EVALUATION OF THE EXPERIMENTAL RECONSTRUCTIONS OF A REAL FRONTAL COLLISION WITH A MATHEMATICAL MODEL

by

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ABSTRACT

In several laboratories in Europe experimental reconstructions of real accidents have been carried out during the last five years to determine and evaluate human tolerance limits. In these studies injuries arising from real accidents are compared with measured data on cadavers and dummies. In addition to this experimental research a new approach will be presented in which the behaviour of vehicle occupants is simulated using the MADYMO Crash Victim Simulator. Both the dummy and cadaver reconstructions are mathematically simulated. Furthermore a mathematical simulation is carried out to predict the behaviour of the driver in the real accident. It is concluded that the mathematical model provides better insight into several aspects of this complex system. Therefore in addition to cadaver and dummy reconstructions a mathematical model is found to be a valuable tool for the analysis of real frontal collisions.

INTRODUCTION

Knowledge about the relation between mechanical load and injuries sustained by the human body is still limited. The main reason for this is that direct experiments to determine such limits can only be carried out with substitutes such as human cadavers and animals, in other words by means of structures, which differ from those of the human body as regards their geometrical and/or material properties.

Instead of a direct method an indirect method can also be applied. By accurately reconstructing accidents whose conditions are well known from accident investigation, parameters determined in the reconstructions, including forces and accelerations, can be related to injuries sustained by occupants in real accidents. In these experimental reconstructions the real occupants are simulated by dummies or cadavers and identical vehicles are used. (e.g. Cesari and Ramet 1975, 1979, Friedel, 1977). In addition to experimental reconstructions, this paper discusses the application of a mathematical Crash Victim Simulator.

The main objective of this mathematical approach is to analyse differences between dummy and cadaver behaviour, to predict the behaviour of the real victim and to study the effect of changes in a number of unknown accident parameters, such as, for instance the actual car deceleration and belt slack.

DESCRIPTION OF THE SELECTED ACCIDENT

For this study it was decided to use accident no. 5 described in a paper by Cesari and Ramet (1979). This accident was a frontal offset collision between a CITROEN GS and a RENAULT 16. In the CITROEN GS (the case car) there were two belted occupants in the front seats. The driver, a 43-year-old male, sustained head trauma without unconsciousness (AIS 1) and fractures of the sixth left rib and of the seventh and eighth right ribs (AIS 3). The right front passenger, a 48-year-old female, sustained a fourth right rib fracture (AIS 2). Analysis of car deformations of the two cars involved in the actual collision, allowed the offset (870 mm to the left) to be determined. The longitudinal axes of both cars just prior to the impact were parallel, while the closing speed was estimated to be 75 km/h.

DESCRIPTION OF THE EXPERIMENTAL RECONSTRUCTION

The accident was reconstructed twice. In the first test, two Part 572 (Hybrid II) dummies were installed as front occupants of the GS. In the second test, a human cadaver simulated the driver whereas a Part 572 dummy was seated in the right front seat. Characteristics of the driver of the GS car in the actual accident and in the two reconstructions are listed in Table 1.

In these reconstructions an offset value equal to that of the actual accident was obtained and the closing speed was 74.2 km/h in the first test and 73.6 km/h in the second.

The human cadaver used in the 2nd reconstruction was a fresh unembalmed cadaver. The cause of death was heart infarct. After decease the body was transported to the Medical University and stored in a cold room at a temperature of 4°C. The cadaver was transported within 7 days of death to the laboratory and tested the day following.

	Sex	Age	Mass (kg)	Stature (m)	Injuries	OAIS
Actual accident	M	43	70	1.65	fracture of 6th left rib and 7th and 8th right ribs Head trauma	3
First reconstruction with dummy	M	-	74	1.72		
Second reconstruction with cadaver	M	66	60	1.72	right: 2 to 7 rib fractures left : 2,3,4 rib fractures sternal fracture right humerus fracture left tibia fracture	4

Table 1 Characteristics of the actual driver of the GS and of the drivers in the reconstructions.

The cadaver was prepared for the test as follows:

- No fractures were observed in an X-ray examination.
- A catheter was placed in the carotid to pressurize the blood system.
- Three triaxial accelerometers were mounted on the skull and their locations recorded.
- One triaxial accelerometer was fixed on the back at T4.
- The cadaver was dressed in a close-fitting garment and placed on the car seat.

