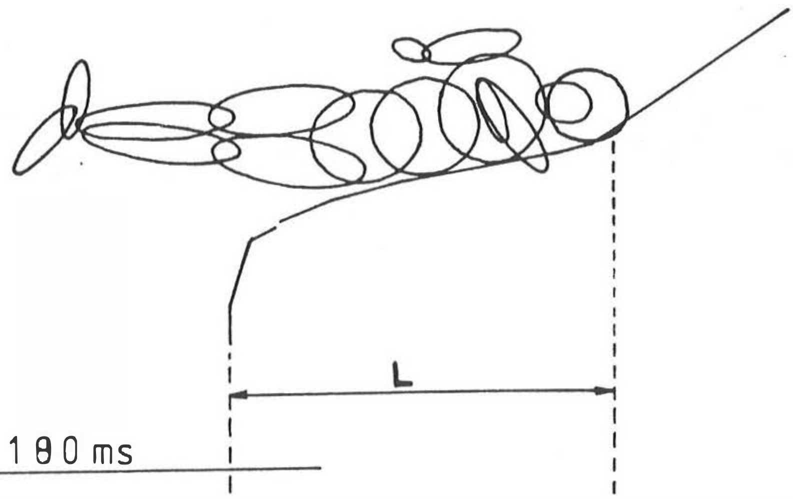
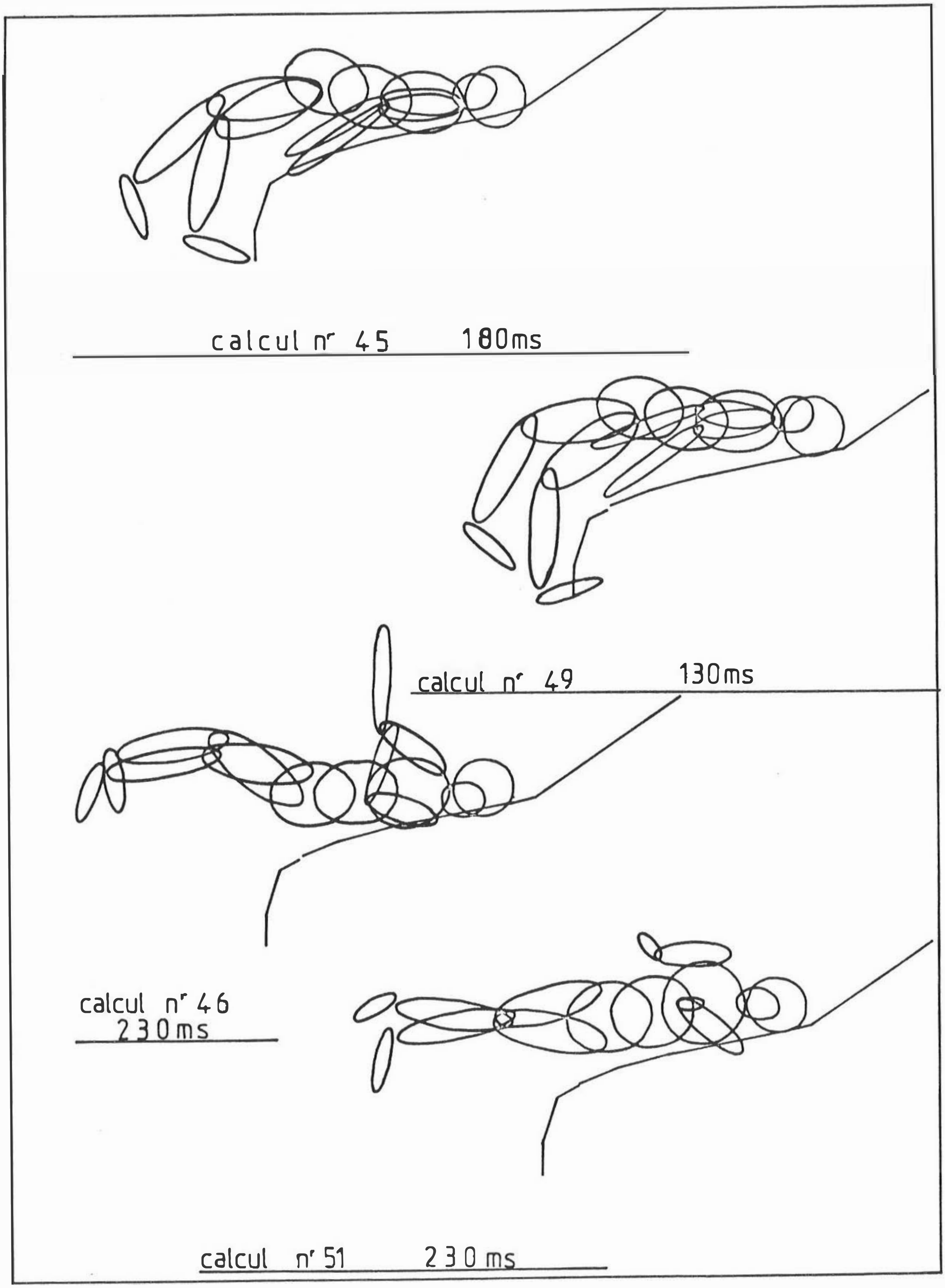
FIGURE N° 6

