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An Advanced Database of the 50th Percentile Hybrid III Dummy

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Abstract

This paper presents a measurement program of a sitting 50th percentile Hybrid III Dummy to determine a database for computer simulations. Geometrical, inertial, joint property and surface compliance measurements have been carried out. A description of the measuring methodology is given.

On the basis of these measurements a 20 segment database for the MADYMO 3D occupant simulation program is developed. The major advancements of this database compared to an earlier 15-segment database developed by TNO [1]* can de summarized as follows:

- Five additional segments are incorporated in this database to account for the hands, the shoulders(clavicles) and the sternum.
- The database includes a complete omni-directional description for the neck as well as the lumbar spine.
- A detailed mathematical surface description is available, for instance to be used for computer animations.
- Segment ellipsoids for contact interactions have been determined in a more accurate way.
- Joint properties are determined with a special developed static joint measuring device.
- Segment surface and thoracic stiffness data are based on a large series of tests with different impactor faces, including tests with a seat belt.

INTRODUCTION

In the field of automobile crash research, computer simulations have shown a strong increase in use, particularly due to the developments in computer hardware and simulation software in the past years. Specifically computer models have proven to be beneficial in reducing the development time of a new vehicle model and in reducing the number of crash tests required. They allow an efficient means of evaluating the influence of parameter changes and moreover they can be used to evaluate the performance of new design concepts even before a prototype has been built. An important requirement for an effective use of computer models is that reliable well validated databases are available particularly for the simulation of the human being in a crash environment.

The objective of this study is the development of a crash dummy database on the basis of a set of well defined measurements and experiments which specify the properties of this dummy.

This study deals with a database for the 50th percentile Hybrid III dummy (Fig. 1). This dummy is generally considered to be one of the most advanced crash test dummies available at the moment. Use of this dummy for the evaluation of vehicle safety performance is standard practice now within the automotive industry. Earlier efforts to develop a database for this dummy were carried out at Wright Patterson Air Force Base (WPAFB) in Dayton, Ohio [2,3]. In their study two dummies were measured: a standing and a sitting one. TNO used the data resulting from these measurements to formulate in 1987 a preliminary 15 segments database of the Hybrid III dummy for the MADYMO 3D occupant simulation model. This database further referred to as SAE database was validated using a series of Hybrid III sled tests conducted by Ford Motor Company. A quite good agreement between simulations and experiments could be observed [1].

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* Numbers in parentheses designate references at end of paper

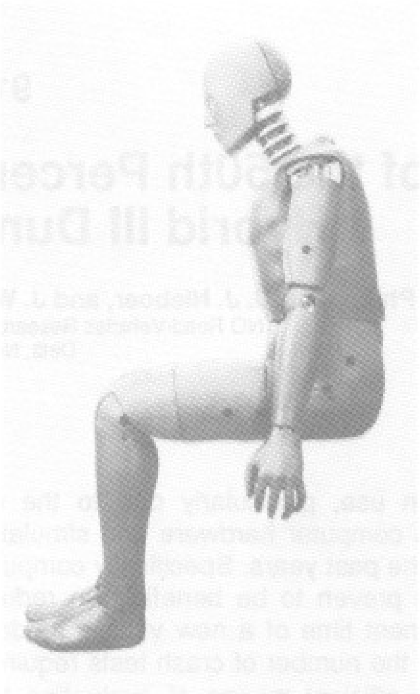


Fig.1 The 50th Percentile Hybrid III dummy

The present research program seeks to optimize this SAE database on the basis of a new more extensive measurement program of the Hybrid III dummy. The measurements are conducted in close co-operation with Wright Patterson Air Force Base where the inertial properties of the dummy have been determined. The most important differences with the earlier WPAFB measurements [2,3] are:

- A division in a larger number of dummy segments to be measured allowing a more detailed, computer representation.
- A detailed surface discretisation of the dummy segments allowing a more realistic visualisation of the simulated dummy kinematics.
- A more accurate contact ellipsoid selection on the basis of the segment surface discretisation.
- A detailed measurement of surface compliancies including ribcage response using static and dynamic tests with different compression faces.
- A more extensive measurement of static and dynamic joint properties particularly with respect to the dummy neck.

