AN IMPROVED HUMAN DISPLAY MODEL

FOR

OCCUPANT CRASH SIMULATION PROGRAMS

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ABSTRACT

Presented is an improved three-dimensional display model of a human being which can be used to display the results of three-dimensional simulation programs that predict the positions of an occupant during impact of a vehicle. The model allows the user to view the occupant from any orientation in any position during the crash. The display model assumes the usual break up of the body into rigid segments which is normal for occupant crash simulation programs, but the shape of the segments in the display model are not necessarily the same as those used in the crash simulation. The display model is proportioned so as to produce a realistic drawing of the human body in any position. Joints connecting the segments are also drawn to improve realism.

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19

INTRODUCTION

In simulating the motion of a human occupant during the crash of a vehicle, the normal approach is to represent the body as a collection of rigid members connected by appropriate joints. The positions of the human at successive increments of time are determined based on the dynamics of the assemblage of members taking into account their mass and moments of inertia, joint properties, etc. There is generally little regard, in these simulation models, to the actual shape of the body parts. After the positions of the segments have been determined, the body could easily be drawn on an x - y plotter or graphic computer terminal in stick form or using some other simple display representation of the body parts. The approach taken by Calspan Corporation [1] in their three-dimensional simulation program was to represent each segment in the display model as an ellipsoid. Two views of the outline (or shadowlines) of these ellipsoids were then drawn as shown in Figure 1.

In many applications, it is desirable to have a more realistic model of the human body that can be used to display the results of these occupant simulation programs. This was the goal of the work presented in this paper. It was assumed that the coordinates of the centers of gravity and direction cosine matrices (or Euler angles) of each body segment at all positions to be displayed were available as output from the simulation programs. Presented here is a means of taking this information and constructing a realistic body around the individual segments, connecting them with appropriate joints and displaying the resulting model on an inexpensive two-dimensional graphic computer terminal.

DISPLAY MODEL

The body segments of the display model developed in this work are represented by non-uniform elliptic cylinders as shown in Figures 2 and 3. The surface of these cylinders can be expressed mathematically in terms of the X", Y", and Z" coordinate system whose origin is at some reference point within the segment, generally the center of gravity, as shown in Figure 2. As functions of parametric coordinates s, t_1, and t_2 this surface is defined as:

$$X''(s,t_1,t_2) = (1-s)(A_1 \cos t_1 + C_1) + s(A_2 \cos t_2 + C_2) \quad (1)$$

$$Y''(s,t_1,t_2) = (1-s)B_1 \sin t_1 + s\, B_2 \sin t_2 \quad (2)$$

$$Z''(s,t_1,t_2) = (1-s)L_1 + s\, L_2 \quad (3)$$

where:

A_1, B_1, A_2, and B_2 are the ellipse semi-axis dimensions as shown in Figure 3.

C_1 and C_2 are the offsets from the X"-axis at the corresponding ellipse end.

L_1 and L_2 are the Z"-displacements of each end ellipse from the center of gravity (the origin of the segment coordinate system).

M_1 and M_2 are constants used to change the length of the outside surface relative to the location of the end ellipses.

s is the axial parametric coordinate.

and

t_1 and t_2 are the circumferential parametric coordinates for the end ellipses.

The parametric coordinates are limited to the following ranges:

$$M_1 \leq s \leq 1 + M_2 \quad (4)$$

$$0 \leq t_1 \leq 2\pi \quad (5)$$

$$0 \leq t_2 \leq 2\pi \quad (6)$$

In order that Equations (1), (2), and (3) define a surface there must be a relationship between t_1 and t_2. This is (see reference [2] for details):

$$A_2 B_1 \tan t_2 = A_1 B_2 \tan t_1 \quad (7)$$

By adjusting the quanties A_1, B_1, etc., each segment of the human body can be represented fairly realistically.