CAR SPEED	DUMMY	POSITION pitching angle of legs	TEST Nr	HEAD IMPACT TIME T	L	HEAD SPEED (in vehicle reference)	CAR SPEED at time T
km/h		deg		ms	m	m/s	m/s
20	FACE	0, 0	14 - 1 14 - 3 17 - 1 20 - 1	200 168 180 180	1.05 0.99 1.06 1.14	7.9 9.3 7.5 7.42	4. 4.7 4.35 4.2
			45 calcul	160	0.91	7,06	4.4
20	SIDE	≃-10,+10	14-2 17-3 17-2	272 212 260	0.94 1.14 1.05	3.65 6.35 4.05	3,3 4-65 3.7
		0., 0. -10,+10	46 51 calcul	210 222	0.86 0.93	6.37 1.35	4. 4.
25	SIDE	≃-10,+10 "	22-2 24-2	200 180	1.24 1.06	6,17 6.7	5.5 5.9
		0., 0 -10,+10	48 50 calcul	171 162	0.94 1.07	7.64 5.41	5.76 5.9
25	FACE	0, 0	22-1 24-1	154 146	1.20 1.20	9.35 11.03	5.79 5.9
			49 calcul	131	0.94	8.85	6 05



calcul n°50 180 ms



calcul n° 45 180ms
calcul n° 49 130ms
calcul n° 46 230ms
calcul n° 51 230 ms

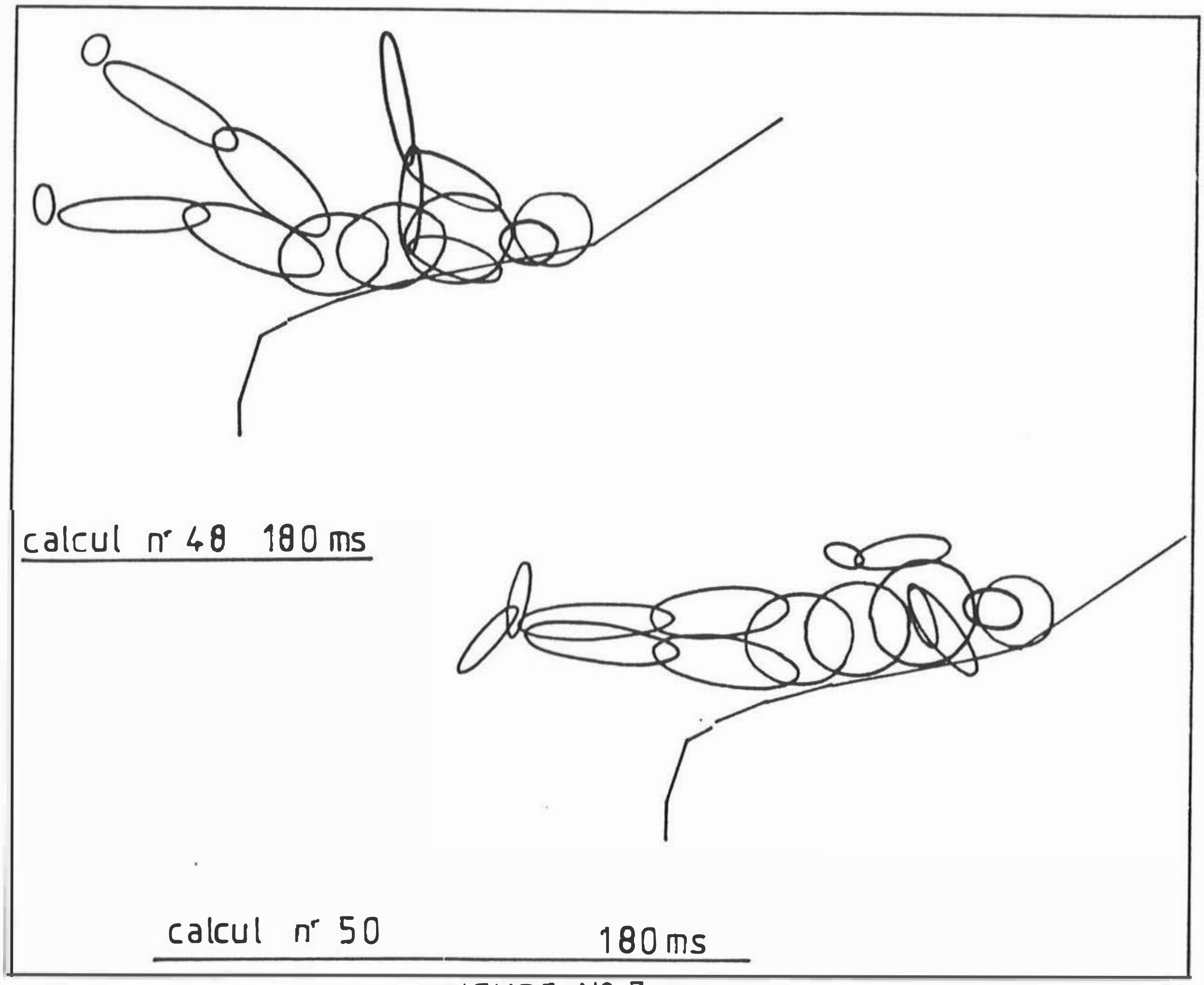


FIGURE N° 7