

**Assessment of the FTSS 4.5 kg aluminium headform as
a possible alternative for EEVC WG17**

by
G J L Lawrence

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**ASSESSMENT OF THE FTSS 4.5 KG ALUMINIUM HEADFORM
AS A POSSIBLE ALTERNATIVE FOR EEVC WG17**

Version: Final

by **G J L Lawrence (TRL Limited)**

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(Ian Knowles)

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Executive summary

The European Union Directive 2003/102/EC was approved by the European Parliament and by the Council on the 17th of November 2003 and published in the Official Journal of the European Union on the 6th of December 2003. The Directive makes use of test methods and test tools produced by the European Enhanced Vehicle-safety Committee (EEVC) by their Working Group 10 and later refined by EEVC Working Group 17. However, most of the Directive's technical prescriptions are contained in a separate document, a European Commission (EC) Decision. As most experts agreed that requiring full compliance with EEVC WG17 in one step would be too demanding, the Directive introduces pedestrian protection in two stages. The first stage requires pedestrian protection to be provided in new car designs using an adaptation of the EEVC WG17 test methods that is somewhat less demanding. Following a feasibility assessment study, a higher level of pedestrian protection could be provided by a second phase. The feasibility study, carried out by TRL, was completed in June 2004.

One proposal in the TRL study, made to improve the feasibility of providing protection for the head and to increase compatibility between the test procedures used in Europe and elsewhere, was to reduce the mass of the adult headform impactor from 4.8 kg to 4.5 kg. Headforms are available with a mass of 4.5 kg, and one of these, produced by First Technology Safety Systems (Europe) BV (FTSS), is made by modifying an EEVC 4.8 kg impactor. Therefore it would appear to be very suitable as a substitute for the 4.8 kg impactor in the Directive, if the TRL proposal is accepted. Nevertheless, before a revised impactor can be introduced into the Directive it will be necessary to produce a specification for the headform with appropriate certification requirements, and the EC feasibility report recommended that the EEVC WG17 should be consulted regarding this. The FTSS headform is made to meet the ISO 4.5 kg headform specification which is very similar in most respects to that of the EEVC impactor, the main differences being in the mass, moment of inertia and certification method. Despite the differences in the certification methods both performance requirements link back to the same biomechanical data.

The FTSS 4.8 kg headform impactor (designed and originally supplied by TNO) has already been assessed and accepted by EEVC WG17 as an 'approved impactor'. Therefore it seemed reasonable to assess this new version as an alternative EEVC WG17 impactor.

The objective of the current study was to assess the FTSS 4.5 kg headform impactor's physical and dynamic properties and, if it was found to be suitable, to produce a specification for it that could be adopted by EEVC WG17 if they choose to select it as an alternative headform. The results have been used to propose an impactor specification and dynamic certification corridor for an EEVC WG17 4.5 kg headform. Even if EEVC WG17 chooses not to adopt this headform, the proposed specification could still be adopted by the EC and included in amendments to the Decision (i.e. the technical prescriptions).

Measurements were made of the physical properties of the headform and a series of dynamic certification tests were performed on it. Data supplied by FTSS were also considered, as were data supplied by JASTI concerning an alternative 4.5 kg headform.

The conclusions of this study were:

- A proposed specification for a 4.5 kg headform impactor has been produced based on the EEVC WG17 4.8 kg adult headform specification.
- A 4.5 kg headform impactor and skin has been obtained from FTSS and assessed against the proposed specification.
- The FTSS headform was found to comply with the proposed specification for dimensions, mass, moment of inertia, and position of centre of gravity and accelerometer seismic masses relative to the geometric centre of the truncated sphere.

- FTSS has provided theoretical (CAD) data which support the data derived by TRL from physical measurements. The FTSS data suggest that a worst combination of manufacturing tolerances will not take the headform out of tolerance.
- Dynamic certification tests have been carried out by TRL and these show that:
 - The headform skin provided with the headform gives consistent results at TRL.
 - TRL obtain lower acceleration results than FTSS when they tested the skin before supplying it to TRL. (TRL and others have found similar disparities in dynamic certification test with the FTSS 2.5 and 4.8 kg headforms.)
- The origins of the current dynamic certification method have been discussed and it is suggested that in hindsight it would have been better if it had been made to match both the acceleration amplitude and acceleration duration of a 'good' pedestrian friendly car bonnet.
- TRL consider it to be essential that the cause of the differences in dynamic certification results between different test houses be established and an appropriate solution be found. Alternatively a new certification method might be developed as an alternative to investigating and resolving the problems with the current one.
- Information has been obtained from JASTI Co., Ltd, that shows that the JAMA-JARI 4.5 kg headform also complies with the proposed EEVC WG17 specification; however, the hardness of the skin may need some minor adjustments once EEVC WG17's dynamic certification requirements have been finalised.
- As a matter of best practice it is recommended that a minimum sample rate of 20 kHz be used in dynamic headform certification tests.

Abstract

The European Union Directive 2003/102/EC, with the associated technical prescriptions in EC Decision 2004/90/EC, introduces pedestrian protection in two stages. The first stage requires pedestrian protection to be provided in new car designs using an adaptation of the EEVC WG17 test methods that is somewhat less demanding. Following a feasibility assessment study, a higher level of pedestrian protection could be provided by a second phase. The feasibility study, carried out by TRL, was completed in June 2004. One proposal in the TRL study, made to improve the feasibility of providing protection for the head and to increase compatibility between the test procedures used in Europe and elsewhere, was to reduce the mass of the adult headform impactor from 4.8 kg to 4.5 kg. The objective of the current study was to assess the FTSS 4.5 kg headform impactor's physical and dynamic properties. The results have been used to propose an impactor specification and dynamic certification corridor for an EEVC WG17 4.5 kg headform. Even if EEVC WG17 chooses not to adopt this headform, the proposed specification could still be adopted by the EC and included in amendments to the Decision.

1 Introduction

The European Union Directive 2003/102/EC was approved by the European Parliament and by the Council on the 17th of November 2003 and published in the Official Journal of the European Union on the 6th of December 2003 (European Parliament and Council of the European Union, 2003). The Directive makes use of test methods and test tools produced by the European Enhanced Vehicle-safety Committee (EEVC) by their Working Group 10 and later refined by EEVC Working Group 17. However, most of the Directive's technical prescriptions are contained in a separate document, a European Commission (EC) Decision (Commission of the European Communities, 2004). As most experts agreed that requiring full compliance with EEVC WG17 in one step would be too demanding, the Directive introduces pedestrian protection in two stages. The first stage requires pedestrian protection to be provided in new car designs using an adaptation of the EEVC WG17 test methods that is somewhat less demanding. Following a feasibility assessment study, a higher level of pedestrian protection could be provided by a second phase. The feasibility study, carried out by TRL, was completed in June 2004 (Lawrence *et al.*, 2004).

One proposal in the TRL study, made to improve the feasibility of providing protection for the head and to increase compatibility between the test procedures used in Europe and elsewhere, was to reduce the mass of the adult headform impactor from 4.8 kg to 4.5 kg. Headforms are available with a mass of 4.5 kg, and one of these, produced by First Technology Safety Systems (Europe) BV (FTSS), is made by modifying an EEVC 4.8 kg impactor. Therefore it would appear to be very suitable as a substitute for the 4.8 kg impactor in the Directive, if the TRL proposal is accepted. Nevertheless, before a revised impactor can be introduced into the Directive it will be necessary to produce a specification for the headform with appropriate certification requirements, and the EC feasibility report recommended that the EEVC WG17 should be consulted regarding this. The FTSS headform is made to meet the ISO 4.5 kg headform specification which is very similar in most respects to that of the EEVC impactor, the main differences being in the mass, moment of inertia and certification method. Despite the differences in the certification methods both performance requirements link back to the same biomechanical data.

The FTSS 4.8 kg headform impactor (designed and originally supplied by TNO) has already been assessed (White and Lawrence, 2000) and accepted by EEVC WG17 as an 'approved impactor'. Therefore it seems reasonable to assess this new version as an alternative EEVC WG17 impactor.

The objective of the current study is to assess the FTSS 4.5 kg headform impactor's physical and dynamic properties and, if it is found to be suitable, to produce a specification for it that could be adopted by EEVC WG17 if they choose to select it as an alternative headform. The results will be used to propose an impactor specification and dynamic certification corridor for an EEVC WG17 4.5 kg headform. Even if EEVC WG17 chooses not to adopt this headform, the proposed

specification could still be adopted by the EC and included in amendments to the Decision (i.e. the technical prescriptions).

2 Method

A headform impactor, complete with one skin and an accelerometer mounting block, was obtained on loan from FTSS. This headform was assessed as described below and additional information was obtained from FTSS, this additional information is given in Appendix C.

Information was also obtained from JASTI Co. Ltd. on the alternative headform impactors made to meet the ISO 4.5 kg and the Japan Ministry of Land, Infrastructure and Transport (MLIT) adult headform requirement (and also information on their 3.5 kg headform). This information is provided in Appendix D and is discussed later, in Section 4.

2.1 Physical properties

2.1.1 Mass

The masses of the component parts of the headform impactor were found using calibrated scales. The assembled mass (with skin, but no accelerometers) was also measured (FTSS supplied one skin). The accelerometers were omitted for these measurements to prevent errors due to drag of the electrical cable. The mass of three Endevco 7264C-2000 uni-axial accelerometers, each with 100 mm length of cable (6 g) was then added to this weight. (The manufacturer's data sheet gives the mass of each accelerometer as 1 g and the mass of the cable as 9 g/m. A cable length of about 100 mm within the headform was found to be required. Therefore the total mass for all three accelerometers and cables is just under 6g.) No allowance was made for the mass of the accelerometer cables outside the headform as this contributes very little to the effective mass during impact.

2.1.2 Dimensions

The EEVC WG17 test method specifies the diameter and the skin thickness for the adult headform impactor. These dimensions were determined using digital callipers, a micrometer and a vernier height gauge as appropriate.

The outer diameter of the headform was measured in several places with the one skin supplied, fitted to the impactor. The skin was then removed from the impactor and its thickness was measured using a micrometer with a deep throat. Care was taken to ensure that the soft skins were not compressed during these operations and a number of measurements were taken at different locations. These results were then averaged and the extent of variation noted.

Measurements were then taken so that the position of the C of G of the seismic masses of the three elements of the accelerometers in the x, y and z planes could be found. These were taken with the FTSS accelerometer mounting block intended for three Endevco 7264C-2000 uni-axial accelerometers. Measurements of the mounting faces and the heads of the cap head accelerometer fixing screws (screwed down tight) were taken such that they could be related to the geometric centre of the sphere. The position of the seismic mass relative to the accelerometer's centres of the fixing holes and mounting faces was taken from the manufacturer's data sheets and used in conjunction with these measurements. Finally these data were used to determine any errors in relation to the WG17 specification, for the positions of the seismic masses to be within cylindrical and spherical tolerances about the geometric centre of the sphere. It was noted that there was clearance (nearly 0.5 mm) between the accelerometer fixing screw supplied by FTSS and the holes in the accelerometer mounting flange. This clearance would allow some variation in the final accelerometer positions and angles. It was also noted that the clearance holes in the accelerometer mounting block for its two fixing screws had some clearance and that there was only a single off-centre location dowel. These two combined allowed some angular and positional variation in the positioning of the mounting block relative to the headform backplate. It was thought likely that the

worst combination of position and orientation within the clearances provided by the holes for screws would introduce additional deviations in the positions of the seismic mass relative to the geometric centre of the headform. Therefore, for the purpose of these measurements it was decided to assume a ‘good’ location of the accelerometers. This was achieved by aligning the diagonal of the mounting block precisely in its intended position (in line with the slots for the transducer wires) before taking the above measurements and by assuming that the accelerometer clamping screws had no clearance. The effects on the accuracies of positioning the seismic mass of the clearance holes in the accelerometer mounting block and in the accelerometer mounting flanges were then found separately. This was done for each accelerometer by taking the worst combination of these clearances and calculating the consequences as an additional error for each positional tolerance.