The seat was adjusted in the same position as in the actual accident. The dummy and cadaver were belted and the belts adjusted to give a limited slack (two fingers spacing in front of the chest).

DESCRIPTION OF THE MATHEMATICAL RECONSTRUCTION

The mathematical simulations in this study were carried out with the MADYMO CVS program (Maltha and Wismans, 1980). This package has been successfully applied earlier, for instance in an evaluation study of a child in a child-restraint system (Wismans et al. 1979). An important aspect of MADYMO is the ability to simulate an arbitrary number of linkage systems with a variable number of elements. It contains a two- and three-dimensional option. It was assumed, based on the results of the experimental reconstructions, that the occupant behaviour could reasonably be simulated two-dimensionally. The mathematical analysis is limited to the behaviour of the GS driver.

Occupant - A nine-segment linkage system was selected to simulate the dummy, the cadaver as well as the real victim (fig. 1). The head, neck, upper arms, lower arms (including hands), upper legs and lower legs (including feet) are simulated each by one rigid element. For the torso three elements are introduced. The neck and spine joints of the dummy are located close to the attachments of the rubber cylinders (representing the neck and spine), with head, thorax and pelvis dummy segments. The locations of the joints of cadaver and real victim are in accordance with definitions given by Reynolds (1978).

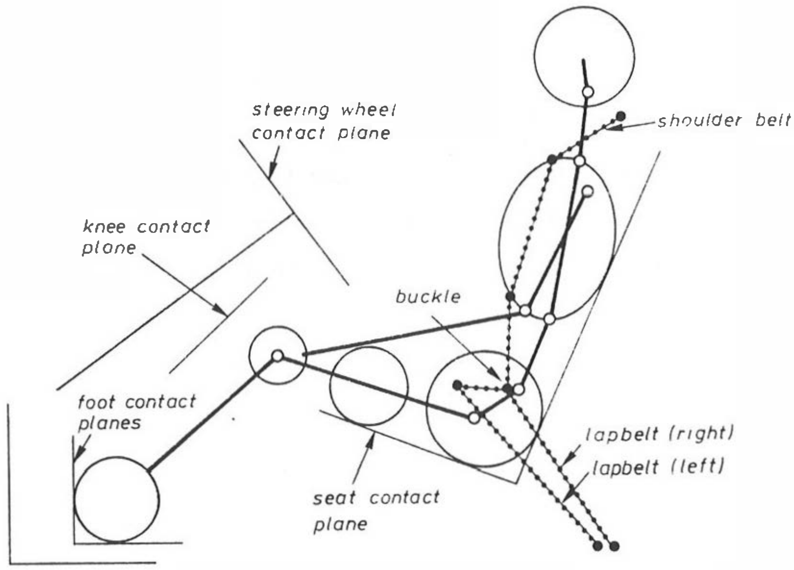

Fig. 1 Schematic representation of the mathematical model.

Dummy - Geometrical data and the mass-distribution of the Part 572 dummy were based mainly on measurements reported by Hubbard and McLeod (1977), while the joint characteristics were derived from data of Bowman et al. (1979). For some of the dummy parameters supplementary measurements were carried out or estimations had to be made.

Cadaver and real victim - To simplify preparation of the sets of input data on the cadaver and the real victim, the preprocessor program ANTROP (Wismans and Maltha, 1980) was developed to calculate dimensions and mass distribution of the human body based on the input of body height and weight. The prediction equations in this program for the segment lengths, locations of the centre of gravity, masses, moments of inertia and body external geometry, were mainly derived from a review of the recent knowledge on human anthropometry presented by Reynolds (1978).

The characteristics of the joints are assumed to be identical for the cadaver and the real victim. For the hip and the spine joints they are based on data given by Robbins (1971) and Nyquist (1975) and for both the neck joints on data of Schneider and Bowman (1978). Range of motion data for the elbow, knee and shoulder were selected from Laubach (1978).

