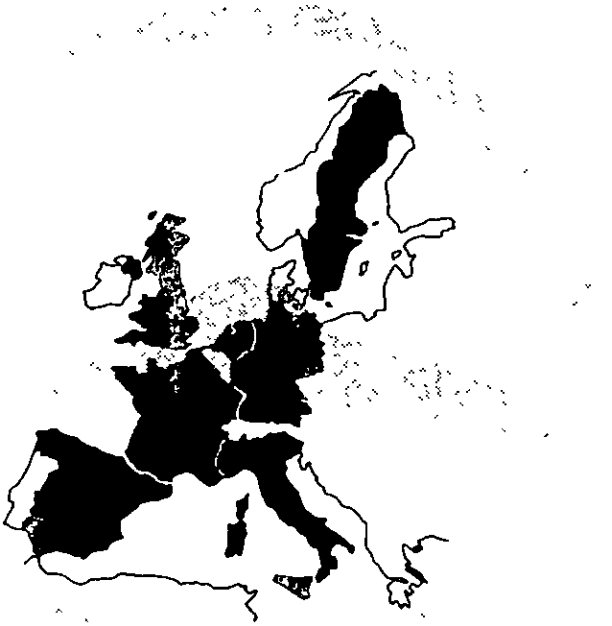
S1-S8-W-18

EEVC/CEVE



European Experimental Vehicles Committee

EEVC Working Group 9

Test Procedures for Defining Biofidelity Targets for Lateral Impact Test Dummies

Presented to the thirteenth ESV Conference. Paris, France. November 1991

Test Procedures for Defining Biofidelity Targets for Lateral Impact Test Dummies

A K Roberts, R W Lowne
M Beusenberg, and D Cesari

On behalf of the European Experimental Vehicles Committee

Abstract

EEVC Working Group 9 published a comprehensive review of the lateral impact cadaver data base at the 1990 IRCOBI Conference in Lyon France. This paper provides a concise description of the test procedures and biofidelity targets which were included in that paper, modified in the light of test experiences. Minor changes have been made to the test procedures and test configurations as further information on the original cadaver tests has become available.

Introduction.

Dummies are frequently designed and evaluated against cadaver data. EUROSID-1 dummy, the production version of the EUROpean Side Impact Dummy was based on published lateral impact cadaver data. EEVC Working Group 9 re-examined the available information on cadaver lateral impact response during 1990 and published a critical review of the data. From this review a general set of biofidelity design targets was developed for a lateral side impact dummy for the differing body areas.

The available information was very restrictive and encompassed only a small cadaver base. Unfortunately not all of the cadaver data or test conditions were appropriate for the specification of a crash test dummy. Some of the uncertainties in the data are due to difficulties in test reproducibility whilst others relate to the impact environment, such as impact velocity, test specification or body contact areas.

EEVC Working Group 9, first published their review and performance targets at the 1990 IRCOBI conference. Since the review was published further details of the concerning the original cadaver test procedures were discovered that affected the biofidelity test procedures, particularly with respect to the sled based rigid and padded wall tests. EEVC WG9 subsequently performed a wide ranging biofidelity test programme on the production EUROSID-1 dummy, based on the updated test procedures. During the course of the test programme several minor alterations to the test details were found to be necessary. This paper presents the test procedures and targets on which the EEVC WG9 biofidelity test programme was based. The results of this test programme were presented at the 1991 ESV conference.[1]

EEVC Review.

General review conclusions.

EEVC, having reviewed all of the cadaver data, test procedures and the types and severities of injury seen in accidents decided that some of the cadaver data were not appropriate for use in defining biofidelity targets. They also concluded that some body areas were more important than others and that the test procedures and body areas should be prioritised. WG9 concluded that the head, thorax, abdomen and pelvis should have a high priority rating based on the significance of injuries to these body areas. Although the abdomen is a high priority area based on injuries, the procedure for the biofidelity test based on the lateral drop of a cavaver or dummy, is considered to be poor in that it is very difficult to control the impact conditions precisely. Whilst the neck and shoulder injuries are not currently considered, their behaviour may affect the kinematics and thus the impact conditions of other body areas. Therefore their biofidelity is considered but at low priority. It should be noted that ISO has also prepared a set of requirements for a side impact dummy. Although the objectives were the same the design targets are slightly different due to the inclusion and exclusion of different data and slight differences in the definition of effective mass. The Targets and test procedures are more closely defined in this document than the similar ISO documents.[2]

Biofidelity Design Targets.

The data from the selected cadaver tests was used to determine a set of biofidelity targets for the dynamic performance of side impact dummies. The masses of the cadavers differ considerably. In order to reduce the scatter due to mass variation, the responses were normalised using a procedure similar to that proposed by Mertz and used by ISO [2,3]. The normalisation procedure is summarised in the Appendix. As previously mentioned the targets were divided into two priority areas related to the risk and severity of injury and to the validity and quality of the cadaver data. The biofidelity test procedures closely follow the original cadaver tests and are spedified in detail in the section on test procedures.

High Priority targets.

Head.

One performance target is specified for the head, in a 200 mm rigid surface drop test based on tests performed by Hodgson and Thomas [4]. The resultant peak head acceleration should be 112g ± 29g.

Thorax.

Impactor. This test is based on impactor tests performed on cadavers by HSRI [5]. Two targets are given; normalised impactor force - time response is shown in Figure 1 and Table I, and normalised dummy T1 lateral acceleration - time response in Figure 2 and Table II

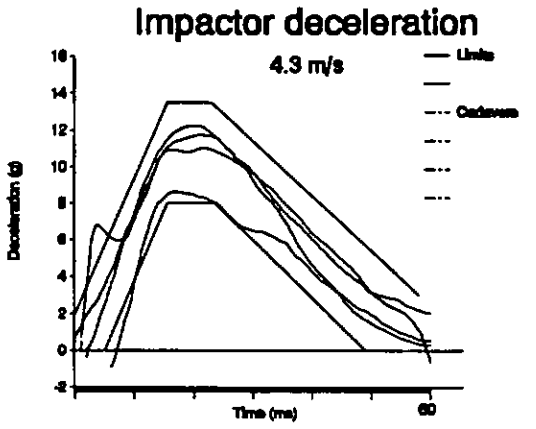


Figure 1 Thorax impactor acceleration target.

Time (ms)	Lower (g)	Upper (g)
0		2.0
5	0	
15.5	8	13.5
24		13.5
24.5	8	
50	0	
58		3.0

Table I. Thorax impactor acceleration corridor coordinates.

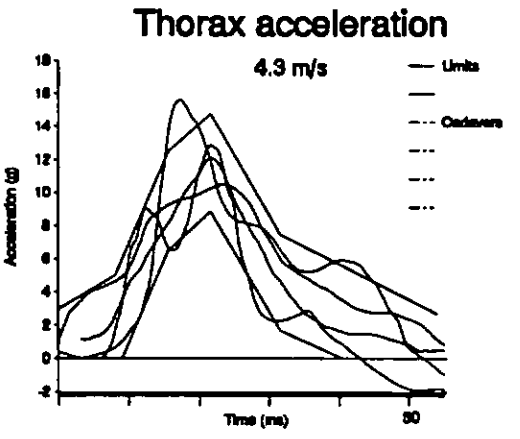


Figure 2. Thorax impactor T1 lateral acceleration.