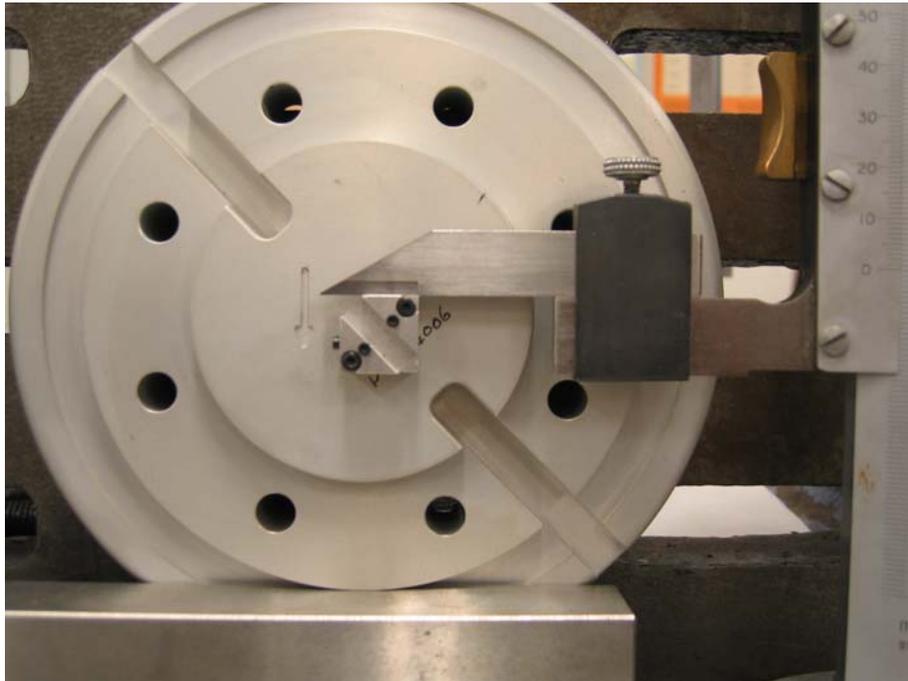


Figure 2.1. Determining the position of an accelerometer mounting face

2.1.3 Centre of gravity of the headform

The centre of gravity (C of G) of the headform was found experimentally. A 25 mm diameter steel rod of known length and mass was inserted into the socket at the rear of the complete headform (without accelerometers). The rod-headform assembly was then placed on to a knife edge support and the balance point was found by adjusting the rod's position on the knife edge. The procedure was repeated three times. The C of G of the headform was then calculated by finding the distance from the geometric centre of the sphere that it needed to be to make equal the clockwise and anticlockwise moments of the headform and the rod assembly about the pivot point. No additional correction was then made for the mass of the three accelerometers and their cables within the headform because their total mass (just under 6g) was considered to be too small to be worth considering. The experimental set-up is shown in Figure 2.2 below.

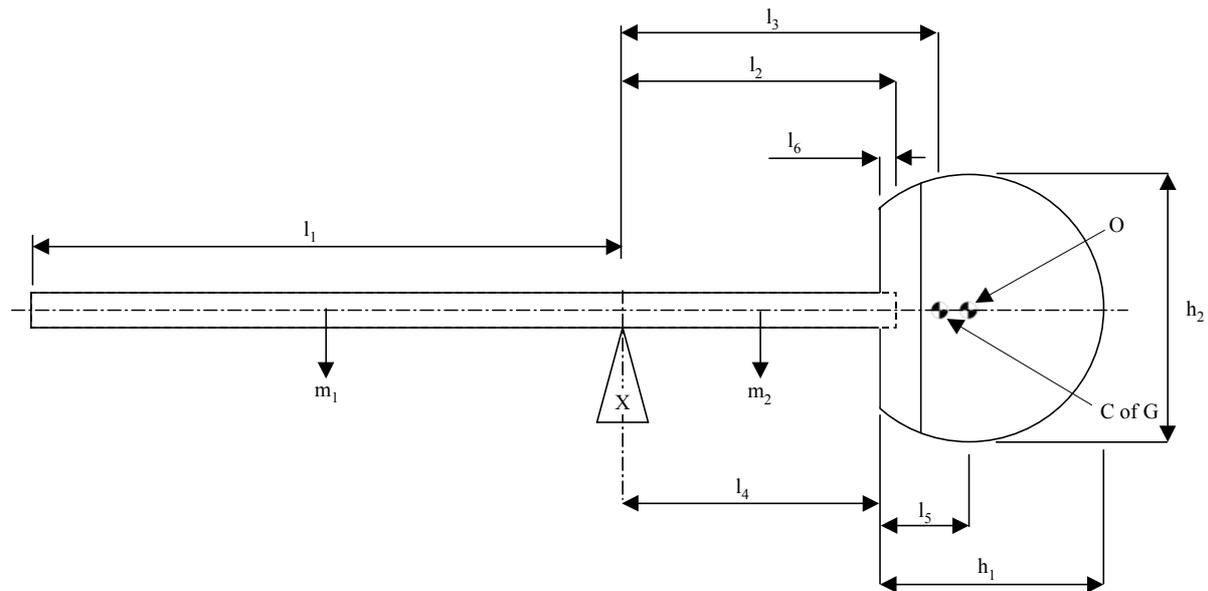


Figure 2.2. Experimental set-up and notation used to calculate the position of the headform's centre of gravity

The measurements and formulae used to calculate the position of the centre of gravity (without an accelerometer) are shown below:

Measured values:

Mass of Rod:	m_R	Overall Height of Headform:	h_1
Mass of Headform:	m_S	Diameter of Sphere:	h_2
Length of Rod:	l_R	Length of Rod to Pivot:	l_1
Depth of Hole in Headform:	l_6		

Calculated values:

$$l_5 = h_1 - h_2/2 \quad l_2 = l_R - l_1 \quad l_4 = l_2 - l_6$$

$$m_1 = (l_1/l_R) \times m_R \quad m_2 = (l_2/l_R) \times m_R$$

Taking moments about pivot 'X':

$$m_1 \times (l_1/2) = m_2 \times (l_2/2) + (m_S \times l_3)$$

$$\text{Position of centre of gravity from centre of sphere (O)} = l_4 + l_5 - l_3$$

2.2 Moment of inertia of the headform

The moment of inertia of the headform about an axis through the C of G and perpendicular to the direction of impact was found using the torsion pendulum. Plasticine (modelling clay) supports were used to hold the headform with its C of G aligned about the centre of the table, with the arrow on the backplate vertical (see Figure 2.3). The period of the table was then found in three conditions below:

- the table with plasticine supports
- the table with plasticine supports and a calibration ring of calculable moment of inertia
- the table with plasticine supports and the headform.



Figure 2.3. Headform on the torsion pendulum table with supporting plasticine

Repeated readings were taken over sufficient cycles to obtain consistent results.

The moment of inertia for the ring (I_R) was calculated from its dimensions and mass. The moment of inertia of the table and plasticine (I_T) was then calculated using the measured periods of oscillation and I_R . It was then possible to determine the moment of inertia of the headform impactor (I_H).

The calculations used are as follows.

$$I_T = I_R T_T^2 / (T_{R+T}^2 - T_T^2)$$

Where I_T = Moment of inertia of table and plasticine.

I_R = Moment of inertia of ring.

T_T = Period of table and plasticine.

T_{R+T} = Period of table, ring and plasticine.

And

$$I_H = I_T (T_{T+H}^2 - T_T^2) / T_T^2$$

Where I_H = Moment of inertia of headform impactor.

T_{T+H} = Period of table, head and plasticine.

The accelerometers were omitted for these torsion pendulum measurements to prevent errors due to dragging of the electrical cables. It was decided that no correction was necessary for the headform's moment of inertia to take account of the effect of a three uni-axial accelerometers and cables. This was because their mass, which lies close to the centre of gravity, is considered too small to have any significant effect on the moment of inertia.

2.3 Dynamic certification

The dynamic certification tests of the 4.5 kg headform supplied were carried out in accordance with the certification procedure for the EEVC WG17 4.8 kg headform impactor. It was decided to select

three equidistant points and to test each point three times in order to get some indication of variability as well as of typical peak values. It was also decided to allow two hours between testing the same point, to allow the skin to recover. Ideally it would have been best to test the area typically involved in vehicle testing. If a typical bonnet angle of 15 degrees is assumed this would mean that the certification impactor would have to be centred on a circle 10 degrees from the headform's fore/aft axis. However, this would have meant a wait of two hours between each test as the deformed areas from each test point would overlap. To obtain an acceptable time for the testing programme an angle of 27 degrees was finally selected so that the area of headform flesh deformed in the certification test of one test point did not overlap with that of the next (TRL estimated a deformed certification contact diameter of 65 mm). In this way, sets of three tests could be conducted without delay before each two hour recovery period. Headform and skin number, time, test point number, temperature, velocity achieved and peak acceleration were all recorded for each test.

Before testing commenced the linear guide of the certification impactor was cleaned and lubricated.

A proposed specification for a 4.5 kg headform impactor was produced by taking nominal values and tolerances directly from the EEVC 4.8 kg adult headform specification or adjusting the 4.8 kg values as appropriate for the reduction in mass. They are referred to as EEVC/TRL values and tolerances in the tables in Section 3 below.

3 Results

The EEVC headform impactors are often referred to as being 'hemispherical' however to be more accurate they should be referred to as a truncated sphere, as shown in the EEVC headform diagram. However, for brevity it will be referred to as a 'hemisphere' or 'sphere' in the following sections.

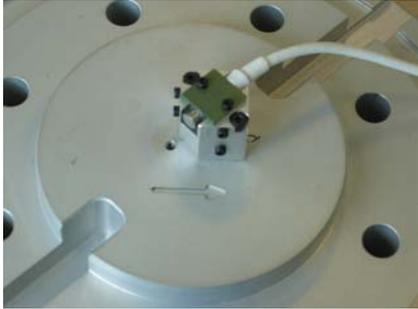
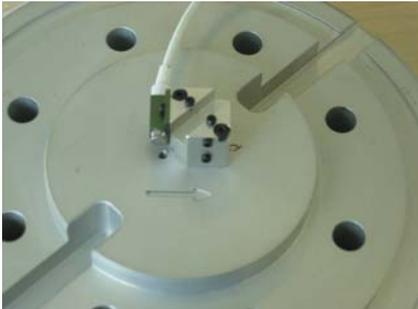
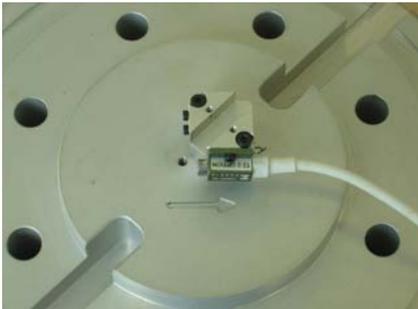
The results of the measurements of mass are given in Table 3.1 below.

Table 3.1: FTSS headform mass compared with the EEVC/TRL values and tolerances

Part	FTSS identification number	Measured mass (kg)	Required value and tolerance (EEVC/TRL)	Within Tolerance?
Backplate (with associated clamping screws, magnetic plate and screws)	DFC04006	1.731	None	
Front 'hemisphere'	DFA04002	1.971	None	
Accelerometer mounting block, type IAU (with associated mounting screws)	None	0.008	None	
Headform skin	DHB05001	0.757	None	
Mass of above as one assembly	N/A	4.467	None	
Allowance for mass of accelerometers and internal cables		0.009	None	
Total		4.476	4.5 ± 0.1 kg	✓

The results of the measurements of headform dimensions of relevance to the EEVC specification are summarised below in Table 3.2. The positions of the seismic mass could not be measured directly, therefore these were found by combining a number of measurements that could be related to the geometric centre of the sphere, as described in Section 2.1.2.

Table 3.2: Results of measurements of dimensions

Dimension	FTSS identification number, etc.	Measured dimension (mm)	Required value and tolerance (EEVC/TRL)	Within tolerance?
Skin thickness	DHB05001	13.9 to 14.0*	13.9 ± 0.5	✓
Overall diameter (assembled)	DFC04006 DFA04002 DHB05001	164.83 to 164.91 †	165 ± 1.0	✓
Position of seismic mass		-3.9 (- = forward)	Cylindrical – along axis 0.00 ± 10 (with respect to geometric centre of sphere)	✓
		$0.16 \begin{smallmatrix} \ddagger \\ +0.05 \\ -0.04 \end{smallmatrix}$	Cylindrical - radial 0.00 ± 1.0 (with respect to geometric centre of 'sphere')	✓
Position of seismic mass		$5.91 \begin{smallmatrix} \ddagger \\ +0.05 \\ -0.04 \end{smallmatrix}$	Spherical 0.00 ± 10 (with respect to geometric centre of 'sphere')	✓
Position of seismic mass		$5.89 \begin{smallmatrix} \ddagger \\ +0.02 \\ -0.02 \end{smallmatrix}$	Spherical 0.00 ± 10 (with respect to geometric centre of 'sphere')	✓

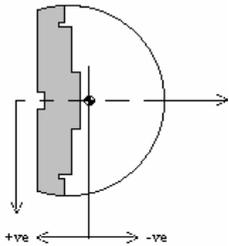
* Range obtained from eight equidistant readings on the 'equator', one reading at the centre of the front face and eight readings on a circle approximately half-way between.

† Range obtained from four readings on the circumference.

‡ These tolerances express the additional potential errors due to clearances in fixing holes; see discussion on this in Section 4.

