EEVC

EUROPEAN ENHANCED VEHICLE-SAFETY COMMITTEE

DEVELOPMENT AND EVALUATION OF THE ES-2 DUMMY

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DEVELOPMENT AND EVALUATION OF THE ES-2 DUMMY

WORKING GROUP 12

J. Wismans	Chair
F. Bermond	INRETS (France & secretary)
G. Gertosio	FIAT (Italy)
T. Kreuzinger	BASt (Germany)
A. Roberts	TRL (UK)
M. van Ratingen	TNO (Netherlands)
M. Svensson	Chalmers (Sweden)

INDUSTRY ADVISORS

K. Bortenschlager	Audi AG (Germany)
H. Öhrn	Volvo (Sweden)
M. Page	CEESAR (France)
H. Leyer	VW AG (Germany)

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SUMMARY

Over the last year, the European Enhanced Vehicle-safety Committee Working Group 12 has assessed and reviewed the performance of the enhanced anthropomorphic test device for lateral impacts, EUROSID-2 (ES-2). The objectives for this work have been the following:

- To verify whether the proposed design is addressing the shortcomings of the regulatory test device EUROSID-1 as identified previously by EEVC and NHTSA
- To make sure that the original EUROSID-1 biofidelity and performance in normal test conditions is preserved.

To reach a well-balanced conclusion, the working group has undertaken a test program to assess the most important requirements for the ES-2 dummy, biofidelity, sensitivity, repeatability, handling, durability, certification and full-scale performance in comparison with EUROSID-1.

In addition, but no less important, the working group has reviewed and explored the findings of full-scale tests conducted at several member organisations within ACEA. ACEA has reported the most important findings in September 2000. Subsequently, WG 12 has further investigated the issues raised in this report.

On the basis of this work, the working group has concluded the following with regards to the ES-2 specifications and performance:

The ES-2 prototype as tested is superior to current test device EUROSID-1 and, hence, a more appropriate test device for regulatory testing. The important shortcomings of the EUROSID-1 have been satisfactorily addressed with ES-2, whilst biofidelity is maintained, in some areas even somewhat improved. It should be noted, however, that the assessment of thorax biofidelity was based on deflection and force-time data only, and does not incorporate an assessment of V*C. It is recommended to adopt the hardware design without further modification and to use the new proposed certification procedures, with the exception of the high velocity pelvis test.

Overall test results in full-scale tests have shown that some critical dummy measurement values for ES-2 have increased compared to EUROSID-1, in particular rib deflection, 17%, and V*C, 23%[1] on average. Other values on the other hand have brought down such as the pubic force (10%) due to improved leg interaction. Contrary to the full-scale results, the ES-2 gave equal or lower values for all critical measurements in the biofidelity tests.

For the large majority of vehicles tested, the different results would not affect pass or fail with respect to current regulatory limits. It should be noted, however, that, maintaining the rating levels in consumer testing, ES-2 results would lead motoring consumers to believe the protection offered in side impact has decreased while in fact the safety performance of these vehicles has not changed.

A force transducer has been developed to measure the force applied to the back plate. It is recommended to use the force transducer in full vehicle assessment.

Finally, the working group believes the ES-2 dummy forms a solid basis for interim harmonisation and will further support activities to help realise this objective.

[1] Percentages normalised to the current tolerance values.

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INTRODUCTION

The EUROSID-1 was developed in the 1980's to meet the needs of the European Commission, in terms of improving vehicle safety in side impact, through the activities of EEVC Working Group 9 [1]. The crash test dummy is now incorporated in ECE Regulation 95 and hence used as regulatory test device in two of the biggest automotive markets, Europe and Japan. Over the same time period another dummy, SID, was being developed in the USA by NHTSA [2]. This dummy is now part of the US side impact standard FMVSS-214. Thus the current regulatory situation is that there are at least two different side impact test procedures using two different side impact dummies. There is a risk that similar tests with the two different dummies do not indicate a common result in terms of improving vehicle safety and thus trauma induced injury. Such diversity causes automotive industry serious concern, especially if they sell the same vehicle in different markets.

ISO has initiated the development of the new side impact dummy WorldSID to replace the existing dummies such that there will be a more advanced world single harmonised side impact test dummy [3]. The realistic time frame for development and evaluation may be up to 10 years before this dummy can go into a legislative test procedure. Starting from an existing regulated dummy, interim harmonisation could be reached much quicker.

There has always been pressure from Europe for the USA to accept the EUROSID-1 dummy in their side impact standard. This has been unsuccessful so far for a number of reasons, some of which have been technical. A new approach for interim harmonisation has been made in terms of upgrading the EUROSID-1 dummy, addressing some of the technical issues that have so far prevented its adoption by NHTSA. At the same time, other issues have been addressed that originate from more than a decade of experience with the EUROSID-1 in Europe. Support for this development comes from NHTSA, Transport Canada, Japan, Australia and others.

This document reports on status of the development of the improved dummy that is referred to as EUROSID-2 (ES-2). In particular, it summarises the results from the ES-2 prototype evaluation in Europe, carried out on behalf of the EEVC WG12. The basis for this work was the scientific result achieved in the consortium of the SID 2000 project of the EC [4]. In addition, the findings of full-scale tests conducted at several member organisations within ACEA [5] are reviewed and explored. Taking into account these findings, conclusions and recommendations are formulated.

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DUMMY ENHANCEMENTS

The technical issues that have so far prohibited the EUROSID-1's adoption by NHTSA and US industry [6] have been identified and documented by the EEVC WG12 [7]. Further issues that need to be addressed if an interim harmonised dummy is to be a reality have been identified through a questionnaire amongst users of the EUROSID-1 dummy world-wide [8]. The complete list of issues has formed the basis for the development of new parts, sensors and procedures for the EUROSID dummy [9]. It should be emphasised that there was no intention in this work to develop a 'new' advanced European side impact dummy or to 'improve' its biomechanical performance as these issues are dealt with in the WorldSID program [3]. The development of ES-2 has been purely one of problem solving sufficient to meet the needs of legislative authorities world-wide. In summary, the following has changed with respect to EUROSID-1. More background is given in Annex A of this report.

DESIGN AND INSTRUMENTATION UPDATES

Head:	Addition of an upper neck load cell (UNLC) at the head and neck interface;
Neck:	Minor improvements to improve handling;
Shoulder:	Coated low friction top and bottom plate and flexible clavicle;
Thorax:	New rib module guide system; new back plate with load cell; tilt sensor;
Abdomen:	Upper lumbar spine (T12) load cell between thoracic spine and abdomen;
Lumbar Spine:	Minor structural changes for T12 load cell;
Pelvis:	End stop buffer in the hip joint, new pubic load cell attachment; tilt sensor;
Legs:	Re-designed upper leg flesh and femur bone.

