THE BIOFIDELITY OF THE EUROSID NECK

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ABSTRACT

This paper deals with the EUROSID neck performance in terms of biofidelity in both lateral and frontal impact directions. The human reference data base comprises the results from volunteer sled tests conducted by the Naval Biodynamics Laboratory in New Orleans.
The EUROSID neck evaluation, according to these data, was performed on the basis of whole dummy sled tests -for lateral direction- and pendulum tests-for frontal direction-. In earlier APR publication (1), it was shown that EUROSID neck responses in lateral direction are rather satisfactory. This conclusion was however based on the basis of the first formulation of neck requirements as proposed by ISO/TC22/SC12/WG5 (2). Recently, these requirements have been completed (3). According to this new formulation, an evaluation of EUROSID neck performance is proposed here.
In order to illustrate the neck behaviour under frontal sollicitations a dozen frontal pendulum tests involving the EUROSID head/neck assembly were carried out by the Vehicle Research and Test Center (4). Results of one of the most severe pendulum test are presented and compared to the corridors generated at TNO (4) using a mathematical simulation of human volunteer behaviour.

1. INTRODUCTION

A first attempt to develop a dummy neck with reliable responses in lateral direction was made by the Association Peugeot-Renault in 1982. This first version was designed to be used on the APROD dummy (5) and built on the basis of human data obtained from low severity sled tests (6). The evaluation of the biofidelity of this neck was performed within the framework of the EEC Comparison Testing Programme in 1982 (7). Following the conclusion of this programme, a new neck prototype has been redesigned and tested. Results showed a much better durability and a satisfactory behaviour of the neck (2).

This prototype was chosen for the EUROPEAN SIDE IMPACT DUMMY EUROSID and evaluated in the framework of an extensive testing programme sponsored by the EEC in 1986, where EUROSID was subjected to a large number of experiments. In this programme, particular attention was given to the evaluation of the neck biofidelity, which comprised six sled tests involving the whole dummy. Some results of one low G-level test were already presented in earlier publication (1), where EUROSID neck responses were compared to data proposed by the ISO/TC22/SC12/WG5 (2). Data for dummy neck requirements have been recently completed by this group with additional results from nine volunteer tests (3). It is therefore necessary to evaluate the EUROSID neck behaviour according to these new requirements. This is presented in section 3 of this paper.
Even the EUROSID neck was not designed for frontal sollicitations, it appeared to be of interest, given its symetrical definition, to compare its behaviour with existing volunteer data in frontal direction. This evaluation was performed by the Vehicle Research and Test Center in East Liberty - Ohio during the beginning of 1986. The test configuration used by this laboratory is a pendulum test, which in fact requires a simple process and involves a lesser cost than a whole dummy sled test. According to a pendulum acceleration pulse defined on the basis of frontal sled tests involving volunteer (9) the EUROSID head-neck assembly was subjected to about eleven frontal pendulum tests, with at least six tests reached maximum velocities and decelerations over 7 m/s and 15 g respectively. Results from one test are given in section 4 together with corridors consisting of head accelerations and excursions.

2. THE EUROSID NECK DESIGN

The EUROSID neck design comprises a central section made of a special 70-shores rubber that links two interfaces, each consisting of two metal disks with rubber buffers inside. The metal disks being linked by means of a screwed half-sphere, which constitutes a pivot as shown in Figure 1. The several neck components were designed in order to reproduce a correct head motion observed with human sled tests in lateral direction, i. e. :

- a pure translation in the plane of impact during the first phase of movement,
- a rotational movement composed by a lateral flexion and a torsion in the final phase of motion.

Figure 2 illustrates this type of head motion.

3. EUROSID NECK BIOFIDELITY IN LATERAL DIRECTION

Six sled tests involving the whole EUROSID dummy were performed as a part of EEVC evaluation programme (1). One test, number EURO 2, was selected for comparison with volunteer data.
As indicated previously, this dummy test will be evaluated with respect to new data available from ISO group (3), which comprise the following type of requirements :