The measured dimensions and masses found for the experimental set-up shown in Figure 2.2 were used with the equations given in Section 2.1.3 to find the position of the centre of gravity relative to the geometric centre of the sphere; the result is shown in Table 3.3 below.

Table 3.3: Position of centre of gravity found experimentally

Impactor type	Measured C of G (mm)	EEVC requirement	Within tolerance?	Sign convention
4.5 kg adult	+1.38	At geometric centre of sphere within ± 5 mm spherical	✓*	

* Assumed to be well within tolerance laterally due to symmetrical design of all components (except lightweight accelerometers and mounting block)

The measurements made on the torsion pendulum were used to find the moment of inertia using the equations given in Section 2.2; the result is given below in Table 3.4.

Table 3.4: Headform moment of inertia (calculated from torsion pendulum test results)

Impactor type	Measured Moment of inertia (kgm^2)	TRL proposed requirement * (kgm^2)	Within tolerance?
4.5 kg adult	0.0110	0.0110 ± 0.001	✓*

* See discussion on target value in Section 4 below.

The results of TRL's dynamic certification test are given below in Table 3.5. These can be compared with the results of FTSS's dynamic certification test, given in Table 3.6, for the same skin (note that these are not at the same test locations on the skin). The test equipment used by FTSS and the impact velocity were to the same specification as those of TRL (EEVC WG17 4.8 kg) and they can therefore be compared directly.

A comparison of the resultant acceleration time histories from one FTSS and one TRL dynamic certification test on the 4.5 kg headform is shown in Figure 3.1. See also a similar comparison for tests of a 4.8 kg headform, in Figure 3 of Appendix A.

FTSS also provided one set of dynamic certification results for a different skin to that tested by TRL and these are shown in Table 3.7. The average peak resultant from all six tests (Tables 3.6 and 3.7) was 384.0 g.

FTSS also provided the results of a series of drop certification tests, which given in Table 3.8. These tests were to the same skin that was tested by TRL but not the same test locations, the tests used FTSS's certification equipment.

It can be seen in Figure 3.1 that the time history plots for these short duration dynamic certification impacts are not smooth curves if the signal has been sampled at 10 kHz. (In fairness to FTSS, they normally sample at 25 kHz, as in Figures 3 and 4 of Appendix B.) The question was asked as to what effect the sample rate had on the accuracy of the measured peak value, which is used to determine

whether the test has been passed or not. It is generally accepted that a half sine wave is a reasonable approximation to a uni-modal impact signal such as this. The error in the measured peak value depends on how the samples occur in relation to the peak of the analogue sample, with the greatest error occurring when samples are taken half a sample interval before and after the analogue peak. The potential error in the peak value increases as the duration of the signal reduces. It can be seen that a half sine duration of 1 ms would be a reasonable approximation to the time histories in Figure 3.1, ignoring the initial soft rise of the acceleration. With this half-sine duration a worst-case error of 1.2 percent was calculated for a sample rate of 10 kHz. At 20 kHz the worst case error is 0.3 percent and at 25 kHz it is 0.2 percent.

Table 3.5: Results of TRL’s dynamic certification tests (Skin No DHB05001)

Impact position (degrees) (relative to cable)	Backplate angle (degrees)	Time (24h)	Date	Temp (degrees C)	Speed (m/s)	Peak resultant acceleration (g)
0	27.0	11.58	12-Apr-05	19.4	9.98	332.8
+120 (LH)	27.2	12.22	12-Apr-05	18.7	10.09	353.4
-120 (RH)	26.9	13.30	12-Apr-05	18.6	10.01	342.7
					<i>Average</i>	<i>10.03</i>
					<i>Coefficient of variation (%)</i>	<i>0.57</i>
0	26.7	13.35	13-Apr-05	21.6	9.98	338.4
+120 (LH)	27.1	10.11	13-Apr-05	20.2	9.99	335.3
-120 (RH)	29.9	10.20	13-Apr-05	19.9	10.01	336.4
					<i>Average</i>	<i>9.99</i>
					<i>Coefficient of variation (%)</i>	<i>0.15</i>
0	26.9	15.35	13-Apr-05	21.6	9.98	343.4
+120 (LH)	27.1	13.55	13-Apr-05	21.8	10.02	340.1
-120 (RH)	26.8	13.59	13-Apr-05	21.8	9.98	339.4
					<i>Average</i>	<i>9.99</i>
					<i>Coefficient of variation (%)</i>	<i>0.23</i>
					<i>Average of all 9 tests</i>	<i>10.00</i>

Table 3.6: Results of FTSS’s dynamic certification tests to skin DHB05001 (to the same skin that was tested by TRL)

Impact position	Backplate angle (degrees)	Time (24h)	Date	Temp (degrees C)	Speed (m/s)	Peak resultant acceleration (g)
1	N/A	N/A	31-Jan-05	20.7	10.06	392.6
2	N/A	N/A	31-Jan-05	20.7	10.05	389.3
3	N/A	N/A	31-Jan-05	20.7	10.05	389.6
					<i>Average</i>	<i>10.05</i>
					<i>Coefficient of variation (%)</i>	<i>0.06</i>

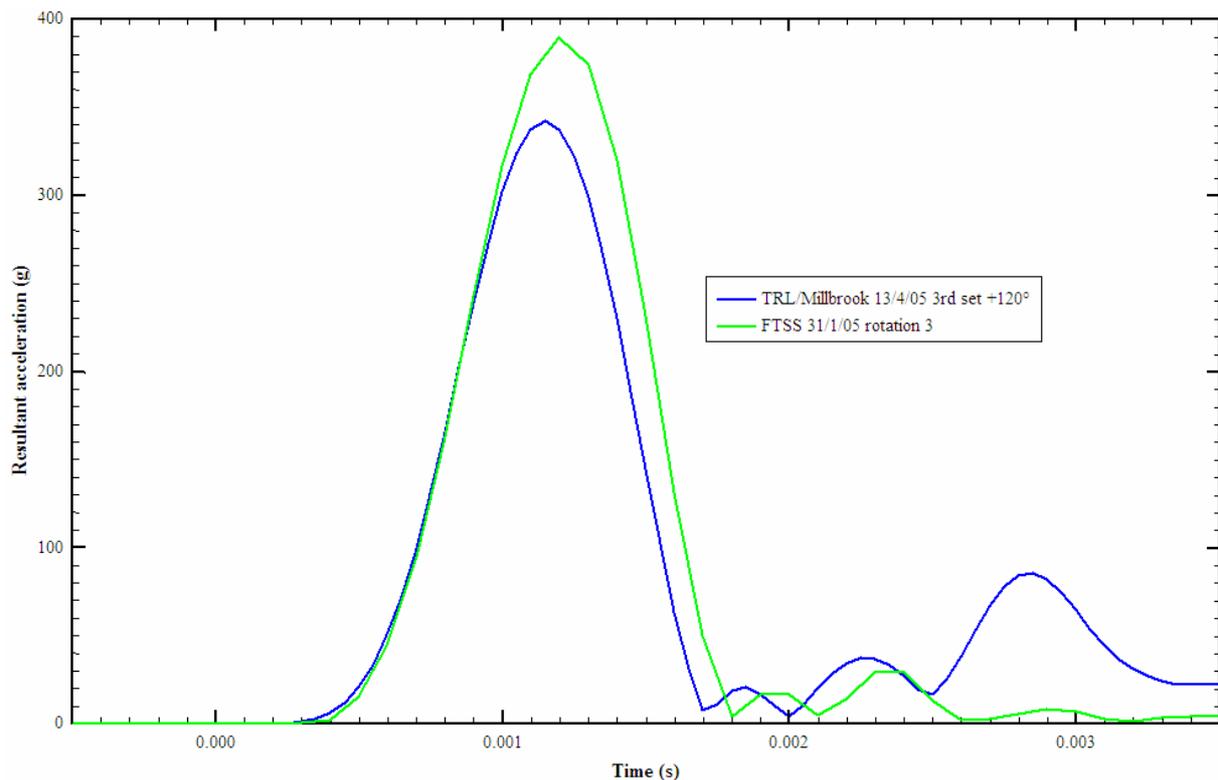


Figure 3.1. Comparison of adult 4.5 kg headform time histories from dynamic certification tests to the same skin, carried out by FTSS and TRL

Table 3.7: Results of FTSS dynamic certification tests to skin DHB05013 (not tested by TRL)

Impact position	Backplate angle (degrees)	Time (24h)	Date	Temp (degrees C)	Speed (m/s)	Peak resultant acceleration (g)	
1	N/A	N/A	28-Feb-05	20.5	10.06	382.3	
2	N/A	N/A	28-Feb-05	20.5	10.08	374.0	
3	N/A	N/A	28-Feb-05	20.5	10.05	376.1	
					<i>Average</i>	<i>10.06</i>	<i>377.5</i>
					<i>Coefficient of variation (%)</i>	<i>0.15</i>	<i>1.14</i>

Table 3.8: Results of FTSS's drop certification tests (to the same headform and skin that was tested by TRL)

Impact position	Backplate angle (degrees)	Time (24h)	Date	Temp (degrees C)	Drop height (mm) (required height 376 ± 1 mm)	Peak resultant acceleration (g)
1	N/A	09.25	31-Jan-05	20.9	N/A	250.0
2	N/A	09.33	31-Jan-05	21.0	N/A	243.3
3	N/A	09.39	31-Jan-05	21.0	N/A	241.1
					<i>Average</i>	<i>244.8</i>
					<i>Coefficient of variation (%)</i>	<i>1.89</i>
					<i>Corridor</i>	<i>225 to 275</i>

4 Discussion

It can be seen from Table 3.1 that the mass of the headform lies close to the nominal value and is well within the proposed tolerance. FTSS have used their Computer Added Design (CAD) system to analyse the effects of their manufacturing tolerances on mass for the worst combination of dimensions and these calculations show that the mass will vary by about plus 0.07 and minus 0.023 kg; therefore the total mass should always be inside the required tolerance, see Table 6 of Appendix 1.

As already noted, it was thought likely that the worst combination of position and orientation within the clearances provided by the holes for screws would introduce additional deviations in the positions of the seismic mass relative to the geometric centre of the headform. The holes concerned are those in the accelerometer mounting block and those in the mounting flanges of the accelerometer. However, these potential errors were removed from the headline measurements reported in Table 3.2. It was noted that the FTSS accelerometer fixing screws were a significantly smaller diameter, at about 1.34 mm, than those supplied by Endevco, of about 1.45 mm. It was assumed that this difference was due to FTSS using a metric alternative to the imperial screw specified by Endevco. The clearance holes in the accelerometer are given by the Endevco data sheet as being between 1.7 and 1.8 mm in diameter. With the distance between the two fixing screws being about 7.5 mm this slack can allow angular errors of about 6 to 7 degrees or radial errors about the nominal screw position of about ± 0.2 mm for the two lateral accelerometers (the fore / aft accelerometer, however, is located by the body being a good fit in a slot and therefore can only be out of position in the direction of the slot). In addition, further errors can be introduced by the clearance in the accelerometer mounting block clamping screw holes, allowing some rotation about the single off-centre locating dowel, by about ± 1 degree. The effects of these clearances were then calculated and have been added as “additional potential errors due to clearances in fixing holes” in Table 3.2. Although it can be seen that these potential additional errors are insignificant, when compared with the specified tolerances, TRL recommends that FTSS consider improving the methods used to locate the accelerometers. This might be achieved by providing two locating dowels to locate the accelerometer mounting block onto the backplate and some additional location for the accelerometers themselves. For improved accelerometer location there are two options suggested by TRL: (a) the use of fixing screws with a larger diameter portion under the head to locate in the fixing hole in the accelerometer flanges, or (b) the provision in the block, at each accelerometer location, of two perpendicular faces or shoulders against which one end and one side of the accelerometer flange can be pressed whilst the screws are tightened. Of these TRL prefers option (b). Nevertheless the current FTSS headform and accelerometer mount clearly meet the positional tolerances for the positions of the accelerometer seismic masses.

It should be noted that TRL did not assess the current FTSS uni-axial accelerometer mounting block when previously assessing the 4.8 and 2.5 kg headforms (White and Lawrence, 2000), as at that time the recommended accelerometer was a tri-axial (an Endevco 7267A) and the positional requirements and tolerance were also different (less demanding). Therefore the comments above also apply to the current EU Directive’s 4.8, 3.5 and 2.5 kg headforms.

FTSS have used their CAD system to determine the positions of the accelerometer seismic masses and it was found that this theoretical study gives very similar results to the TRL physical measurements, see Table 5 of Appendix C.