The characteristics of the dummy are obtained by various measurements. A subdivision can be made into geometric, mass distribution, joint property and segment surface stiffness measurements. The equipment used in the tests and the applied measurement techniques will be described here, in conjunction with examples of typical measurement results. In this study one sitting Hybrid III dummy was measured. Detailed results of the modeling efforts will be presented in a separate paper.

SEGMENT AND JOINT SPECIFICATION

SEGMENTS – The first step in developing a multi-body model of a crash dummy is the division of the dummy in a number of segments and the specification of the parts which belong to each segment. The segments are selected by dividing the dummy into functional components. Each part of the dummy having significant mass and a flexible connection with other parts is considered as a segment. Dummy parts which do not show any relative motion are considered to be part of one segment. The dummy is divided in 17 main segments listed in Table 1.

Table 1 Division of dummy in segments

Main segments:

- Head
- Neck
- Upper Torso
- Abdomen
- Lower Torso
- Upper Arms (2)
- Lower Arms (2)
- Hands (2)
- Upper Legs (2)
- Lower Legs (2)
- Feet (2).

Subsegments upper Torso:

- Thoracic Spine
- Clavicles (left & right)
- Sternum assembly and part of the ribs

The Upper Torso has been devided into a number of subsegments allowing a more detailed representation of this segment. These subsegments are also included in Table 1. The clavicle subsegments are proposed to account for shoulder/clavicle flexibility while a separate ribcage subsegment is important for simulating inertial effects of the ribcage. Moreover due to this subdivision, dummy interaction with a belt or airbag restraint system can be simulated more realistic.

Ref. [4] provides a detailed description of each segment. A hardware list of the various parts is included in this reference.

JOINTS – In present dummy designs usually four types of joints (connections) between segments can be distinguished:

• pin joints	(one degree of freedom)
• universal joints	(two degrees of freedom)
• ball and socket joints	(three degrees of freedom)
• flexible connections	(allowing up to six degrees of like neck and spine freedom)

The joint centre of a pin or hinge joint is located at the rotation axis of the pin joint. An universal joint is a combination of two pin joints where usually the two rotation axes intersect. This intersection is taken as joint centre. For a ball and socket joint the rotation centre is taken as joint centre (usually in the centre of the "ball").

The current approach in Crash Victim Simulation models is to introduce two joints in the lumbar spine and neck as a model for the potential movement in these structures. The location of these "joints", called joint centre, will be in the centre of the endplates of the flexible structure as far as both ends of the lumbar spine and the lower end of the neck are concerned. For the upper end of the neck this joint centre coincides with the centre of the pivot located between head and neck, i.e. the so called nodding joint.

The following joint types can be distinguished in the Hybrid III dummy in agreement with above definitions:

- *neck and lumbar spine:*
  flexible rubber structures represented by joint centres in the end points,
- *knee and clavicle:*
  pin joints,
- *shoulders, elbow and wrist:*
  universal joints,
- *hip and ankle:*
  ball and socket joints

A more detailed description of these joints can be found in reference [4].

CO-ORDINATE SYSTEMS – A local right-handed coordinate system has been defined for each segment and subsegment. Geometrical and mass distribution properties will be expressed relative to these coordinate systems. The coordinate axes are selected in such a way that in general in the sitting position of the dummy all z-axes are directed upward, all x-axes are directed forward and all y-axes are directed to the left. The location of the origin and the coordinate axes is selected on the basis of well defined landmarks in the dummy segments. Usually the origin of the local coordinate system has been selected in one of the joint centres of the segment while the coordinate axes often coincide with joint axes. An illustration of each segment coordinate system is given in Fig. 2.