REVISED CERTIFICATION PROCEDURES

Neck:	Re-defined, more consistent certification input and output criteria;
Thorax:	Full rib module test of 1 m/s deleted. Optional damper and rib only test in case full rib modules fail to comply with the certification test requirement;
Abdomen:	Decrease of certification test severity;
Lumbar spine:	Re-defined, more consistent certification input and output criteria;
Pelvis	Increase of certification severity. *(Finally not implemented, see evaluation)*

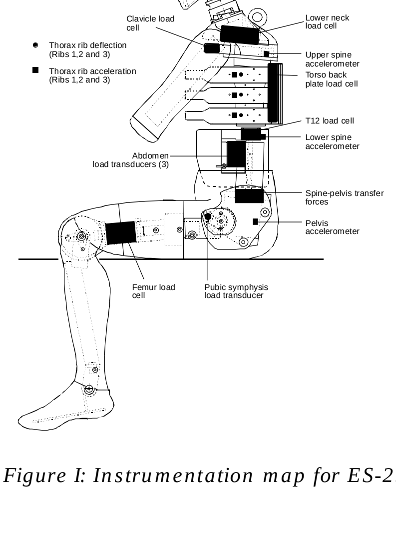

Figure I: Instrumentation map for ES-2.

EVALUATION

ES-2 prototypes have been evaluated in Europe, the USA, Canada and Japan. The test programme has been carried out in three consecutive phases: design try-out, selection of the definite dummy configuration and assessment of the final dummy performance [9]. In the third and last phase, ES-2's superiority to EUROSID-1 as regulatory test device has been evaluated. This assessment includes biofidelity, sensitivity, repeatability, certification, handling, durability and full-scale car crash performance.

The final evaluation phase in Europe has been carried by the EEVC WG12 and by the Association of European Car Manufacturers ACEA [5]. The subjects covered in the evaluation of EEVC are biofidelity, certification, sensitivity, repeatability, handling, durability and (to lesser extent) full-scale test performance. ACEA has contributed with a series of vehicle tests that covered different vehicle types in actual European as well as American test procedures. From here on, a summary of the most important results of the ES-2 evaluation in Europe will be given.

BIOFIDELITY

A crash test dummy has to satisfy several types of requirements. One of the important requirements is that it exhibits a good degree of biofidelity. For the ES-2, the goal of the biofidelity assessment was to demonstrate that the changes introduced have not negatively affected the dummy's biofidelity with respect to the EUROSID-1. Hence, the tests have been focussed on those body regions that have altered significantly, i.e. the thorax and pelvis-femur.

The thorax biofidelity has been assessed in two types of tests: full body pendulum tests and "Heidelberg" sled tests. Both tests have been recommended by the EEVC to assess the biofidelity of side impact dummies [10] and were used to verify the biofidelity of EUROSID-1 in the past [11]. Linearly guided impactor and "Heidelberg" sled test responses have been used to assess the biofidelity of the pelvis [10]. In particular, the linearly guided impactor test requirement is based on more recent data [12].

Results of biofidelity testing are given in Annex B and show that the biofidelity of the ES-2 dummy is maintained and even improved in some areas with respect to EUROSID-1. It is concluded that the modifications have not changed significantly the dummy's biofidelity. It should be noted, however, that the assessment of thorax biofidelity is based on deflection and force-time data only, and does not incorporate an assessment of V*C.

CERTIFICATION

The proposed certification procedures for the ES-2 dummy (see Annex A) were assessed by BASt in Germany and by the manufacturer prior to release of the first prototype. In general, the ES-2 prototype met the specifications of the standard EUROSID-1 dummy. In addition, it fulfilled the new proposed certification requirements for the neck, lumbar spine, abdomen and pelvis. In particular for neck and lumbar spine, the new procedures were found less problematic. Calibration test results for the ES-2 prototype are given in Annex C.

Some refinements for thorax and pelvis certification procedures are recommended. The ES-2 prototype rib meets the EUROSID-1 criteria, however, this was not easily achieved. The modified configuration of the rib guide system seems to have its effect on the corridors at the proposed three impact speeds. If after finalisation of the global evaluation programme this remains a concern, the corridors for the prototype rib performance may have to be re-adjusted.

For the pelvis, a revised procedure has been proposed at higher velocity of impact (see Annex A). The proposed test, at higher velocity, was difficult to perform due to the gross motion of the pelvis and dummy after the pendulum hit it. It is therefore recommended not to implement the new procedure for the pelvis. Furthermore, it was reported that in their tests the pendulum force was relative low in the corridor, whereas the pubic symphysis force was relatively high. This effect is considered to be the direct result of the upper leg modification.

SENSITIVITY

The evaluation of the sensitivity of the ES-2 prototype potentially involves a wide range of aspects. The dummy should be sensitive to impact severity but less responsive to small changes in impact angle, temperature or such-alike parameters. The temperature sensitivity of ES-2 was assumed to be unchanged with respect to EUROSID-1. The work of WG12 focused primarily on impact direction sensitivity.

TRL performed 72 full body pendulum tests on the shoulder, thorax, abdomen, and pelvis. Five directions were tested per body part, e.g. forward of lateral +20 and +10 degrees, lateral and rearward of lateral -10 and -20 degrees. The oblique tests were done three times and the pure lateral tests six times. Annex D gives the results of these tests.

The ES-2 rib deflection gave results below those for pure lateral impacts for the forward oblique condition, whilst rearward oblique tests gave slightly higher results. The effect was similar to that seen in tests with the prototype EUROSID [11]. On EUROSID-1 rib displacement was measured at a point on the rib between the piston and the damper, whilst on ES-2 the displacement transducer is positioned on the rib to the rear of the piston. It seems likely that the change in position of the rib displacement point of measurement can have an effect on the measured values of the displacement when oblique loading components are present. The ES-2 abdomen was less responsive to changes in impact angle than the thorax. The ES-2 pelvis had a low sensitivity to changes in impact angle for the rearward oblique and pure lateral tests, tests in the frontal oblique condition resulted in a higher pubic force. The latter may be caused by interference of the modified upper leg with the impactor and/or more concentrated loading due to the change in contact profile of the impactor for forward oblique loading.

In general, the sensitivity of the parameters studied was found to be acceptable, and comparable for EUROSID-1 and the ES-2 prototype in the test conditions reviewed.

REPEATABILITY

The level of repeatability of dummy responses is often expressed in the coefficient of variation. For most existing dummies, a coefficient of variation of 10% is considered to be acceptable. To assess the repeatability of the ES-2 dummy, the peak responses in the biofidelity sled tests and the sensitivity tests were used. The lateral pendulum tests on the shoulder, thorax abdomen and pelvis at TRL were repeated six times, giving a firm base for a repeatability analysis. From the “Heidelberg” sled tests only a limited number of samples is available, however, comparable data are available from the tests performed on the first production EUROSID-1 in the 1991 [11]. In Annex E the results are summarised.

