TECHNICAL REPORT

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Road vehicles — Anthropomorphic side impact dummy —

Part 3 : Lateral thoracic impact response requirements to assess biofidelity of dummy

Véhicules routiers — Mannequin anthropomorphe pour essai de choc latéral — Partie 3 : Caractéristiques de réponse du thorax à un choc latéral permettant d'évaluer la biofidélité d'un mannequin

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Foreword

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The main task of ISO technical committees is to prepare International Standards. In exceptional circumstances a technical committee may propose the publication of a technical report of one of the following types:

— type 1, when the necessary support within the technical committee cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development requiring wider exposure;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical reports are accepted for publication directly by ISO Council. Technical reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 9790-3, which is a technical report of type 3, was prepared by Technical Committee ISO/TC 22, *Road vehicles.*

ISO/TR 9790 consists of the following parts, under the general title *Road vehicles — Anthropomorphic side impact dummy*:

— *Part 1: Lateral head impact response requirements to assess biofidelity of dummy*

— *Part 2: Lateral neck impact response requirements to assess biofidelity of dummy*

— *Part 3: Lateral thoracic impact response requirements to assess biofidelity of dummy*

— *Part 4: Lateral shoulder impact response requirements to assess biofidelity of dummy*

— *Part 5: Lateral abdominal impact response requirements to assess biofidelity of dummy*

— *Part 6: Lateral pelvis impact response requirements to assess biofidelity of dummy*

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Road vehicles — Anthropomorphic side impact dummy —

Part 3 :
Lateral thoracic impact response requirements to assess biofidelity of dummy

1.0 INTRODUCTION

The impact response requirements presented in this Technical Report are the result of a critical evaluation of data selected from experiments agreed to by experts as being the best and most up-to-date information available.

Three lateral thoracic impact response requirements are defined: one based on the cadaver drop tests of Association Peugeot-Renault (1)*, a second based on the cadaver sled tests of the University of Heidelberg (2) and a third based on cadaver impact tests conducted by HSRI (3). All data sets were normalized to represent the response characteristics of a 50th percentile adult male using either the method described by Mertz (4) or an extension of the method developed by Lowne (5).

2.0 SCOPE AND FIELD OF APPLICATION

This Technical Resport is one of six reports that describe laboratory test procedures and impact response requirements suitable for assessing the impact biofidelity of side impact dummies. This Technical Report provides information to assess the biofidelity of lateral thoracic impact response.

3.0 ISO REFERENCES

ISO DP 9790-1 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Head Impact Response Requirements to Assess the Biofidelity of the Dummy.

*Numbers in parentheses denote papers listed in References, Section 7.0.

ISO DP 9790-2 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Neck Impact Response Requirements to Assess the Biofidelity of the Dummy.

ISO DP 9790-4 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Shoulder Impact Response Requirements to Assess the Biofidelity of the Dummy.

ISO DP 9790-5 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Abdominal Impact Response Requirements to Assess the Biofidelity of the Dummy.

ISO DP 9790-6 Road Vehicles - Anthropomorphic Side Impact Dummy - Lateral Pelvis Impact Response Requirements to Assess the Biofidelity of the Dummy.

4.0 REQUIREMENT NO. 1

4.1 Original Data

A series of cadaver drop tests was conducted by APR (1). Each cadaver was suspended a prescribed distance above the impact surface by ropes that supported its shoulders, hips and legs. When the ropes were released, the cadaver dropped freely and impacted its side against the impact surfaces. A triaxial accelerometer was screwed to the fourth dorsal vertebra to measure thoracic acceleration. Rib cage compression was measured from a slow motion movie of the impact. The impact surface consisted of two instrumented load surfaces, one for measuring the thorax contact force and the other for measuring the hip contact force. Response data for the APR 1 meter drop tests onto rigid impact surfaces and 2 meter drops onto padded impact surfaces are listed in Table 1. The lateral thoracic force-time curves for these tests are shown in Figures 1 and 2, respectively. The curves shown in these figures were provided by A. Fayon of Association Peugeot-Renault.

4.2 Normalized Data

The force-time curves shown in Figures 1 and 2 were normalized to represent the response characteristics of a 50th percentile adult male using the technique described by Mertz (4). The normalized force-time curves for the 1 meter rigid surface impacts and 2 meter padded impacts are depicted in

Figures 3 and 4, respectively. If the normalization procedure was exact, then for each impact configuration each normalized cadaver curve would map onto a single curve which would be the force-time curve of the standard size subject. Consequently, the best estimate of the force-time curve of the 50th percentile adult male is the average of the normalized curves for each impact configuration. Such curves are shown in Figures 5 and 6 along with proposed response corridors for 1 meter rigid and 2 meter padded impacts, respectively. It should be noted that these corridors are in good agreement with other corridors developed from the same data but using linear regression analysis (6).