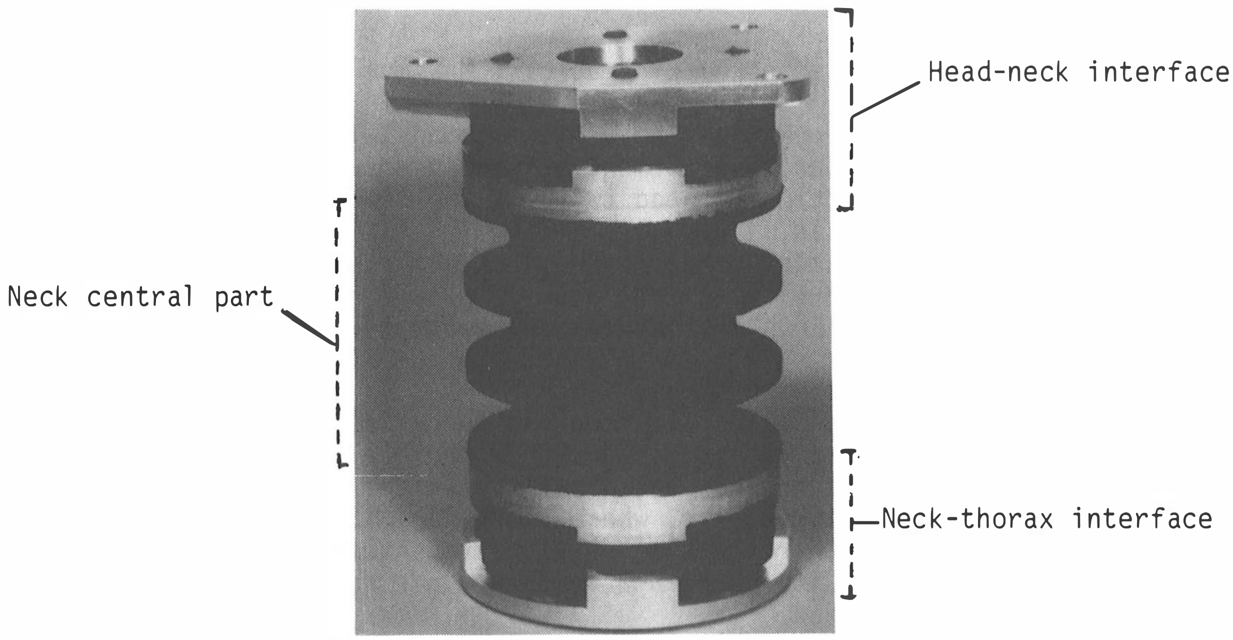

Figure 1 : EUROSID NECK DESIGN

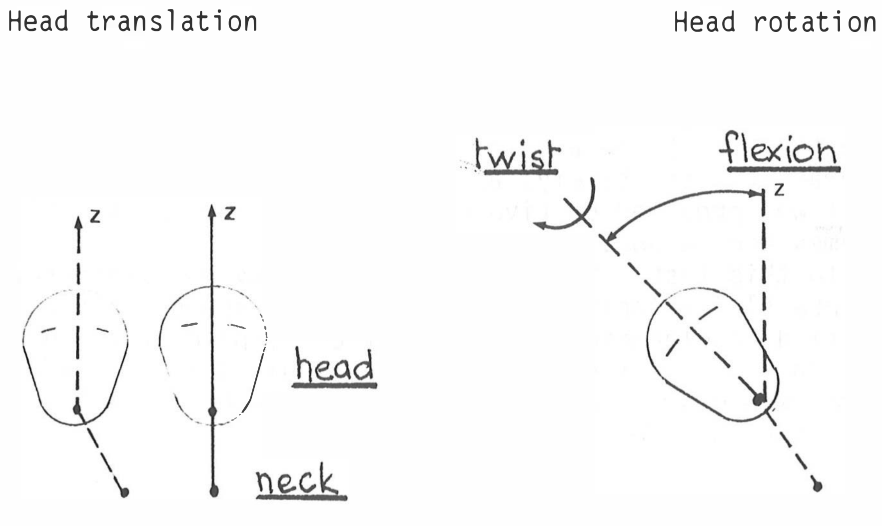

Figure 2 A

Figure 2 B

Figure 2 : HEAD MOTION AS OBSERVED IN HUMAN LATERAL SLED TESTS

- T1 (first thoracic vertebra) kinematics : Maximum horizontal displacement and acceleration,
- Head angular motion : Maximum head flexion and twist. The head flexion is defined as the angular displacement of the inferior-superior axis of the head relative to vertical ; head twist is the head rotation about its inferior-superior axis,
- Head linear displacement : Maximum head c. g. displacements relative to T1 in horizontal and vertical directions,
- Head acceleration : Frontal, lateral and vertical accelerations of the head c. g.,
- Time of maximum head excursion.

For each kinematical parameter, a required range for a dummy neck response is specified. The new formulation differs from the previous one (2) mainly because the requirements are now based on 9 volunteer tests results, i. e. with nine different subjects, whereas previous ISO recommendations have been proposed with respect to only one volunteer test.
In the following, results of EURO 2 tests are presented.

3.1. TESTS SET-UP

The dummy was placed on the seat in the upright sitting position. The seat was fixed to the sled similar to the one used by Ewing* (6) in a sideward position. A wooden side board was fixed vertically to the seat in order to limit the dummy translationnal motion. To secure the dummy to the seat, a restraint system comprising shoulder straps, a lap belt and a nylon belt around the chest was used. Prior to the test, the anterior-posterior axis of the dummy's head was approximatly horizontal.
The dummy was instrumented with accelerometers located in the head and the spine respectively at T1 and T4. For the computation of head relative motion with respect to T1, three aluminium targets were fixed onto the head skull and neck bracket respectively, as shown in Figure 3. Cinematographic coverage of the test was provided by five high speed cameras with a filming frequency of 500 frames per second.
According to this test set-up, the EUROSID dummy was subjected to a test where maximum sled velocity and acceleration reached 6 m/s and 7 G respectively. The sled acceleration-time history corresponding to EURO 2 test is plotted in Figure 4 together with the required pulse. Except for the first 25 ms, where small deviations occured, EURO 2 acceleration pulse lies within the corridor.

* In the test set-up used by APR, the sled was decelerated by means of polyurethane tubes after a specified displacement in order to achieve the 6 m/s initial velocity.

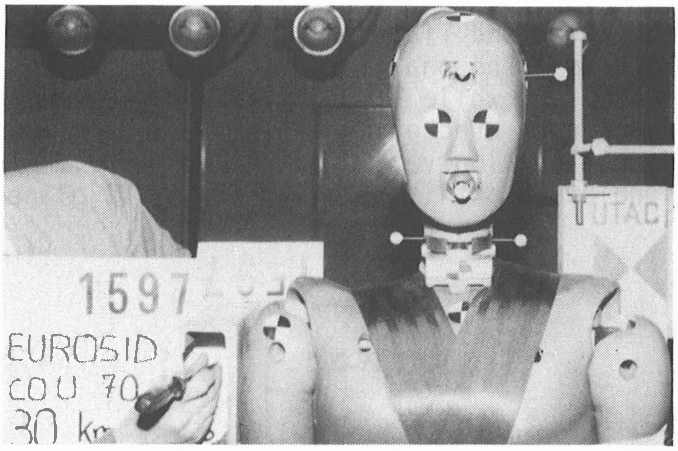

Figure 3 : HEAD INSTRUMENTATION USED FOR EURO 2 SLED TEST

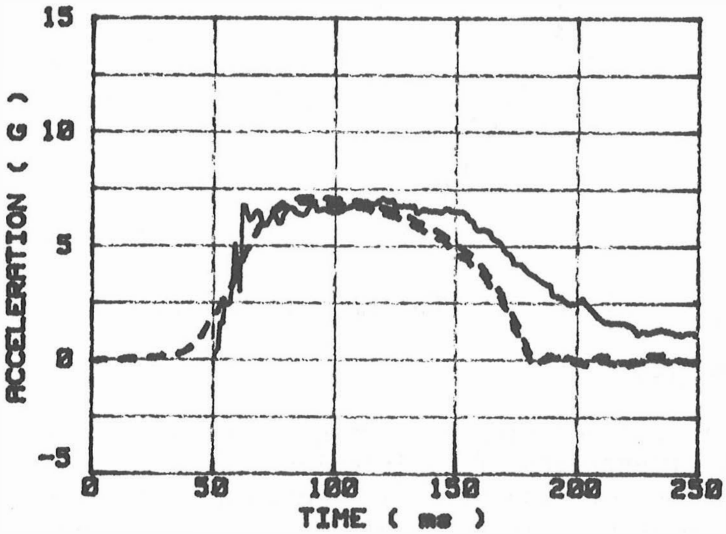

Figure 4 : SLED ACCELERATION-TIME HISTORY FROM EURO 2 TEST COMPARED WITH ACCELERATION-TIME CORRIDOR OBTAINED FROM VOLUNTER TESTS (DASHED LINES)

Head and T1 coordinate systems

The orientation of head and T1 coordinate systems is indicated in Figure 5. Both are right-handed orthogonal systems. Head coordinate system of EUROSID is located at the c. g., while T1 coordinate system is fixed near the base of the neck and on the neck bracket. Head and T1 y axes are paralled to the direction of sled acceleration vector but opposite to the sled displacement direction. The plane of impact is here defined by YZ plane.

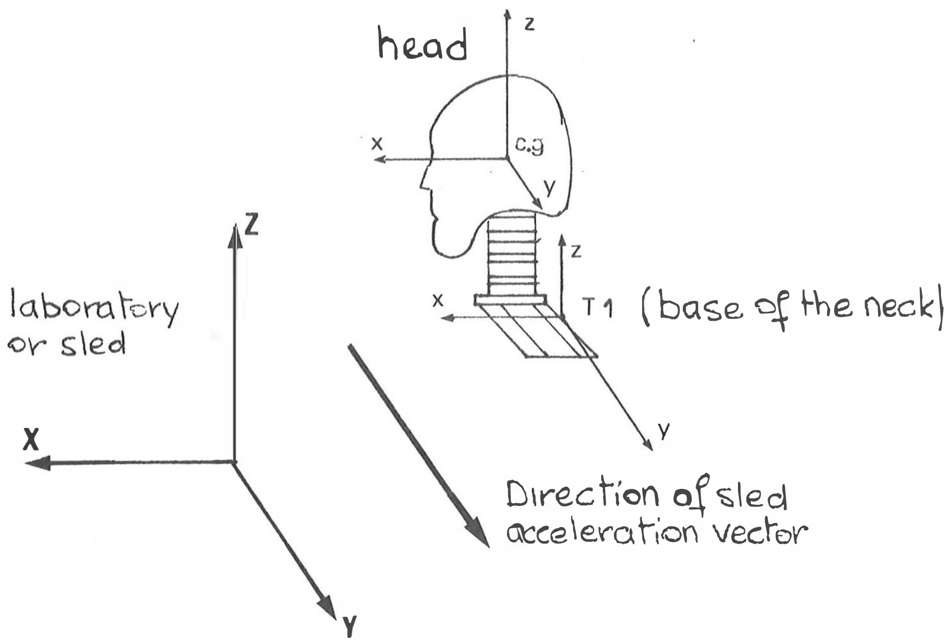

Figure 5 : HEAD AND T1 COORDINATE SYSTEMS

3.2. T1 KINEMATICS

The trajectory of T1-origine with respect to the sled is illustrated in Figure 6 with the orientation of T1 inferior-superior axis. It appears that for EURO 2 tests, the rotation of T1 is negligible, the maximum angle reached being about 4 degrees. Also negligible are displacements of T1-origine along x and z axis respectively when compared to the horizontal displacement. The maximum magnitude of this displacement relative to the sled is 46 mm which corresponds to lower limit of the required range, i. e. between 46 mm and 63mm (3). One can also observed that, as shown in Figure 6, the T1 trajectory is represented by a pure translation in the impact plane.