The ES-2 prototype shows a good repeatability on the parameters assessed, showing CVs lower than 6% for all except the shoulder (10% on the impactor force). The repeatability of the ES-2 is equivalent or slightly better than the repeatability of EUROSID-1.

HANDLING AND DURABILITY

The handling of the dummy during assembly and disassembly has been reviewed by BASt in Germany. In general, it was found easier to dismount and mount the prototype ES-2 than it was with the EUROSID-1. In particular, the (dis)assembly of the modified rib modules was found to be considerably improved compared to EUROSID-1. Also, the H-point back plate has been modified and was easier to be (dis)mounted.

No major durability problems were encountered during the EEVC WG12 and ACEA test programmes.

FULL-SCALE PERFORMANCE

An important part of the ES-2 evaluation programme in Europe consisted of the full-scale performance evaluation. The main goal was to investigate the effectiveness of the changes made in addressing the major concerns observed with the EUROSID-1, in particular the “flat-top” rib issue, back-plate interference and pubic symphysis loading. Furthermore, by direct comparison of the responses between EUROSID-1 and ES-2 the level of similarity of the two dummies could be determined.

For this purpose, a total of 13 vehicle tests have been performed with the ES-2 prototype. ACEA performed 5 EURONCAP-type, 3 ECE R95, 2 FMVSS 214 tests and 1 FMVSS 201 (pole) test with ES-2 in various vehicles from different manufacturers. TRL and TNO each performed 1 EuroNCAP-type test on behalf of EEVC. In most cases, comparable crash test data were available for the EUROSID-1. An overview of the complete full-scale test program is given in Table I.

In addition, two series of sled tests have been carried out. ACEA conducted 6 tests (3 tests with, 3 without airbag) on a sled-on-sled system that simulates dummy-to-door interaction [5]. More sled tests were done by the EEVC to investigate the effect of the upper leg modification in reducing pubic force loading.

Table I: Overview of full-scale tests carried out with the ES-2 prototype dummy by ACEA and EEVC.

Test type	Test Lab	Vehicle data
ACEA		
ECE R95 @ 50 km/h	Renault/LAB	Peugeot 406 sedan without side-airbags
	Renault/LAB	Renault Megane with torso-head side-airbag
	Porsche/ DaimlerChrysler	E-class, 1700 kg, side-airbag (in door) and window-curtain bag
EuroNCAP @ 50 km/h	Volkswagen	VW Lupo, 1061 kg, no side-airbag
	Volkswagen	VW Polo (4-door), 1228 kg , no side-airbag
	Ford	Ford Focus (5-door) without side-airbag (2×)
	Volvo	Volvo S80, 1810 kg, inflatable curtain and side-airbag
FMVSS 214 @ 54.7 km/h	Porsche/Audi	4-door sedan, thorax-pelvis airbag
	BMW	4-door sedan, 1906 kg, thorax airbag, hps
FMVSS 201 @ 32.2 km/h	BMW	4-door sedan, 1860 kg, thorax airbag only
EEVC		
EuroNCAP @ 50 km/h	TRL	Mid-size family saloon, no side-airbag
EuroNCAP @ 50 km/h	TNO	Ford Focus (sedan) without side-airbag

ACEA Task Force Dummy has reported the most important findings of its part of the evaluation in September 2000 [5]. A summary of dummy parameters is given in Table 12 of Annex F. It was concluded that the flat top issue and knee interaction concerns have been adequately addressed. For the back plate, contradicting results were found: most values were significantly reduced, but still in one case a repeatable increase of force from „uncritical“ (350 N) to „critical“ (1350 N, 1540 N) was observed (with respect to the penalty limit used by EuroNCAP). More importantly, most of the ES-2 measured values were found to be higher than those of ES1, even in cases where a flat top was not present for EUROSID-1. A higher sensitivity of the new ribs in the ES-2 dummy was noted, specifically related to an earlier response from the onset of a side airbag. Some questions arose regarding oscillatory rib

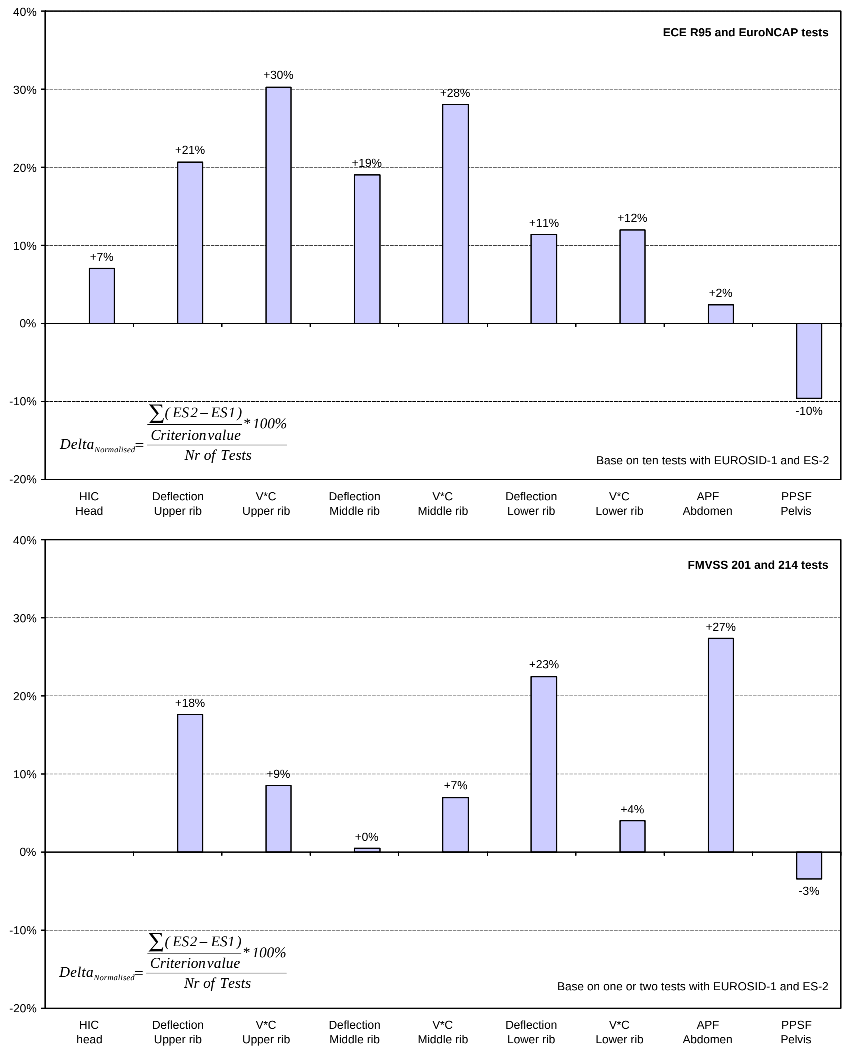

Figure II: Average normalised percentage of change in key measurements between ES-2 and EUROSID-1. Top: EuroNCAP, ECE test conditions (ACEA and EEVC). Bottom: FMVSS 214/201 (ACEA).

deflections ("damping characteristics of rib modules") and high frequency rib accelerations impeding reliable TTI calculation. Horizontal head positioning on the prototype tested was also found to be difficult.