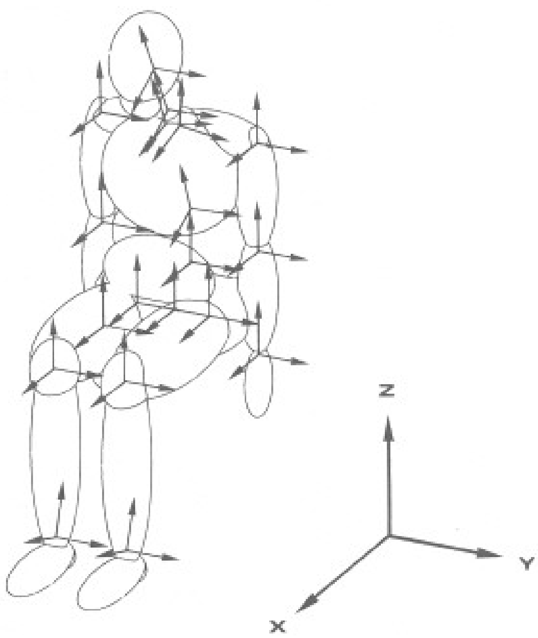


Fig. 2 Hybrid III dummy model with local segment coordinate systems.

GEOMETRY

Different types of geometrical measurements have been carried out within this study. The most important ones for the model development are the determination of the joint locations within the individual segments and the determination of a detailed surface description. These measurements are conducted at a disassembled dummy.

JOINT POSITION AND ORIENTATION – Determination of the position of the joint centres and joint axes directions has been conducted with a so-called Perceptor. This is a 3-dimensional measuring device provided with a digitizing arm to measure the x,y,z co-ordinates of a point in space [2,4]. Most of the geometrical joint data have been determined in an indirect way since the requested joint data usually are not directly accessible by the perceptor. In case of a ball and socket joint for instance, the position of a number of points on the joint surface can be measured from which the joint centre co-ordinates can be calculated. Additional measurements of landmarks specifying segment local co-ordinate systems and corresponding co-ordinate transformations were performed to express the joint centre positions and joint axis orientation in the segment local co-ordinate systems.

SURFACE DESCRIPTION – The outside surface of the dummy segments in most Crash Victim Simulation models is represented by means of ellipsoids. These ellipsoids are used for visual presentation of the occupant kinematics as well as for the calculation of the contact interaction between dummy segments and environment (e.g. the vehicle interior). The location and dimensions of these ellipsoids is usually estimated on the basis of global segment dimensions like width and length. In this study for the visualization of the dummy an accurate graphical surface description of the dummy segments was required in addition to an ellipsoid description for contact interactions. It was decided to integrate the generation of both surface descriptions in such a way that the ellipsoid description is derived from the detailed graphical surface description.

The first step is the measurement of the position of a large number of points on the segment surfaces. The x, y, z co-ordinates of these points were digitized with an accuracy of 2-3 mm. In order to obtain a complete description of the segment surfaces the dummy segments had to be measured in several positions. For each position also the co-ordinates of a number of landmarks (at least three), specifying the segment local co-ordinate system, were digitized. In this way a complete surface description could be obtained by combining the measurement results in the various positions using co-ordinate transformations. The digitized points were further processed using a CAD/CAM system ("Norskdata") resulting in a surface description according to the VDA-Flächenschnittstelleformat (VDAFS Version 2.0). Fig. 3 illustrates the results of this mathematical description.

SEGMENT ELLIPSOIDS – The specification of the segment ellipsoids was also performed on the CAD/CAM system. The parameters describing the ellipsoids are the ellipsoid axes, the location of the ellipsoid centre relative to the segment co-ordinate system and the orientation relative to this co-ordinate system [4].

These parameters were optimized visually by simultaneous graphical presentation from different view points, of the ellipsoid and the detailed surface description. In this procedure also the potential contact function of the ellipsoid was taken into account. In other words potential contact areas of the dummy were approximated more accurately than areas of the dummy surface which usually do not have interactions with other segments or with the environment. Fig. 2 illustrates the resulting ellipsoids.

INERTIAL PROPERTIES

The mass and moments of inertia measurements are carried out at Wright Patterson Air Force Base (WPAFB). The following properties are measured for each dummy segment:

- mass,
- location of centre of gravity in local co-ordinate system,
- principal moments of inertia at the segment centre of gravity,
- orientation of the principal axes co-ordinate system.