The surface in a coordinate system X, Y, Z attached to the screen of the graphic terminal, where Z is perpendicular to the screen, can be obtained from:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \bar{A}\,\bar{D} \begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} + \bar{A} \begin{bmatrix} X'_{CG} \\ Y'_{CG} \\ Z'_{CG} \end{bmatrix} + \begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} \quad (8)$$

where X", Y", and Z" are defined in Equations (1), (2), (3), $\bar{D}$ is the direction cosine matrix of the segment, X'_{CG}, Y'_{CG}, Z'_{CG} is the position of the center of gravity of the segment, $\bar{A}$ is the direction cosine matrix associated with the users desired viewing direction of the body, and X_T, Y_T, Z_T correspond to displacements needed to assure that the body appears approximately at the center of the terminal screen. It is assumed that $\bar{D}$, X'_{CG}, Y'_{CG}, and Z'_{CG} are available as output from the occupant simulation programs. The yaw, pitch and roll angles which determine the $\bar{A}$ matrix are selected by the user to give any desired view of the body.

The shadow lines (or outlines) of the body segments in the screen coordinate system can be determined by noting that the Z component of the normal to the surface along these outlines must be zero. Thus:

$$n_Z = \frac{\partial X}{\partial t}\frac{\partial Y}{\partial s} - \frac{\partial Y}{\partial t}\frac{\partial X}{\partial s} = 0 \qquad (9)$$

where n_Z is the Z component of the normal. As s varies from 0 to 1, Equation (9) gives the value of the t parameter for the shadow lines. Since these are straight lines, only the end points need be determined. Evaluating (9) at $s = 0$, and also $t = t_1$, results in:

$$\left(\frac{\partial X}{\partial t_1}\frac{\partial Y}{\partial s} - \frac{\partial Y}{\partial t_1}\frac{\partial X}{\partial s}\right)\Big|_{s=0} = 0 \qquad (10)$$

Using Equation (7) to eliminate t_2 from this expression results in a fourth degree polynomial in cos t_1 which can be solved explicitly for values of t_1 producing the shadow lines. The X, Y, Z coordinates of one end of the shadow lines can then be determined using Equations (8). The other end can be determined by using Equation (7) to find the t_2 values corresponding to t_1 obtained by solving Equation (10). Further details on this procedure can be found in References [2], [3], [4]. A display of the resulting shadow lines for the entire body are shown in Figure 4.

In order to complete the display, realistic joints were added between the segments. This was accomplished using circular arcs, straight lines, and clip and crease connections. Details of these connections can be found in References [2], [3], [4], and [5]. The final display is shown in Figure 5. Using different yaw, pitch and roll angles (selected by the user), other views of the body can be obtained as shown in Figure 6. Figures 5 and 6 show the same position of the occupant as that in Figure 1 produced by Calspan. As can be seen more realistic diagrams can be obtained from this improved display model.

Recently several modifications and improvements have been made in the basic display model. First, a change has been made in the approach used to decide which of the two shadow lines between adjacent segments must be connected. In the original approach the shadow lines to be connected were selected on the basis of the t parameter in the definition of the surface of the elliptic cylinder. The shadow lines of two adjacent body segments corresponding to the most similar t parameters at the appropriate ends were connected. This gave acceptable results in most situations. However at times the wrong shadow lines were connected, as shown in Figure 7. The new approach is based on the cross product of two imaginary vectors in each segment as shown in Figure 8. The shadow lines are (X_1,Y_1) to (X_2,Y_2) and (X_3,Y_3) to (X_4,Y_4) for one segment and (X_5,Y_5) to (X_6,Y_6) and (X_7,Y_7) to (X_8,Y_8) for the other. The imaginary vectors are defined as:

$$
\begin{aligned}
\vec{V}_1 &= (X_2 - X_3,\ Y_2 - Y_3) \\
\vec{V}_2 &= (X_4 - X_1,\ Y_4 - Y_1) \\
\vec{V}_3 &= (X_6 - X_7,\ Y_6 - Y_7) \\
\vec{V}_4 &= (X_8 - X_5,\ Y_8 - Y_5)
\end{aligned}
\qquad (11)
$$

If the sign of the cross product $\vec{V}_1 \times \vec{V}_2$ is opposite from that of $\vec{V}_3 \times \vec{V}_4$, then a connection is drawn from (X_2,Y_2) to (X_6,Y_6) and from (X_4,Y_4) to (X_8,Y_8). Otherwise (X_2,Y_2) connects with (X_8,Y_8) and (X_4,Y_4) connects with (X_6,Y_6). This approach seems to produce the proper connections. Figure 9 shows the same view as in Figure 7 except the determination of which shadow lines are to be connected is accomplished using this new method.