According to ACEA, the ES-2 can be used as an interim alternative side impact dummy harmonised for FMVSS 214 and ECE R95 providing the remaining technical issues, observed during the ACEA test program with the ES-2 prototype, are resolved satisfactorily in an acceptable time frame. In Annex F these issues are addressed in more detail.

The objective of the full-scale barrier tests by EEVC was to assess the effect changing the side impact dummy from EUROSID-1 to ES-2 might have on the European Directive side impact test incorporated in EuroNCAP. The main dummy results of the two tests relative to EUROSID-1 are given in Annex G. The mid-size family saloon tested at TRL was chosen to evaluate the performance of ES-2 because the performance of the EUROSID-1 seen in previous EuroNCAP tests in the car was relatively close to the ECE R95 legislative limits in some areas. The measurements obtained with the ES-2 prototype at TRL were found to be similar to those with EUROSID-1. Differences could be attributed to normal measurement spread, contact differences due to other position and measurement error due to loose of connection. No change in the full-scale performance from EUROSID-1 to ES-2 was indicated by this test. At TNO, more significant differences were seen, specifically with respect to the rib displacements, but all measured values stayed well below the regulatory limits.

The overall differences between ES-2 and EUROSID-1 in full-scale tests can be studied on the basis of ACEA and EEVC tests. To get a handle on the effect on the criteria in relation to the existing regulatory limit, the average normalised percentage of change in key measurements has been calculated (see Annex F). Figure II shows the results for European and US tests. Relevant dummy measurement values for ES-2 in the European test condition have increased compared to EUROSID-1, especially rib deflection, 17%, and V*C, 23% on average. For details of variations in the ACEA tests, see Annex F, Table 12. Note that these differences include test and vehicle variability as well. Other values on the other hand have brought down such as the pubic force (10%) due to improved leg interaction. Regarding reduced back plate loads it is recommended that back plate loads be measured in full scale tests for vehicle assessment. Based on the experience gained in the measurement of the back plate load, in the future a limit should be considered.

Finally, the EEVC studied the effect of the upper leg changes in detail in a series of sled tests at BASt in Germany. Results are given in Annex H. In these tests, the ES-2 prototype pelvis shows considerable improved performance in the case of large upper leg abduction. The metal-to-metal contact observed with EUROSID-1 is eliminated. More significantly, the ES-2 prototype legs exhibit more realistic behaviour in the event of knee-to-knee contact. The sharp interference peak in the pubic symphysis load signal is eliminated.

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CONCLUSIONS

The ES-2 dummy is a modified EUROSID-1 dummy with increased injury assessment and measurement capabilities developed to meet the needs of legislative authorities world-wide. The test program carried out by the working group shows that the dummy is indeed improved and addresses the main concerns expressed with the EUROSID-1.

The biofidelity of the dummy is maintained and even improved in some areas. It should be noted, however, that the assessment of thorax biofidelity is based on deflection and force-time data only, and does not incorporate an assessment of V*C.

The dummy met the EUROSID-1 and the new certification requirements. Repeatability, sensitivity durability and handling properties are all equivalent or improved compared to the EUROSID-1.

The full-scale tests carried out in this test program show that values for ES-2 are generally higher than EUROSID-1. This particularly holds for rib deflections and V*C. As the biofidelity is comparable to that of EUROSID-1, this could be primarily attributed to the deletion of flat tops and reduction of back plate interference in combination with a higher sensitivity of the new ribs in the ES-2 dummy. Moreover, the changes found in the thorax region could also be attributed to changes in the response of other body parts. The back plate loads can now be measured and it is recommended to do so in full vehicle assessment.

For the large majority of vehicles tested, the different results would not affect pass or fail with respect to current regulatory limits. It should be noted, however, that, maintaining the rating levels in consumer testing, ES-2 results would lead motoring consumers to believe the protection offered in side impact has decreased while in fact the safety performance of these vehicles has not changed.

Finally, the working group believes the ES-2 dummy forms a solid basis for interim harmonisation and will further support activities to help realise this objective.

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A. Roberts, D. Hynd	TRL
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ANNEX A: DUMMY IMPROVEMENTS

REVISED PARTS AND SENSORS

Important changes to the dummy design have been made in following areas:

Head - The EUROSID-1 head has been revised to accommodate a new 6-channel upper neck load cell (Figure 1-A,B, capacities: Fx = 10 kN, Fy = 10 kN, Fz = 15 kN, Mx = 300 Nm, My = 300 Nm and Mz = 300 Nm). The new load cell particularly improves the assessment of HIC in the event of head contact. Head mass and centre of gravity (CoG) have been restored to those of EUROSID-1. See [A1], Annex A for more details.

Neck - The neck of the EUROSID-1 dummy consist of central moulded rubber beam with buffered interface plates on top a bottom side connected to the central moulding by half spherical screws. The neck has been slightly modified to prevent buffer dislocation and to accommodate the upper neck load cell (Figure 1-C,D).

Shoulder Assembly - The shoulder design of the EUROSID-1 includes clavicles that can move between two parallel metal plates. In (vertical) impacts to the shoulder, contact between the moving clavicle and the metal plates may occur, however, this should not substantially restrict the clavicle motion, i.e. inward movement of the upper arm. The new shoulder assembly has top and bottom plates covered with a low friction coating and an increased edge radius in order to minimise the binding of the shoulder. The clavicle flexibility is increased with a factor 3 to reduce the built up of friction loads in case of vertical impact loads on the arm (Figure 1, E, F). Additional modifications to the EUROSID-1 shoulder assembly include the re-design of the shoulder foam cap, arm to clavicle attachment screw and the elastic cord holder.

Thorax - The main concern of the EUROSID-1 dummy has been the rib "flat top" problem [A2]. Under certain impact conditions, the inward stroke of the ribs will be limited, which shows up as a plateau in the deformation response. Assuming that the problem is caused by rib binding, the piston guide bearing was replaced by a new guide system based on standard linear needle bearings with line contact on standard rails (Figure 1, G, H). See [A1], Annex C for more details.