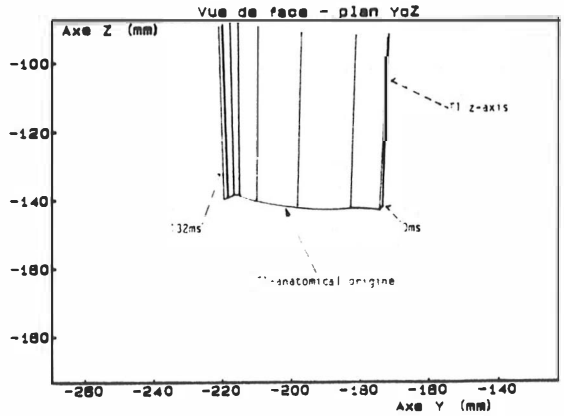

Figure 6 : T1-KINEMATICS RELATIVE TO THE SLED OBTAINED FROM EURO 2 TEST

In Figure 7 are plotted horizontal acceleration-time histories for T1 and T4 respectively. Both curves have a major peak followed by several peaks of lesser amplitude. Maximum magnitudes reached by the major and the secondary peak are 13 G and 7.54 G for T1 and 15.5 G and 8 G for T4 respectively. It can be emphasized that such shape of T1 acceleration curve is also observed with volunteers (6).
Figure 8 illustrates T1 acceleration-time history for EURO 2 test with T1 acceleration corridor defined from volunteer tests (3). It follows that EURO 2 T1 responses meet both corridor shape and peak magnitude requirements.

3.3. HEAD KINEMATICS

During the first part of motion, the head in test EURO 2 describes a pure translation in the plane of impact, with the displacements of head c. g. along x and z axis almost negligible. The duration of this first motion is about 42 ms. Then the head movement becomes threedimenssional with the c.g describing a circular arc and the head rotating about its antero-posterior axis and its inferior-superior axis respectively.
An illustration of head motion relative to T1 in test EURO 2 is proposed in Figure 9. This graphical output, where the head is represented by a cube, is generated by a computer programme called Anafilm-3D.
This cubic representation of the head well describes angular and linear head displacements.

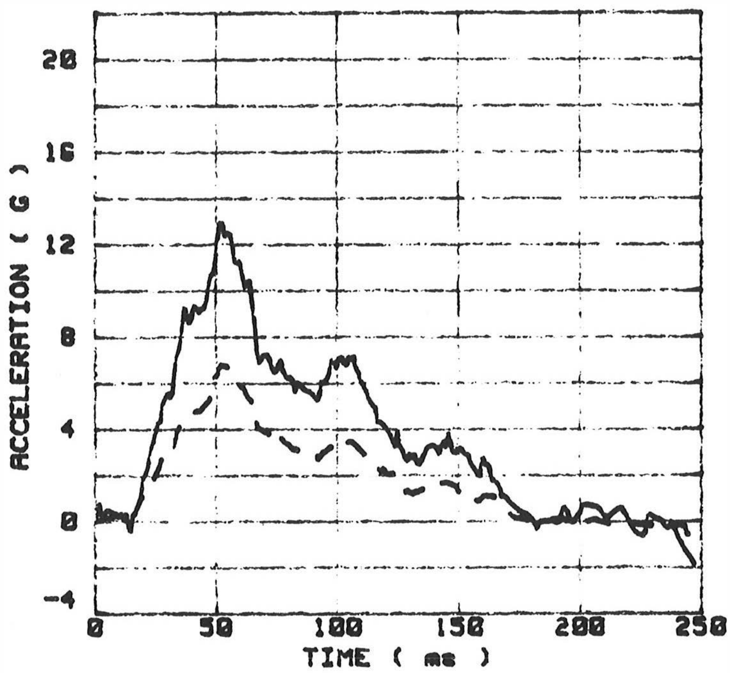

Figure 7 : HORIZONTAL ACCELERATION-TIME HISTORY FOR T1 ---- AND T4 ——
OBTAINED FROM EURO 2 TEST

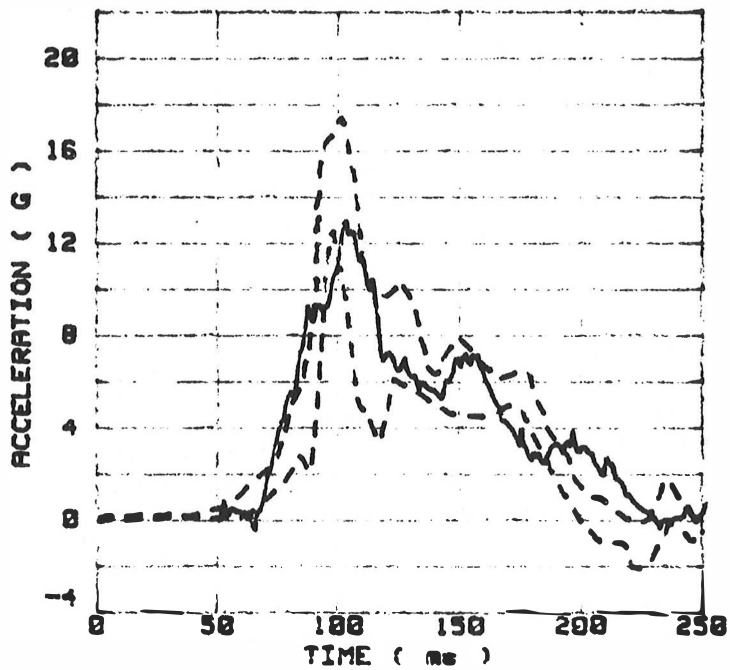

Figure 8 : COMPARISON BETWEEN T1 HORIZONTAL ACCELERATION-TIME HISTORY IN TEST EURO 2 AND T1-CORRIDOR OBTAINED FROM VOLUNTEERS TESTS (DASHED LINES)