The maximum deflections of the impacted ribs relative to the thoracic spine were normalized using the technique of Mertz (4). These normalized deflections are listed in Table 1 along with the number of fractured ribs that each cadaver experienced. The average of the normalized deflections for the 2 meter padded impacts is 43 mm. This value represents the best estimate of the deflection response of the 50th percentile adult male. For the 1 meter rigid impact, three distinct deflections were observed: large deflections (63 mm and 68 mm) with massive rib fractures (14 and 13 fractured ribs), 36 mm deflection with 5 fractured ribs and 16 mm deflection with no fractured ribs. This large range of deflections makes it difficult to estimate the response of a standard subject to a 1 meter rigid surface impact based on this data. However, one can estimate such a deflection response for the 1 meter rigid condition based on the 2 meter padded data. Mertz (4) has shown that peak force is directly proportional to the impact velocity for the padded and rigid impacts. A similar relationship should hold for peak deflections. Thus, an estimate for the maximum normalized deflection for a 50th percentile male is,

$$D_1 = (V_1/V_2)D_2 = 30 \text{ mm}$$

where

D_2 = 43 mm
V_1 = 4.4 m/s
V_2 = 6.3 m/s

4.3 Response Requirements

For a 1 meter drop onto a rigid impact surface the resulting normalized thoracic impact force vs time response should lie within the corridor shown in Figure 5 and the maximum normalized deflection of the impacted ribs relative to the thoracic spine should be between 25 and 35 mm.

For a 2 meter drop onto the padded surface described under Test Setup, the resulting normalized thoracic impact force vs time response should lie within the corridor shown in Figure 6 and the maximum normalized deflection of the impacted ribs relative to the thoracic spine should be between 38 and 48 mm.

The dummy data must be normalized in order to adjust for changes in effective mass due to slight differences in dummy position at impact. See Section 4.5 Normalization Procedure.

4.4 Test Setup

The dummy is to be suspended over the impact surfaces using ropes to support its shoulders, hips and legs. A "quick release" device is to be provided to allow the dummy to drop freely. The sagittal plane of the dummy is to be horizontal. The dummy's arms are to be rotated forward and upward so as to not contact the thoracic loading surface. The two loading surfaces are to be located to intercept the dummy's pelvis and thorax separately. For the padded tests, 140 mm x 140 mm x 420 mm blocks of open cell urethane foam (APR padding) should be used. The characteristics of this foam are described in the Appendix. When the dummy is dropped onto the prescribed impact surfaces its responses should meet the appropriate requirements described previously.

4.5 Instrumentation

Each impact surface is to be instrumented with an inertia compensated load cell. The dummy is to be instrumented with a transducer to measure the deflection of the impacted ribs relative to the thoracic spine. High speed movies of the impact event are to be taken. Impact force and chest deflection measurements are to meet SAE Channel Class 180 filter requirements.

4.6 Normalization Procedure

Determine the impulse by integrating the force-time curve. Calculate the effective mass using the following relationship,

$$M_e = [\int_0^T Fdt] / (Tg + V_o) \quad (1$$

where $\int_0^T Fdt$ is the impulse, V_o is the impact velocity, T is the pulse duration corresponding to a velocity change of V_o, and g is the acceleration of gravity. The mass ratio, R_m, used by Mertz (4) to normalize the APR cadaver data is,

$$R_m = 38\ kg/M_e \quad (2$$

Calculate the mass ratio for the test using Equations 1 and 2.

Since it is assumed that the dummy has the same thoracic stiffness as the standard subject, the stiffness ratio, R_k, is equal to 1.

The normalizing factors for force, time and displacement are given by,

$$R_f = (R_m R_k)^{\frac{1}{2}} \quad (3$$

$$R_t = R_x = (R_m)^{\frac{1}{2}} (R_k)^{-\frac{1}{2}} \quad (4$$

Normalize the force-time curve by multiplying each force value and each time value by their corresponding normalizing factors. Normalize the maximum rib to spine deflection by multiplying it by R_x.

5.0 REQUIREMENT NO. 2

5.1 Original Data

A series of cadaver sled tests was conducted at the University of Heidelberg for NHTSA (2). In these tests the cadaver was placed in a seat, 1 meter from a vertical side panel that was rigidly attached to the seat. The seat and side panel were gradually accelerated to the desired impact velocity. The sled was abruptly stopped causing the cadaver to translate towards the side panel and impact it at the desired velocity. The side panel had two instrumented impact surfaces, one for the shoulder/thorax and the other for the pelvis/femur. Rigid surface impact tests were conducted at impact velocities of 6.8 m/s and 8.9 m/s. Padded surface impacts were conducted at 8.9 m/s. Table 2 summarizes the test conditions. Note that there are only two or three tests for each of these three configurations. The lateral thoracic force-time curves that were provided by NHTSA are shown in Figures 7, 8 and 9, respectively. These curves were obtained using a 100 Hz Finite Impulse Response (FIR) filter (3). Such filtering must be done to the dummy data since the FIR filter may have significantly distorted the amplitude and phase of the cadaver data.

5.2 Normalized Data

The force-time curves shown in Figures 7, 8 and 9 were normalized using the technique of Mertz (4). The resulting normalized force-time curves are shown in Figures 10, 11 and 12, respectively. As noted previously, the best estimate of the force-time curve of the 50th percentile adult male is the average of the normalized curves for each impact configuration. These average curves along with proposed response corridors are depicted in Figures 13, 14 and 15.