The EUROSID-1 dummy is equipped with a rectangular, sharp edged torso back plate made of a plastic housing filled with lead. The torso back plate is mounted on the rigid thoracic spine box and determines the interface of the EUROSID-1 with the seat. The existing back plate is known to grab into the seat during a crash test, which may result in unrealistic dummy kinematics and contribute to the "flat tops". The new torso back plate has a curvature in the XY-plane based on human anthropomorphic data provided by UMTRI [A3]. Apart from the curved shape, the back plate is reduced in width from 180 to 140 mm to extent the thorax oblique angle envelop up to 20 degrees aft impacts. A 4-axis torso back plate load cell has been developed to measure the loads transferred to the spine (Figure 1-I, capacities: Fx = 3 kN, Fy = 3 kN, Mx = 160 Nm and My = 160 Nm).

Abdomen/Lumbar Spine - The unwanted impact location sensitivity of the abdomen load cells was identified very early on and has resulted in the improved load cells that are currently supplied for EUROSID-1 [A4]. In addition, to be able to assess the load transfer between the lower and upper torso, a T12 (upper lumbar spine) load cell has been developed (Figure 1-J, capacities: Fx = 14 kN, Fy = 14 kN, Mx = 1000 Nm and My = 1000 Nm). The lumbar spine itself has not changed as no evidence for “ringing” could be found. See [A1], Annex D for more details.

Pelvis - The current EUROSID-1 upper femur to iliac wing connection at the pelvis H-point allows 15° of upper leg abduction. At the end of this range of motion the upper femur bracket and the H-point back plate may make metal- to metal contact. The revised H-joint configuration has an increased size bearing allowing 19° of upper leg abduction (Figure 1-K, L, M). A rubber buffer at the inside of the H-point back plate will become effective at 15° abduction. The remaining 4° are available to damp the contact.

A plastic tube stop prevents metal to metal in the remote event of using the full available stroke of the rubber damper when reaching the maximum 19° of upper leg abduction. This prevents plastic deformation and damage of the parts in the joint assembly. The H-point back plate has been reduced in diameter (from 80 to 75 mm) to ease the installation of it in the H-point foam block cavity. The H-point back plate has a rounded outer edge to prevent pelvis flesh or foam block cutting during impact. Additionally, the torque heads of the pubic symphysis load transducer bushes are reduced in size. This will minimise the interference with upper femur buffer in the event of combined upper leg flexion and adduction. See [A1], Annex G for more details.

Legs – The EUROSID-1 legs are Hybrid II parts. Each leg consists of a rigid femur bone structure with a lead filled cup covered with low-mass foam part to simulate the thigh flesh. The rigid femur bone with integrated lumped mass results in high support reaction forces at the knees and the pubic symphysis in the event of leg contact during the impact. To reduce these peaks, the femur shaft and thigh flesh are revised to reflect a more humanlike mass distribution (Figure 1-N, O). The femur bone is reduced in mass and high-mass foam is used for the thigh flesh part. The mass shift between the parts is 2.75 kg. Apart from these two parts the legs remain on Hybrid II standard. It is advised to use the upper femur load cell in the leg configuration. The mass of the standard Hybrid-III femur load cell was reduced with 250 gram by the introduction of Aluminium end parts. See [A1], Annex I for more details.

Positioning tools - In response to the request for a seating procedure for EUROSID-1 by EEVC WG13, a set of angle transducers have been developed. These transducers, installed in the pelvis and the thorax allow measurement of the dummy orientation about the body x- (anterior-posterior) and y- (left-right) axes. Once the dummy is installed in the vehicle, the transducers are hooked up to a portable read-out unit, which shows the four angles (two from each transducer) simultaneously. This facilitates setting up the dummy in the required position. The transducers are available for both EUROSID-1 and ES-2. A second tool for the positioning procedure is still in development. This is basically a tape measure, but a specially designed to measure accurately the distance between the dummy H-point and the door. This tool is developed because the existing tools can not be used in the small and narrow spaces inside a vehicle.

REVISED CERTIFICATION PROCEDURES

A number of certification procedures for EUROSID-1 has been reviewed, either because the procedures cause problems in practice (lumbar spine and neck) or because the severity of the test does not reflect the actual load level the component experiences in crash testing (abdomen and pelvis). Furthermore, in parallel to the design changes to the thorax, some refinements to the thorax certification procedures are proposed. ES-2 certification procedures are written down in the ES-2 User Manual [A5].

Lumbar Spine - The EUROSID-1 lumbar spine certification is performed as a dynamic test on a Part 572 pendulum. A head (form) is attached to the lumbar spine which is instrumented with three angular potentiometers that measure the fore and aft angle on the pendulum base plate and the top angle on the head form (relative to the shaft of the fore potentiometer). The potentiometer signals are used as input for an algorithm, which calculates the position and angle of the two dimensional head form.

In practice EUROSID-1 lumbar spines often fail to certify. It is felt that the set of requirements for the lumbar spine certification is more tight than strictly necessary for the desired performance of the part during full scale testing. Therefore, a re-evaluation of the lumbar spine certification procedure has been performed based on a theoretical analysis and a review of original test data.

It has become clear that the pendulum acceleration is responsible for many test certification failures, due to the presence of relatively large vibrations in the signal. These vibrations were found to be laboratory dependent. An alternative velocity change corridor was developed for the input corridor that is less sensitive for laboratory differences (Figure X). Besides that, it is found that the current certification output criteria have not been uniquely determined in the past. A proposed set of revised output criteria has been developed that better meets the desired specification. These proposed revised criteria are given in Table 1. Output criteria 4, 5 and 6 have changed with respect to the current criteria. See [A1], Annex F for more details.

Table 1.
Revised lumbar spine certification output criteria (angles in degrees, times in ms).

	Criteria	**Target**
1	Maximum head form flexion angle	45.0 - 55.0
2	Time of maximum head form flexion	39.0 - 53.0
3	Maximum fore angle dQA	31.0 - 35.0
4	Time of maximum fore angle dQA	44.0 - 52.0
5	Maximum aft angle dQB	between 0.8 * dQA + 2.0 and 0.8 * dQA + 4.5
6	Time of maximum aft angle dQB	44.0 - 52.0

Neck - The neck and lumbar spine tests are essentially the same. A head form is used to load the neck in a 3.4 ± 0.1 m/s dynamic test with a Part 572 pendulum. To line up with the new lumbar spine procedure, the method used for the lumbar spine was followed for the neck. The requirement for the pendulum acceleration is replaced with one for the pendulum velocity change for impacts between 3.3 – 3.5 m/s and a proposed set of revised output criteria has been developed that better meets the desired specification. These new criteria for the neck are given in Table 2. See [A1], Annex B for more details.

Table 2.
Revised neck certification output criteria (angles in degrees, times in ms).