The original display program was written in BASIC on a small minicomputer. We have recently converted the program to FORTRAN on a commercial time sharing system, and have been investigating the display of output from other occupant simulation programs. Figures 10 and 11 show two positions taken from the UCIN program developed at the University of Cincinnati [6]. In the UCIN model only 12 body segments were used, as compared to 15 for the Calspan model. The feet and neck were not included as separate segments in the UCIN simulation, but were lumped with the other segments of the body. However in displaying the body, feet and neck certainly add realism, and thus data was created for these segments from the 12 existing ones to use in the plot.

EXTENSIONS UNDER DEVELOPMENT

Several additional modifications of the display model are currently under development. The approach used to connect segments to form realistic joints works well for the head-neck, upper-lower leg, upper-lower arm and between the three torso segments for all position and viewing angles. Likewise the connections between the neck and upper torso and between the lower torso and upper legs appear realistic in most cases as shown in Figures 5 and 11; however, for some positions of the body and viewing angles these two connections could be improved. Figure 6 shows a left shoulder which is somewhat distorted. The arm appears higher than it should be because of the connection which is made between the neck and upper torso. It thus seems that at times the neck should be connected to the arms rather than upper torso to gain better realism. Figure 10 shows an extra curve between the upper leg and lower torso in the side view and a distorted buttocks in the front view.

Modifications are currently underway to improve these two connections in order to obtain a better display model. Also under investigation are techniques to remove hidden lines from the display to further improve realism.

ACKNOWLEDGMENT

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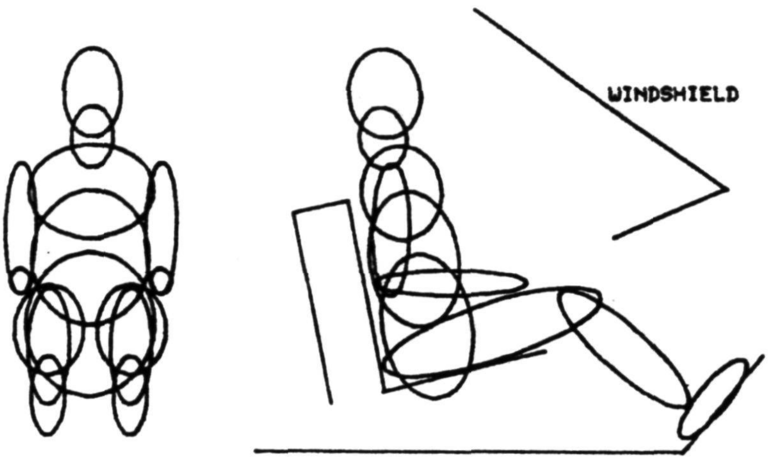


Figure 1.- Calspan display model.

