MULTIPLE CINEPHOTOGRAMMETRIC DETERMINATION OF THORAX DEFORMATION UNDER BELT LOAD *

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INTRODUCTION

As shown by MACKAY, in spite of belt wearing, thorax injuries are still very frequent and of high severity. In many cases the belt itself is responsible for thorax injuries.

Examining both the belt related injuries and the different possible parameters to estimate the thorax injury tolerance, the thorax shape variation under the belt loading is likely to show a fair relationship with the injury potential. The purpose of this paper is to describe a methodology based on a cinephotogrammetric technique that will be used to evaluate thorax dynamic deformation.

1. SEAT-BELT INJURIES AND POSSIBLE PARAMETERS OF ASSESSMENT

Seat-belt injuries are quite different from those resulting from impacts by rather large and rigid surface areas, such as steering-wheels or dashboards. In this last case, experimental studies such as VOIGT's show that thorax injuries generated by a frontal impact, for the most consist in multiple, symetrical, quite lateral rib fractures ; sternum fractures are very uncommon.

On the contrary, as showed the accident analysis of PATRICK and the experimental work of SCHMIDT, under seat-belt loading, resulting fractures are essentially located along the strap path, including both the sternum and the ribs. Considering the belt geometry, they are obviously unsymmetrical.

Concerning the parameter which could be used for an injury criterion, cadaver tests have shown that acceleration data do not correlate with injury severity.

Belt tension loads have been demonstrated as more useful, but, for an equal value of tension, the load sustained by the thorax can be very different, depending on the belt geometry. Then the results are quite specific of a given impact configuration. Thorax deflection has been currently used as an intermediate parameter expressive of the chest response to impact in a lot of experimental work with impactors (NAHUM). It is very useful when the impacted zone is predetermined or when the striker has a surface wide enough to produce

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a bending load in all the ribs in a frontal impact. But in the case of an unsymmetrical loading by belt, a single deflection measurement is not enough.

It seems more adequate to know the exact force applied to the thorax and its deformation pattern under this force. The knowledge of both the resultant force and the deformation response requires a techniques enabling to control the geometric variations of the thorax and the belt for all impact duration. The cinephotogrammetric technique can provide such an information.

2. PHOTOGRAMMETRIY AND MOTION MEASUREMENT

2.1. PRINCIPLE

Stereophotogrammetry enables to determine the position of a point of an objet in the three dimensional space from a couple of pictures of this object taken under different angles at the same time.

The geometrical principles used to determine this position are exposed in appendice. The determination can be analog by use of stero-autographs which directly provide the plot of the observed points to build contour maps. This method found many applications in anthropomorphic studies (see for instance HERTZBERG and HERRON). But it needs sophisticated apparatus quite incompatible with high rate of shooting. Analytical methods are more suitable for the analysis of rapid phenomena and avoid camera location, shooting axis orientation and focal length constraints. In these methods, the point position is calculated from coordinates measured on films. All needed corrections can be entered in the calculation programm.

2.2. MOTION MEASUREMENT

Classical photogrammetric cameras are not convenient for motion studies. The multiple exposure technique using stroboscopic lighting have led to some applications (see AYOUB). But in this domain, mainly cinematographic cameras are useful.

Owing to the small size of the picture , and the mechanical features of high speed cameras, accuracy is lower but remain satisfactory for filming rates up to several hundred frames/second with 16 mm film size.

The picture synchronisation problem can be solved quite simply with two cameras. Assuming a small time error, coincident pictures can be found (GARNOV). But, more generally, time synchronisation of data is obtained by interpolation.

This motion picture method has been used for sport mouvement studies (MILLER, DUQUET) and for crash experiments analysis (BECKER, ROBBINS, CHAPON).

3. DYNAMIC THORAX DEFORMATION MEASUREMENT BY MULTIPLE CINEMATOGRAPHY

To study thorax deformation, analytical photogrammetric methods applied to cinematography can suit if, at any moment, enough points scattered all over the thorax can be measured. By locating properly these points, it is possible to approximate the surface of the thorax by a set of plane facets, enabling in a second step to compute section profiles or contour maps.