	Criteria	**Target**
1	Maximum head form flexion angle	49.0 - 59.0
2	Time of maximum head form flexion	54.0 - 66.0
3	Maximum fore angle dQA	32.0 - 37.0
4	Time of maximum fore angle dQA	53.0 - 63.0
5	Maximum aft angle dQB	between 0.81 * dQA + 1.75 and 0.81 * dQA + 4.25
6	Time of maximum aft angle dQB	54.0 - 64.0

Abdomen - In the EUROSID-1 certification, the impact is delivered by a 23.4 kg impactor, diameter 152.4 ± 0.25 mm, to which a wooden block is attached. The shape of the wooden block corresponds to that of the simulated car door armrest that was used in the original APR biomechanical tests. The prescribed impact velocity is 6.3 m/s. The certification acceptance requirement is 6.4 ± 0.5 kN internal force.

Several years of full scale test experience with the EUROSID-1 dummy have shown that the level of abdominal forces measured in side impacts are much lower than those measured in certification tests. The average measured force level lies well below the injury criterion value of 2.5 kN internal force. The average value lies around 2 kN, and the maximum value recorded in a test has been 4.5 kN. It has therefore been suggested that the certification test impact severity should be reduced in order to certify the dummy using approximately the same loading level as in full scale tests. A new certification test has been defined at 4.0 ± 0.1 m/s, resulting in loading values closer to those experienced in actual crash tests. The proposed certification requirement is given in Table 3. See [A1], Annex E for more details

Table 3.
Revised abdomen certification criteria (4.0 ± 0.1 m/s).

	Criteria	**Target**
1	Peak abdomen force (internal)	2.45 ± 0.25 kN between 10.0 and 12.3 ms
2	Peak impactor force (external)	4.4 ± 0.4 kN between 10.6 and 13.0 ms

Report obtained from the EEVC web site www.eevc.org

Pelvis - The EUROSID-1 pelvis certification test requires an impact on the lateral aspect of the upper leg and pelvis area. The pendulum used is the standard part 572 pendulum of 23.4 ± 0.02 kg mass. The prescribed impact velocity is 4.3 ± 0.1 m/s. The certification requires an impactor force of 4.9 ± 0.5 kN and a pubic symphysis load of 1.34 kN ± 0.30 kN. Actual (full scale) measurement values of the EUROSID-1 show that the maximum pubic symphysis force measured is around 6.6 kN, and the average value 3.4 kN. This is significantly higher than values measured in the certification.

It is concluded that the impact severity of the pelvis tests should be increased. As an alternative for the standard pelvis certification procedure at 6.3 ± 0.1 m/s impact speed has been developed. The proposed certification requirement is given in Table 4. As the test is significantly more sever special attention should be paid to catch the dummy after the impact. See [A1], Annex G for more details.

Table 4.
Revised pelvis criteria (6.3 ± 0.1 m/s).

	Criteria	**Target**
1	Peak impact force	11.0 ± 1.2 kN between 9.5 and 12.5 ms
2	Peak pubic compression force	3.05 ± 0.35 kN between 10.0 and 13.0 ms

Note: This revision is finally not implemented, see evaluation

Thorax - The EUROSID-1 rib unit certification procedure is elaborate. Besides the full rib module tests also damper and rib only certification tests are required. The rib units are tested in a drop rig (Figure X), with an impactor mass of 7.78 kg. The EUROSID-1 is tested on four speed levels: 1.0, 2.0, 3.0 and 4.0 m/s.

The ES-2 rib module the certification procedure is essentially not changed, however, two adjustments are proposed.

The lowest drop-rig certification impact speed 1.0 m/s, is felt to be redundant. The reason is that the impact energy of this test in very low 3.9 J. This energy level less than 10% of the energy level that is necessary to produce the injury criterion displacement of 42 mm. Moreover, the test speed is far below the contact speed that can be expected in a full-scale car crash. Therefore it proposed to skip the full rib certification test with 1.0 m/s impact speed for ES-2.

The damper and rib only tests can be considered as acceptance tests for these sub-assemblies. It is proposed to skip these tests as long as the full rib modules comply with the certification test requirement. The additional damper and rib only tests are to be performed to check the parts in case of the full rib certification fails.

Report obtained from the EEVC web site www.eevc.org

Figure 1: New parts and sensors for the ES-2 dummy.

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A3. Schneider, L.W., Robbins, D.H., Pflüg, M.A., Development of anthropometrically based design specifications for an advanced adult anthropomorphic dummy family, NHTSA Editor, Dec. 1993.
A4. AAMA, AIAM, IIHS, RE: Petition for Rulemaking, December 22, 1997.
A5. ES-2 User Manual

ANNEX B: BIOFIDELITY TEST RESULTS

The EEVC WG12 has assessed the biofidelity of the ES-2 dummy thorax and pelvis. Unless mentioned otherwise, the test procedures and reference target corridors used are those established by the EEVC [B1] and used for EUROSID-1. The biofidelity of the EUROSID-1 production version is reported previously [B2].

THORAX

Full body pendulum tests - TNO Automotive in the Netherlands performed full body pendulum tests. The dummy thorax was impacted at 4.3 m/s and 6.7 m/s using the Part 572 23.4 kg mass impactor. The T1 lateral and pendulum acceleration results for both the ES-2 prototype and the EUROSID-1 are given in Figure 2. As EEVC does not give targets for 6.7 m/s, the responses at higher velocity are compared to the ISO TR9790 corridor given for pendulum acceleration only [B3].

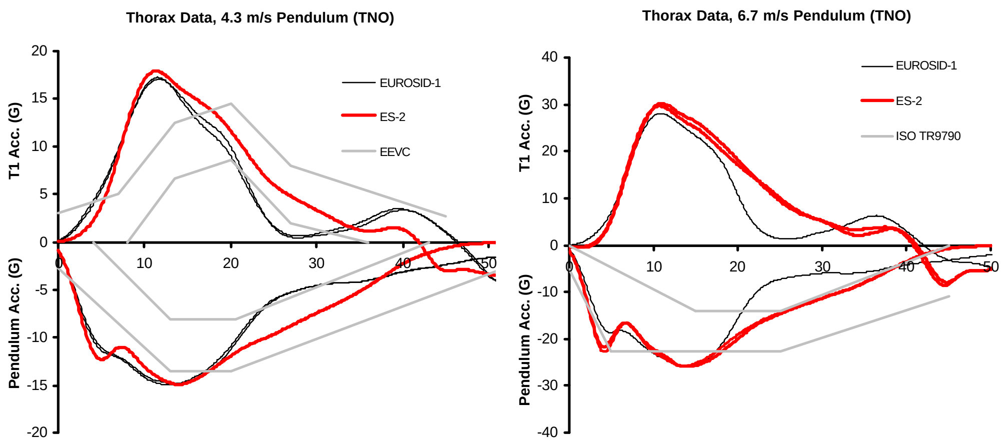

Figure 2: Thorax impactor and T1 lateral accelerations (4.3 and 6.7 m/s).