The position of the centre of gravity for the assembled headform, found experimentally to be +1.38 mm, was well inside the required tolerance. In comparison, FTSS using their CAD system calculate a theoretical error of 0.54 mm which is within the expected experimental error of the TRL method. It is thought that manufacturing tolerances for individual components, that meet the tolerance on total mass, are very unlikely to move the centre of gravity outside its tolerance. However, FTSS might consider carrying out a sensitivity analysis of their manufacturing tolerances to confirm this.

The measured moment of inertia of the FTSS 4.5 headform was found to be 0.0110 kgm^2 . Currently EEVC WG17 has no target value for the moment of inertia for a 4.5 kg headform. The WG17 requirement for their 4.8 kg headform is a moment of inertia of $0.0125 \pm 0.001 \text{ kgm}^2$ and using the ratio of masses gives a pro rata value of $0.0117 \pm 0.0009 \text{ kgm}^2$. However, the philosophy of WG17, for originally deciding what moment of inertia to specify, was to first develop a design that met all

their more critical targets including: mass, certification performance and accelerometer mounting requirements. Then, once they had developed child and adult impactors to meet these requirements they fixed their moment of inertia requirement about the nominal value of those designs and added a comparatively small tolerance. The pedestrian working group of the International Organization for Standardization (ISO WG2) also decided that the moment of inertia was less important than other requirements. However instead of fixing a small tolerance around an acceptable impactor they have chosen to specify a large tolerance (0.0075 to 0.02 kgm² for their 4.5 kg impactor). A wide tolerance as specified by ISO might result in two or more complying headform designs that give slightly different results in vehicle tests, especially in tests that are not normal to the surface. As car manufacturers are requesting that variability be minimised, the EEVC approach of specifying a tight tolerance about the value obtained with a satisfactory headform design appears the best approach. Although the measured moment of inertia of the FTSS headform lies within the pro rata tolerance of the EEVC 4.8 kg headform it lies towards the lower end. Therefore, TRL propose that the moment of inertia values be fixed around the value found for the FTSS design, which is a modified version of the 4.8 kg headform that has already been used for many years, and has been proven to meet the EEVC requirements and to be robust and durable. This would give a moment of inertia requirement of 0.0110 kgm². A pro rata value for the tolerance would be ± 0.0009 kgm², however it is proposed to retain the original tolerance of ± 0.001 kgm² as the adjustment is so small. Again, FTSS have used their CAD system to calculate the effect of nominal values and the worst combination of manufacturing tolerances on moment of inertia. They have obtained a very similar nominal value to that of TRL and the worst combination indicates that the moment of inertia will always be within the proposed tolerance.

The biomechanical performance the heads of occupant dummies are often specified in terms of a peak acceleration corridor when the head is dropped a prescribed distance onto a rigid steel plate. This method has the advantage that it links back directly to biomechanical data obtained from tests with similar impact conditions. However, pedestrian accidents often result in higher head impact velocities than used in these biomechanical tests. The EEVC test methods require a headform test speed of 40 km/h, which is far higher than that obtained in a drop test of a few hundred millimetres. Therefore, EEVC WG17 decided to transfer the biomechanical data to a high-speed certification test by first making a headform and a number of headform skins that complied with the drop test corridor and then specifying a high-speed certification corridor about the data obtained from a large number of certification tests using their high-speed 1 kg linearly-guided impactor method. This method of transfer can be used once again for a 4.5 kg headform impactor. It is therefore helpful that the headform skin supplied by FTSS has a performance that is in the middle of the drop test corridor (see Table 3.8) making it ideal for obtaining the middle of a high-speed test corridor.

Certification tests are used to test the complete impactor system and show that its performance is as intended. It can be seen that the dynamic certification results obtained by TRL and FTSS are repeatable. However, the TRL results are significantly lower than those of FTSS. This trend has also been found with the FTSS 2.5 kg child and the 4.8 kg adult headforms, where again TRL (at their Millbrook facility) obtain lower resultant accelerations than FTSS with the same headform skin. A TRL committee paper for WG17 is reproduced in Appendix A; this presents and discusses the differences found between TRL's and FTSS's results with the 2.5 kg and 4.8 kg headforms. TNO and others have also found differences between their certification results and those of FTSS, however, an investigation by Been (2002) failed to identify the cause. It is possible that one or both test facilities (TRL and FTSS) have some subtle differences or flaws in their equipment or procedures. The TRL comparison paper in Appendix A appears to show that there is a difference in the actual impact velocity or impact energy of the impactor. This is likely to be due to either velocity measurement equipment that give a systematically high reading at TRL or a low reading at FTSS or due to frictional effects in the linear guide of the 1 kg impactor removing energy at TRL or adding energy at FTSS. However, without a thorough investigation these possible causes of these differences are more conjecture than fact. It is thought that most other test houses tend to obtain results somewhere between those of TRL and those of FTSS. Without knowing the cause of the differences it is not possible to know whether the corridor should be centred about the TRL or FTSS results. From the current data there are three options for producing a provisional certification corridor:

- A corridor of the same width as for the current 4.8 kg headform (75 g) centred about the FTSS results.
- A corridor of the same width as for the current 4.8 kg headform centred about the TRL results.
- A wider corridor than for the current 4.8 kg headform (100 g) centred about the midpoint of the FTSS and TRL mean results. This midpoint is 362.1 g.

With some rounding these three options would give 342.5 to 417.5 g, 302.5 to 377.5 g and 310 to 410 g respectively. Given the uncertainties about which, if any, results are 'correct' TRL would prefer the third option in order to provide a workable provisional requirement. However, TRL consider it essential that the cause of these differences be established and an appropriate solution be found. Once this has been done, a narrower corridor can then be defined and used.

TNO when developing the current headform dynamic certification test had a target of producing a repeatable test method that produced a headform impact similar to the protection criterion of HIC 1000. They also decided to avoid the use of a deformable impact partner, because although this would provide a more realistic representation of a 'good' pedestrian friendly car, it would also add complications in controlling the performance of the deformable partner. However, this combination of targets resulted in a high-speed dynamic certification test procedure using a comparatively lightweight rigid certification impactor that produces a very short duration impact when compared with a pedestrian friendly car; this can be seen in Figure 4.1. In hindsight it would have been better to devise a certification test method that better matched both the acceleration amplitude and acceleration duration of a 'good' car bonnet. Therefore developing such a new test method might be a good alternative to investigating and resolving the problems with the current one.

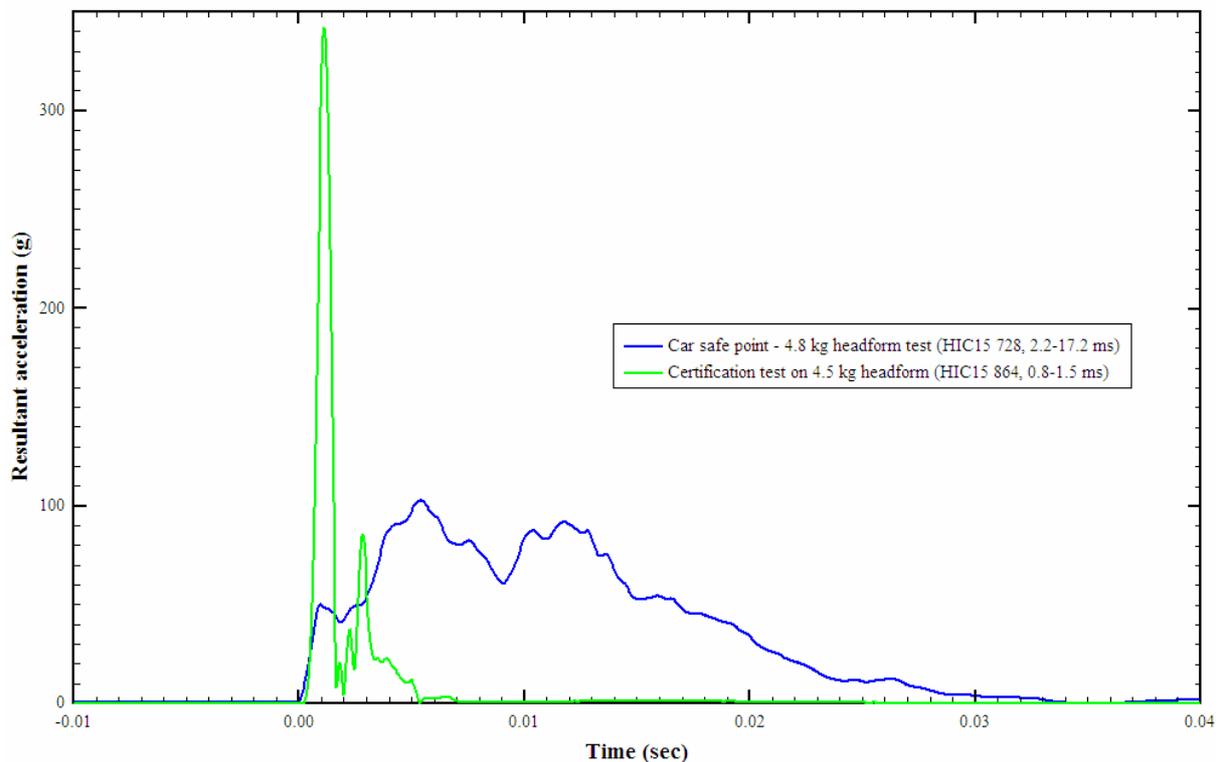


Figure 4.1. Comparison of time histories from a dynamic headform certification test (10.0 m/s) and a headform to bonnet test on a safe point on a car (11.1 m/s)

With the exception of the issues relating to the dynamic certification method and suitable corridors, it can be seen that the FTSS 4.5 kg headform meets all of the requirements of the proposed specification (given in the results tables) which has been copied or adapted from EVC WG17's specification for their 4.8 kg headform. The necessary changes to the adult headform specification and certification

requirements for a 4.5 kg adult headform have been made to appropriate extracts from the technical prescription for the implementation of Article 3 of the Directive 2003/102/EC and are given in Appendix A.

The Japan Ministry of Land, Infrastructure and Transport (MLIT) with the help of IHRA, the Japan Automobile Manufacturers Association, Inc. (JAMA) and the Japan Automobile Research Institute (JARI, who are also members of the ISO and IHRA working groups) have developed a pedestrian head protection requirement. The Japanese requirement is based on the ISO / IHRA headform specifications for 3.5 kg child and 4.5 kg adult impactors. With the exception of the wide moment of inertia tolerance, the 4.5 kg adult MLIT headform specification is very similar to that proposed for an EEVC WG17 4.5 kg headform. Headforms to meet this specification have been developed by JARI under contract to JAMA (Matsui *et al.*, 2003; Matsui and Tanahashi, 2004). It would obviously help global harmonisation if it could be shown that the JAMA-JARI headform meets the EEVC specification. TRL thought it likely that the actual moment of inertia of this design might lie close to or within the proposed EEVC WG17 tolerance. Therefore the manufacturer of the JAMA-JARI adult headform (JASTI Co., Ltd.) was asked to provide data on the properties of their headform. It can be seen from data provided by JASTI Co., Ltd, reproduced in Appendix D, that the JAMA-JARI 4.5 kg headform complies with the proposed EEVC specification. As well as providing data from their CAD design software (Computer Aided Design) JASTI also provided TRL with the results from physical measurements of two examples of their 4.5 kg headform. These data also show that these two examples of their headform comply with the proposed EEVC specification.

There have been a number of reports of problems with headform accelerometers being excited into resonance. This happens particularly in windscreen impacts, but can happen more rarely in bonnet impacts. In windscreen impacts the acceleration decays very rapidly when the windscreen breaks; this step change in acceleration is likely to be exciting the accelerometer resonance. Because of this it would be preferable to use damped accelerometers, to avoid this resonance. The JAMA-JARI headform has been developed with two versions, one uses undamped accelerometers but is able to meet the ISO (and EEVC) tolerances for accelerometer position; this is the version discussed in the previous paragraph. The other uses a Japanese made damped accelerometer type, but cannot meet the ISO (or EEVC) tolerances on accelerometer position because of its large size. However, TRL now understands that a much smaller version of this accelerometer has been developed. This will allow the headform to meet much tighter tolerances on accelerometer position. It is small enough that it would probably meet any of the various sets of tolerances (EEVC WG17, EU Directive, GTR, IHRA, ISO, Japan MLIT) with the correct mounting block. The use of this accelerometer should be considered when more details are available, and if it appears to be suitable its use should be encouraged.

It was estimated that sampling these short duration dynamic certification impacts at 10 kHz could give an error in the measured peak value of 1.2 percent, which would be an error of 4-5 g in the peak value. While this error is not large it is not negligible either, especially if it is compared instead to the width of the pass corridor. Most test houses currently sampling at 10 kHz will have equipment that would be capable of higher sample rates. It is therefore recommended that a sample rate of at least 20 kHz be used in dynamic headform certification tests. This is a best practice recommendation to test houses, not a proposal for a change to the test procedure. This recommendation should be included in the headform users' manual. The error in HIC value in vehicle tests, caused by using a 10 kHz sample rate, is expected to be much smaller in percentage terms, especially in tests to safe vehicles such as the test shown in Figure 4.1; therefore no recommendation is made for higher sample rates in vehicle tests.