Time (ms)	Lower (g)	Upper (g)
0		3.0
8		5.0
9	0	
15.5	6.5	12.5
21.5	8.9	14.8
31.5	1.7	7.5
40.5	0	
54		2.7

Table II. Thorax impactor T1 acceleration corridor coordinates.

Sled. These tests are based on sled tests performed at Heidelburg for NHTSA [6]. Targets are given for normalised wall forces for rigid and padded wall impacts. The impact velocities specified take into account the rebound velocities of the original tests.

a. Rigid Wall. The normalised thorax wall force - time target at 7.6 m/s is shown in Figure 3 and Table III and the normalised wall force - time target at 10.3 m/s is shown in Figure 4 and Table IV

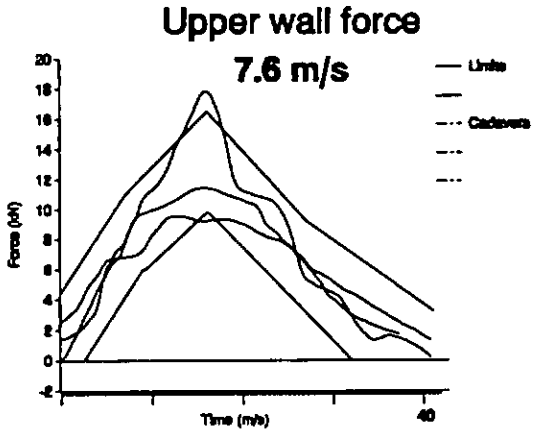


Figure 3. Thorax rigid wall force. (7.6 m/s)

Time (ms)	Lower (kN)	Upper (kN)
0		4.5
2.5	0	
7		11.0
9	6.0	
16	9.8	16.5
27		9.25
32	0	
41		3.25

Table III. Thorax rigid wall force target corridor coordinates. (7.6 m/s)

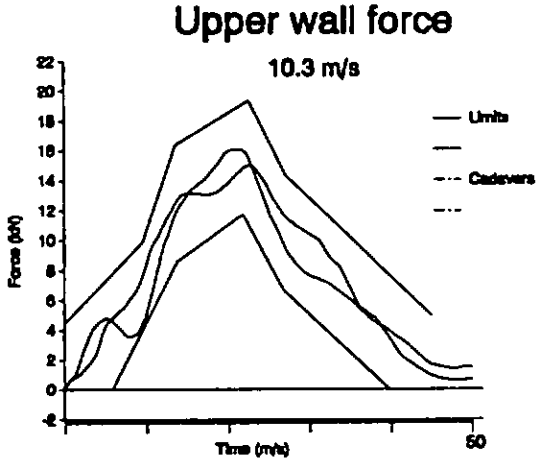


Figure 4. Thorax rigid wall force (10.3 m/s)

Time (ms)	Lower (kN)	Upper (kN)
0		4.5
6	0	
9.5		9.9
13.5		16.4
14	8.6	
22	11.75	
22.5		19.4
27	6.7	14.4
40	0	
45		5.0

Table IV. Thorax rigid wall force corridor target coordinates. (10.3 m/s)

b. Padded Wall. The normalised thorax wall force - time target at 10.3 m/s into the APR padding is shown in Figure 5 and Table V

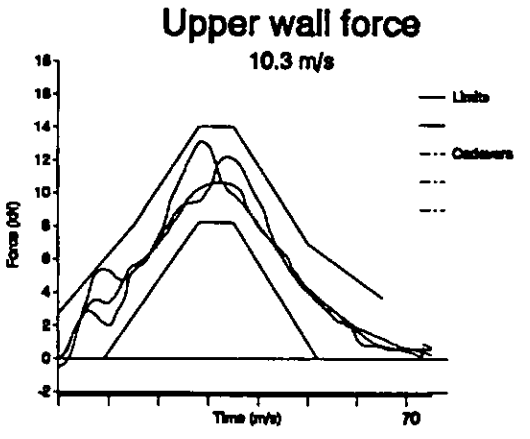


Figure 5. Thorax padded wall force (10.3 m/s)

Time (ms)	Lower (kN)	Upper (kN)
0		2.8
9	0	
15		8.0
28	8.2	14.0
35	8.2	14.0
50		6.9
52	0	
65		3.7

Table V. Thorax padded wall force corridor coordinates. (10.3 m/s)

Abdomen.

The abdomen target is based on free fall cadaver lateral drop tests performed by APR.[7] For the 1m drop tests on the abdomen, the normalized impact force - time target is shown in Figure 6 and Table VI.

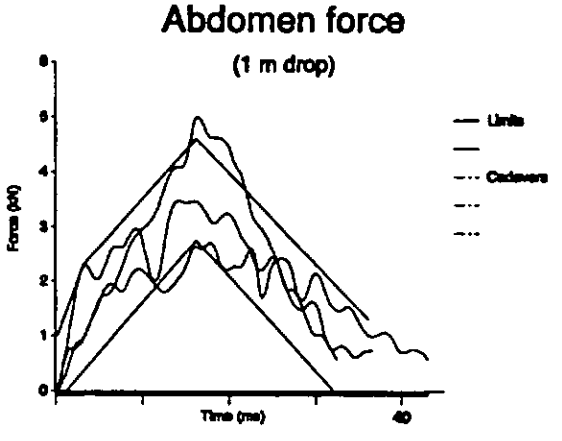


Figure 6. Abdomen drop test force-time target. (1m)

Time (ms)	Lower (kN)	Upper (kN)
0		1.0
1	0	
3		2.3
16	2.75	4.6
32	0	
36		1.3

Table VI Abdomen drop test force-time target corridor coordinates. (1m)

Pelvis.

Impactor. The pelvis test and target is based on impactor tests performed by INRETS[8] . A simple peak normalised force - impactor velocity target corridor is shown in Figure 7 and Table VII. The corridor is based on a least squares linear regression model of the results of impactor tests on cadavers:

$$\text{Force (KN)} = -0.62 + 1.066\ (\text{Impactor velocity (m/s)}).$$

No fixed impact velocity is prescribed for the tests except that the velocity must be between 6.0 m/s and 10.0 m/s.

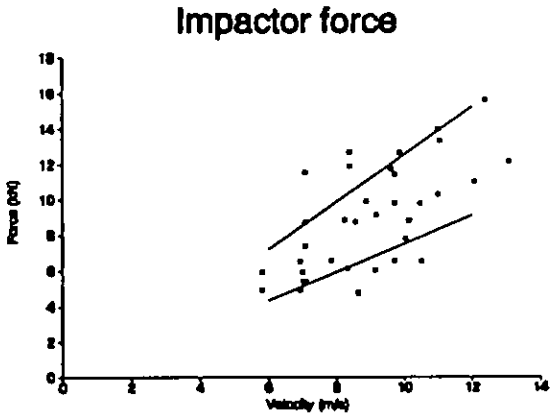


Figure 7. Pelvis impactor force-velocity target corridor.

Velocity (ms)	Upper (kN)	Lower (kN)
6	7.22	4.33
10	12.55	7.53

Table VII. Pelvis impactor target corridor coordinates.