3.1. PRELIMINARY STATIC TEST

A first faisability test has been realized in static conditions on a baboon's thorax. The subject was lying on the back on a flat horizontal surface. Two cameras (16 mm Photo Sonic 1B) filmed the anterior face of the thorax while a compression load was applied by a diagonal belt (cf fig. 1).

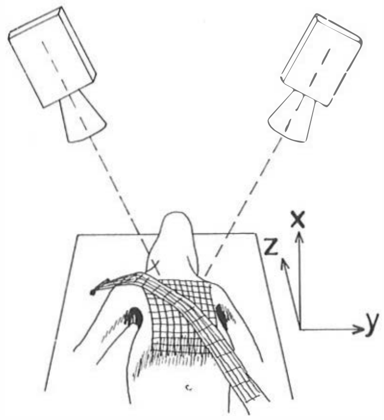


Fig. 1

Arrangement of cinematographic cameras for the static test on a baboon's thorax. Angle between shooting axes is about 60°.

The points to be measured were defined as intersections of longitudinal and transversal lines drawn on the skin and on the strap. Fig. 2 shows a couple of pictures of the thorax, before load application, from the test films.

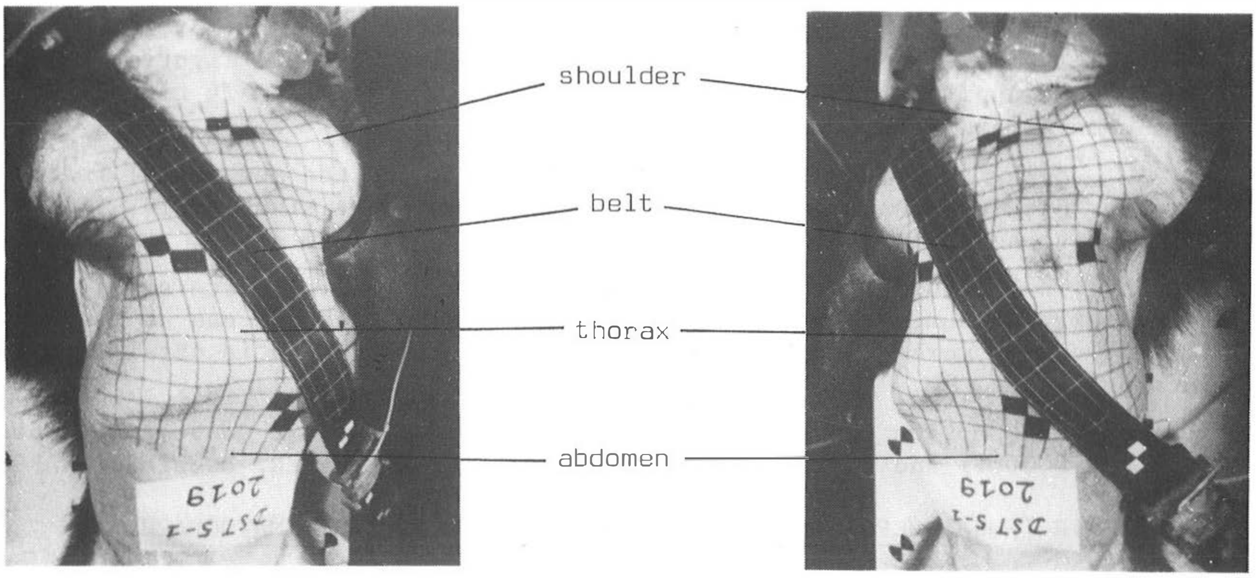


Fig. 2

Pictures from the 16 mm films taken during the static test before load application. The pace of the thorax grid is about 3 cm.

These films are analyzed on a Benson digitizer which provides the film coordinates of the network points. Then the data are processed by a CII IRIS 80 computer.

On Fig. 3, the lines linking the network points which have been located, are projected on the back rest plane. It must be noted that the grid is not complete.