A detailed description of the measurement methodology can be found in Refs. [2,4].

The following accuracies could be obtained, except for the smaller elements like hands, feet and neck:

- weight: 0.02 N
- centre of gravity: 0.004 m
- moments of inertia: 1%
- principal axes orientation: 3 degrees.

The mass distribution measurements also have been conducted for the subsegments except for the soft, flexible structures (i.e. abdominal insert and ribcage-sternum). For these flexible segments only the mass values have been determined.

JOINT PROPERTIES

The stiffness of the connection between the different segments is one of the parameters having a major effect on the movement and position of the dummy segments in a crash environment. In order to specify the joint properties two concepts will be introduced here first:

- **Degrees of freedom of a joint**, defined as the number of independent joint motions possible in a joint.
- **Range of motion**, defined as the total motion possible for a degree of freedom. In most cases the range of motion will be dependent on the external load applied on the joint.
- **Free range of motion**, defined as txe range of motion if only a small load is acting on the joint to compensate for friction and the effect of gravity.

In the Hybrid III dummy, according to above definitions, the lumbar spine, neck and the two clavicle joints do not possess any free range of motion.

Static and dynamic joint properties have been determined in this study with existing or special developed methods. In these tests the joint range of motion is determined as function of the externally applied load. For joints (or joint motions) where these test methods could not be applied only the free range of motion has been determined. This measurement was done manually using an inclinometer.

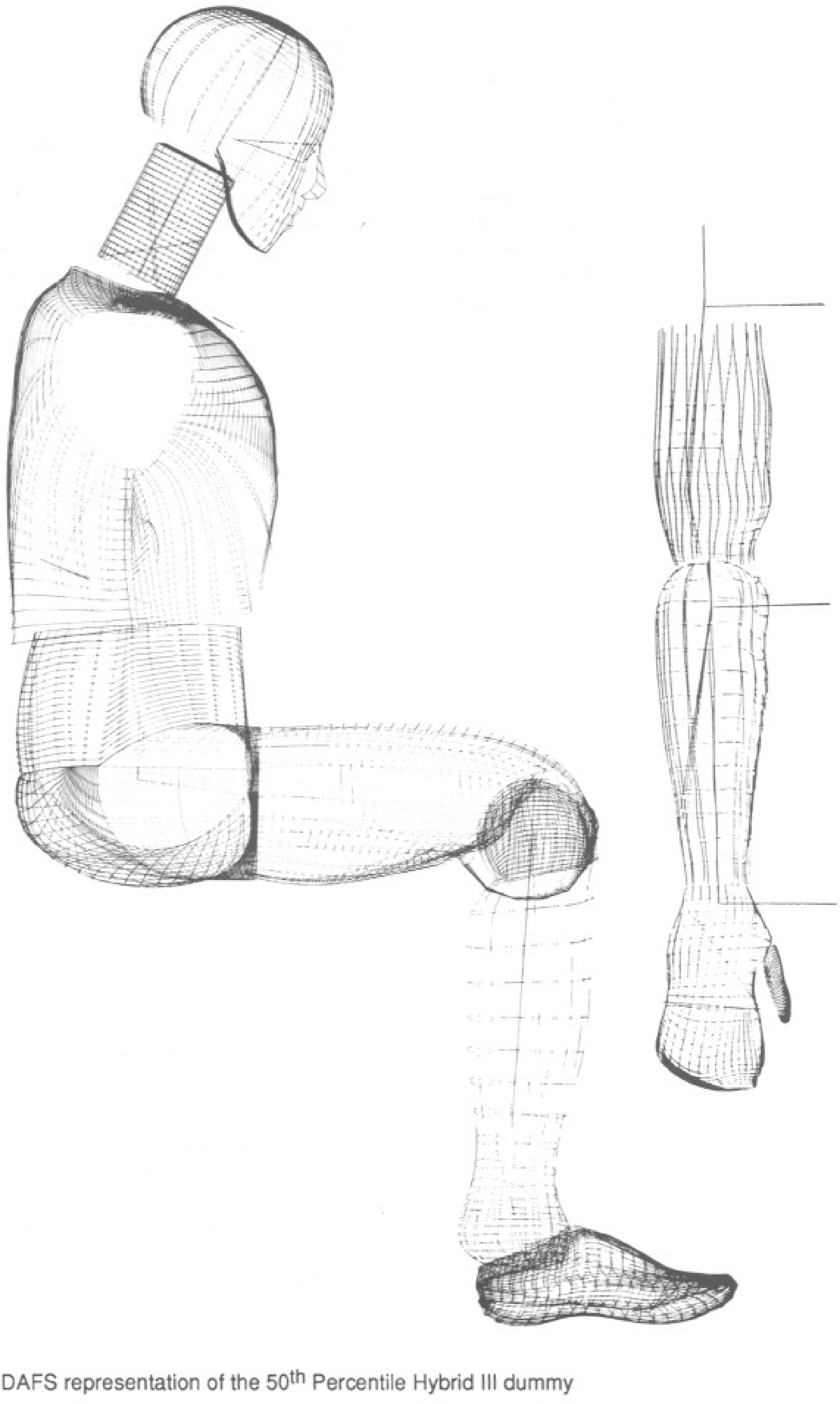
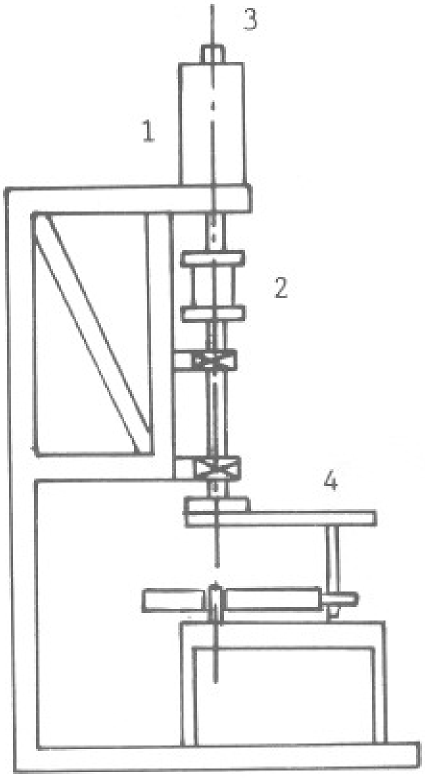