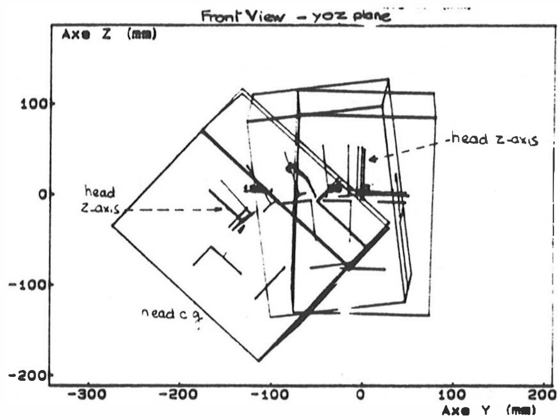

Figure 9 : HEAD KINEMATICS RELATIVE TO T1 IN TEST EURO 2 GENERATED BY ANAFILM-3D PROGRAMME

More simple representation of head motion in EURO 2 test is proposed in Figure 10, where the orientation of z-axix indicates head flexion. The peak magnitude reached by head c. g. lateral and vertical displacements relative to T1 are 134 mm and 31.5 mm respectively.
Also shown in Figure 10 are the required range from volunteer tests. While head c. g. lateral displacement is within the 130-162 mm range, the head c. g. vertical displacement is about 50 percent lesser than the lower volunteer limit i. e. 64 mm (3). Head rotations reached 50 degrees for the flexion and 19 degrees for the twist respectively. We can note that head flexion angle in EURO 2 test is much closer to volunteer data (44 and 59 degrees) than head torsion (32 and 45 degrees).
It should be noted that both linear and angular peak displacements of the head in EURO 2 test take place approximatly at the same time, i. e. 120 ms as shown in Figure 10. Thus, its corresponds to the time of maximum head excursion.
Due to the difference in the definition of the time zero between NBDL and APR (6), (10) the time of maximum head excursion in EURO 2 test has to be shifted of about 50 ms, which give 170 ms. This value is in accordance with volunteer data (3), which require a time range of 159 ms to 175 ms.

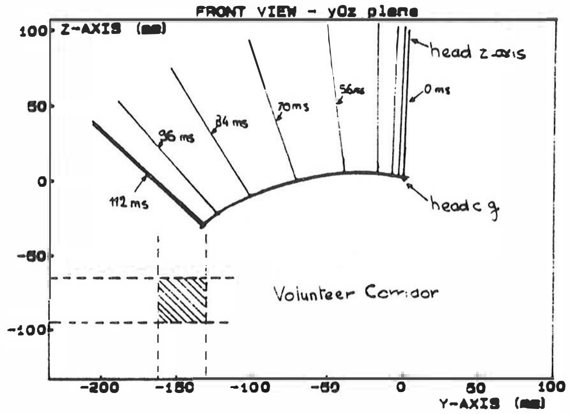

Figure 10 : HEAD C. G. TRAJECTORY WITH THE ORIENTATION OF HEAD Z-AXIS IN THE IMPACT PLANE OBTAINED FROM EURO 2 TEST

In Figure 11 a and b are respectively compared y and z components of the head c. g. acceleration in EURO 2 test with volunteer corridors.
The maximum head c. g. accelerations obtained are 9 G in lateral and 6 G in vertical direction. The lateral component in EURO 2 test being close to 8 G ; 11 G volunteer range, while the vertical component is of 2 G lesser than the required range.

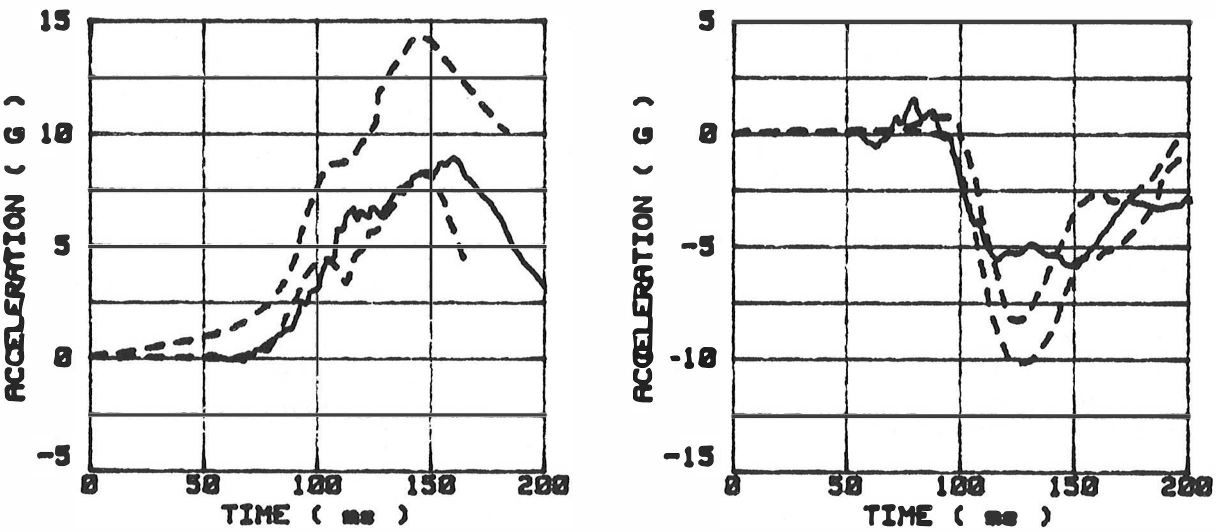

Figure 11 : HEAD ACCELERATION-TIME HISTORIES ALONG Y (FIGURE 11 A) AND Z (FIGURE 11 B) DIRECTION RESPECTIVELY IN TEST EURO 2 COMPARED WITH VOLUNTEER DATA (DASHED LINES)

4. EUROSID NECK BIOFIDELITY IN FRONTAL DIRECTION

As part of a research programme conducted at VRTC (4) several already existing necks as well as new improved neck designs were tested in frontal direction using a pendulum test configuration. In the section, pendulum input conditions and the specifications for a dummy neck evaluation in frontal direction are proposed. Results from one of the most severe pendulum test involving EUROSID head-neck assembly are presented with respect to the specifications (4).

4.1. PENDULUM TEST CONDITIONS

Dummy neck evaluation can be performed using a sled configuration, which reproduces input conditions used by NBDL in volunteer tests. Such a test configuration involves, however, a complicated process and a high cost. On the contrary, a pendulum configuration is more simple and requires a basic instrumention and thus a shorter time for data processing. The pendulum pulse used in the standard Part 572 calibration differs from the most severe NBDL volunteer tests due to the effect of angular velocity of the pendulum and to the maximum impact velocity which is limited to 7 m/s and quite inferior to the maximum of 17 m/s obtained with volunteer tests.
To compensate this lower impact velocity, a pendulum pulse was created by HOEN and WISMAN (11) with a larger rate of onset and peak acceleration magnitude than in volunteer tests. Using a judicious combination of impact materials a pulse was defined with a lenght reproducing the full rise up to the maximum acceleration, as shown in Figure 12.

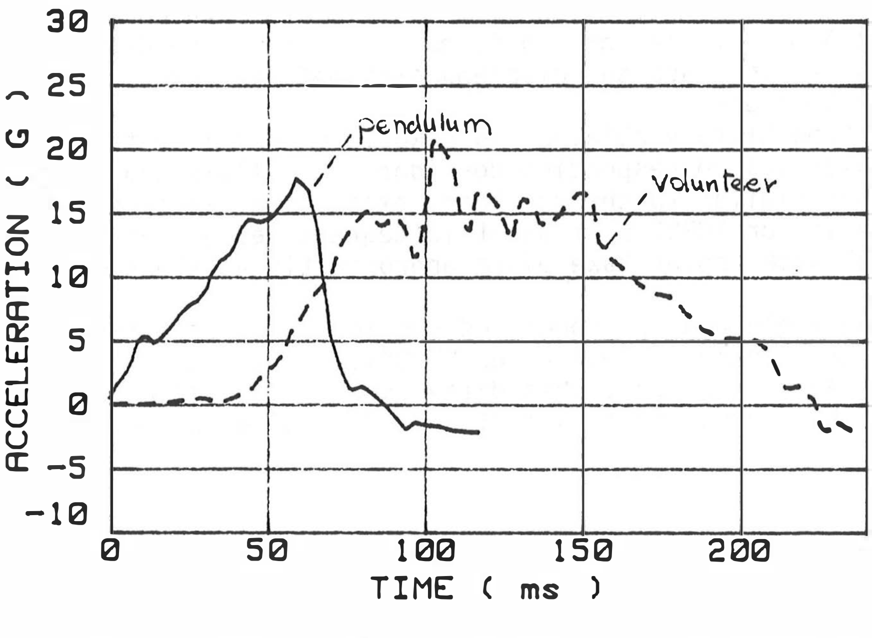

Figure 12 : PENDULUM PULSE COMPARED WITH VOLUNTEER T1 ACCELERATION-TIME HISTORY

4.2. NECK PERFORMANCE REQUIREMENTS

Mathematical simulations were conducted by TNO (11) with the pendulum pulse shown in Figure 12 and using a two pivot neck model. Bases on results of these simulations, a set of kinematical requirements were defined, including the following corridors :