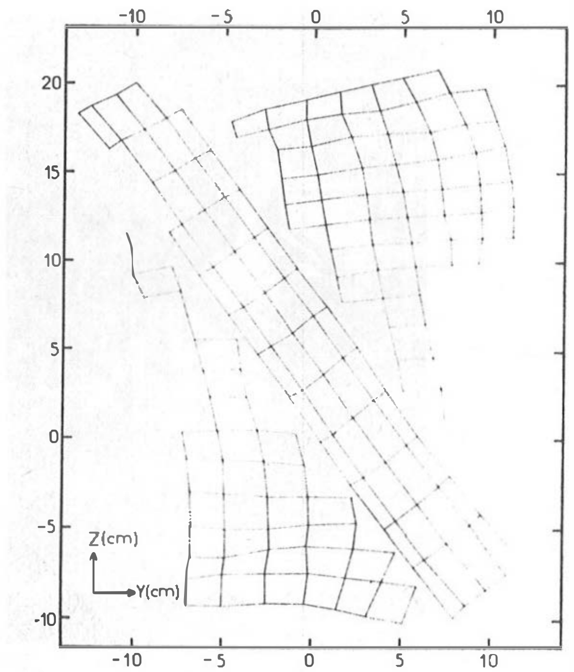


Fig. 3

ZY plot of longitudinal and transversal lines between computed points from data of pictures shown in fig. 2

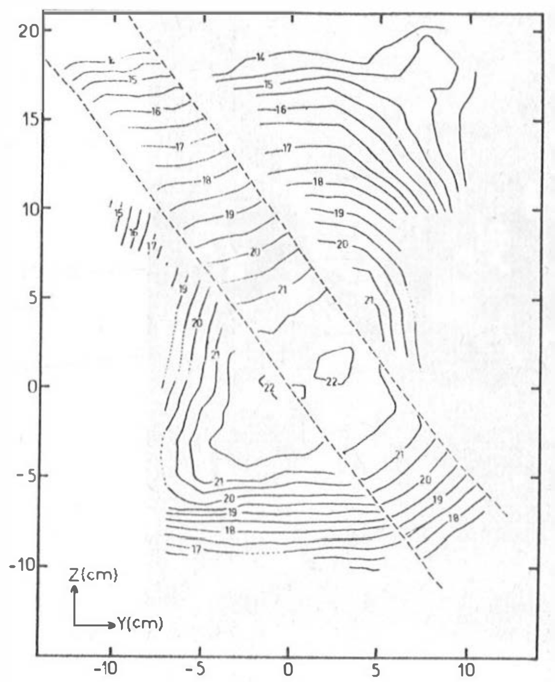


Fig. 4

Contour map of anterior face of the thorax corresponding to the surface shown in fig. 3. The shoulder relief (right upper corner) and the slope of thoraco-abdominal junction (lower part) are clearly displayed