Fig. 3 A VDAFS representation of the 50th Percentile Hybrid III dummy

STATIC JOINT PROPERTIES – Most of the pin- and ball- and socket joints in the dummy were measured with a special developed apparatus, illustrated in Fig. 4. The device consists of a horizontal non-moving platform and a rotating unit powered by a hydraulic device (1). This rotating unit can rotate about a vertical rotation axis oriented perpendicular to the platform. This axis is oriented vertically in order to minimize gravity effects. For a joint under investigation only the two adjoining segments are used in this measurement. One segment is rigidly mounted in such a way that the rotation axis of the measuring device is aligned with the joint centre (or joint axis) of the joint).



1 = hydraulic motor
2 = torque transducer
3 = potentiometer
4 = lever

Fig. 4 Test set-up for the static joint measurements

The other joint segment is moved by a lever(4) parallel to the rotation axis of the measuring device and connected to the rotating unit. The torque applied by the rotating unit is measured with a torque transducer(2), while the rotation angle is measured with a rotational potentiometer(3). The guidance of the rotating unit is such that the friction is very small.

The apparatus is manually controlled and the rotational motion of the rotation unit stops if the applied torque is close to a specified value (first joint stop). Then the motion is reversed until the second joint stop is detected. Finally the rotation is reversed until the initial starting position is reached again. A typical result of this test is shown in Fig. 5 for the flexion-extension motion in the shoulder.