- Head c. g. acceleration-time corridor for x (frontal) and z (vertical) component respectively,
- Head angle-time corridor,
- ·Neck angle-time corridor.

In the following section, EUROSID neck behaviour as regards these corridor is discussed.

4.3. EUROSID NECK TEST RESULTS

About eleven frontal pendulum tests were carried out by VRTC using the EUROSID head-neck assembly. In six of these tests, input conditions were similar in severity to the most violent volunteer test. Maximum impact velocity and deceleration reached were 7 m/s and 15 g respectively. Under such conditions, the neck showed good durability. Results from one pendulum test are presented in the following.

In figures 13 and 14 are plotted EUROSID head acceleration-time histories along x and z axis respectively with the corresponding corridors. The vertical acceleration component in EUROSID test shows some differences with the corridor, but the shape of its curve is almost similar to that of the corridor.

The rate of onset of EUROSID head longitudinal component is higher than that of the corridor as shown in Figure 14. One can observe that this EUROSID head response is characterised by three succesive peaks which take place during the first 100 ms ; variations in terms of acceleration drop between these peaks appear to increase the discrepancies between EUROSID head response and that of the corridor.

Neck angle-time history obtained in EUROSID pendulum test is compared in Figure 15 with its corresponding corridor. It follows that EUROSID neck angle is reasonably similar to the corridor, except for difference in peak magnitude, which is for EUROSID of about 18 degrees lesser. Both corridor and EUROSID peak neck angles take place approximatly at the same time, i. e. 100 ms.

EUROSID head angle and the specified corridor are respectively plotted in Figure 16. Head angle variation for EUROSID appears to be greater than that of the head angle corridor. This difference in variation may suggest that the EUROSID head-neck pivot is softer in frontal direction than that of the volunteer.

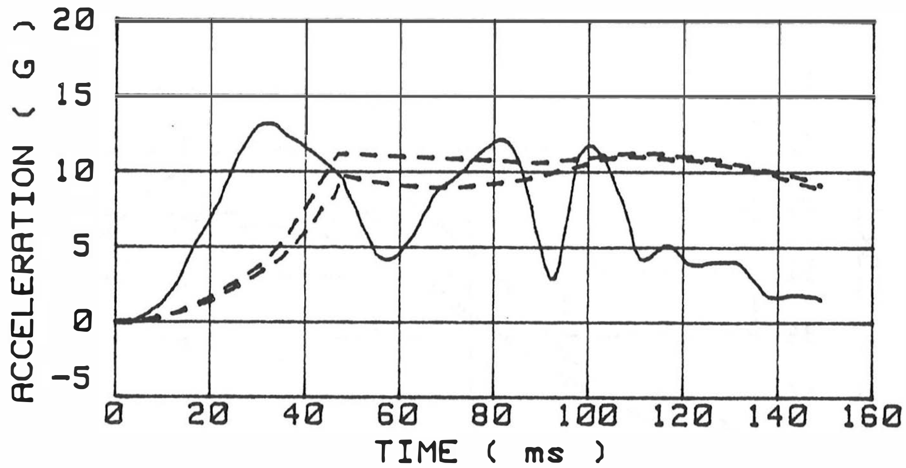

Figure 13 : FRONTAL HEAD ACCELERATION-TIME HISTORY IN EUROSID FRONTAL PENDULUM TEST COMPARED WITH A CORRIDOR GENERATED BY TNO