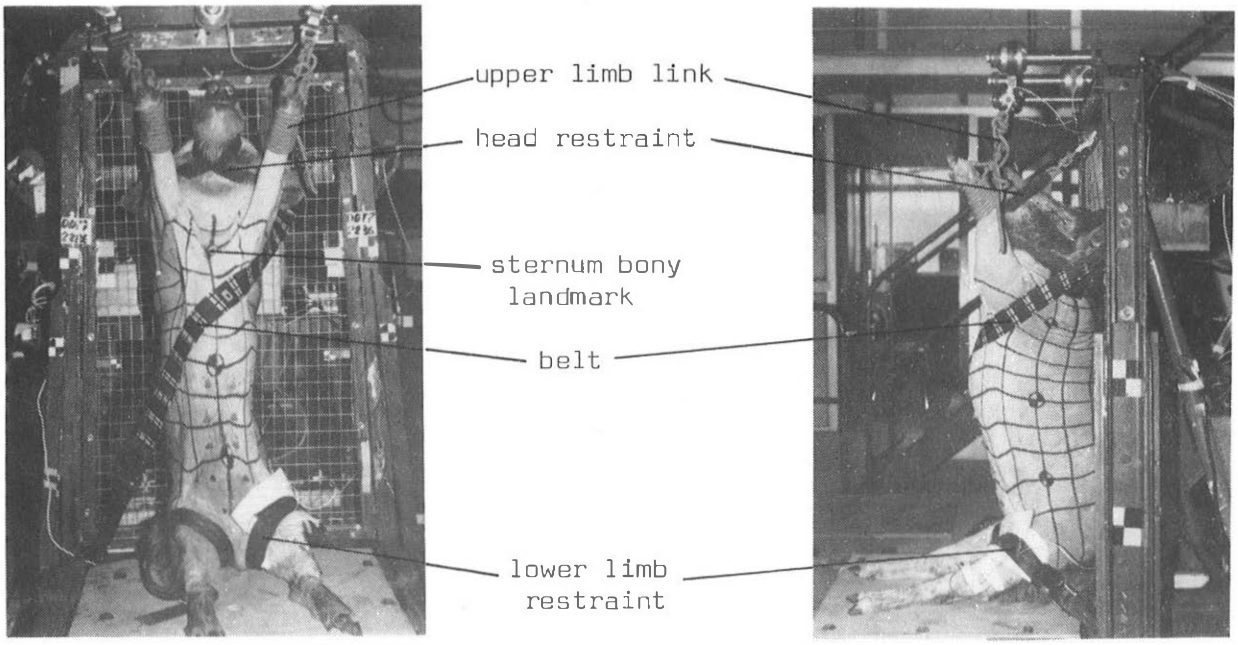
In fact some points can't be located because either they are hidden by the strap, or they can't be seen by both cameras (points on the edge). Each quadrilateral can be divided into two triangles by a diagonal line with the same orientation as the strap. Then, it is possible to compute the intersection of this set of triangle with cutting planes. Fig. 4 shows the intersection lines obtained with cutting planes parallel to the back rest and 0,5 cm spaced. These lines are equivalent to the contour lines that could have been given by an analytical method. Other sections along the belt plane or transversal planes have also been made.

These curves demonstrate that it is possible to quantify the thorax relief from 16 mm high speed motion pictures. So, it was decided to apply this method to the analysis of the overall deformation of the thorax (and not only the anterior face) in dynamic tests with belt restraint.

3.2. DYNAMIC TESTS

3.2.1. Experimental arrangement

The tests are performed on medium size pigs (50-60 kg). As shown on fig. 5, the subject is sitting on a sled, supported by a metallic grating back rest and held upright by the aid of three links fastened to the upper limbs and the head. The thorax is restrained by a diagonal strap passing under the left shoulder.



Front view | Side view

Fig. 5

Subject in place on the sled for a frontal impact

In fact preliminary tests have shown that, due to the particular anatomical features of the shoulder girdle of the pig and the upward position of the arms, the normal wearing of the belt leads to apply nearly the whole load on the neck. In the chosen configuration the belt path crosses the sternum in its lower third. The lower part of the body is restrained by two straps around the thighs

The sled is launched by a system using the energy of an inertial reel and the stopping distance is controlled by the deformation of plastic tubes.

Some mechanical parameter (belt and link tension, thoracic spinal and sternal acceleration, sled deceleration) as well as physiological parameters (EKG, aortic pressure) are recorded during impact, but won't be examined here.

The thoracic network of longitudinal and transversal lines for the purpose of photogrammetry, defines 120 points distributed all ower the thorax and the abdomen. To cover this area, 5 motion picture cameras, filming at about 500 frames/second, are necessary. They are positionned as shown on fig. 6. Two cameras are mounted on a rigid frame fixed on the sled behind the subject. The three others are located around the stopping area. Three metallic targets, two fixed on the spinous processes of T2 and T12 and one fixed to the first sternum segment, enable to control the good solidarity between skin and rib cage and to refer the external deflection to internal geometric variations.