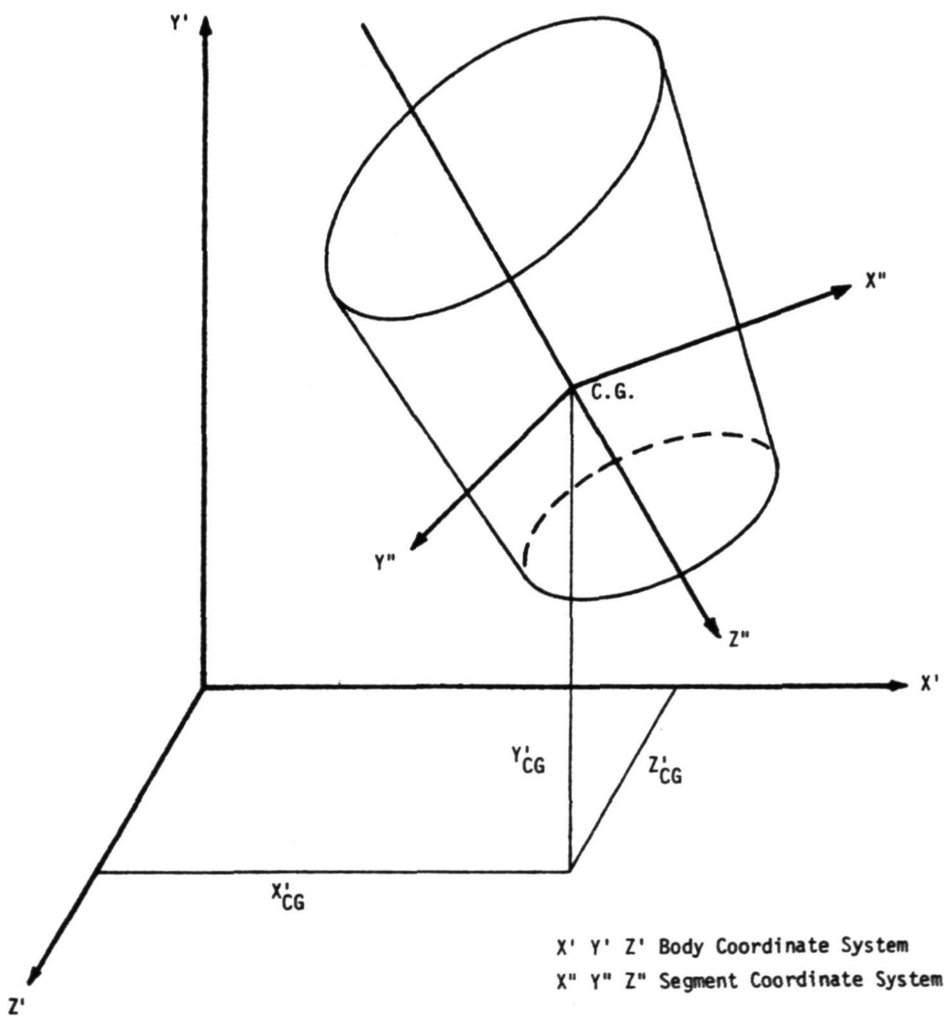


Figure 2.- Non-uniform elliptic cylinder.