For the EUROSID-1, the results reproduce the test results published previously e.g. by Harigae, et al. [4]. Both T1 and the pendulum signals show a dip in the unloading phase. At 6.7 m/s, the response is considerably below the lower boundary of the ISO corridor in the unloading phase.

For the ES-2 prototype, the results show a loading phase similar to that of EUROSID-1. The initial peak in the pendulum acceleration signals is somewhat more pronounced, most likely due to the extra 100 gram moving mass in the needle bearing design. Unlike the EUROSID-1, the unloading signals fit well in the ISO corridor.

"Heidelberg" sled tests - Full body sled tests were performed at the Transport Research Laboratory (TRL) in the UK. Three types of sled test against an instrumented wall are performed to collect the data necessary for comparison with the available corridors of impacts of 7.6 m/s against rigid wall, 10.3 m/s against rigid wall and 10.3 m/s against padded wall. The set-up is equivalent to that used by the University of Heidelberg for the PMHS tests and is described in [B1]. Both the EUROSID-1 and the ES-2 prototype are subjected to the three test types. Tests were repeated two or three times. The results of these are given in Figure 3. According to the EEVC procedure, a shift in time is allowed to align the maximum of the signal with maximum of the corridor. This shift is not applied in the graphs.

In addition to the EEVC requirements, ISO gives target values for the lateral T1 and T12 acceleration responses. These data are given in Table 5 for both dummies.

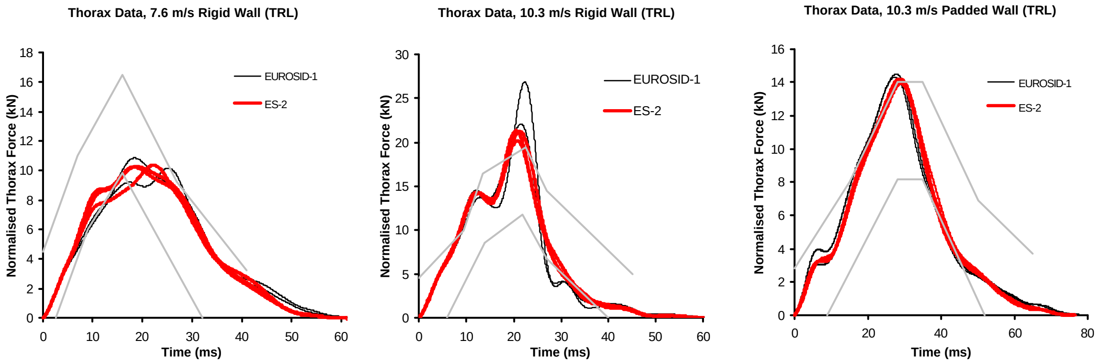

Figure 3: Thorax rigid and padded wall force (7.6 and 10.3 m/s) in "Heidelberg" test.

Table 5: Normalised dummy thorax accelerations, 7.6 m/s rigid wall.

Dummy	T1 accel. (g)	T12 accel. (g)	Rib acceleration (g)		
			Top	Mid	Bottom
EURO-SID-1	45.0 37.6	61.9 72.0	133.9 146.2	106.2 115.5	126.4 127.8
ES-2	47.5 40.7 39.1	57.5 55.3 63.3	138.5 134.9 164.2	88.9 93.6 100.0	81.9 98.3 102.6

From these sled tests, it was observed that the ES-2 dummy and force plate measurements at the thorax are very similar to those for the EUROSID-1 dummy. Hence, no apparent change in the biofidelity of the dummy was found.

PELVIS

Linearly guided impactor tests - Linearly guided impactor tests have been performed at INRETS in France. Both the EUROSID-1 and the ES-2 prototype have been subjected to impacts between 3.3 and 10.6 m/s using a guided 23.4 kg impactor. The results of these tests are given in Figure 4. Comparison is made against two sets of requirements: those given by the EEVC [B1] and those derived more recently by the EEVC, which are now considered by IHRA[B5]. As the original biomechanical tests used a 17.3 kg impactor that was no longer available, the EEVC corridors have been scaled to the 23.4 kg impactor mass.

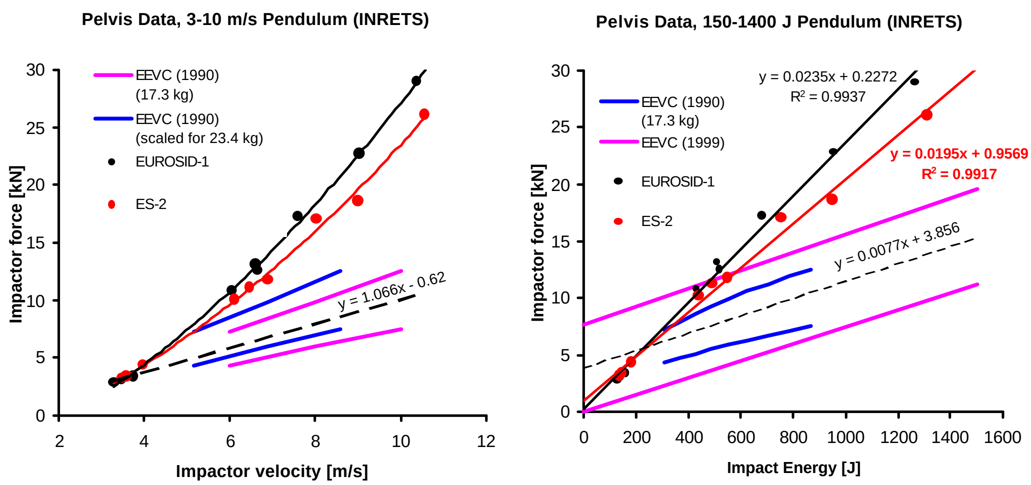

Figure 4: Pelvis impactor force/velocity and force/energy for EUROSID-1 and ES-2.

Table 6: Peak pelvis acceleration compared with the targets considered by IHRA .

Test condition **Target pelvis acceleration**	**3.4 m/s impactor test (g)** **25.5 - 42.5**	**6.6 m/s impactor test (g)** **47.0 - 77.0**
EUROSID-1	13.71 11.69	68.59 75.17
ES-2	15.5 15.84	70.82 64.59

In Table 6, the maximum pelvis accelerations obtained in the impactor tests are compared with the corridors specified in [B5]. Both dummies meet the criteria at the 6.6 m/s condition, but are below the targets at 3.4 m/s. However, for both test conditions the ES-2 prototype responses are more close to the biofidelity targets than those of the EUROSID-1. Only for low energy levels (under 300 J) the dummy responses for EUROSID-1 and ES-2 are within the corridor. The ES-2 prototype is close to the EUROSID-1 but showing marginal improvement.