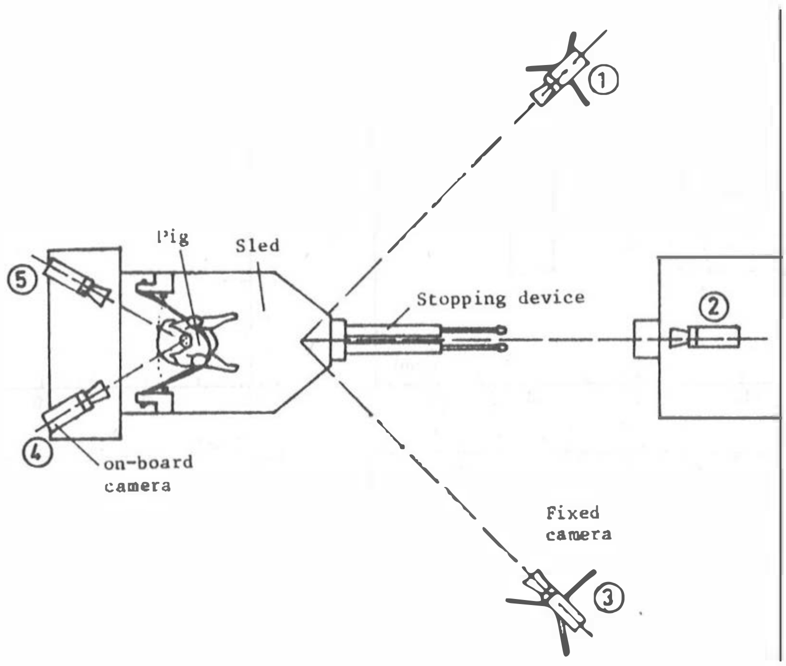


Fig. 6

Top view of camera arrangement for dynamic thorax deformation measurement

3.2.2. First results

The data from the first tests give an idea of the thorax deformation encountered in a 30 km/h frontal crash. On fig. 7, the external surface of the thorax is displayed by two projection plots (side view and front view) at two times : before impact (t = 0) and when belt tension is maximum (t = 67.6 ms).

It can be seen that the strap penetrates the tissues causing a marked bent of the sternum. The antero-posterior diameter decrease reaches about 30 % at the level of sternum belt crossing. This clearly appears on fig. 8 when only the median posterior and anterior longitudinal lines have been drawn. This way of displaying which only needs the computation of a few points can be repeated with a frequency high enough to plot a deflection curve versus time. As belt direction and tension can be computed in the same time, the dynamic load/deflection curve of the thorax under belt action can be set out. At this time only one curve is available and won't be presented here.