5 Conclusions

- 1) A proposed specification for a 4.5 kg headform impactor has been produced based on the EEVC WG17 4.8 kg adult headform specification, see Appendix A.
- 2) A 4.5 kg headform impactor and skin has been obtained from FTSS and assessed against the proposed specification.
- 3) The FTSS headform was found to comply with the proposed specification for dimensions, mass, moment of inertia, and position of centre of gravity and accelerometer seismic masses relative to the geometric centre of the truncated sphere.
- 4) FTSS has provided theoretical (CAD) data which support the data derived by TRL from physical measurements. The FTSS data suggest that a worst combination of manufacturing tolerances will not take the headform out of tolerance.
- 5) Dynamic certification tests have been carried out by TRL and these show that:
 - a) The headform skin provided with the headform gives consistent results at TRL.
 - b) TRL obtain lower acceleration results than FTSS when they tested the skin before supplying it to TRL. (TRL and others have found similar disparities in dynamic certification test with the FTSS 2.5 and 4.8 kg headforms.)
- 6) The origins of the current dynamic certification method have been discussed and it is suggested that in hindsight it would have been better if it had been made to match both the acceleration amplitude and acceleration duration of a 'good' pedestrian friendly car bonnet.
- 7) TRL consider it to be essential that the cause of the differences in dynamic certification results between different test houses be established and an appropriate solution be found. Alternatively a new certification method might be developed as an alternative to investigating and resolving the problems with the current one.
- 8) Information has been obtained from JASTI Co., Ltd, that shows that the JAMA-JARI 4.5 kg headform also complies with the proposed EEVC WG17 specification; however, the hardness of the skin may need some minor adjustments once EEVC WG17's dynamic certification requirements have been finalised.
- 9) As a matter of best practice it is recommended that a minimum sample rate of 20 kHz be used in dynamic headform certification tests.

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Appendix A. Headform certification – comparison of FTSS & Millbrook results with same skins (EEVC WG17 / DOC 260)

FTSS's certification tests are those carried out routinely before head skins are despatched to customers. Note: test points on the skins are not comparable between different test series, and FTSS and Millbrook were not using the same head sphere.

Table 1. Peak resultant accelerations (g)

	Adult (skin DBB 04029)	Child (skin DAB 04022)
FTSS (TRL) *	391, 383, 403	474, 464, 466
FTSS (FTSS) **	390.8, 383.4, 402.6	477.3, 467.7, 467.5
Millbrook, July 2004	345, 346, 339	412, 407, 413
Millbrook, Sept / Oct 2004	369, 352, 362	448, 412, 409

* Data processed by TRL. FTSS is understood to have a low frequency hardware filter (3 kHz); this in combination with TRL's CFC 1000 digital filter may have caused excessive filtering (outside CFC 1000 corridor), but this is probably not significant.