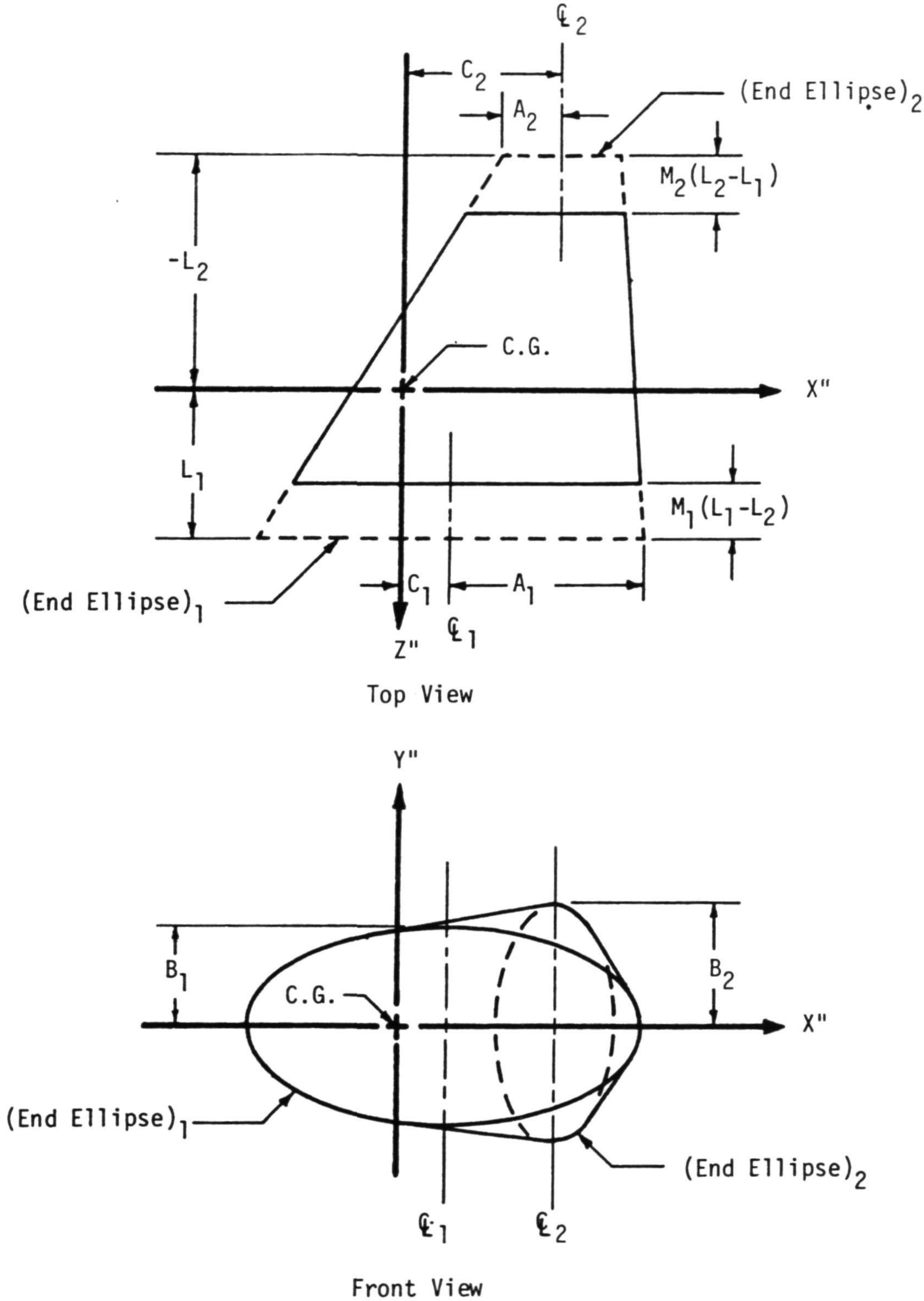
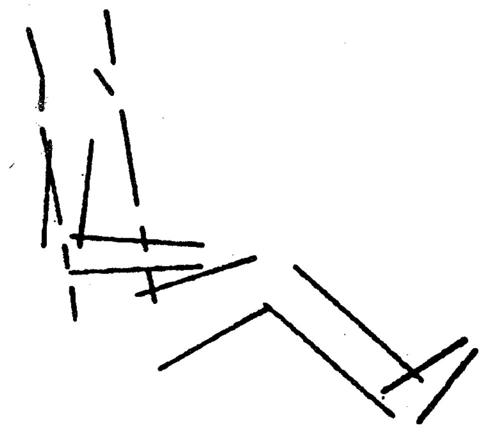
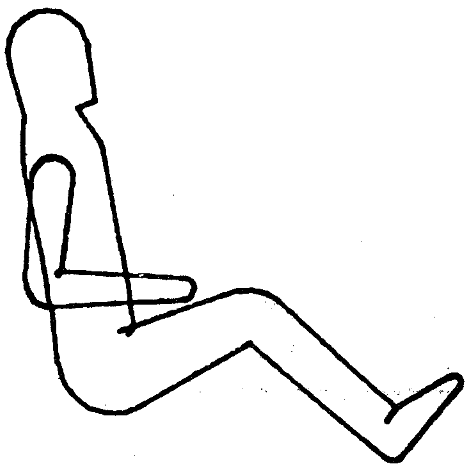


Figure 3.- Dimensions for non-uniform elliptic cylinder.



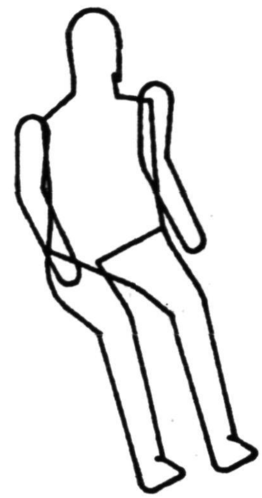
YAW = 270   PITCH = 0   ROLL = 0

Figure 4.- Shadow lines.



YAW = 270   PITCH = 0   ROLL = 0

Figure 5.- Display with connections.



YAW = 200 PITCH = 45 ROLL = 0

Figure 6.- General orientation of the display model.

POSITION NUMBER DESIRED ?

YAW= 200.00 PITCH= 10.00 ROLL= 0.

Figure 7.- Display using old method of determining which shadow lines connect.