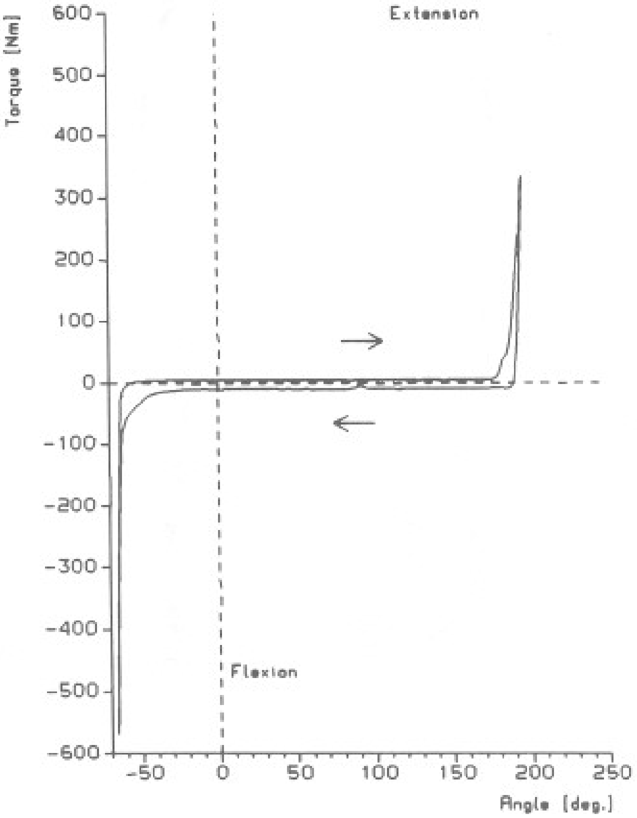


Fig. 5 Static shoulder characteristics: flexion-extension.

For the neck and spine both static bending and torsion tests are carried out. Fig. 6 illustrates the spine frontal bending test. The loads in these tests were applied manually. Neck and spine rotations and displacements as well as external loads have been recorded. Tests have been conducted in the following directions.

- flexion - extension (forward/backward)
- oblique flexion - extension (45° forward/backward)
- lateral flexion (sideward right/left)
- torsion

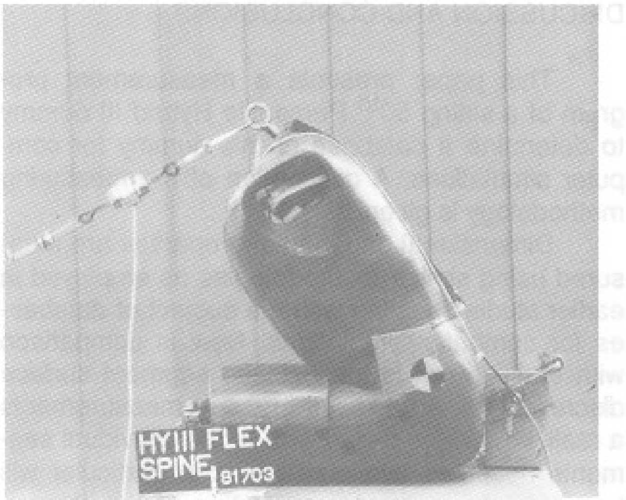


Fig. 6 Set-up of spine bending test.

DYNAMIC JOINT PROPERTIES – In addition to the static tests for some of the joints also dynamic tests were carried out. The dynamic bending stiffness of the neck was measured in a test set-up similar to the standard Hybrid III neck pendulum calibration test. Selected impact velocities are 2, 4 and 6 m/s. The loads in the head-neck joint are measured by a six-axis load cell. The movement of the head is recorded on high speed-film. The neck is mounted to the pendulum. A wooden symmetrical head instrumented with a triaxial accelerometer is mounted to the neck, mainly since the centre of gravity of the original dummy head is positioned 13 mm in front of the z-axis of the neck which would result in extra torsion of the neck during oblique and lateral tests.