** Values from FTSS's certification sheets.

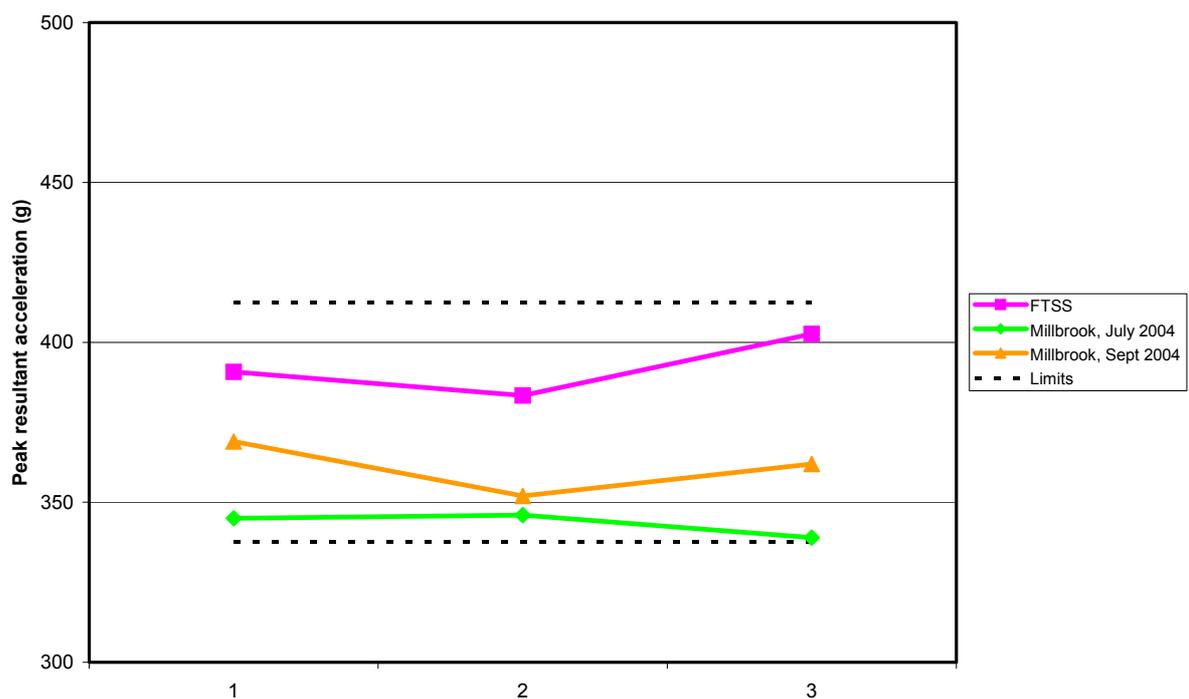


Figure 1. Comparison of adult headform certification results

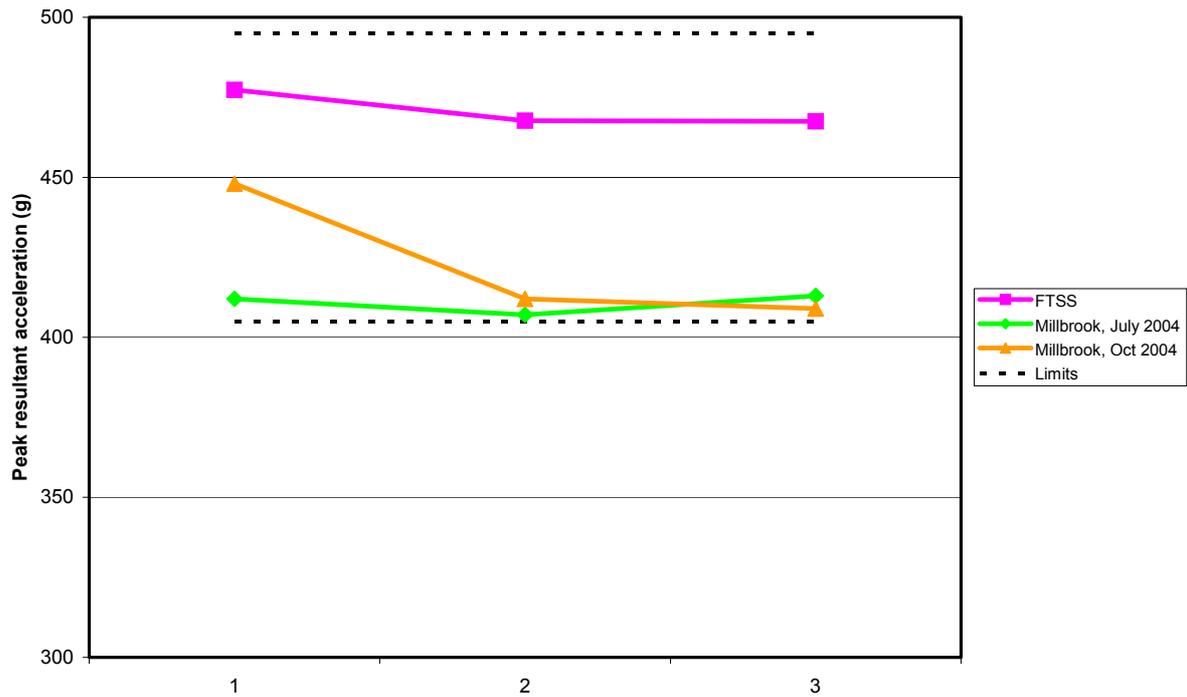


Figure 2. Comparison of child headform certification results

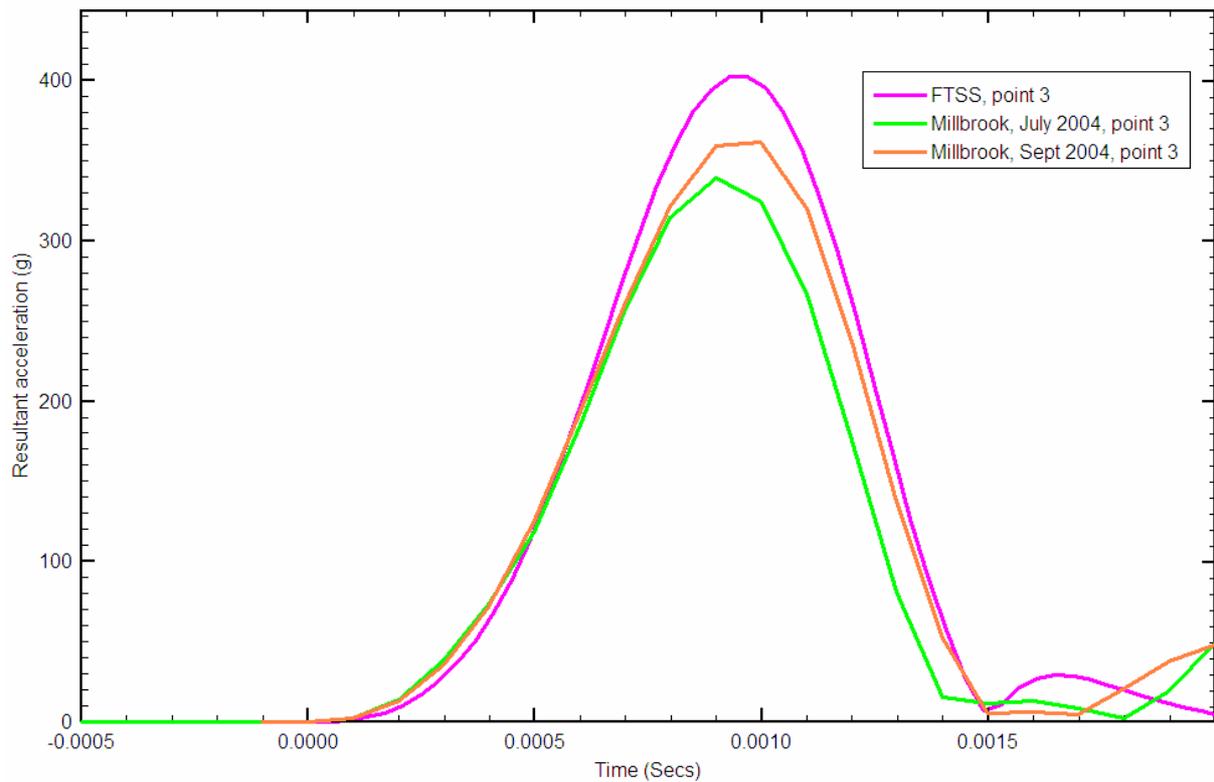


Figure 3. Comparison of adult headform time histories

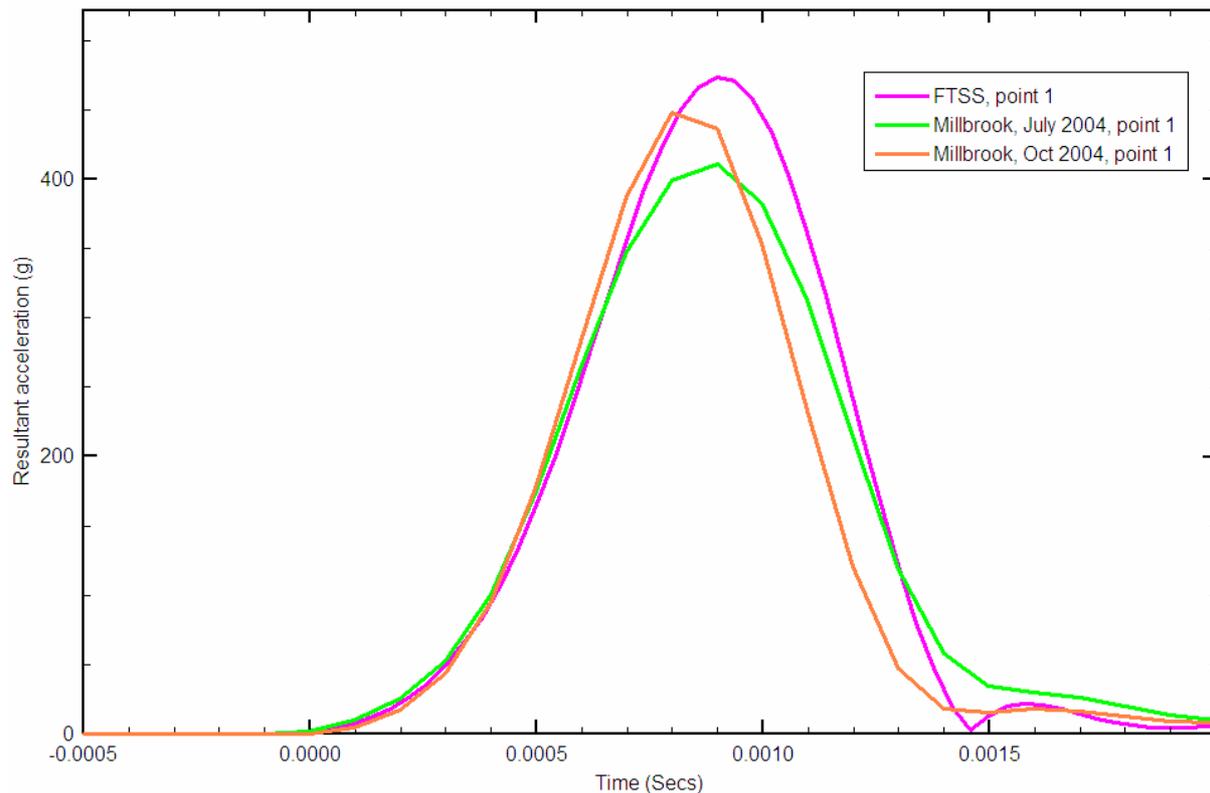


Figure 4. Comparison of child headform time histories

- It can be seen in Figures 1 and 2 that FTSS's results give higher accelerations than those obtained at Millbrook.
- The later Millbrook results tend to be closer to the original FTSS results than were Millbrook's earlier results. This suggests that ageing effects on the head skin are not the cause of the differences found.
- Adult headform time histories are compared in Figure 3. Point 3 data were selected as the differences are greater. While these are resultant accelerations, they should be very close to the acceleration vector in the impact direction, especially over the main part of the impact. The impact should be in line with the headform centre of gravity, so the headform shouldn't rotate significantly. The integral of these curves should therefore provide an indication of the headform's velocity change, and this ought to be fairly consistent for impacts within the certification impactor's velocity tolerance, as the rebound phase (i.e. coefficient of restitution) probably doesn't vary much. However, it can be seen that there are significant differences in the area under the curves in Figure 3, both between the FTSS and Millbrook results and between the two Millbrook results. The Millbrook test integrals are 17 percent (July) and 7 percent (Sept) lower than that of the FTSS test. This could be caused by differences in impact velocity or by some other mechanism that loses or gains energy during the impact. It isn't possible from these data to decide which of these results is most nearly correct.
- Child headform time histories are compared in Figure 4. The Millbrook test integrals are 5 percent (July) and 13 percent (Oct) lower than that for the FTSS test. Again, the FTSS result implies a greater velocity change but this time the velocity change doesn't account for the difference between the Millbrook results, as the higher Millbrook peak is from the test with the lower velocity change.
- The lower sample rate used by Millbrook (10 kHz) will have slightly reduced peak values and integrals, but probably not by enough to affect the above conclusions.

Appendix B. Extract from EC Decision with proposed changes to the specification, to switch from a 4.8 to a 4.5 kg adult headform impactor for phase two

Notes:

Some of the changes proposed by the feasibility study contractor (TRL) could be put into phase one as well as phase two, including the new BLE energy & velocity graphs. It has been assumed here that the 4.8 kg headform would be retained for the phase one windscreen tests; however the EC could choose to use the 4.5 kg headform for this test also. (It has been assumed that the Decision as amended would still include both phase one and phase two tests.)

In the proposed changes below it has also been assumed that the proposed change to use the 3.5 kg child / small adult headform, instead of the 2.5 kg headform, will be accepted for phase two. It has been assumed that the current name of the 3.5 kg headform would be retained, however if the 2.5 kg headform were dropped the 3.5 kg headform could be referred to as a 'child headform' with much less risk of confusion.

Chapter VII: CHILD/SMALL ADULT AND ADULT HEADFORM TO BONNET TOP TESTS

3.4.1 Test apparatus

3.4.1.1 The adult and child/**small adult** headform impactors shall be rigid spheres fitted with a synthetic skin and shall comply with Section 4 of this Chapter and with Figures 13 and 14 respectively of this Part. **The diameter shall be 165 ± 1 mm for both headforms**, as shown in Figures 13 and 14. The total impactor masses, including instrumentation, shall be 4.5 ± 0.1 kg for the adult headform and 3.5 ± 0.07 kg for the child/**small adult** headform impactor.

4. HEADFORM IMPACTORS

4.1. Adult headform impactor

4.1.1 The adult headform impactor is a sphere made of aluminium and of homogenous construction.

4.1.2 The sphere shall be covered with a 13.9 ± 0.5 mm thick synthetic skin, which shall cover at least half of the sphere.

4.1.3 The centre of gravity of the adult headform impactor, including instrumentation, shall be located in the centre of the sphere with a tolerance of ± 5 mm. The moment of inertia about an axis through the centre of gravity and perpendicular to the direction of impact shall be 0.0110 ± 0.001 kgm².

The text of Sections 4.2 to 4.2.4.2 of Chapter VII, Child headform impactor, should be replaced by the text of Sections 4 to 4.4.2 of Chapter V.

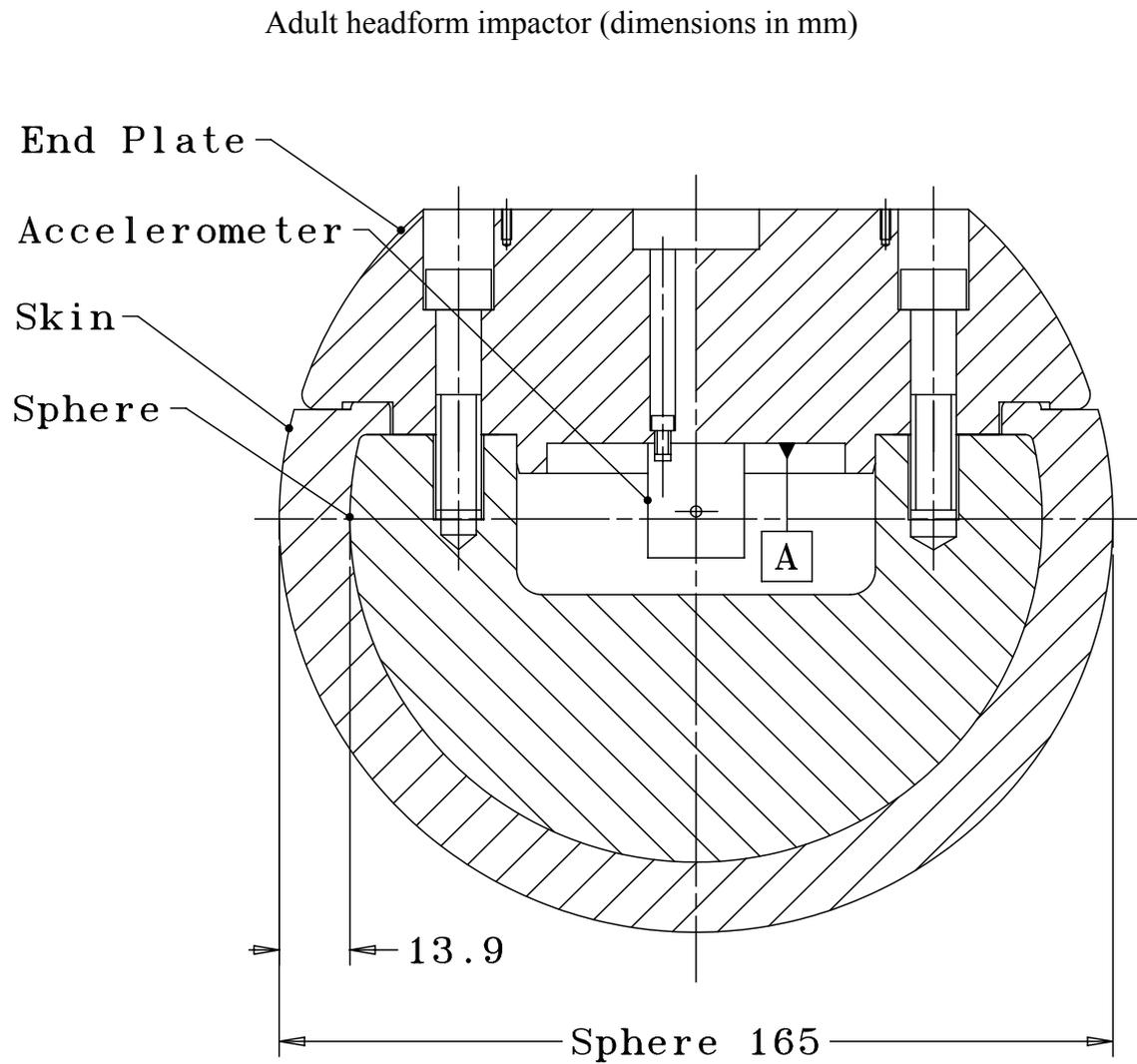
Figure 13

Figure 14 of Chapter VII, Child headform impactor, should be replaced by Figure 10 of Chapter V.

APPENDIX I

CERTIFICATION OF IMPACTORS

1. CERTIFICATION REQUIREMENTS

- 1.1 The impactors that are used in the tests detailed in Part II are required to comply with appropriate performance requirements.

The requirements for the lower legform impactor are specified in Section 2; the upper legform impactor requirements are specified in Section 3 and the adult, child and child/small adult headform impactor requirements are specified in Section 4.

4. HEADFORM IMPACTORS

- 4.1 The **child**, child/small adult and the adult headform impactors shall meet the requirements specified in paragraph 4.2 when tested as specified in paragraph 4.3.

The stabilised temperature of the impactors during certification shall be $20^{\circ} \pm 2^{\circ}$ C.

4.2 Requirements

~~4.2.1 When the child headform impactor is impacted by a linearly guided certification impactor, as specified in paragraph 4.3, the peak resultant acceleration measured by one triaxial (or three uniaxial) accelerometer in the headform shall be not less than 405 g and not more than 495 g. The resultant acceleration time curve shall be uni-modal.~~

- 4.2.2 When the child/small adult headform impactor is impacted by a linearly guided certification impactor, as specified in paragraph 4.3, the peak resultant acceleration measured by one triaxial (or three uniaxial) accelerometer in the headform shall be not less than 290 g and not more than 350 g. The resultant acceleration time curve shall be uni-modal.

- 4.2.3 When the adult headform impactor is impacted by a linearly guided certification impactor, as specified in paragraph 4.3, the peak resultant acceleration measured by one triaxial (or three uniaxial) accelerometer in the headform shall be not less than **310** g and not more than **410** g. The resultant acceleration time curve shall be uni-modal.

- 4.2.4 The instrumentation response value CFC, as defined in ISO 6487:2000, shall be 1000. The CAC response value, as defined in ISO 6487:2000, shall be 1000 g for the acceleration.

4.3 Test procedure

- 4.3.1 The headform impactors shall be suspended as shown in Figure 7. The headform impactors shall be suspended with the rear face at an angle between 25° and 90° with the horizontal, as shown in Figure 7.

- 4.3.2 The certification impactor shall have a mass of 1.0 ± 0.01 kg. This mass includes those propulsion and guidance components which are effectively part of the impactor during impact. The linear guidance system shall be fitted with low friction guides which do not contain any rotating parts. The diameter of the flat impactor face shall be 70 ± 1 mm, while the edge shall be rounded by a 5 ± 0.5 mm radius. The face of the certification impactor shall be made of aluminium, with an outer surface finish of better than 2.0 micrometers.
- 4.3.3 The certification impactor shall be propelled horizontally at a velocity of 7.0 ± 0.1 m/s into the stationary ~~child and~~ child/small adult headform impactors and at a velocity of 10.0 ± 0.1 m/s into the stationary adult headform impactor. The certification impactor shall be positioned so that the centre of gravity of the headform impactor is located on the centre line of the certification impactor, with tolerances of ± 5 mm laterally and ± 5 mm vertically.
- 4.3.4 The test shall be performed on three different impact locations on each headform impactor. Previously used and/or damaged skins shall be tested in those specific areas.