Belts - The dummy, cadaver and real victim were restrained by a static three-point belt. The standard belt force interaction model in MADYMO was replaced by a more advanced model that accounts for the three-dimensional belt geometry (fig. 1). This routine has options for initial slack, energy dissipation, permanent deformation and force equalisation for the buckle loop. Slippage between shoulder belt and torso can be accounted for by prescribing the force in the lower part of the shoulder belt as a ratio of the force in the upper part. A more advanced model to account for this complex slippage mechanism is under development. Most of the parameters in the belt model were determined from static force-deflection characteristics of the belt material, while corrections were introduced, for instance to account for deformations in the shoulder and abdomen.

Geometrical contacts - Contacts between occupant and car interior were simulated by a number of ellipses connected to the occupant and planes connected to the vehicle (fig. 1). Measurements of static force-deflection characteristics for contact between the head and steering-wheel, the dummy and the seat and for the knee contact were carried out, while viscous damping and friction coefficients for these contacts were estimated.

Initial position - The initial position of the dummy and cadaver just prior to impact were obtained from high-speed movie analysis. An interactive computer program was developed to adjust the initial position of the real victim.

Car deceleration - The car deceleration-time histories near the B-pillars (in the rearward-forward directions) as measured in the dummy and cadaver reconstructions, were approximated by straight-line segments and used as input for the model simulations. The deceleration measured in the cadaver reconstruction was observed to be lower in comparison with the dummy reconstruction.

RESULTS OF THE EXPERIMENTAL AND MATHEMATICAL RECONSTRUCTIONS

In the interest of keeping it compact in format, only a limited number of results will be included in this paper. A more detailed description is given by Wismans and Maltha (1980).

Fig. 2 shows the resulting kinematics of the dummy as predicted by the mathematical model. In the experiment, as well as in the mathematical reconstruction, knee contact was detected, but none between head and steering-wheel.

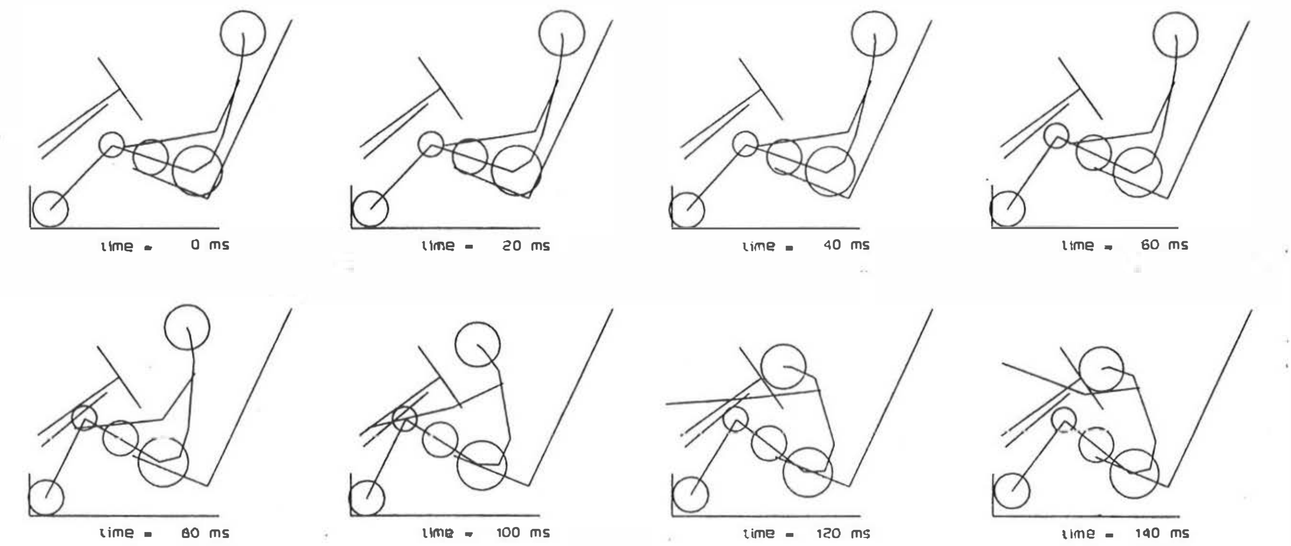

Fig. 2 Kinematics of the dummy predicted by the mathematical model.

Belt forces, resulting head and chest accelerations, and femur load from the dummy test and from the mathematical simulation are compared in fig. 3.