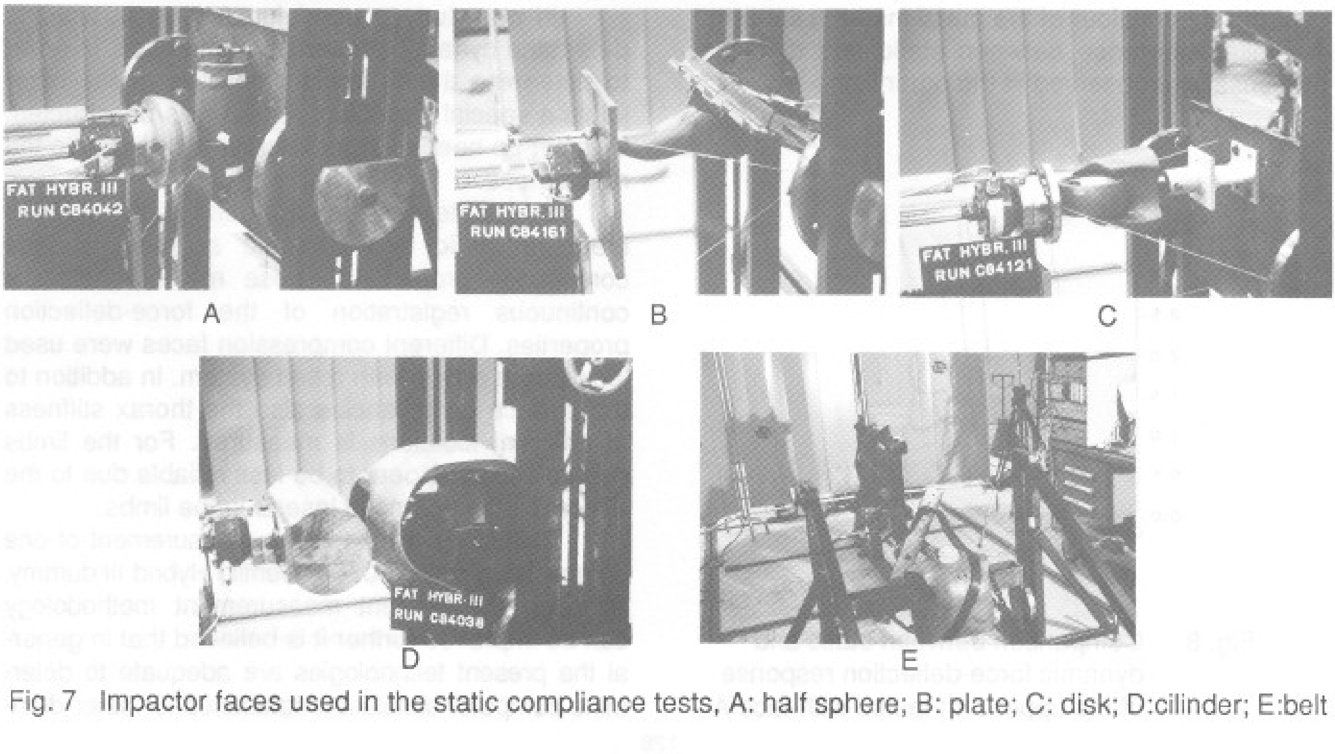
For the other joints in the dummy a similar test set-up as used for the neck was developed. Due to resonances observed during the tests, preliminary results obtained with this test unit couldn't be applied yet for the present database development.

SURFACE COMPLIANCE

An important capability of a Crash Victim Simulation model is the simulation of the contact interaction between dummy segments with other dummy segments and/or the environment. For a correct prediction of this response the surface compliance is required which is dependent on the skin covering thickness and density as well as the compliance of the underlying structure like e.g. the ribcage. Measurements have been conducted with several penetrating surfaces and for different test locations on the dummy surface. Static as well as dynamic tests have been performed.

STATIC SURFACE COMPLIANCE – The static force deflection characteristics are determined using a manual controlled, electrically powered piston. The force applied by this piston is measured by a loadcell between the piston and the compression face. The deflection of the segment surface is equivalent to the displacement of the piston which is measured by a potentiometer.

The compression faces used in this study, which are illustrated in Fig. 7 are connected to the piston. In case of the seat-belt "compression face" a slightly different test set-up is used. Both end points of the belt are connected to a steel rod. This rod is attached to the piston. In case of the thorax



A B C

D E

Fig. 7 Impactor faces used in the static compliance tests, A: half sphere; B: plate; C: disk; D:cilinder; E:belt

belt compression test the deflection of the sternum is measured with the standard transducer of the thorax. For the abdomen and lower torso belt compression test a string potentiometer is attached to the middle of the belt in order to record the deflection.