Table 1: Summary of response requirements for headform impactors

Impactor & mass	Certification velocity [m/s]	Lower Boundary [g]	Upper Boundary [g]
Child 2.5 kg	7	405	495
Child/small adult 3.5 kg	7	290	350
Adult 4.5 kg	10	310	410
Adult 4.8 kg	10	337,5	412,5

Appendix C. Additional information provided by FTSS

CAD Analysis for FTSS ISO 4.5 kg Adult Pedestrian Head Form Impactor

CAD Analysis for FTSS ISO 4.5 Kg Adult Pedestrian Head Form Impactor.

FTSS Part no: D.H

Document date: 22 April 2005

Introduction:

The ISO Head form Impactors (4,5 KG) have been developed in 2003 based upon the design of JARI-JAMA presented in paper 443 “Development of JARI-JAMA Pedestrian Child and Adult Head-Form Impactors”, Yasuhore Matsui, et al.¹

The head forms complies with the ISO Adult head biofidelity requirements, as described in the document mentioned above, and is certified according to the standard adult head drop test similar to the CFR 49, part 572, subpart E head drop test. As well as a high speed tests according to the EC/2004/90 Directive

Table 1: Specifications as described in ISO/TC22/SC10/WG2 N622 an N623

Specifications		
Mass		4.50 ± 0.100 Kg.
Diameter		165 ± 1 mm
Skin thickness		Not specified
Location of C.G.		± 10 mm from the Ge.C
Mass Moment of Inertia Y and X-axis about C.G. (perpendicular to direction of impact)*		0.0075- 0.0.200 kgm ² *
Seismic mass location of accelerometer	X-direction	± 10 mm of Ge.C*
	Y-direction	± 10 mm of Ge.C*
	Z-direction	± 1 mm (in X-Y dir) of Ge.C* ± 10 mm in Z-direction of Ge.C*
Seismic mass location of accelerometers X-Y		Within 10 mm radius of Ge.C

Ge.C = Geometric centre of the sphere.

C.G = Centre of Gravity.

X-direction = perpendicular to impact direction.

Y-direction = perpendicular to impact direction.

Z-direction = impact direction

*Not specified in ISO requirements, reference Japan MLIT.

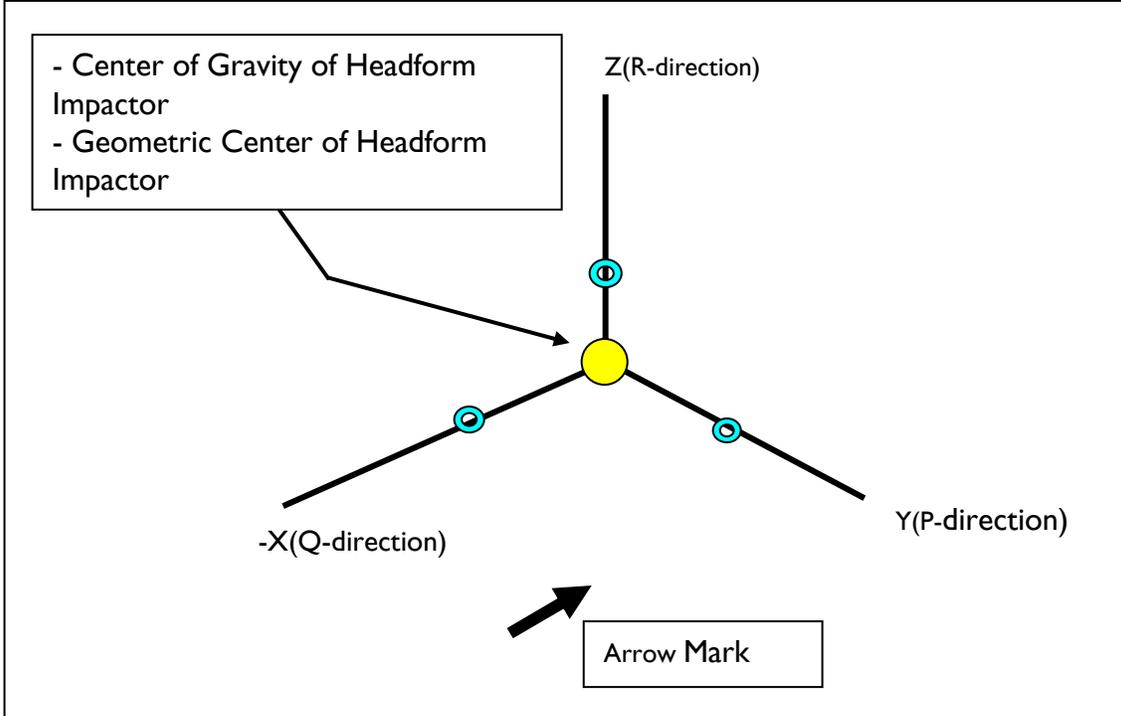
The design and specification of the headform has been based upon the design made by TNO Automotive, modification to this design have been made in 2003 to accommodate changes from regulatory bodies. These changes are reflected in the specifications in the table above.

¹ Development of JARI-JAMA Pedestrian Child and Adult Head-Form Impactors”, Yasuhore Matsui, et al, paper 443.



Below is the coordinate system for the headform impactors.

Z-direction = direction of Flight.



Results:

The results of the CAD analyses can be found in the tables 3 to 8 below. These results show that the required parameters are within the limit values as set out in the directive (table 1).

Table 2: Parts list for analyses 4.5 Kg. Impactor

Description	QTY
ADULT SPHERE 4,5 KG, IMPACTOR	1
SKIN PVC ADULT	1
ADULT END PLATE FOR 4,5 KG	1
SCREW M8 Cap head x 40 Long	6
SCREW M2 Cap head x 16 Long	2
Endevco 7268C accelerometer	1

Optional Accelerometer Arrangement

Mounting block	1
SCREW M1.4 Cap Head x 3 Long	6
Endevco 7264C accelerometer	3



Table 3: MMI analyses

Moment of Inertia [kgm ²]	Around	Calculated value	Japan MLIT Specification
4.5 Kg Impactor, calculated value	X-axis	0.0111 kgm ²	0.0075-0.0200 kgm ²
	Y-axis	0.0116 kgm ²	0.0075-0.0200 kgm ²
	Z-axis	0.0123 kgm ²	No spec.

Table 4: Location of CG of 4.5 Kg impactor

4.5 Kg Impactor	X	Y	Z
CG from Geometric Centre of Sphere	< 0.01 mm	< 0.01 mm	0.54 mm

Table 5: Location of acceleromter 7264C (3x) seismic masses from Ge.C
Used Mount block I.AU

Accl seismic mass positions to Geometric Centre of Sphere	X	Y	Z
X-Direction	-5.79 mm	0 mm	0 mm
Y-Direction	0 mm	5.79 mm	0 mm
Z-direction	0	0	3.87 mm

Tolerance study:

The FTSS 4.5 KG Adult headform impactor machined parts are manufactured and inspected to a tolerance of 0.1 mm. In order to see the effect of a possible deviation from the specified MMI and CG an additional Cad analyses was carried out. This analysis was done with the sphere and endplate outer surfaces 0.1 mm smaller, at smallest dimension which is acceptable within the specified tolerances.

Table 6: Tolerance study for headform MMI.

Case	Moment of Inertia [kgm ²]	Mass [kg]	X-axis [kgm ²]	Y-axis [kgm ²]	Z-axis [kgm ²]
	Specification as Japan MLIT	4.50 ±0.100	0.0075- 0.0200	0.0075- 0.0200	
0	Nominal values 4.5 kg impactor w/o accelerometers or wires.	4.491	0.01110	0.01105	0.01213
1	4.5 Kg Impactor, calculated value with all dimensions at min. tolerance	4.468	0.01101	0.01096	0.01206
2	4.5 Kg Impactor, calculated value with all dimensions at max. tolerance	4.561	0.01131	0.01126	0.01236
3	All end-plate tolerances at max. all sphere tolerances at min.	4.491	0.01110	0.1105	0.01213



Table 8: Tolerance study for C.G. position

Case	CG from Geometric Centre of Sphere,4.5 Kg Impactor	X	Y	Z
1	calculated value with 0.1 mm taken from sphere outer diameter and end plate	< 0.01mm	< 0.01mm	0.59 mm
2	calculated value with all dimensions at max. tolerance	< 0.01mm	< 0.01mm	0.54 mm
3	All end-plate tolerances at max. all sphere tolerances at min.	< 0.01mm	< 0.01mm	0.84 mm

Author: Wiebe Onvlee

Dated: April 22, 2005

Appendix D. Information provided by JASTI on the alternative Japanese 3.5 and 4.5 kg headforms

Key information has been selected from that supplied by JASTI. TRL comments are in {}.

To: Mr G. Lawrence of TRL

ISO/Japanese Head Form Impactor

Prepared by JASTI Co., LTD

May/2005

Contents;

1. General
2. 4.5kg Adult Head form impactor
3. 3.5kg Child Head form impactor
4. Calibration method
5. Biofidelity by two calibration methods
6. Specification of seismic mass of each accelerometer
7. Summary

1. General

JASTI has been involved to develop JARI/JAMA head form impactors since 2001.

We were requested to develop only the skins for Adult and Child headform impactor as the original project. Then, we faced to control the best certification result which was very much influenced by a head core surface smoothness or roughness.

We tested many different surface finishes so as to get the constant and repeatable certification results.

We manufacture and deliver the current ISO/JARI head form impactors world wide more than two years now.

We believe our developed head forms are very reliable, repeatable, and stable performance for long life.

JARI/JAMA and JASTI have been testing the skin life more than two years.

It is our great pleasure to be able to cooperate with your works for European regulation. We shall support your works whenever you need our assistance and additional works, etc.

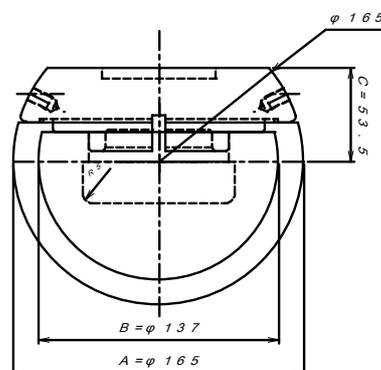
Attachment 4. ESV papers {TRL: not included here, see reference section of main paper}

Please refer the paper for ISO headform impactor development published on ESV conference in 2003 Nagoya.

2. 4.5kg Adult head form impactor (Please refer attachment 1. Adult {TRL: not included here})

The specifications are;

ISO Adult 4.5kg	Skull No.IA-***	Skin No.***	
	Standards	Result	
A (mm)	165.0±1	164.5	D i a m e t e r
B (mm)	137.0	137.0	
(A-B)/2 (mm)	14.0±0.5	13.8	Skin thickness
C (mm)	53.5	-	CG Location of Geometric center
(mm)	±2.0	-0.80	CG Location from Geometric center
Moment of Inertia (kgm ²) around Y axis	from 0.0075 to 0.02	0.011	
total Weight (kg)	4.5±0.1	4.49	



Attachment 1. Adult {TRL: not included here}

Please refer the actual measured results from our production head forms as

Case 1; ISO Adult 4.5kg Skull No. IA107, Skin No.870

Case 2; ISO Adult 4.5kg Skull No. IA102, Skin No.611,

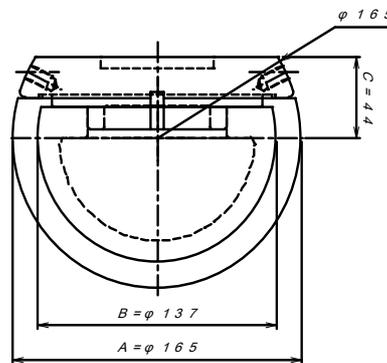
Case 3; ISO Adult 4.5kg Skull No. IA115, Skin No. 542

Each case results include the measured specification and drop and impact test results.

3. 3.5kg Child Head form Impactor; (Please refer attachment 2. Child {TRL: not included here})

The specifications are;

ISO Child 3.5Kg		Skull No.IC-*** Skin No.***		
		Standards	Result	
A	(mm)	165.0±1	164.6	D i a m e t e r
B	(mm)	137.0	137.0	
(A-B)/2	(mm)	14.0±0.5	13.8	Skin thickness
C	(mm)	44.0	-	CG Location of Geometric center
	(mm)	±2.0	-0.50	CG Location from Geometric center
Moment of Inertia (kgm ²) around Y axis		from 0.0075 to 0.02	0.0091	
Total Weight	(kg)	3.5±0.07	3.49	



Attachment 2. Child {TRL: not included here}

Please refer the actual measured results from our production head forms as

Case 1; ISO Child 3.5kg Skull No. IC-110, Skin No.612

Case 2; ISO Child 3.5kg Skull No. IC-130, Skin No.2143

Case 3; ISO Child 3.5kg Skull No. IC-131, Skin No.2161

Each case results include the measured specification and drop and impact test results.