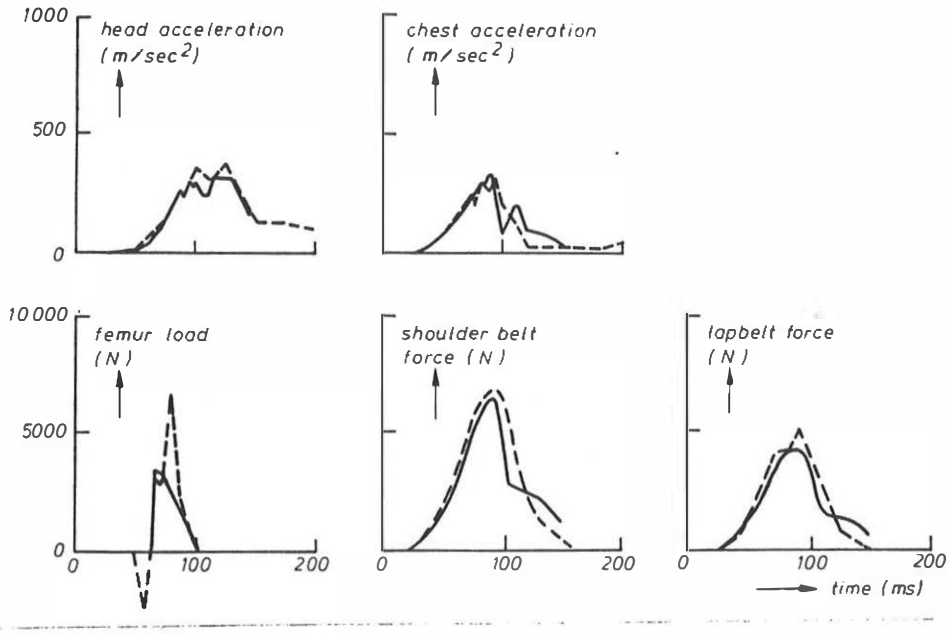

Fig. 3 The results of the dummy test compared with the dummy model predictions.
---- : experiment
—— : model

Maximum head and chest accelerations, HIC and maximum belt and femur loads are summarized in Table 2 and results of the cadaver test and the corresponding mathematical simulation are also included.

	Max. accelerations head (m/s^2)	Max. accelerations chest (m/s^2)	Max. belt loads shoulder (N)	Max. belt loads lap (N)	Max. femur load (N)	HIC
			first reconstruction			
dummy	369	315	6670	4900	6400	316
model of dummy	315	325	6270	4190	3370	240
			second reconstruction			
cadaver	2)	264	4080	2650	1)	2)
model of cadaver	224	213	5643	3490	3577	97

Table 2 Results of experimental and model simulations; 1) not measured; 2) not analysed.

Sensitivity study - A limited sensitivity study was undertaken, first to evaluate the model's sensitivity to some model parameters which had to be estimated, second to explain differences between dummy and cadaver test results and finally to analyse the differences between experimental results and model predictions. Results of this study are given by Wismans and Maltha (1980). Some of the findings are summarized below:

- Rather extreme changes, for instance in the damping coefficient of the seat, the friction between dummy and seat and deformation of the dummy, due to the belt load, scarcely affected the resulting chest accelerations and belt loads. So long as the changes introduced did not result in contact between the head and the steering-wheel the effect on the resultant head accelerations were also found to be slight.
- The maximum belt loads and chest accelerations in the cadaver experiment were found to be lower than in the dummy test. This could be explained partly by a slighter car deceleration in the cadaver reconstruction: using the car deceleration of the cadaver reconstruction as input in the dummy model resulted in a reduction of the belt loads and chest accelerations by about 20%.
- The nature of the knee contact is very important. If the knee hits the ignition key, which is much more solid than the surrounding material, the femur load is found to increase considerably. This could explain the differences between predicted femur load and measured load in the dummy experiment (the

differences are also partly caused by inertia effects; the load on the knee joint instead of on the femur is calculated in the model). In the case of more violent knee contact the belt loads are found to decrease, which could explain the differences between model predictions and test results in the belt loads of the cadaver. The leg injury on the cadaver indicates such a more violent contact.