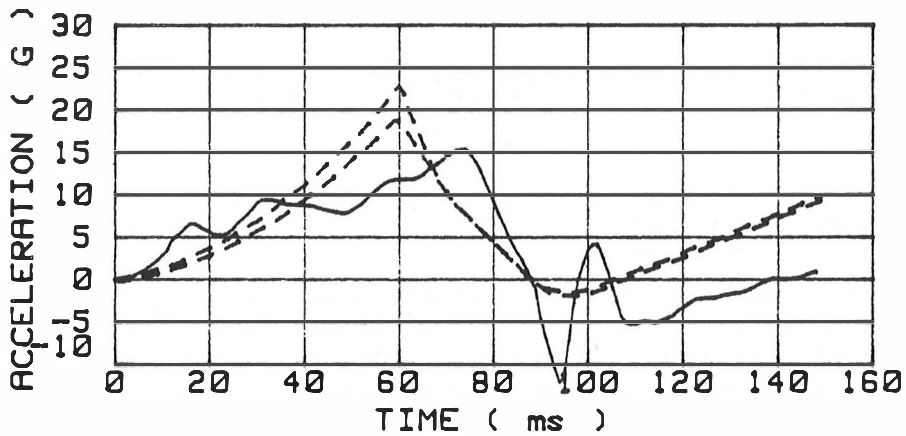

Figure 14 : VERTICAL HEAD ACCELERATION-TIME HISTORY IN EUROSID FRONTAL PENDULUM TEST COMPARED WITH A GENERATED BY TNO

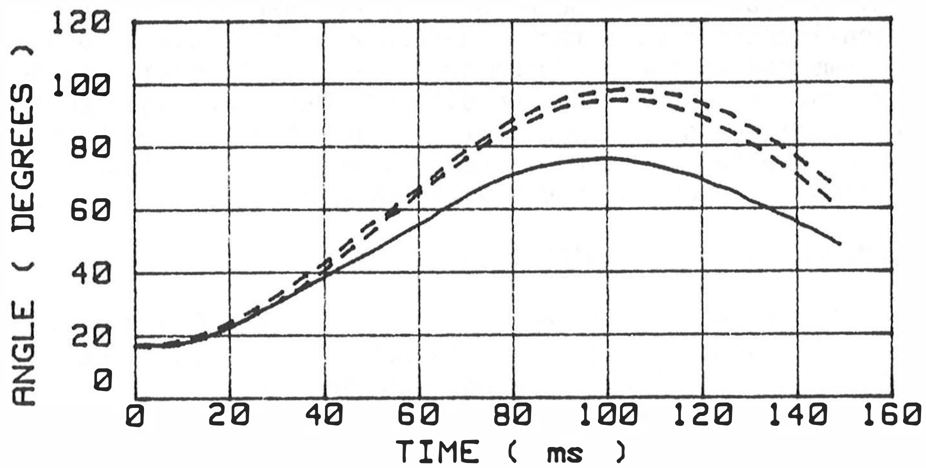

Figure 15 : NECK ANGLE-TIME HISTORY IN EUROSID FRONTAL PENDULUM TEST COMPARED WITH A CORRIDOR GENERATED BY TNO

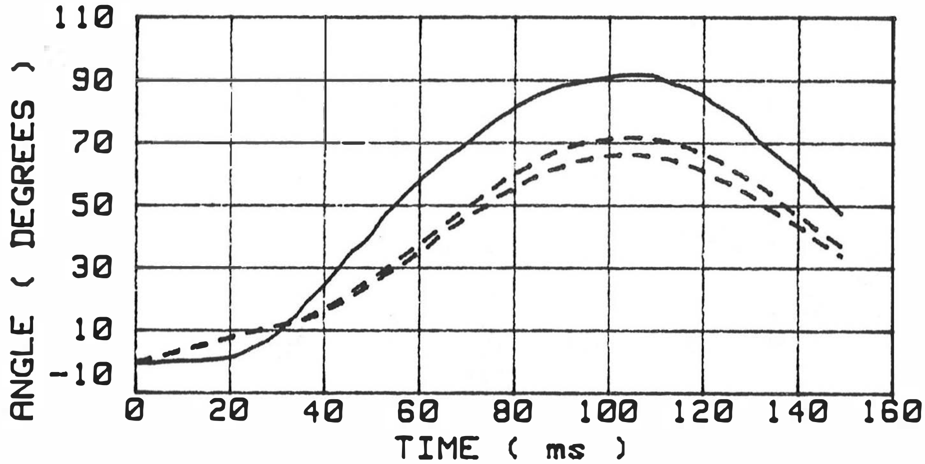

Figure 16 : HEAD ANGLE-TIME HISTORY IN EUROSID FRONTAL PENDULUM TEST COMPARED WITH A CORRIDOR GENERATED BY TNO

5. DISCUSSION - CONCLUSION

In this study, the EUROSID neck biofidelity was evaluated on the basis of volunteer data in lateral and in frontal impact directions respectively. The performance of this neck in lateral direction were evaluated by comparing results from one sled test, where the entire EUROSID was involved, with those from nine volunteer tests. The EUROSID dummy was in fact subjected to the same impact conditions as for the volunteers. For the frontal impact direction, the neck performance were evaluated in VRTC using a simple pendulum test involving the EUROSID head-neck assembly. The performance criteria and the pendulum pulse were established from volunteer tests on the basis of mathematical simulations conducted by TNO. Furthermore, the neck was tested in a sled configuration with the head-neck assembly bolted to a buck on a Hyge sled. Compared to the pendulum test, this last configuration is more closer to volunteer initial test conditions. Data dealing with sled (frontal) evaluation are given in an annex of this paper together with results from tests with the Hybrid III neck, since they were not available in time.
The conclusions to be drawn from this study can be resumed as follows :

5.1. PERFORMANCE IN LATERAL DIRECTION

5.1.1. The responses of the base (T1) of the EUROSID neck in terms of kinematics and dynamics are close to volunteer data.
5.1.2. The head relative motion with respect to T1 is similar to that observed with volunteers.

5.1.3. Lateral head flexion and head c.g lateral displacement are respectively within volunteer corridors. Head torsion and head c.g vertical displacement are however lesser than those from volunteer tests. The magnitude of the vertical displacement of the head c.g could be achieved for the EUROSID neck by decreasing the stiffness of its upper pivot, i.e of the head neck interface. The head torsion could be also increased by a translation of the neck upper pivot in the forward direction.

5.1.4. The time corresponding to the maximum head excursion is in the case of EUROSID neck in accordance with the time range defined from volunteer tests.

5.1.5. Head c.g acceleration along y and z axis respectively appear to be slightly lesser than those from volunteers. It seems, however, that higher head accelerations can be achieved with a significative change of neck design. In fact, the role of head acceleration in lateral impact is less important than that of head excursion, i.e head kinematics.

5.2. PERFORMANCE IN FRONTAL DIRECTION

Conclusions, about the EUROSID behaviour in this direction, given in the following, will be based rather on results from sled test configuration, which is much closer to volunteer experiments (see figure 1A) than the pendulum tests described in chapter 4 of this paper. Furthermore, sled tests presented in the annex are interesting because they allow a comparison with the Hybrid III neck. From these data, it follows that :

5.2.1. The EUROSID head-neck assembly experiences much greater excursions, closer to the volunteer (figure 2A) than the Hybrid III. The Hybrid III neck does not flex as much as the EUROSID neck (figure 3A) which indicates that the Hybrid III neck is too stiff (figure 4A) to reproduce the kinematic behaviour seen in the volunteer test.

5.2.2. The dynamical behaviour of the both necks in x-direction is shown in figures 5A and 6A with the volunteer data. It is easily seen that the Hybrid III neck (figure 6A) reproduced the dynamic response in the x-direction better than the EUROSID because the Hybrid III was designed for this response.

5.2.3. The difference in terms of z-direction (figures 7A and 8A) between the mechanical necks and volunteer is significant. Such differences are due to the human head-neck muscle interaction and the kinematic of the head-neck structure.

Finally, the principal task following this study remains the evaluation of EUROSID as well as Hybrid III neck biofidelity at a higher level of violence. Conclusions for the improvement of these necks could be drawn after such further evaluation.

REFERENCES

1. F. BENDJELLAL and All.
   "Presentation related to the Neck Component" ; seminar on THE EUROPEAN SID IMPACT DUMMY - EUROSID - BRUSSEL, December 11th, 1986
2. H. MERTZ
   "Lateral Neck Bending Response Requirements" - ISO/TC22/SC12/WG5 - Document Number 139, Draft 1, September 1985
3. H. MERTZ
   "Lateral Neck Bending Response Requirements" - ISO/TC22/SC12/WG5 - Document Number 139, February 1987
4. "Head-neck Simulator Development" : Progress Report - April 1985/MAY 1986 Project SRL-59 - Vehicle Research and Test Center, East Liberty, Ohio
5. B. HUE
   "Summary of the technical evolution of the APROD" Laboratory of Physiology and Biomechanics PEUGEOT/RENAULT - ISO-Document TC22/SC12/WG5/N77
6. C.L. EWING and All.
   "Dynamic response of human head and neck to -Gy impact acceleration" Proceedings of the 21st Stapp Car Crash Conference
7. PEUGEOT SA/RENAULT
   "Development of a more convenient dummy than the PART 572 one for side collisions" Final Report, EEC Biomechanics Programme - Phase III, Project F10, 1981
8. I.D. NEILLSON
   "The EUROSID side impact dummy" Proceedings of the 10th ESV Conference, OXFORD, 1985
9. J. WISMANS and CH. SPENNY
   "Head Neck response in frontal flexion" Proceedings of the 28th Stapp Car Crash Conference, 1984
10. F. BENDJELLAL and All.
    "Development of a dummy neck for lateral collisions - Part 1 : Accidentological aspect of the work - Constitution of data base" Draft, ESV 1985
11. Th. HOEN and J. WISMANS
    "Definition of a Pendulum Test for the Evaluation of Dummy Head-Neck Assemblies" Second Interim Report, Phase II, Project SRL-59, Draft, September 1985

A N N E X

RESULTS FROM OHIO STATE UNIVERSITY U.S.A.

SLED TESTS

The most promising necks, as determined by pendulum evaluation tests (Hybrid III and EUROSID), were tested on the sled. The head/neck assemblies were bolted to a buck on the HYGE sled for testing. The sled pulse which was used is similar to the Ewing pulse, and the maximum acceleration resemble the acceleration measured at T1 of a volunteer subjected to the Ewing pulse (see figure 1A).