Sled. As for the sled test conditions for the thorax, these tests are based on the sled tests performed for NHTSA at Heidelburg[6]. Targets for three configurations of sled test are given.

a. Rigid Wall. Normalised pelvic acceleration target range for impacts at 7.6 m/s and 10.3 m/s.

Normalized pelvis acceleration at 7.6 m/s 52.7 - 87.9 g.
Normalized pelvis acceleration at 10.3 m/s 79.5 - 132.5 g.

The normalised wall force - time target at 7.6 m/s is shown in Figure 8 and Table VIII and that at 10.3 m/s in Figure 9 and Table IX.

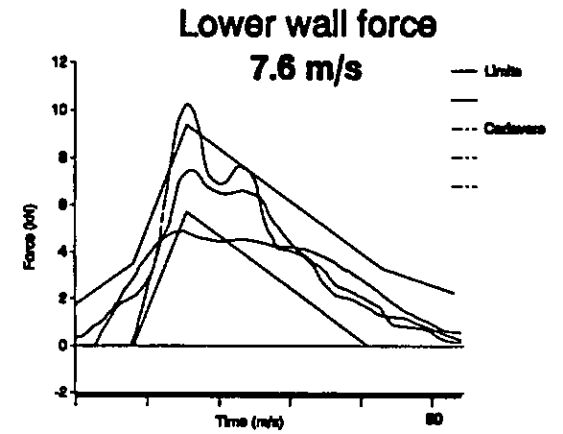


Figure 8. Pelvis rigid wall force target. (7.6 m/s)

Time (ms)	Lower (kN)	Upper (kN)
0		1.75
8	0	3.5
15.5	5.7	9.4
41	0	3.3
53		2.25

Table VIII. Pelvis rigid wall force target corridor coordinates. (7.6 m/s)

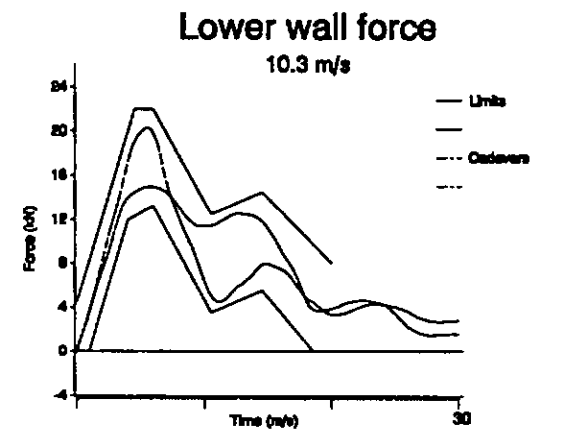


Figure 9. Pelvis rigid wall force target. (10.3 m/s)

Time (ms)	Lower (kN)	Upper (kN)
0		4.5
1	0	
4	12.0	
4.5		22.0
6	13.25	22.0
10.5	3.2	12.5
14.5	5.5	14.5
17		11.0
18.5	0	
20		8.0

Table IX. Pelvis rigid wall force target corridor coordinates. (10.3 m/s)

b. Padded Wall. The target range for normalized pelvis acceleration at 10.3 m/s is 65.8 - 109.7 g.

The normalised wall force - time target at 10.3 m/s is shown in Figure 10 and Table X.

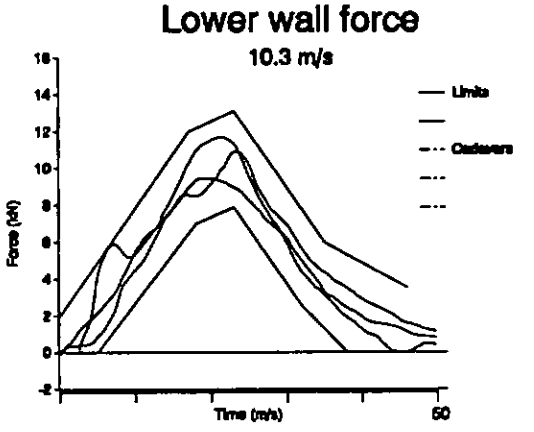


Figure 10. Pelvis padded wall force target. (10.3 m/s)

Time (ms)	Lower (kN)	Upper (kN)
0		2.0
5	0	
17		12.0
18	7	
23	7.9	13.1
32	2.5	
35		6.0
38	0	
46		3.5

Table X. Pelvis padded wall force target corridor coordinates. (10.3 m/s)

Low Priority targets

Neck

As the kinematics of the head/neck system are considered to be of some importance, flexion angles and trajectories of the head are defined as biofidelity targets. The test procedure is based on volunteer tests reported by Ewing[9]. Analysis of the original human volunteer data by Wismans et. al. [10] has shown that the response of the head and neck is principally determined by the T1 lateral acceleration and velocity change. Therefore the T1 acceleration is chosen as the main input requirement for neck biofidelity.

The targets for the neck performance are:-

1. Maximum head flexion angle: between 44 and 59 degrees.
   (The head flexion angle is defined as the angle between the projection of the inferio-superior axis of the head in the plane of impact at t = 0 and the time to maximum head flexion).

2. Maximum horizontal displacement of the centre of gravity of the head: between 130 and 162 mm.
   (The horizontal displacement of the head centre of gravity is defined as the relative displacement of the centre of gravity of the head, projected in the plane of impact measured in the $T1_y$ direction, between t = 0 and the time of maximum horzontal displacement of head centre of gravity).

3. Maximum vertical displacement of the centre of gravity of the head:
between 64 and 94 mm.

(The downward vertical displacement of the head centre of gravity is defined as the relative displacement of the centre of gravity of the head, projected in the plane of impact and measured in the $T1_z$ direction, between t = 0 and the time of maximum horzontal displacement of head centre of gravity).

Note $T1_z$ = Vertical direction, $T1_y$ = Lateral impact direction and $T1_x$ is the forward direction (perpendicular to the $T1_z$ and $T1_y$ directions)

Shoulder.

Two test conditions for the shoulder are described; a dynamic test based on studies by APR[11], and a quasi static test based on tests reported by Lowne et al.[12] For the dummy, the dynamic performance is more significant than the quasi static test, which is intended to ensure sufficient lateral displacement of the shoulder.

Since clear, unambiguous dynamic displacement data are not available, a displacement-time target corridor is not specified. The targets for the shoulder are a normalised impactor force-time corridor and a minimum displacement requirement.

Dynamic Target. The normalised shoulder force - time target corridor is shown in Figure 11 and Table XI.

Normalized shoulder deflection: at least 32 mm.

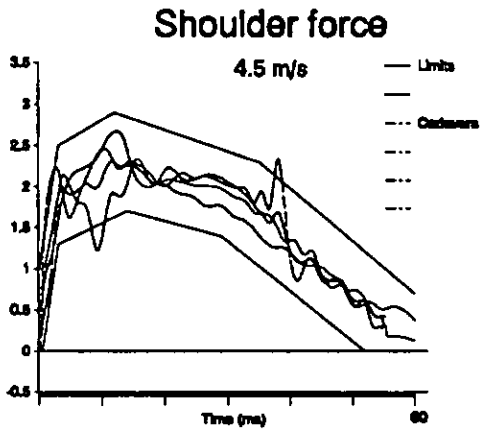


Figure 11. Shoulder impactor force-time target corridor.