5.3 Response Requirements

For a 6.8 m/s rigid surface impact, a 8.9 m/s rigid surface impact and an 8.9 m/s padded surface impact, the normalized force-time curves of the dummy must lie within the appropriate corridors shown in Figures 13, 14 and 15, respectively. Again, the dummy data must be normalized in order to adjust for changes in its effective mass caused by slight differences in dummy positioning. See Section 5.6 - Normalization Procedure.

5.4 Test Setup

A seat with an instrumented side panel is to be secured to an impact sled, sideways to the direction of travel. The top edge of the side board is to be 540 mm above the seat plane. The surface of the seat is to have a low coefficient of friction to assure that the dummy will translate relative to the sled without rotating. The dummy is to be placed on the seat at a sufficient distance from the side board to assure that the sled is completely stopped prior to impact. For padding tests, 140 mm x 140 mm x 420 mm blocks of APR open cell urethane foam are to be fastened to the thorax and pelvis impact surfaces.

5.5 Instrumentation

The dummy is to be instrumented to measure the deflection of the impacted ribs relative to the thoracic spine. Two inertia compensated load transducers are to be mounted to the side board, one at the thorax level, the other at the hip level. High speed movies of the impact event are to be taken. Impact force and chest deflection measurements are to be recorded using SAE Channel Class 1000 and 180 filters, respectively. Impact forces are to be filtered using a 100 Hz FIR filter (3) for comparison to the response corridors shown in Figures 13, 14 and 15.

5.6 Normalization Procedure

Determine the impulse by integrating the force-time curve. Calculate the effective mass using the following relationship,

$$M_e = [\int_0^T Fdt] / (V_0) \quad (1$$

where $\int_0^T Fdt$ is the impulse, V_0 is the impact velocity and T is the pulse duration corresponding to a velocity change of V_0. The mass ratio, R_m, used to normalize the cadaver data is,

$$R_m = 38 \text{ kg}/M_e \quad (2$$

Calculate the mass ratio for the test using this Equation.

Since it is assumed that the dummy has the same thoracic stiffness as the standard subject, the stiffness ratio, R_k, is equal to 1.

The normalizing factors for force and time are given by,

$$R_f = (R_m R_k)^{\frac{1}{2}} \quad (3$$

$$R_t = (R_m)^{\frac{1}{2}} (R_k)^{-\frac{1}{2}} \quad (4$$

Normalize the force-time curve by multiplying each force value and each time value by their corresponding normalizing factors.

6.0 REQUIREMENT NO. 3

6.1 Original Data

A series of cadaver impact tests was conducted by HSRI (3). The cadavers were seated in an upright position with one arm raised so that the lateral aspect of the chest could be impacted. The impactor had a flat, rigid impact surface which was 150 mm in diameter and its mass was 23.4 kg. The impact velocity was 4.3 m/s. Impactor deceleration-time histories are shown in Figure 16. The corresponding lateral acceleration-time histories of the cadavers' first thoracic vertebrae are depicted in Figure 17. These curves were obtained using a 100 Hz Finite Impulse Response (FIR) filter (3). Similar filtering must be done to the dummy data since the FIR filter may have significantly distorted the amplitude and phase of the cadaver data. The mass of each cadaver and the number of rib fractures are summarized in Table 3.

6.2 Normalized Data

The acceleration-time curves shown in Figures 16 and 17 were normalized to represent characteristics curves for a 50th percentile adult male interacting with a 23.4 kg impactor using an extension of Mertz's technique (4) that was developed by Lowne (5) for a two mass system. The normalizing factors for a two mass system can be defined as follows:

Impactor Acceleration Factor

$$(R_a)_p = (R_k)^{\frac{1}{2}} \ (R_m)^{\frac{1}{2}} \ (M_p + M_c)^{\frac{1}{2}} \ (M_p + M_s)^{-\frac{1}{2}} \qquad (1$$

Thoracic Acceleration Factor

$$(R_a)_T = (R_k)^{\frac{1}{2}} \ (R_m)^{-\frac{1}{2}} \ (M_p + M_c)^{\frac{1}{2}} \ (M_p + M_s)^{-\frac{1}{2}} \qquad (2$$

Time Factor

$$R_t = (R_k)^{-\frac{1}{2}} \ (R_m)^{\frac{1}{2}} \ (M_p + M_c)^{\frac{1}{2}} \ (M_p + M_s)^{-\frac{1}{2}} \qquad (3$$

where,

Thoracic Mass Ratio

$$R_m = M_s/M_c \qquad (4$$

Thoracic Stiffness Ratio

$$R_k = K_s/K_c \qquad (5$$

and,

M - Mass

K - Stiffness

The subscripts are defined as,

a - acceleration

k - stiffness

m - mass

p - impactor

c - cadaver

s - standard subject

t - time

T - thorax

Mertz (4) has shown that for geometrically similar subjects, the thoracic stiffness ratio is equal to the ratio of characteristic lengths, or,

$$R_k = L_s/L_c \qquad (6$$

Unfortunately, no length dimensions are given for the cadavers. Only their total body masses are given. If we extend the assumption of geometric