Attachment 6. ENDEVCO 7264C type

Please refer the accelerometer location include the distance between geometric center and seismic mass of each accelerometer.

All calibration tests results from drop and linear impact tests are as follows

ISO	Skin Serial No.	Skull Serial No.	ISO Drop test (G)					Impact test for 1kg probe (G)				
			Type 1	Type 2	Type 3	Av.	Total Av.	0°	120°	240°	Av.	Total Av.
Adult 4.5 kg	#870	IA-107	252	253	249	251	252	381	371	386	379	378
	#611	IA-102	255	251	252	253		359	375	380	371	
	#542	IA-115	254	250	250	251		381	380	385	382	
Child 3.5 kg	#612	IC-110	270	267	270	269	268	323	312	345	327	315
	#2143	IC-130	271	275	270	272		310	309	301	307	
	#2161	IC-131	266	264	261	264		318	313	307	313	

4. Calibration method

4.1 Head drop test

Test system; 49 CFR Part 572 ATD (Crash test dummy) Head drop test stand

Certification Requirements as table follows

Headform	Drop Height (mm)	Lower Boundary (G)	Upper Boundary (G)	Angle		
				Type1	Type2	Type3
Adult 4.5 kg	376± 1	225	275	80°	100°	90°
Child 3.5 kg	376± 1	245	300	80°	70°	65°

Note; Angle with rear face relative to vertical plane.

4.2 Linear impact test

Test system; Linear impact test system

Impactor : Weight; 1.0±0.01 kg

Face diameter; 70±1 mm

Surface finish; better than 2.0 micrometer

Certification Requirements as table follows

Headform	Impactor velocity (m/s)	Lower Boundary	Upper Boundary	Impact points
Child 2.5 kg	7.0± 0.1	405	495	•Suspended at an angle between 25° and 90° from the horizontal to rear face •Impacted three different locations.
Small Adult 3.5 kg	7.0± 0.1	290	350	
Adult 4.8 kg	10.0± 0.1	337.5	412.5	

All tests are done by using ENDEVCO 7264C; Attachment 6 (ENDEVCO 7264C)

Please refer the accelerometer locations include the distance between a geometric center and seismic mass of each accelerometer.

5. Biofidelity by two different test method

Crash test dummy 6years old head is 3.5kg and 50%ile Adult dummy is 4.5kg.

Each Adult and Child drop test corridors are the same band as ISO head forms.

So, if each Pedestrian Head form impactor meets the required drop test corridor.

The same impactor must pass the linear impact test corridor as well.

Because the head itself fulfill the required performance by the biofidelity from a drop test.

Please refer the Attachment 3 and 3.1, our comparison test results between the drop and impact test results by using the same head form.

6. Specification of seismic mass of each accelerometer

As seen Attachment 4, ESV paper specification table (see page7) {TRL: not included here, see reference section of main paper} we had developed ISO head form followed ±10 mm in measurement axis and ±1 mm in perpendicular for seismic mass location of each accelerometer.

But JARI discovered too high HIC value due to accelerometer resonance effect by using undamped accelerometer, ENDEVCO 7264B, under JNCAP windshield impact test. (see attachment 5. {TRL:

not included here}) However, KYOWA accelerometer with damper type is much larger size which needs $\pm 30\text{mm}$ instead of $\pm 10\text{mm}$. They do not show a resonance effect by windshield impact test. It is required only special purpose for windshield impact test to change 10 mm to 30 mm for using Kyowa accelerometer which has damper and bigger size, not for mal-performance of the head form.

7. Conclusion

The specifications from ISO 3.5kg and 4.5kg are quite reasonable as meeting biofidelity.

The calibration method as drop test is to be more common test procedure by all test houses and automobile manufactures worldwide.

8. Summary

We are very excited to be able to work with you and would like to support your activity.

We hope these report including our actual test results as well as our real measured data may assist your preparation for WG requirements.

If you find unclear points and/or question, please feel free to contact us any time.

Thank you very much for having this opportunity.

Attachment 3: Comparison Test

Study about Head form impactor

1. Introduction.

We have been developing and manufacturing JARI/ISO Adult and Child head form impactor as well as EU Adult and Child head form impactor.

Meanwhile, we face to make our EU head form impactor passed the calibration corridor by EEVC WG17.

We study and review the current WG17 1.0kg linear impact calibration method.

2. Procedure

A) JARI/ISO skin drop test

We test our JARI/ISO Adult and Child head form with new skins.

EU Adult head form are tested with above ISO adult and Child passed skins.

B) EU skins linear impact and drop test

We use the same skins which passed EU Adult linear impact test for JARI/ISO head form test by 1.0kg linear impactor at 7m/sec and 10m/sec.

3. Reference

A) Hybrid- 50th Male dummy Head Assembly weight; 4.5kg]

3 years old child dummy Head assembly weight ; 2.5kg

6 years old child dummy Head assembly weight ; 3.5kg

B) Head drop test at 376mm height

	ATD Dummy calibration corridor		Head form impactor calibration corridor
50 th	225 - 275G	ISO/Adult	4.5kg 225 – 275G
3 YO	250 - 280G	EU Child	2.5kg (250 -280G)
6 YO	245 - 300G	ISO/Child	3.5kg 245 – 300G

4. Findings

We tested two types of skins as shown Figure.1 and 2.

A). JARI/ISO skins passed drop test and ACEA drop, that is ISO Child and linear impact, that is EU Small Adult linear impact test.

But, the skins can not pass EU adult linear impact test.

B). EU skins passed EU Adult linear impact test and JARI/ISO and ACEA drop and linear impact test.

JARI/ISO and ACEA head form with ISO skins passed by drop test and linear impact test except EU Adult head form linear impact test. EU skins shows higher side of corridor by all other tests. However, according to authorized ATD dummy calibration head drop test, JARI/ISO and ACEA passed at reasonably accepted level.

EU adult is also human head representative and must passed around reasonable level as well, however, EU corridor seems to be higher than reasonable level.

Serial No.	ISO Adult	ISO Child	EU Small Adult	EU Adult
(Corridor)	(225 ~ 275)	(245 ~ 300)	(290 ~ 350)	(337.5 ~ 412.5)
I-1	248	264	292	320
I-2	245	263	312	316
I-3	244	263	310	305
Av.	246	263	305	314

Figure.1 A) Test results with ISO Skins

Serial No.	ISO Adult	ISO Child	EU Small Adult	EU Adult
(Corridor)	(225 ~ 275)	(245 ~ 300)	(290 ~ 350)	(337.5 ~ 412.5)
E-1	275	297	340	361
E-2	274	297	338	367
E-3	273	289	335	359
Av.	274	294	338	362

Figure.2 B) Test results with EU Adult Skins

5. Comparison data between Head drop and Linear impact test

We find the EU skins calibration corridor by linear impact test seems to be higher than the bio-fidelity. Then we try to compare the calibration corridor by drop and linear impact test. Each test are conducted by the same head form with same skins for having co-relation between Head drop test and linear impact test.

The test system itself are exact same system and setting in order to eliminate any additional changes.

The result shows by I/D which means the ratio as Impact test value by drop test.

These tested head forms must be reasonably accepted by bio-fidelity from ATD head drop test.

ISO Child/EU Small Adult real test result ratio is about 1.20

TNO ACEA Child study by papers form JSAE 20025357 is 1.30.

EU Adult real test result ratio is about 1.34, however, the requested corridor ratio is 1.50.

EU Child real test result ratio is about 1.36, however, the requested corridor ratio is 1.70.

The I/D ratio by certification corridor and actual test results as follows,

		Mean Boundary		I/D
		Drop	Impact	
H-3 50th Head	Certification	250	-	-
ISO Adult 4.5 kg	Certification	250	-	-
	Test Results	252	378 (10.0m/s)	1.50
EU Adult 4.8 kg	Certification	(250)	375	1.50
	Test Results	236	316	1.34
ISO Child 3.5 kg/ EU Small Adult 3.5 kg	Certification	272.5	320	1.17
	Test Results	268	315	1.18
TNO test data	Test Results	265	344	1.30
H-3 3years Head	Certification	265	-	-
EU Child 2.5 kg	Certification	(265)	450	1.70
	Test Results	308	419	1.36

6. Conclusion

We are not sure the requested linear impact test corridor reasonable or not.

However, all head form corridors can be calibrated and proved by the drop test as means of biofidelity based on ATD dummy study..

We are very happy this test study might be referred by TRL study for future test procedure and pleased to support TRL further study, if we need to continue by the different type of skins as well as different test method.

Thank you very much for your time.

Kind regards

Yoshi Ozawa

JASTI Co., LTD

4-3 Miyoshi, Koto-ku, Tokyo 135-0022

JAPAN

TEL;+81-3-5245-3661

FAX; +81-3-5245-8596

E-Mail; ozawa@jasti.co.jp

URL; <http://www.jasti.jp>

Attachment 3.1: Comparison test result

We studied ISO vs, EU test before and the results are noted as follows,

Test result with ISO Skins

Serial No. (Corridor)	ISO Adult (225 ~ 275)	ISO Child (245 ~ 300)	EU Small Adult (290 ~ 350)	EU Adult (337.5 ~ 412.5)
I-1	248	264	292	320
I-2	245	263	312	316
I-3	244	263	310	305
Av.	246	263	305	314

Result

We tried to test ISO drop and EU impact using same skin.

The skin can pass both ISO Adult and Child corridor, even EU Small Adult Impact corridor.

But fails to EU Adult Impact corridor.

Test result with EU Adult Skins

Serial No. (Corridor)	ISO Adult (225 ~ 275)	ISO Child (245 ~ 300)	EU Small Adult (290 ~ 350)	EU Adult (337.5 ~ 412.5)
E-1	275	297	340	361
E-2	274	297	338	367
E-3	273	289	335	359
Av.	274	294	338	362

Result

We also tried to test ISO drop and EU Impact using the skins which can pass EU Adult corridor.

The skin can pass all test corridor but shows a bit of high G value closed to the upper limitation in ISO drop tests.

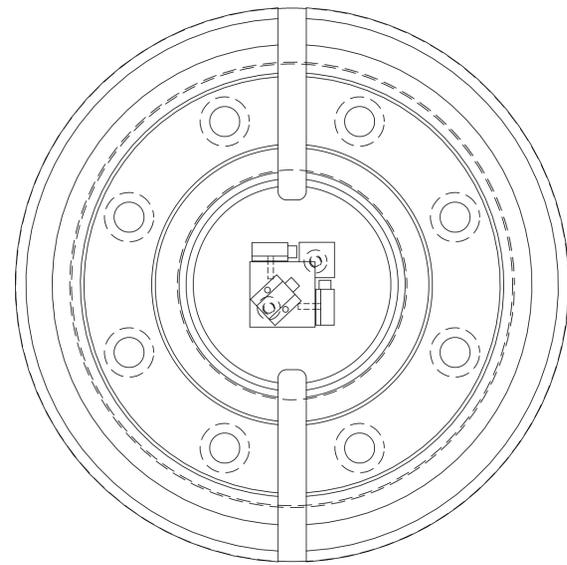
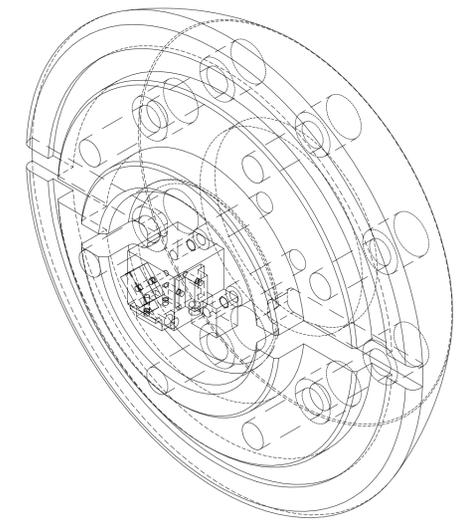
Test result using EU Child Skins

Serial No. (Corridor)	Impact (405 ~ 495)	Av.	Drop ()	Av.
E-5	413	412	303	300
	409		293	
	415		305	
E-6	406	407	297	299
	406		298	
	409		303	
E-7	434	439	320	325
	446		327	
	436		329	
Av.		419		308

Result

In Drop test, the Skin which can pass EU Child corridor behaves around -100G compared to Impact test re:

Specification of the accelerometers' locations.
 ISO Adult and Child have same locations.



	X-axis	Y-axis	Z-axis
Acc. X	9.21	0	0
Acc. Y	0	9.21	0
Acc. Z	0	0	8.11