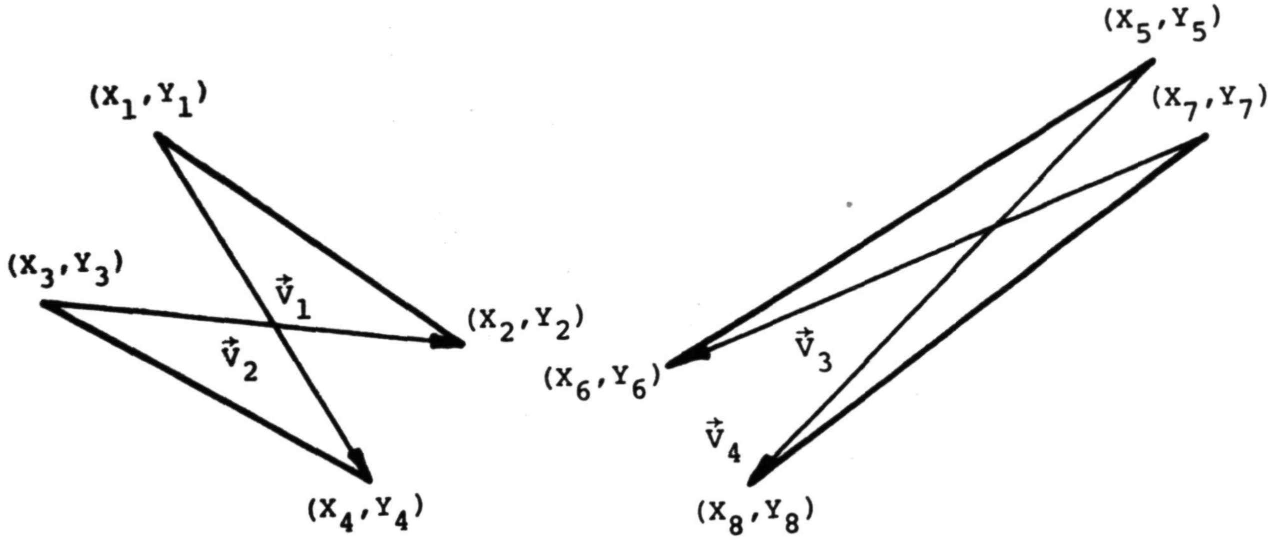


Figure 8.- New method of determining which shadow lines connect.