Time (ms)	Lower (kN)	Upper (kN)
0		1.0
0.5	0	
3	1.3	2.5
12		2.9
14	1.7	
29	1.4	
35		2.3
52	0	
60		0.7

Table XI. Shoulder impactor force target corridor coordinates.

Static Target. Lateral displacement of the shoulder plunger relative to the spine under a 200 N lateral force: 55 mm.

Biofidelity Test Procedures.

All of the biofidelity tests should be performed in a temperature controlled environment regulated between 20°C ± 2°C. It should be noted that some of the test procedures may be different from those specified in the EUROSID Users' Manual used for dummy certification. (eg: Impactor specification for the dynamic shoulder test). The procedures described in this paper are based as closely as possible on the original cadaver test procedures with appropriate setting up procedures defined for dummy evaluation.

Head drop test procedure.

Test description. The test is to be conducted using only the dummy's head. The head is to be positioned with a 200 mm ± 2 mm space between it and a flat, rigid impact surface. The impact surface is to be horizontal and the head oriented so that its mid-sagittal plane makes an angle of 35° with the impact surface and its anterior-posterior axis is horizontal. A quick release mechanism is required to drop the head onto the impact surface. The added mass of the support mechanism should not exceed 70 gm.

Test Instrumentation. The dummy head is instrumented with a triaxial accelerometer located at its centre of gravity.

Data Processing. Accelerations are to be filtered using to CFC 1000. No normalisation procedures are defined for this configuration.

Neck test procedure.

Test description. The sled acceleration should lie within the corridor specified in Figure 12 and Table XII. The measured T1 lateral acceleration must also meet the corridor specified in Figure 13 and Table XIII. Since neck biofidelity is considered, the T1 lateral acceleration is of more importance than the sled deceleration. Therefore slight deviations in sled acceleration from the corridor specified in Figure 12 and Table XII can be tolerated provided the T1 lateral acceleration meets the corridor specified in Figure 13 and Table XIII. Sled velocity should be 6.9 ± 0.2 m/s.

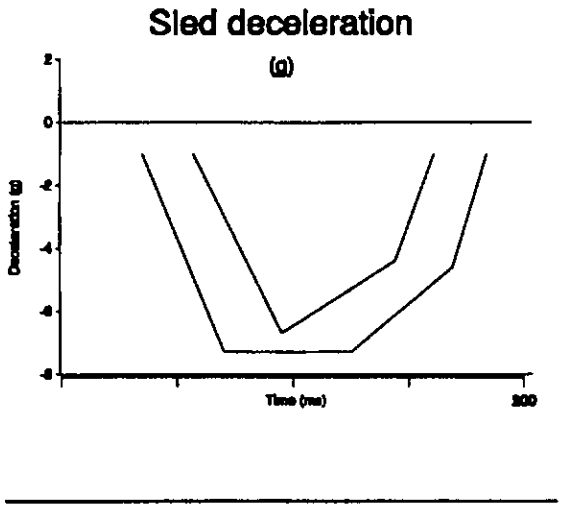


Figure 12. Sled acceleration for the Ewing neck test.

Time (ms)	Upper (g)	Lower (g)
35		-1.0
57	-1.0	
71		-7.3
95	-6.7	
125		-7.3
144	-4.4	
161	-1.0	
169		-4.6
184		-1.0

Table XII. Sled acceleration corridor coordinates for the Ewing neck test.

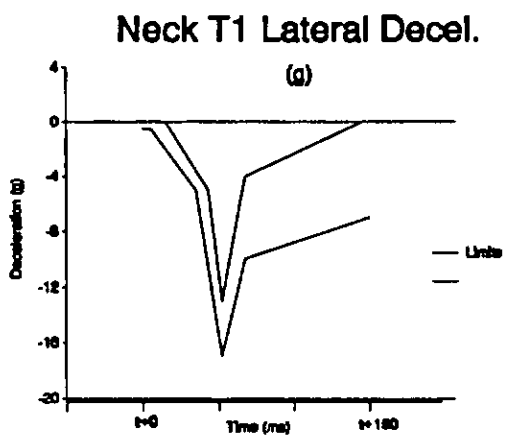


Figure 13. T1 lateral acceleration for neck test.

Time (ms)	Upper (g)	Lower (g)
t	0.0	-0.5
t+ 5		-0.5
t+ 15	0.0	
t+ 35		-5.0
t+ 43	-5.5	
t+ 52	-13.0	-17.0
t+ 67	-4.0	-10.0
t+145	0.0	
t+150		-7.0

Table XIII. T1 lateral acceleration corridor coordinates for neck test.

The time 't' for the T1 lateral acceleration is 50 ms after t = 0 of the sled acceleration corridor.

The complete dummy is to be seated in a nominally upright position in a test seat, functionally similar to the one used by Ewing. The test seat should be rigidly mounted on a sled, facing sideways (90°) to the direction of sled travel. A vertical, lightly padded side board is to be rigidly attached to the seat to restrict upper torso rotation and pelvis translation of the dummy. The top of the sideboard should extend to a level 40 to 50 mm below the top of the dummy's shoulder. The dummy should be positioned against the vertical side board such that the midsagittal plane of the dummy is vertical and perpendicular to the direction of sled travel. The thorax movement is to be restrained with a strap attached to the back of the seat to limit shoulder forces. The pelvis is to be restrained by a lap belt and an inverted 'V' pelvis strap tied to the lap belt. Both arms should be positioned alongside the thorax and restrained with suitable straps. The anterior-posterior axis of the head is to be horizontal.

Test instrumentation. The dummy is to be instrumented with a uniaxial accelerometer at the base of the neck (T1) with its sensitive axis directed laterally. Also the sled acceleration is to be measured. Photographic targets for measuring head c.g. translation in horizontal and vertical direction relative to T1, head rotation (angular rotation of the inferior-superior axis of the head relative to the vertical) and the horizontal translation of the base of the neck (T1) relative to the sled are necessary. Sufficient cameras are required to record all the relevant dummy and head displacements. Neck accelerations should be measured to CFC 180.

Data processing. No normalisation procedures are defined for the neck test.

Shoulder impactor test procedure.

Test description. The shoulder impactor test shall be performed on a complete dummy using a linearly guided impactor. The impactor mass shall be 23.4 kg with a smooth flat face 6" diameter, the edge of the impact face being relieved with a 6mm radius. The dummy shall be seated upright with no additional lateral supports on a flat horizontal rigid surface with the legs straight and parallel. The arms shall be positioned parallel to the thorax. The axis of the impactor shall be aligned with the shoulder pivot ± 10 mm and at 90° to the mid sagittal plane. Impact velocity at the point of impact shall be 4.5 m/s ± 0.1 m/s.

Test instrumentation. For/aft impactor acceleration shall be measured according to CFC 180. Photographic targets should be fixed to the impactor and the dummy upper thoracic spine to calculate the shoulder deflection relative to the spine from high speed film. The external shoulder displacement is defined as the lateral displacement of the face of the impactor relative to the upper thoracic spine perpendicular to the anterior posterior axis of the dummy.

Data processing. Impactor acceleration shall be normalised according to the procedure described in the Appendix based on a thorax standard mass (M_s) of 20.5 kg.