Tests results were digitized from film. Performance of the necks were evaluated by the criteria established from volunteer tests, and they are categorized into dynamic response and kinematic behavior. The dummy head x and z accelerations at the c.g were used to compare with the volunteer head c.g acceleration for dynamic comparison. The kinematic response between the dummy and the volunteer can be based on the head/neck excursions.

Figure 2A shows the head/neck trajectories of the volunteer, and figure 3A and figure 4A are the plots of EUROSID and Hybrid III neck/head trajectories, respectively. Though the plots do not show trajectories of identical points because of the different in dimension between the two mechanical necks (the Hybrid III neck, 156 mm long is approximately 20 mm longer than the EUROSID neck)*, essential comparisons can be made. The EUROSID head/neck experiences much greater excursions, closer to the volunteer than the Hybrid III. The Hybrid III neck does not flex as much as the EUROSID neck, which indicated that the Hybrid III neck is too stiff to reproduce the kinematic behavior seen in the volunteer test. However, from the high speed film taken of the sled test, the chin of the dummy head on the EUROSID neck contacted the neck mounting brace. This contact occured because the head could not rotate enough about the occipital condyle. Nonetheless, such contact spikes can be eliminated by allowing the head to rotate more about the occipital condyle.

Plots in figure 5A through 7A show the dynamic behavior of the mechanical necks as compare with the volunteer data. It is easily seen that the Hybrid III neck reproduced the dynamic reponse in the x-direction better than the EUROSID neck because the Hybrid III was designed for this response. In the head z-acceleration, the difference between the mechanical necks and volunteer is significant. Such differences are due to the human head/neck mucle interaction and the kinematic of the head/neck structure. It should be noted that the spikes on the acceleration traces for the EUROSID neck have been eliminated between 90 and 120 msec.

*Both the Hybrid III and the EUROSID neck is mounted on the Hybrid III neck brace during the sled tests.