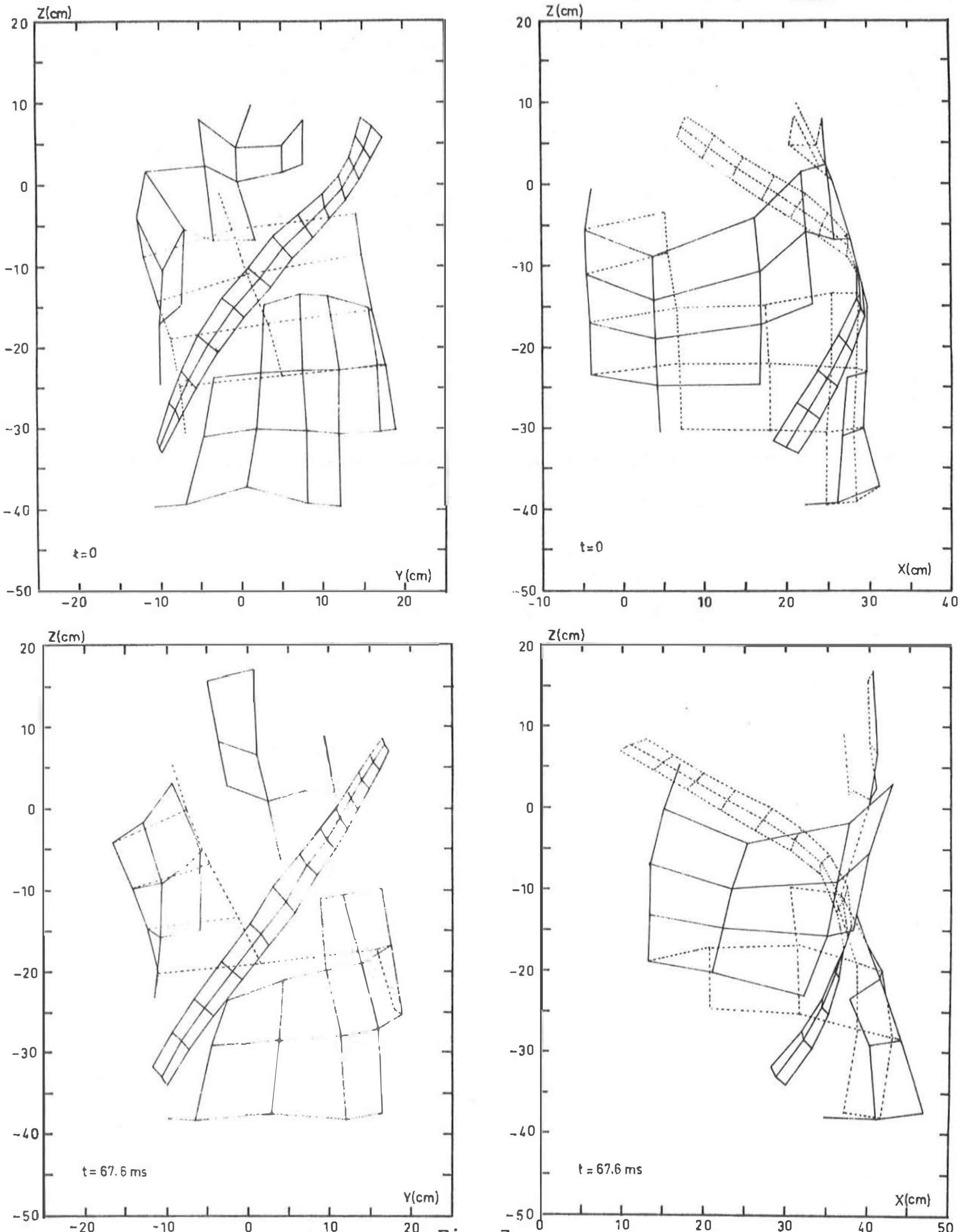


Fig. 7

ZY (front view) and ZX (side view) plots of thoracic network points during a 30 km/h frontal impact. Upper plots : initial configuration ; lower plots : shape at time of maximum belt load.