Shoulder quasi-static test procedure.

Rigidly support the thorax of the dummy in a vertical position to prevent lateral translation of the spine. Adjust the upper arm to a position of 40° forward of the torso line. Apply a lateral force to the outer extremity of the shoulder, adjacent to the arm pivot, with a 50 mm diameter plunger. Allow the shoulder and plunger to displace in any direction and record the maximum lateral displacement of the plunger with respect to the spine with an applied lateral force of 200N.

Thorax impactor test procedure.

Test description. The thorax impactor test shall be performed on a complete dummy using a linearly guided impactor. The impactor shall have a mass of 23.4 kg and a smooth flat face 6" diameter. The dummy shall be seated upright with no additional lateral support on a flat horizontal rigid surface with the legs straight forward and parallel. Both arms shall be positioned vertically upright above the head. The axis of the impactor shall be aligned with centre of the rib cage (vertically and laterally), at 90° to the mid-sagittal plane. The impact velocity shall be 4.3 m/s ± 0.1 m/s.

Test instrumentation. The fore/aft impactor acceleration and the T1 lateral acceleration shall be measured according to CFC 1000 and filtered with a 100 Hz Finite Impulse Filter (FIR) *.

Data processing. Impactor and dummy accelerations shall be normalised according to the procedure described in the Appendix based on a thorax standard thorax mass (M_s) of 29.6 kg.

Abdomen drop test procedure.

Test description. The dummy is to be suspended above the impact surface with its midsagittal plane horizontal and its abdominal region in line with the top surface of the armrest. The armrest should contact the abdomen section just superior to the iliac crest and without interfering with the lower thoracic ribs. The simulated armrest is constructed of rigid hardwood. The armrest is 7 cm in width and should protrude 4.1 cm above the surrounding surface (Ref 7, Fig 1). The length of the armrest must be sufficient to prevent the dummy from striking the ends. The arm on the impact side is positioned 40° forward such that no contact with the arm takes place. The surrounding surface is made of hardwood and should be large enough to prevent the dummy from striking the edges. A quick-release mechanism is to be used to drop the dummy from a distance of 1 m measured between abdomen and armrest.

* The FIR filter programme is available to EUROSID users from TNO.

Test instrumentation. The simulated armrest is to be mounted on a piezoelectric load cell. If a piezoelectric load cell is not used the armrest must also be fitted with a uniaxial accelerometer, mounted vertically. Additionally lateral acceleration at T12 should also be recorded for normalisation procedures. Forces and accelerations should comply with CFC 180.

Data processing. If a piezoelectric load cell is not used the load cell must be inertia compensated according to Equation 1. High speed camera coverage is required to determine abdominal penetration. Abdomen penetration is defined as the vertical displacement of the thoracic spine (directly over the armrest) relative to the top surface of the armrest measured from the time of first contact of the abdominal surface with the armrest. Impactor forces are to be normalised according to the procedure described in the Appendix based on an abdominal standard mass (M_s) of 16.4 kg.

Pelvis impactor test procedure.

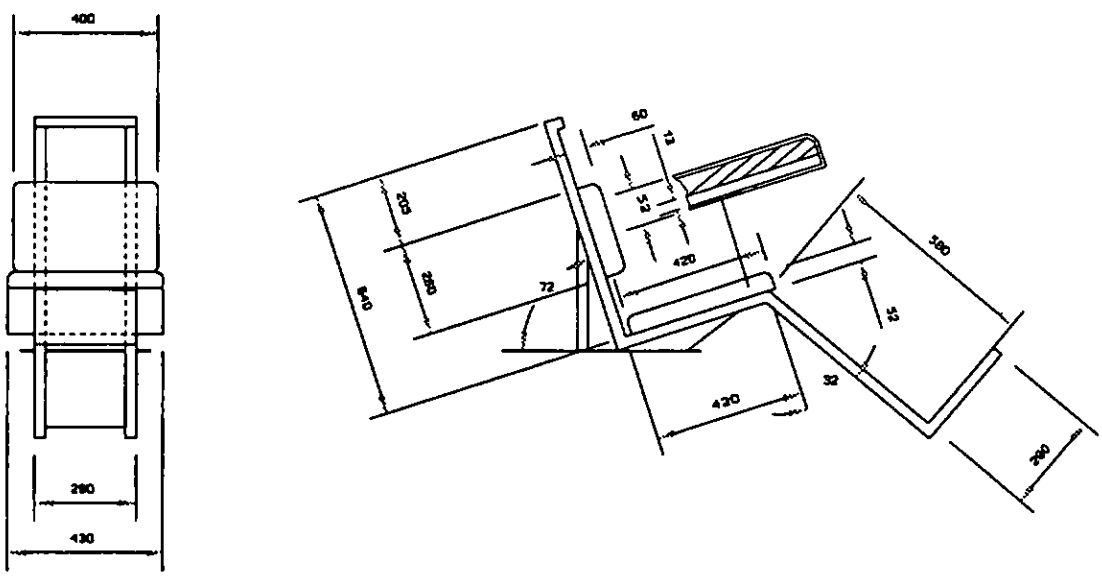


Figure 14. Pelvis impactor test seat.

Test description. The pelvis impactor test is performed on a complete dummy. The dummy should be sat on a fixed seat shown in Figure 14. The foam material used for the seat should be a polyethylene foam 40 mm thick having a density of 47.0 kg/m^3 or an alternative with similar properties. The upper arms should be positioned alongside the

thorax (0°) and no addition lateral support to the dummy is to be given. The legs of the dummy shall be positioned perpendicular to the impact direction and parallel with each other. The linearly guided impactor shall have a mass of 17.3 kg and a smooth spherical impact face of radius 175 mm and a outer diameter of 120 mm. Impact velocity must be between 6.0 m/s and 10.0 m/s, the axis of the lateral impact being centred on the hip pivot point.

Test instrumentation. Impactor acceleration and pelvic acceleration shall be measured according to CFC 1000.

Data processing. The impactor acceleration shall be normalised according the procedure described in the Appendix based on a pelvic standard mass of (M_s) of 14.5 kg.

Whole body sled test procedure.

Test description. The whole body tests can be performed on either a standard deceleration impact sled or on a HYGE impact sled. The sled must be fitted with a rigid vertical impact wall onto which two force measuring plates are fitted. Perpendicular to the rigid wall a rigid low friction bench seat is attached, in line with the motion of travel of the sled. The dimensions of the test seat and force measuring load cells are given in Figure 15. (The sliding test seat used by the University of Heidelberg for the cadaver tests was 1.5 m in length.) Since precise positioning of the horizontal slats is not available, the slats can be replaced by an alternative low friction surface for dummy testing. The dummy must be supported vertically on the non struck side during the acceleration phase of a non HYGE impact sled. The arms of the dummy are to be placed alongside the thorax (0°). Impacts are to be performed into the rigid wall at two impact velocities 7.6 and 10.3 m/s. One further test is to be performed at 10.3 m/s into the same wall onto which two foam blocks are mounted. Impact velocity tolerance shall be ± 0.1 m/s. The specified impact velocity includes any rebound velocity that may exist with a deceleration type sled. On both types of test sled the dummy must strike the wall at the prescribed velocity. The block specification is described in Section 3. The upper pad is to be located on the thorax force plate, the upper surface of the pad being in line with the top edge of the plate, parallel to the seat pan. The lower pad is to be located on the pelvis plate with the lower surface of the pad resting on the seat pan.