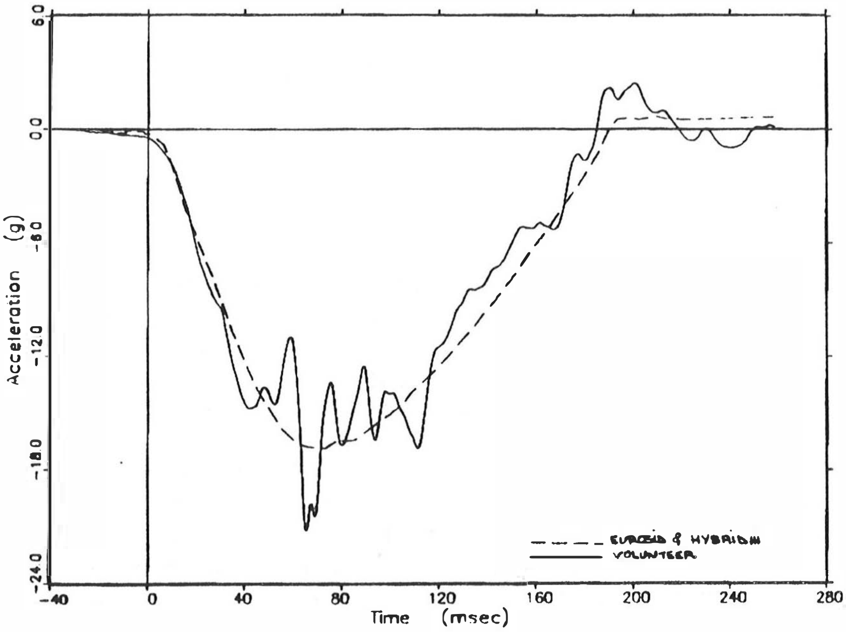

Figure 1A : T1 ACCELERATION

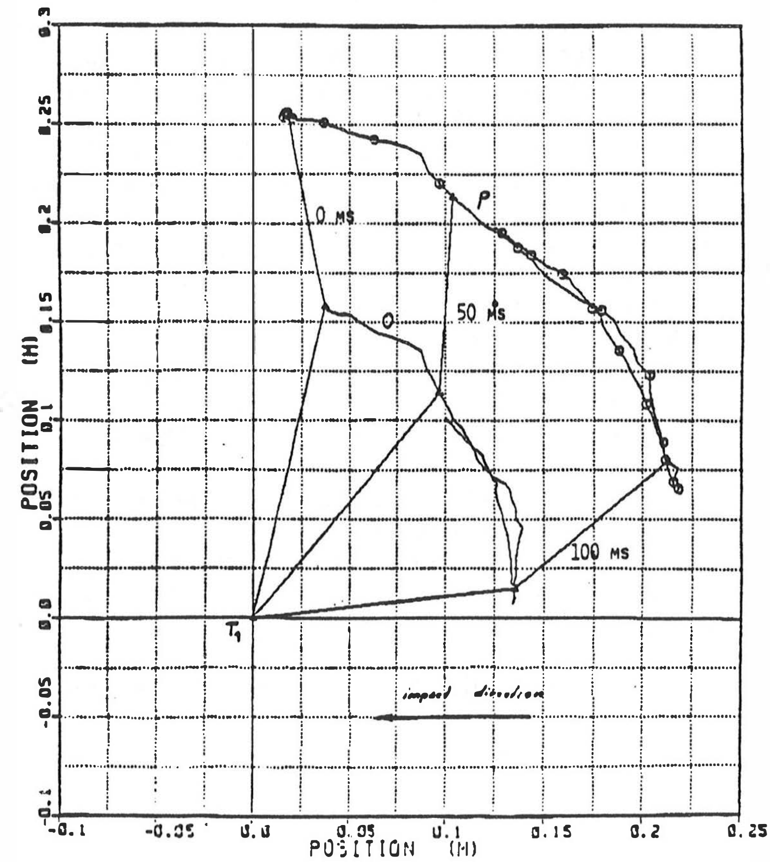

Figure 2A : VOLUNTEER HEAD/NECK TRAJECTORIES
FRONTAL VOLUNTEER TESTS LX 36/6

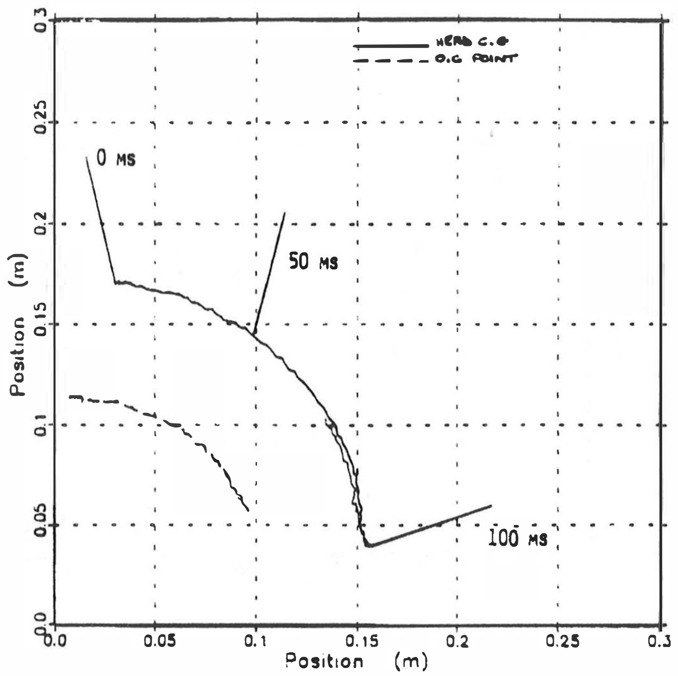

Figure 3A : EUROSID HEAD/NECK TRAJECTORIES

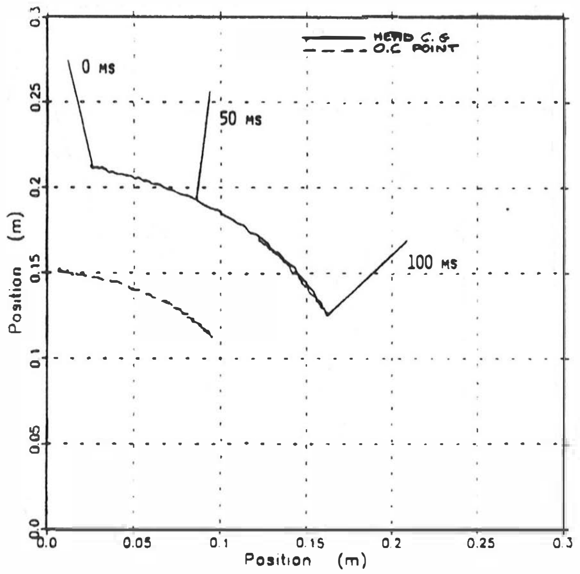

Figure 4A : HYBRID III
HEAD/NECK TRAJECTORIES

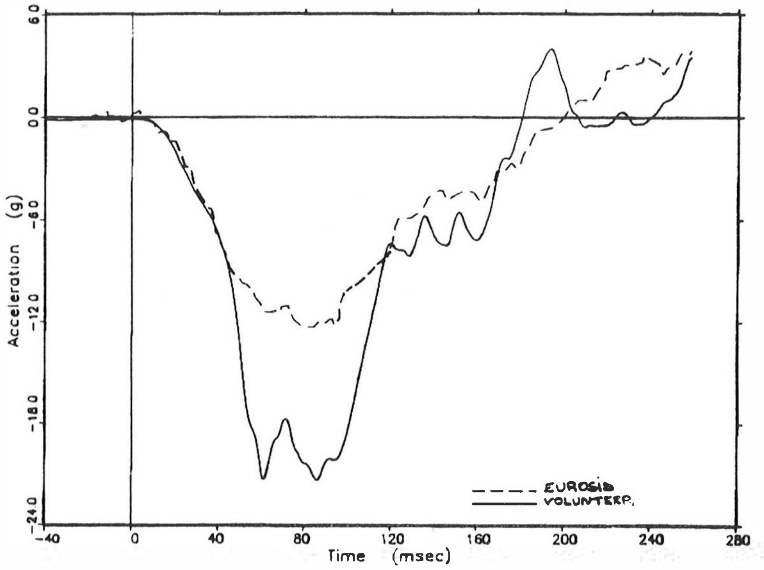

Figure 5A : EUROSID
HEAD X-ACCELERATIONS

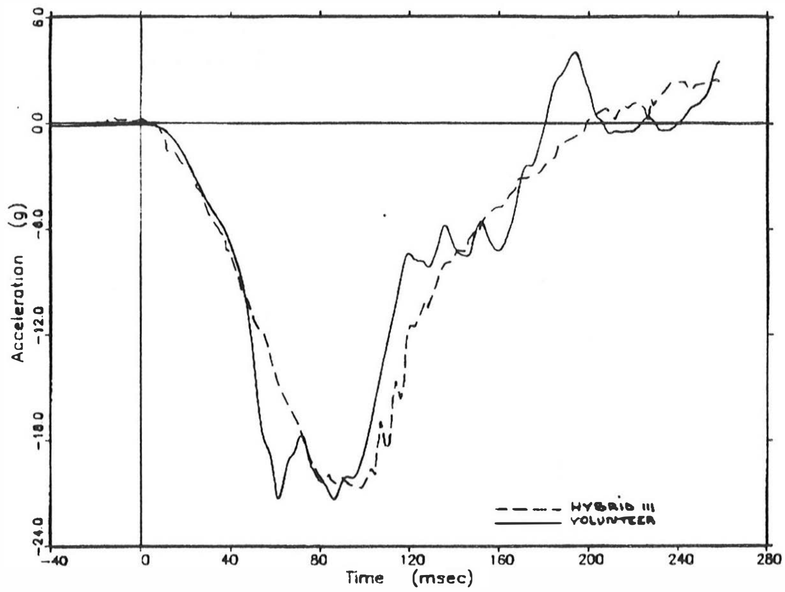

Figure 6A : HYBRID III
HEAD X-ACCELERATIONS

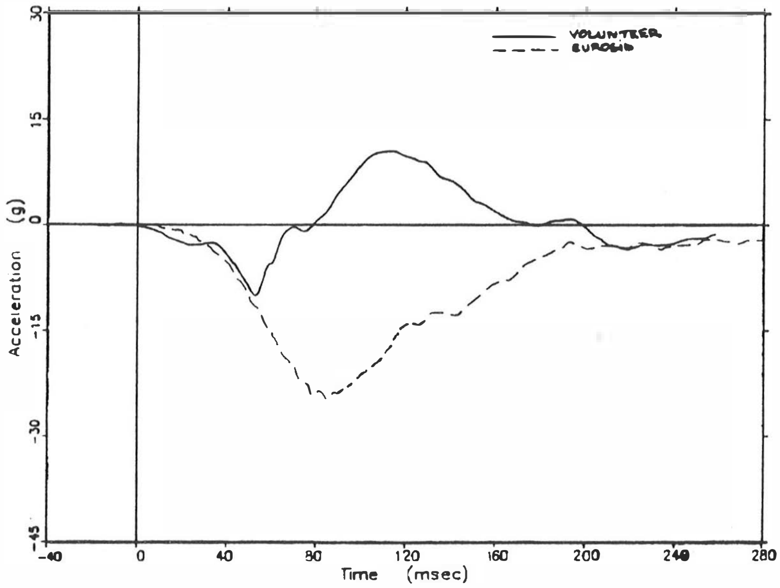

Figure 7A : EUROSID
HEAD Z-ACCELERATIONS

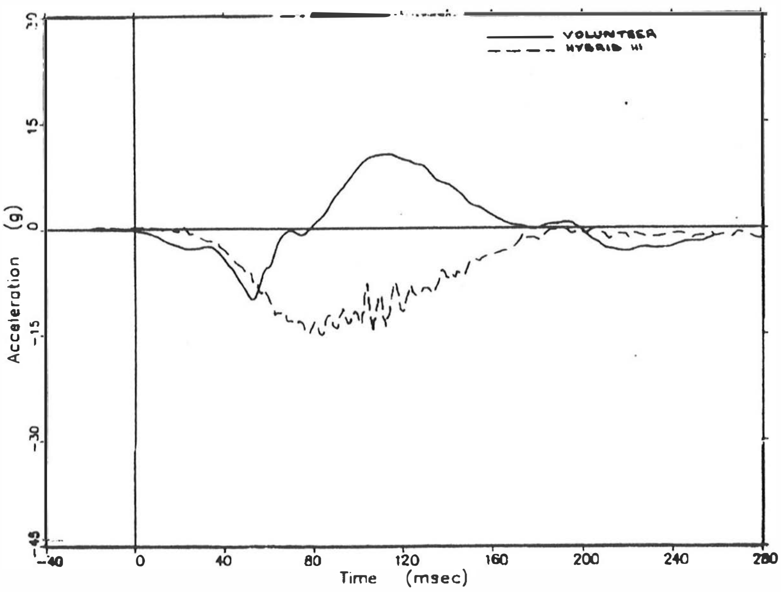

Figure 8A : HYBRID III
HEAD Z-ACCELERATIONS