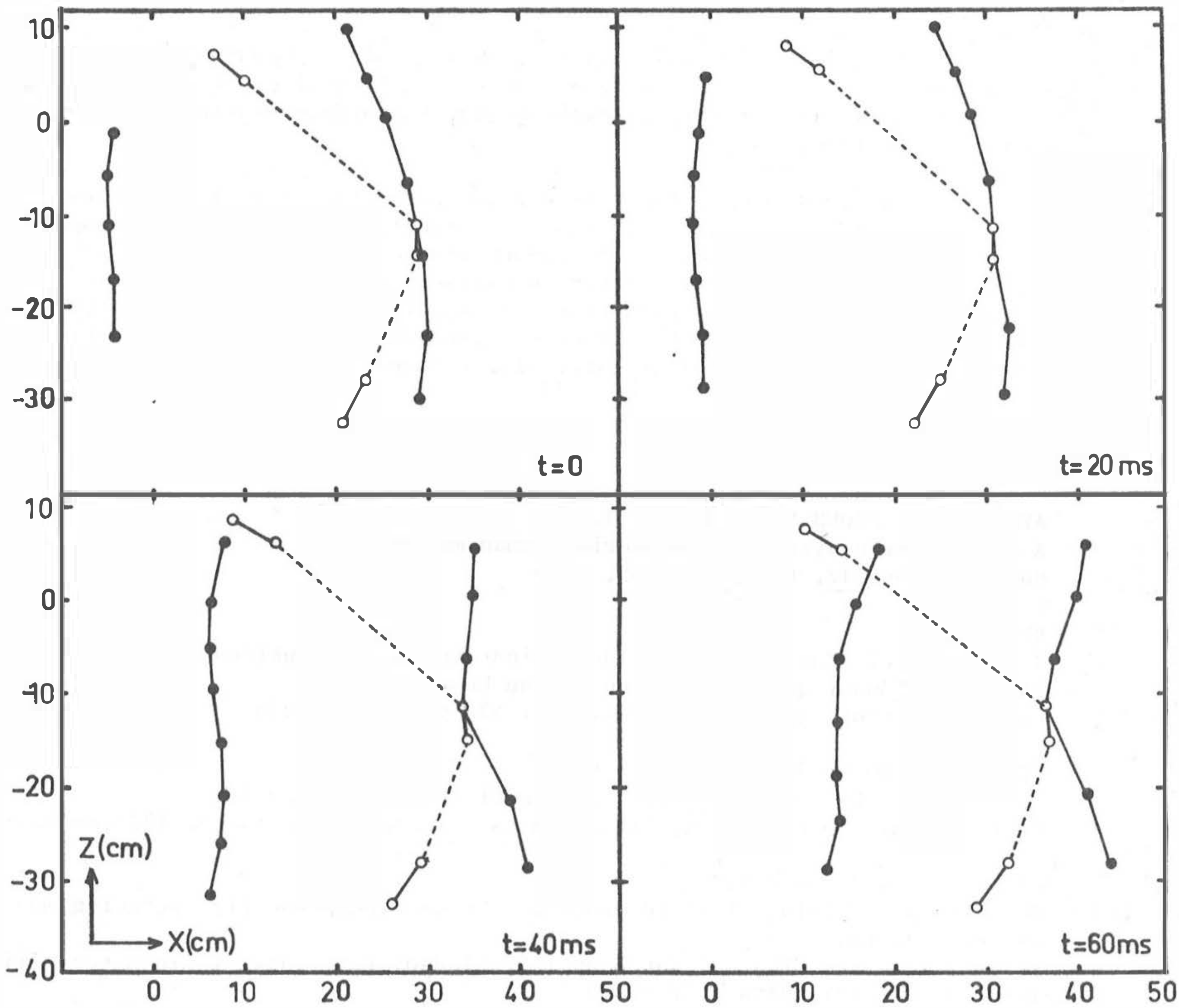


Fig. 8

ZX plot (side view) of ventral and dorsal median lines (dark circles) of the thoracic network and some belt axial segments (empty circles) at different times of impact. The antero-posterior deflection can easily be measured on these plots.

CONCLUSION

The method which has been described enables to evaluate the thorax deformation under the action of safety belt in a frontal crash. This deformation is displayed graphically by means of facets surface drawings, section profiles and contour maps.

In a first stage, the antero-posterior deflection of the thorax, which is the simplest deformation index for frontal impact, will be compared to the injury level produced by the impact and to the other recorded parameters (acceleration, force, etc...). These comparisons should allow to say if A-P deflection in a good intermediate parameter for injury level prediction in frontal impacts with belt restraint. For other configurations, this parameter will likely be inadequate and other indices expressing the deformation have to be searched.

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A P P E N D I C E

Principle of determination of spacial coordinates

Let A be the point whose coordinates are X, Y and Z in the fixed laboratory coordinate system and x, y and z in the camera coordinate system. The origin C of this latter is the point by which all the light beams forming the image on the film plane pass. Its coordinates are U, V and W. The relation between the coordinates of A in the two systems is

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} & R & \end{bmatrix} \begin{bmatrix} X - U \\ Y - V \\ Z - W \end{bmatrix} \quad \text{with} \quad R = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \tag{1}$$

where R is a 9 cosine matrix expressing the camera orientation with respect to the fixed reference system.