Note. It is advisable to restrain the legs from excessive lateral articulation after the dummy strikes the wall in order to prevent damage to the knee joints.

Test Instrumentation. Plate forces shall be measured CFC 1000 and lateral dummy accelerations at T1 and at the pelvis CFC 180. The force measuring plates are to be inertia compensated by placing an accelerometer in the centre of each force plate, its axis perpendicular to the surface of the plate.

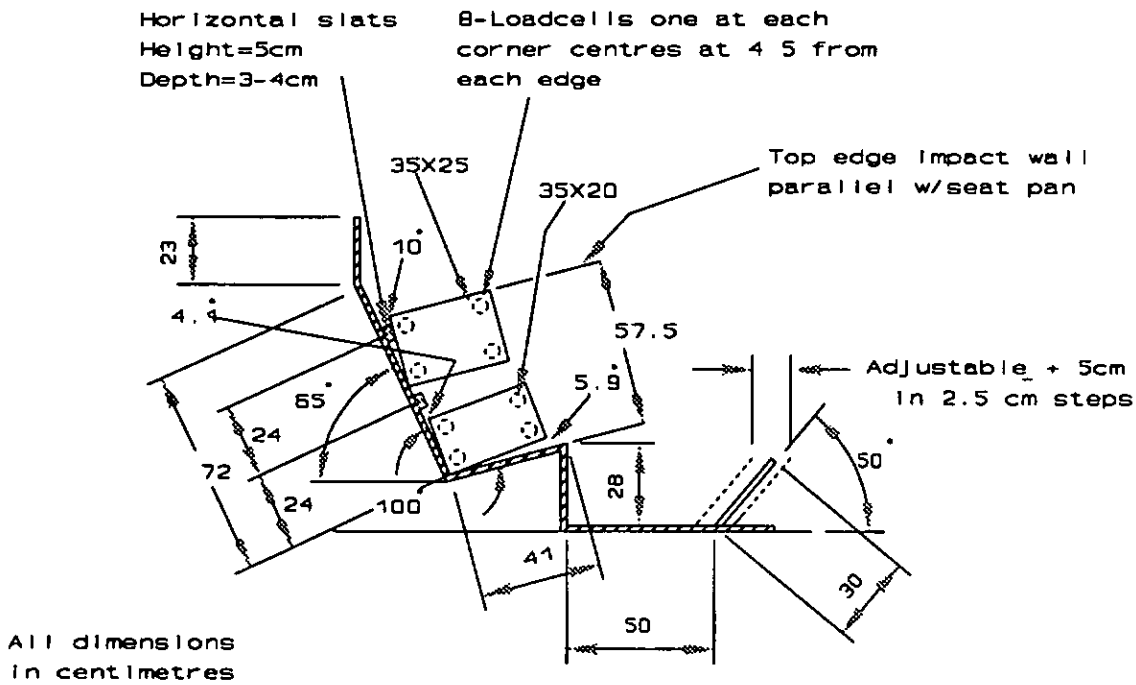


Figure 15. Heidelburg Impact Sled Seat.

Data Processing. The resultant, inertia compensated, forces derived using Equation 1.

$$F_i = \sum F_{plate} + (M_{plate} A_{plate}) \qquad \text{Equation 1.}$$

Where F_i = Inertia compensated plate force
F_{plate} = Plate force
M_{plate} = Mass of plate
A_{plate} = Acceleration of plate, where acceleration is positive in the direction of impact of the dummy

All forces and dummy accelerations must be normalised according to the procedure described in the Appendix to a standard mass (M_s) of 37.0 kg for the thorax and a standard mass M_s of 24 kg for the pelvis, and both filtered with a 100 Hz FIR filter.

APPENDIX

Data Processing and Normalisation.

To permit comparisons between cadaver and dummy tests and dummy to dummy tests common data processing procedures must be adopted. The following sections detail the methods that should be used to enable valid comparisons to be made.

Instrumentation and Data Processing.

All instrumentation and filtering is to meet the ISO standard - ISO 6487:1987. [13] and recommended Channel Filter Classes (CFC). Wall forces for the sled impacts and impactor forces for the thorax impactor tests must be filtered using a 100hz Finite Impulse Filter (FIR). (A copy of a recommended FIR Fortran filtering programme called 'THRXINJ' is available to EUROSID users from IW-TNO, the suppliers of the dummy.)

Time zero does not exist for most of the biofidelity assessment tests, therefore all responses should be time shifted by eye to give the best match to the overall shape of the target corridors.

Normalisation Procedures.

To reduce variations in cadaver output and test conditions all data channels for the targets have been normalised according to a procedure developed by Mertz and Lowne and detailed in the ISO requirements[2,3]. For the biofidelity tests all of the data must be normalised in a similar way to reduce scatter due to test setup variability. Normalisation procedures are defined for the appropriate test condition. Impactor normalisation is based on a two mass spring model while the sled and drop tests on a single mass spring model, since the effective mass of the striking object is infinite.

To perform normalisation a standard effective mass for the associated body part is required. In this analysis the effective mass for each cadaver has been derived from the original transducer records. As the effective mass of the body varies during the period of the test, a decision has to be made regarding the time at which the effective mass should be defined. For normalisation, this is not too critical provided the same definition is used for the dummy tests. For the thorax impactor tests this was selected to be when the impactor velocity was at a common velocity with the lateral velocity of the spine. For the shoulder and pelvis this was taken to be at the end of the main pulse as there was no means of determining the time of common velocity in the base cadaver tests. In the sled tests the effective mass is taken at the end of the main wall force pulse. The standard body part mass was then determined for each group of cadavers in the test - Equation 2. In determining the standard masses for the thorax and pelvis in the wall tests an average standard mass for all three test conditions has been taken although the data suggests that different values for the three different test conditions would be appropriate.

Table XIV gives the standard masses derived from this analysis. These standard masses should be used for the dummy normalisation procedures. For cadaver-to-dummy comparisons to be made, normalisation of the cadaver and dummy data must be based on the same standard mass. The body part standard masses used in this analysis will in some instances be different from those of other analyses as the cadaver sample on which this study is based may differ.

$$M_s = 76 * \left(AVERAGE \left[\frac{Effective\ body\ part\ mass}{Total\ cadaver\ mass} \right] \right) \quad \text{Equation 2.}$$

Test Procedure	Body Part Standard Effective Mass (kg)
Shoulder impactor	20.5
Thorax impactor	29.6
Abdomen drop	16.4
Pelvis impactor	14.5
Rigid and Padded wall	
Upper force (thorax)	37.0
Lower force (pelvis)	24.0

Table XIV. Normalisation Standard Effective Masses

Single spring-mass system. For the purposes of normalising the results of the sled impacts and the drop tests, the cadaver and dummy can be considered to be modelled by a single mass-spring system impacting an infinite mass.