The number of loading locations is dependent on the segment to be tested. For the head, for instance, seven different locations have been selected. Dependent on the segment one or more impactor faces were used. In total more than 60 tests have been conducted.

DYNAMIC SURFACE COMPLIANCE – The dynamic force-deflection characteristics are measured with a spring loaded guided impactor. Tests are conducted with two impactor faces i.e. face A (a rigid half sphere) and face C (a flat rigid disk) as presented in Fig. 7. The impactor mass is 6.875 kg (face A) and 9.15 kg (face B). Impactor velocities were varied between 1 and 5.5 m/s. No higher velocities or impactor masses were selected in order to avoid damage of the tested dummy segments. The impactor face is provided with an uniaxial accelerometer. The impactor displacement is measured with a linear potentiometer.

For most of the segment locations for which dynamic measurements were carried out, also static test results were available. This allows a direct comparison between the dynamic and static compliance of a dummy surface. Fig. 8 shows typical results for tests on the upper arm. In these tests face A was used in combination with a flat plate support. A large difference can be observed here between static and the (high velocity) dynamic response which could be explained by the dynamical behaviour of the metal insert in the arm. A similar difference between static and dynamic response was observed in the other limbs.

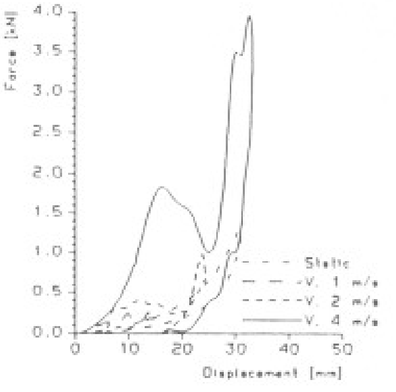


Fig. 8 Comparison between static and dynamic force-deflection response of the upper arm tested with face A

DISCUSSION AND CONCLUSIONS

This paper presents a measurement program of a sitting 50th Percentile Hybrid III dummy to determine a database of this dummy for computer simulations. A description of the measuring methodology is given.

Dimensional and inertial properties are measured using similar methodologies as employed in earlier studies dealing with the subject of databases for computer simulations. New in comparison with earlier work is the detailed segment surface discretisation. As a result of these measurements a realistic surface description of the individual segments becomes available which in particular will be useful for computer animation of the dummy model. As shown in the present study this discretisation allows the selection of the contact ellipsoid parameters to be carried out in a more accurate way. In future new methods for contact calculations might become available in occupant simulation models which directly employ the surface descriptions in the contact algorithms.

Joint resistive properties are measured using static and dynamic test set-ups. For the static properties of joints with a single centre of rotation a special joint measuring device has been developed where the external torque is exerted on the joint segment by a hydraulic powered unit. The external applied torque as function of the joint rotation is automatically recorded in this test set-up, allowing a fast and accurate registration of the static joint properties. The advantage of this method is that a relative large torque can be applied in a very accurate way.

In our study a pendulum set-up is used to determine dynamic properties of the neck. In order to determine the dynamic properties of the other joints a special pendulum set-up was constructed. This set-up needs further improvements due to the resonances.

Special test set-ups are used in this study to measure static and dynamic segment surface compliance properties. These methods allow a continuous registration of the force-deflection properties. Different compression faces were used including a set-up with a belt system. In addition to the surface compliancies also the thorax stiffness at different locations is measured. For the limbs dynamic tests appear to be less reliable due to the dynamic effect of metal inserts in the limbs.

This study relates to the measurement of one dummy i.e. a sitting 50th percentile Hybrid III dummy. Although the present measurement methodology can be improved further it is believed that in general the present technologies are adequate to determine computer simulation databases for other dummies like the present side impact dummies (EUROSID, SID and BIOSID), different sized frontal crash dummies (5th and 95th percentile Hybrid III) and various sized child dummies.

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