From (1) a set of two equations can be written as follows

$$\frac{y}{x} = \frac{d\ (X - U) + e\ (Y - V) + f\ (Z - W)}{a\ (X - U) + b\ (Y - V) + c\ (Z - W)}$$

$$\frac{z}{x} = \frac{g\ (X - U) + h\ (Y - V) + i\ (Z - W)}{a\ (X - U) + b\ (Y - V) + c\ (Z - W)} \tag{2}$$

developping and rearranging (2) yields 2 equations of the form

$$P_1 X + P_2 Y + P_3 Z = Q_1$$

$$P_4 X + P_5 Y + P_6 Z = Q_2 \tag{3}$$

in which P and Q are functions of :

- a, b, c, ... i, U, V and W which express the location and orientation of camera
- y/x and z/x which come from film analysis as explained farther

If a single camera give a system of two equations for three unknowns X, Y and Z, then two cameras will be sufficient to solve the problem.

Camera calibration and film data reduction

For each camera the optical system can be schematically represented by fig. A2. Polar coordinates of point A are R and θ. For the image A' they are R' and θ'. The system is considered good enough to have no tangential distortion, then $\theta = \theta'$. Between object and image coordinates there is the following relation :

$$\frac{R}{x} = k \frac{R'}{x'}$$

If k is constant there is no distortion. But k can vary with θ and with R especially in case of wide angle lenses. The values of k/x' are measured with a radial calibration grid and stored for further data conversion by interpolation.

For data reduction, the film coordinates y' and z' of each point are measured and converted into polar values R' and θ . After correction of R' (multiplication by k/x') for lens distortion and magnification, the conversion into cartesian coordinates give y/x and z/x whcih are used for resolution of equations (3).

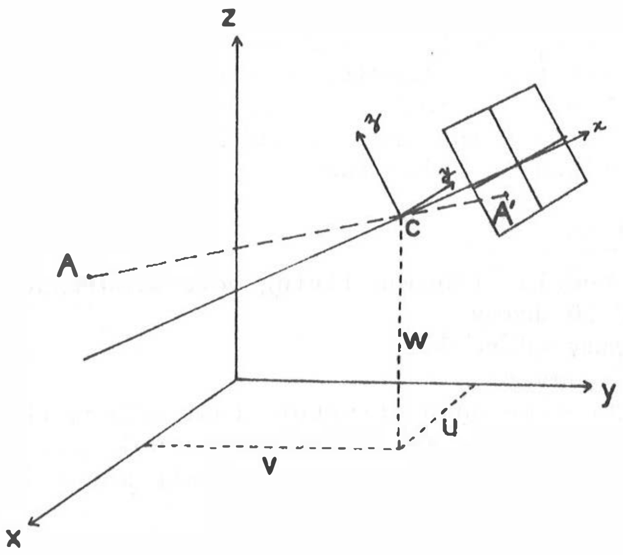

Fig. A1

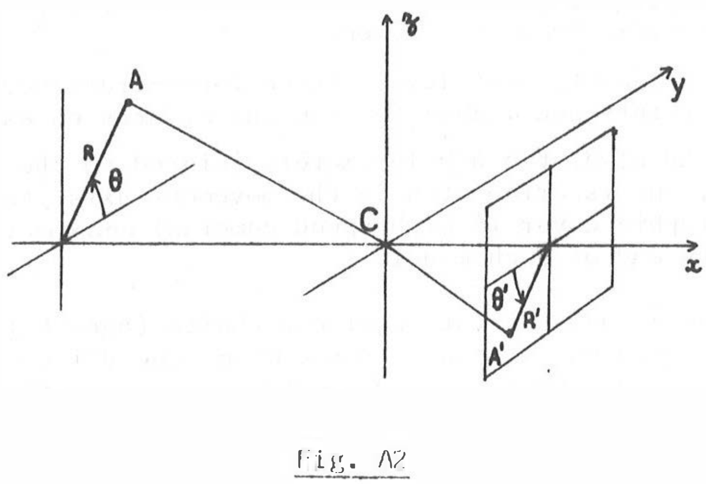

Fig. A2

Relation between object and image coordinates in camera reference system