Under these conditions the equations of motion of the mass are:-

$$x = V_o \sqrt{\frac{M}{k}}\, Sin\left(\sqrt{\frac{k}{M}}\, t\right) \qquad \textbf{Equation 3.}$$

$$\ddot{x} = -V_o \sqrt{\frac{k}{M}}\, Sin\left(\sqrt{\frac{k}{M}}\, t\right) \qquad \textbf{Equation 4.}$$

Where V_o is the impact velocity
M is the effective body mass
and k is the spring stiffness

Displacement, force, acceleration and time can then all be normalised to a standard (s) set of values from the observed value in the 'i'th test (i).

Thus
$x_s = x_i * R_x$ (Displacement normalisation)
$F_s = F_i * R_f$ (Force normalisation)
$\ddot{x}_s = \ddot{x}_i * R_a$ (Acceleration normalisation)
$t_s = t_i * R_t$ (Time normalisation)

Where:

$$R_x = \sqrt{\frac{M_s}{M_i}} * \sqrt{\frac{K_i}{K_s}} \qquad \textbf{Equation 5.}$$

$$R_f = \sqrt{\frac{M_s}{M_i}} * \sqrt{\frac{K_s}{K_i}} \qquad \textbf{Equation 6.}$$

$$R_a = \sqrt{\frac{M_i}{M_s}} * \sqrt{\frac{K_s}{K_i}} \qquad \textbf{Equation 7.}$$

$$R_t = \sqrt{\frac{M_s}{M_i}} * \sqrt{\frac{K_i}{K_s}} \qquad \textbf{Equation 8.}$$

M_s and K_s are the standard effective mass and standard stiffness
M_i and K_i are the effective mass and stiffness for test 'i'.

These factors were used to normalise the cadaver data using characteristic cadaver body dimensions as a substitute for stiffness (see Ref 3).

The same equations are used to normalise the dummy test results. Under these conditions, $K_1 = K_2$, M_s is the standard effective mass from the cadaver tests and M_i is the effective mass determined in each test with the dummy.

Thus the normalising factors for the sled and drop tests with the dummy become:-

$$R_x = \sqrt{\frac{M_s}{M_i}} \qquad \textbf{Equation 9. (Displacement)}$$

$$R_f = \sqrt{\frac{M_s}{M_i}} \qquad \textbf{Equation 10. (Force)}$$

$$R_a = \sqrt{\frac{M_i}{M_s}} \qquad \textbf{Equation 11. (Acceleration)}$$

$$R_t = \sqrt{\frac{M_s}{M_i}} \qquad \textbf{Equation 12. (Time)}$$

Spring - two mass system. For the impactor tests, the normalisation is based on a spring and two mass model (Figure 16)

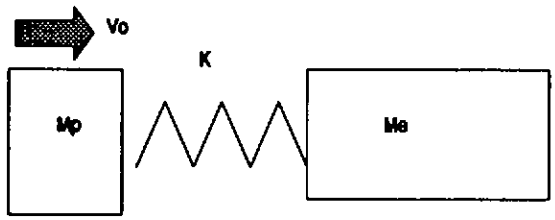


Figure 16. Two Mass - Spring Model.

The relevant equations of motion for this system are:-

$$x_p = \sqrt{\left(\frac{M_p}{K}\right)}\left(\frac{M_e}{M_p+M_e}\right)^{\frac{3}{2}} Sin \sqrt{\left(\frac{K(M_p+M_e)}{M_pM_e}\right)}\, t + \left(\frac{M_pV}{M_p+M_e}\right) t \qquad \text{Eq. 13.}$$

$$\ddot{x}_p = -\sqrt{\left(\frac{K}{M_p}\right)}\sqrt{\left(\frac{M_e}{M_p+M_e}\right)} Sin \sqrt{\left(\frac{K(M_p+M_e)}{M_pM_e}\right)} . t \qquad \text{Eq. 14.}$$

$$x_b = \sqrt{\left(\frac{M_e}{K}\right)}\left(\frac{M_p}{M_p+M_e}\right)^{\frac{3}{2}} Sin \sqrt{\left(\frac{K(M_p+M_e)}{M_pM_e}\right)}\, t + \left(\frac{M_pV}{M_p+M_e}\right) t \qquad \text{Eq. 15.}$$

$$\ddot{x}_e = -\sqrt{\left(\frac{K}{M_e}\right)}\sqrt{\left(\frac{M_p}{M_p+M_e}\right)} Sin \sqrt{\left(\frac{K(M_p+M_e)}{M_pM_e}\right)} . t \qquad \text{Eq. 16.}$$

Where x_p, $\ddot{x}_p$ and M_p are the displacement, acceleration and mass of the impactor and x_b, $\ddot{x}_b$ and M_e are the displacement, acceleration and effective mass of the body part.

Impactor force and acceleration can be normalised according to the equations;

$F_{p(s)} = F_{p(i)} * R_p$ (Impactor force normalisation)
$\ddot{x}_{p(s)} = \ddot{x}_{p(i)} * R_p$ (Impactor acceleration normalisation)

and the body part response can be normalised according to:-

$\ddot{x}_{b(s)} = \ddot{x}_{b(i)} * R_b$ (Cadaver or dummy acceleration normalisation)

The time can be normalised using:

$t_{(s)} = t_{(i)} * R_t$

where the (s) suffix refers to the results normalised to the standard mass, the (i) suffix to the result of the 'i'th. test, the 'p' suffix refers to impactor readings while the 'b' suffix refers to responses measured on the cadaver or dummy.

The normalising factors are given by:

$$R_p = \sqrt{\left(\frac{K_s}{K_i}\right)} \cdot \sqrt{\left(\frac{M_{e(s)}}{M_{e(i)}}\right)} \cdot \sqrt{\left(\frac{M_p + M_{e(i)}}{M_p + M_{e(s)}}\right)} \qquad \textbf{Equation 17.}$$

$$R_b = \sqrt{\left(\frac{K_s}{K_i}\right)} \cdot \sqrt{\left(\frac{M_{e(i)}}{M_{e(s)}}\right)} \cdot \sqrt{\left(\frac{M_p + M_{e(i)}}{M_p + M_{e(s)}}\right)} \qquad \textbf{Equation 18.}$$

$$R_t = \sqrt{\left(\frac{K_i}{K_s}\right)} \cdot \sqrt{\left(\frac{M_{e(s)}}{M_{e(i)}}\right)} \cdot \sqrt{\left(\frac{M_p + M_{e(i)}}{M_p + M_{e(s)}}\right)} \qquad \textbf{Equation 19.}$$

These equations have been used to normalise the cadaver responses for the impactor tests using a characteristic cadaver body dimension to represent K.

These equations are used also to normalise the dummy data, but here $K_t = K_s$ and the equations reduce to:-

$$R_p = R_t = \sqrt{\left(\frac{M_{e(s)}}{M_{e(i)}}\right)} \cdot \sqrt{\left(\frac{M_p + M_{e(i)}}{M_p + M_{e(s)}}\right)} \qquad \textbf{Equation 20.}$$

$$R_b = \sqrt{\left(\frac{M_{e(i)}}{M_{e(s)}}\right)} \cdot \sqrt{\left(\frac{M_p + M_{e(i)}}{M_p + M_{e(s)}}\right)} \qquad \textbf{Equation 21.}$$

For dummy response normalisation, the effective mass for the body part in the test, $M_{e(i)}$, should be established as described below, while the standard effective mass, $M_{e(s)}$, is taken from Table XIV.