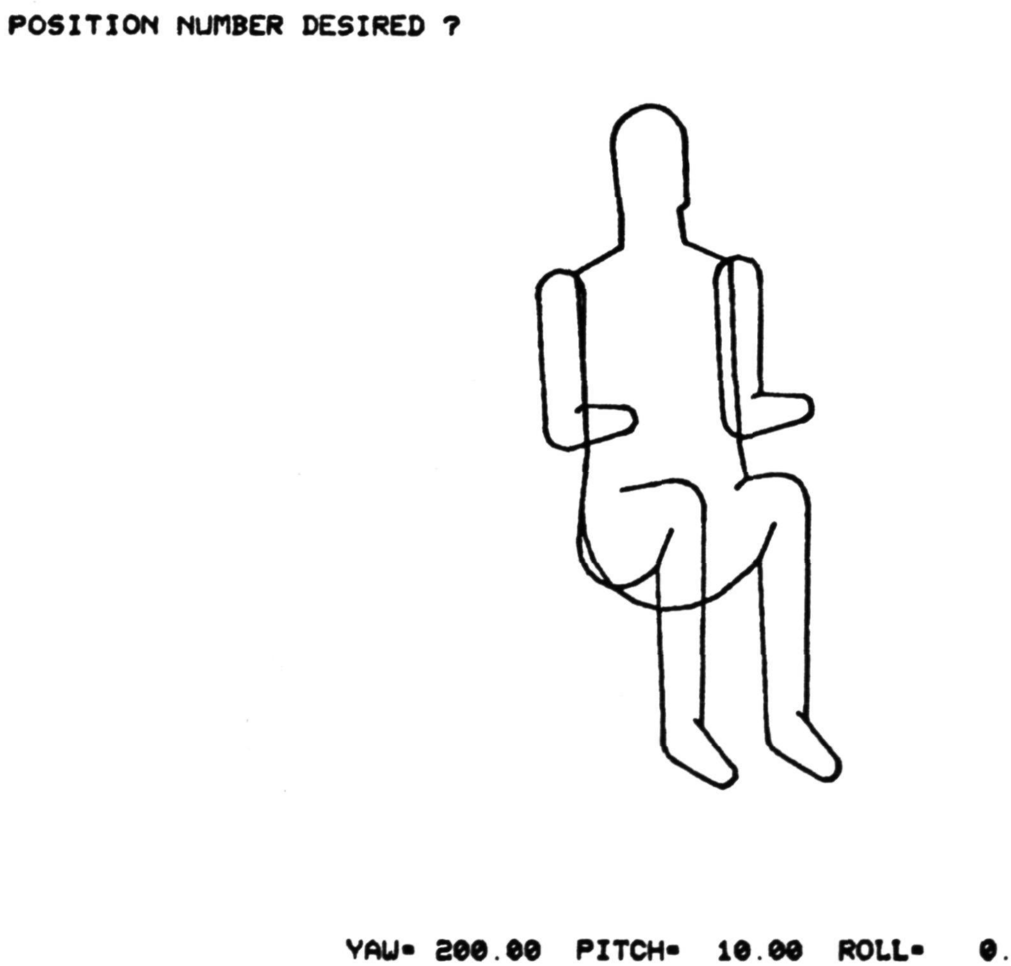


Figure 9.- Display using new method of determining which shadow lines connect.

POSITION NUMBER DESIRED ?

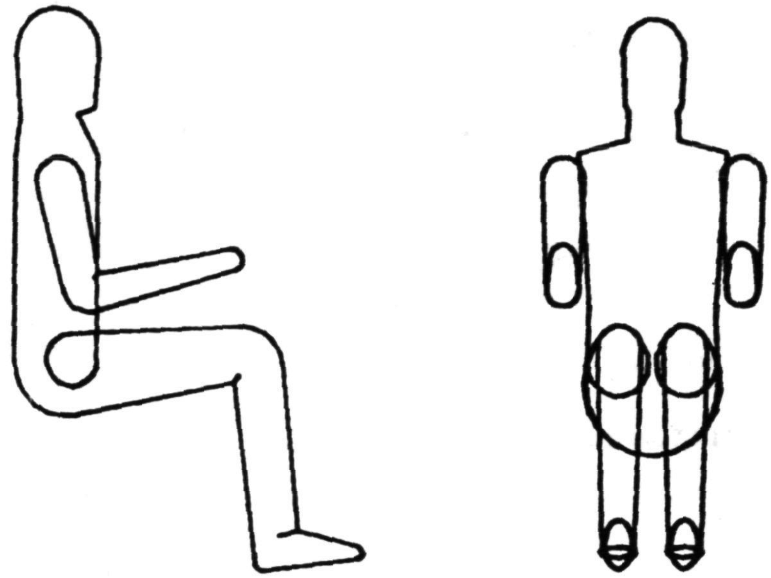


Figure 10.- First position from UCIN program.

POSITION NUMBER DESIRED ?

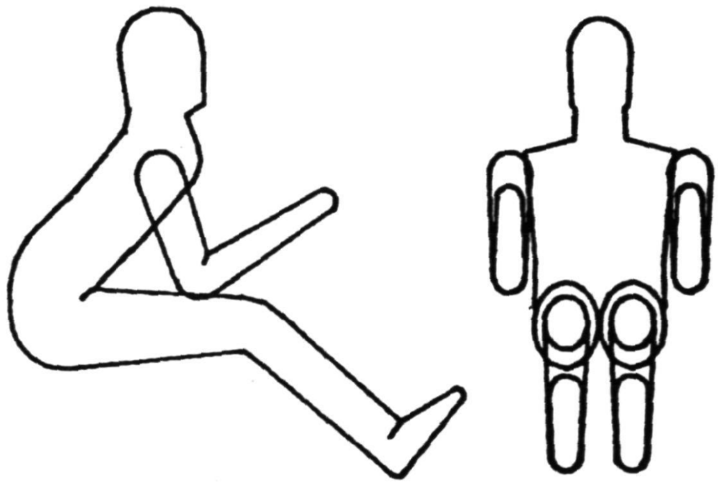


Figure 11.- Last position from UCIN program.