- In the cadaver reconstruction, the head is inclined backwards at an angle of about 30° just before the impact. An upright position of the head in the model demonstrates a slight increase of maximum belt loads and head acceleration (less than 2%) and a decrease in maximum chest acceleration (about 12%).

PREDICTION OF THE BEHAVIOUR OF THE REAL VICTIM

One of the advantages of a mathematical model is its ability in general to simulate the mass distribution and dimensions of the real victim more realistically than is possible with the available dummies or cadavers. With the preprocessor ANTROP, already discussed, the anthropometry of the real victim was estimated on the basis of body weight and height. The joint characteristics, belt slippage and body deformations due to the belt load were taken as identical with those of the cadaver model. The car deceleration was derived from the dummy reconstruction. The resulting predictions for the behaviour of the real victim are shown in Table 3 (simulation 1).

Simulation real driver	maximum accelerations head (m/s^2)	chest (m/s^2)	maximum belt loads shoulder (N)	lap (N)	maximum femur load (N)	HIC
1. reference	442	303	8418	4488	4364	248
2. less severe car deceleration	311	221	6904	3958	4050	141
3. 5% slack in all belts	497	328	9039	4639	5048	328
4. increase slip between shoulder belt and thorax	869 1)	287	6833	4953	4107	815
5. anchorage point shoulder belt on thorax 0.1 m lower	1110 1)	256	7913	4285	4427	1517

Table 3 Predictions for the behaviour of the real victim; 1) head contact with most rigid part of steering-wheel.

In the real accident some of the accident parameters may differ from the experimental simulations. With the mathematical model the effect of such differences can be evaluated. Table 3 shows the influence of some variations.

In simulation 2 the less severe deceleration of the car in the cadaver simulation was used as input and resulted in a considerable decrease (20 - 40%) in the selected output quantities. In simulation 3, 5% slack in all belt parts was introduced, resulting in a roughly 10% increase in the output quantities (HIC increased about 30%). In simulations 4 and 5 the interaction between shoulder belt and torso was changed; in simulation 4 by increasing the slip between the upper and lower part of the shoulder belt, while the anchorage point of the belt on the thorax was not changed; in simulation 5 by keeping the slip constant but lowering the anchorage point on the thorax by 0.1 m. The effect of these changes on the maximum chest acceleration and femur load were found to be slight, however the maximum head acceleration (and HIC) was greatly affected by this change due to contact of the head with the steering-wheel (in the model contact with the most rigid part of the steering-wheel was simulated; contact with the less rigid parts decreased the head acceleration and the HIC).

DISCUSSION AND CONCLUSIONS

The objective of this study was to evaluate whether, in addition to experimental research a mathematical Crash Victim Simulator is a useful tool in the field of reconstructions of real accidents. The comparison between dummy test results and dummy model results (fig. 3) showed that the mathematical model predicts the behaviour of a dummy in a frontal crash quite well. The only striking difference was observed in the femur load. It could be shown that this difference was probably caused by contact of the knee or lower leg with a relatively rigid part of the car interior.

To simulate the cadaver reconstruction mathematically, a preprocessor ANTROP was developed which generates the dimensions and mass distribution of the human body based on input of total body height and body mass. The differences between predictions made with the cadaver model and the results of the cadaver experiment can possibly be explained, as in the case of the dummy reconstruction, by the nature of the knee contact.

Based on the good agreement between model predictions and test results a mathematical Crash Victim Simulator can be considered to be reliable for the simulation of head-on collisions. Further improvement of the model is desired to describe the interaction between shoulder belt and thorax (slip) more realistically. This mechanism is not yet completely understood while, on the other hand, it is found to be very important for the overall performance.

The mathematical predictions made in this study for the behaviour of the real victim should therefore be interpreted qualitatively rather than quantitatively. Nevertheless such predictions offer valuable information in the direction of achieving better insight into the importance of the various accident parameters (table 2) so that correlation of injuries sustained in the real accident with measured quantities in the experimental reconstruction can be made with more confidence.

In this study the mathematical model was applied after the experimental reconstructions were finished. Based on the results achieved in this study it is expected that other head-on collisions already reconstructed experimentally, can also be analysed in more detail with a mathematical model. In future experimental reconstructions of accidents, inclusion of a mathematical model in the research methodology is advisable in order to take advantage of the opportunities a mathematical model offers.

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