Impactor normalisation.

Shoulder. a) Determine the effective mass of the shoulder area using Equation 22. The effective mass should be evaluated by integration to the end of the initial impactor pulse.

$$M_e = \frac{\int F_p \, dt}{V_0} \qquad \text{Equation 22.}$$

Where M_e = Effective mass of the body part (kg)
F_p = Impactor force (N)
V_0 = Lateral impact velocity (m/s)

b) Normalise the impactor force and time using Equation 20.

Thorax. a) Determine the effective mass of the dummy part using Equation 23. The effective mass should be determined when the impactor and dummy are at a common velocity by integrating to the time when the velocity of the impactor equals that of T1. (On the first occasion if two should exist.)

$$M_e = \frac{\int M_p \ddot{x}_p \, dt}{\int \ddot{x}_b \, dt} \qquad \text{Equation 23}$$

Where M_e = Effective mass of the body part (kg)
M_p = Mass of the impactor (kg)
$\ddot{x}_p$ = Impactor acceleration (m/s^2)
$\ddot{x}_b$ = Body part lateral acceleration at T1 (m/s^2)

b) Normalise the impactor acceleration and the time using Equation 20 and the thorax acceleration using Equation 21.

Pelvis. a) Determine the effective mass of pelvis area of the dummy using Equation 24. The effective mass should be evaluated by integration to the end of the initial impactor pulse.

$$M_e = \frac{\int F_p \, dt}{V_0} \qquad \text{Equation 24.}$$

Where M_e = Effective mass of the body part (kg)
F_p = Impactor force (N)
V_0 = Lateral impact velocity (m/s)

b) Normalise the impactor acceleration and the time using Equation 20 and the thorax acceleration using Equation 21.

Abdomen drop test. a) Determine the effective mass of the abdomen part using Equation 25. The effective mass should be evaluated by integration to the end of the initial impactor pulse.

$$M_e = \frac{\int F_a \, dt}{\int \ddot{x}_{T12} \, dt + (T*g)} \qquad \text{Equation 25.}$$

Where M_e = Effective mass of abdomen (kg)
F_a = Force on the armrest (N)
$\ddot{x}_{T12}$ = Lateral acceleration of T12 (m/s^2)
T = Pulse length (s)
g = gravity (m/s^2)

b) Normalise the armrest force using Equation 10, time using Equation 12 and displacement by Equation 9.

Sled normalisation.

a) Determine the effective mass of the dummy part (thorax and pelvis) using Equation 26. The effective mass should be taken at the end of the initial wall force for the appropriate body part.

$$M_e = \frac{\int F \, dt}{V_o} \qquad \text{Equation 26.}$$

Where M_e = Effective mass of the body part (kg)
F = Compensated impact wall force (kN)
V_0 = Initial impact velocity (m/s)

NOTE - V_0 should be taken to be the same as for the thorax, even though the profile of the seated dummy will cause the pelvis to impact the wall after the shoulder/thorax complex. It should be assumed that at the time of impact of the pelvis the dummy-to-wall velocity has not decreased.

b) Normalise the wall forces using Equation 10, dummy acceleration using Equation 11 and time using Equation 12.

Specification of Impact Padding.

The sled test padded wall padding was developed by APR. The polyurethane foam blocks were 140mm x 140mm x 420mm with a density of 135 → 150 gm/l. The quasi-static force/deflection characteristics (with a loading rate of 100 mm/min) are shown in [Ref 2].

References.

1. Roberts A.K. - The Biofidelity of the Production Version of the European Side Impact Dummy EUROSID-1. - Thirteenth ESV Conference. Paris France. 1991.

2. ISO Technical Reports 9790 1 - 6.

   a. ISO/TC22 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Head Response Requirements to Assess the Biofidelity of the Dummy. ISO/DTR 9790-1 Ref No ISO/TC22/SC22/WG5 N1554 E.

   b. ISO/TC22 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Neck Response Requirements to Assess the Biofidelity of the Dummy. ISO/DTR 9790-2 Ref No ISO/TC22/SC22/WG5 N1554 E.

   c. ISO/TC22 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Shoulder Response Requirements to Assess the Biofidelity of the Dummy. ISO/DTR 9790-3 Ref No ISO/TC22/SC22/WG5 N1554 E.

   d. ISO/TC22 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Thoracic Response Requirements to Assess the Biofidelity of the Dummy. ISO/DTR 9790-4 Ref No ISO/TC22/SC22/WG5 N1554 E.

   e. ISO/TC22 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Abdominal Response Requirements to Assess the Biofidelity of the Dummy. ISO/DTR 9790-5 Ref No ISO/TC22/SC22/WG5 N1554 E.

   f. ISO/ Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Pelvic Response Requirements to Assess the Biofidelity of the Dummy. ISO/DTR 9790-6 Ref No ISO/TC22/SC22/WG5 N1554 E.

3. Mertz H J. - A Procedure for Normalising Impact Response Data. - SAE paper 840884, Warrendale, PA. USA. 1984.

4. Hodgson V R and L M Thomas. Head Impact Response. Wayne State University School of Medicine. Vehicle Research Institute Report VRI 7.2 SAE. 1975.

5. Robbins D H, R J Lehman and K Augustyn. Prediction of Thoracic Injuries as a Function of Occupant Kinematics. Proc. 7th. ESV Conf. Paris, 1979.

6. Eppinger R H, K Augustyn and D H Robbins. Development of a Promising Universal Thoracic Trauma prdeiction Methodology. Proc. 22nd Stapp Car Crash Conf. SAE paper 780891. 1978

7. Walfisch G, A Fayon, C Tarriere, J Rosey, F Guillon, C Got, A Patel and R Stalnaker. Designing a Dummy's Abdomen for Detecting Injuries in Side Impact Collisions. Proc 5th IRCOBI Conf. Birmingham, 1980.

8. Cesari D, M Ramet and R Bouquet. Tolerance of Human Pelvis to Fracture and Proposed Pelvic Protection Criteria to be Measured on Side Impact Dummies. Proc Ninth ESV Conf. 1982.

9. Ewing, C L, D J Thomas, P L Majewski, R Black and L Lustik. Measurement of Head, T1 and Pelvic Response to -Gx Impact Acceleration. Proc 21st Stapp Car Crash Conf. Oct 1977. SAE paper 770927.

10. Wismans J., H. van Oorschot, H.J. Woltring - Omni-Directional Human Head-Neck Response. 30th STAPP Car Crash Conference, San Diego California USA, Oct. 1986. SAE paper 861893;

11. Bendjellal, F, G Walfisch, A Fayon and C Tarriere. APR Biomechanical Data. APR, Nanterre, France 1984.

12. Lowne R W and A K Roberts. Design of the MIRA Side Impact Dummy (Appendix). Page 357, Biomechanics of Impacts in Road Accidents - Proceedings of the seminar held in Brussels 21-23 March 1983.

13. ISO 6487:1987 Road Vehicles - Techniques of measurement in impact tests - Instrumentation.

Acknowledgements.

Participating members of EEVC Working Group 9 are -

M Beusenberg
K-P Glaeser
R W Lowne (Chairman)
A K Roberts (Secretary)
D Cesari
E G Janssen
A Pastorino