<u>“Heidelberg” Sled Tests</u> - The results of the full body sled tests for the pelvis are given in Figure 5. Additionally, the normalised dummy pelvis acceleration data for all tests are shown in Table 3. Both dummies meet the EEVC target acceleration criteria at the 10.3 m/s padded condition and give similar responses. The responses of both dummies at the rigid wall

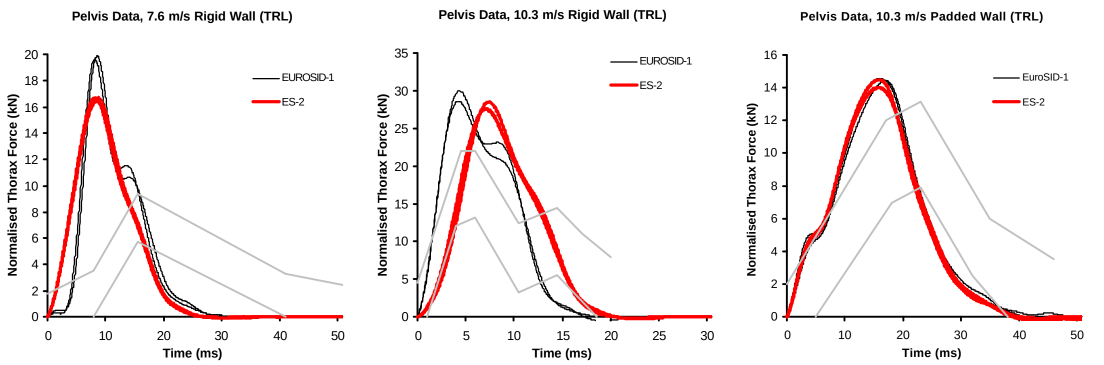

Figure 5: Pelvis rigid and padded wall force (7.6 and 10.3 m/s) in "Heidelberg" test.

conditions are exceeding the EEVC targets. However, for all three conditions, the ES-2 prototype responses are slightly closer to the biofidelity targets than those of the EUROSID-1. The overall conclusion is that the ES-2 biofidelity measures are somewhat lower than for the EUROSID-1 dummy, but the change only represents a small improvement in biofidelity.

Table 7: Peak normalised pelvis accelerations.

Test condition **EEVC target acceleration**	**7.6 m/s RW (g)** **52.7- 87.9**	**10.3 m/s RW (g)** **79.5-132.5**	**10.3 m/s PW (g)** **65.8-109.7**
EUROSID-1	166.4 158.1	277.1 277.8	99.1 99.3 105.0
ES-2	141.8 139.9 140.3	238.1 236.6 243.4	92.3 95.7 100.2

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Report obtained from the EEVC web site www.eevc.org

ANNEX C: CALIBRATION TEST RESULTS

Table 8: Overview of ES-2 calibration test results.

Body Region	Criterion	Target	Measured values
Head	Res. Accel. [g]	100 – 150	123 LHS, 125, 142 RHS
Neck	Speed [m/s]	3.3 – 3.5	3.39, 3.35, 3.33
	Max Rotation [°]	49 – 59	53.9, 57.0, 57.6
	t(max rot) [ms]	54 – 66	61.6, 57.2, 60.6
	Max Angle A [°]	32 – 37	33.8, 34.5, 34.9
	t(max A) [ms]	53 – 63	57.1, 56.3, 59.3
	Max Angle B [°]	A=33.8: 29.1 - 31.6 A=34.5: 29.7 - 32.2 A=34.9: 30.0 - 32.5	30.8 31.4 31.9
	t(max B) [ms]	54 – 64	57.7, 56.9, 59.5
Shoulder	Speed [m/s]	4.2 – 4.4	4.23, 4.29, 4.29
	Max. Accel. [g]	7.5 – 10.5	9,5, 9.2, 9.63
Top Rib	Deflection at 2.0, 3.0 and 4.0 m/s [mm] (19 N/.mm)	23.5 – 27.5	24.5, 27.3
		36.0 – 40.0	36.3, **40.2**
		46.0 – 51.0	46.9, **51.3**
Mid Rib	Deflection at 2.0, 3.0 and 4.0 m/s [mm] (16.4 N/.mm)	23.5 – 27.5	25.5
		36.0 – 40.0	38.8
		46.0 – 51.0	50.1
Bottom Rib	Deflection at 2.0, 3.0 and 4.0 m/s [mm] (16.4 N/.mm)	23.5 – 27.5	24.1
		36.0 – 40.0	36.2
		46.0 – 51.0	49.2
Abdomen	Speed [m/s]	3.9 – 4.1	3.98, 4.00, 4.06
	Pendulum Force [kN]	4.0 – 4.8	4.3, 4.4, 4.42
	t(F pend) [ms]	10.6 – 13.0	11.6, 11.7, 11.6
	Force [kN]	2.2 – 2.7	2.4, 2.4, **2.79**
	t(F) [ms]	10.0 – 12.3	11.0, 11.5, 11.5
Lumbar spine	Speed [m/s]	5.95 – 6.15	5.95, 6.08, 6.00
	Max Rotation [°]	45 – 55	46.1, 47.3, 48.8
	t(max rot) [ms]	39 – 53	46.3, 46.1, 45.4
	Max Angle A [°]	31 – 35	31.5, 31.2, 33.5
	t(max A) [ms]	44 – 52	45.8, 45.8, 46.0
	Max Angle B [°]	A=31.5: 27.2 - 29.7 A=31.2: 27.0 - 29.5 A=33.5: 28.8 - 31.5	28.3 28.3 30.4
	t(max B) [ms]	44 – 52	46.2, 47.3, 46.2
Pelvis	Speed [m/s]	6.2 – 6.4	6.27, 6.23, 6.3
	Pendulum Force [kN]	9.8 – 12.2	10.0, 9.8, 9.94
	t(F pend) [ms]	9.5 – 12.5	11.4, 11.5, 11.3
	Pubic force [kN]	2.7 – 3.4	2.97, 2.93, 3.16
	t(F pubic) [ms]	10.0 – 13.0	12.1, 11.8, 11.6

ANNEX D: SENSITIVITY TEST RESULTS

Impact direction sensitivity was investigated in 72 full body pendulum tests on the shoulder, thorax, abdomen, and pelvis. Five directions were tested per body part, e.g. forward of lateral +20 and +10 degrees, lateral and rearward of lateral -10 and -20 degrees. The oblique tests were done three times and the pure lateral tests six times. The results are given in Figure 6, Figure 7 and Figure 8.

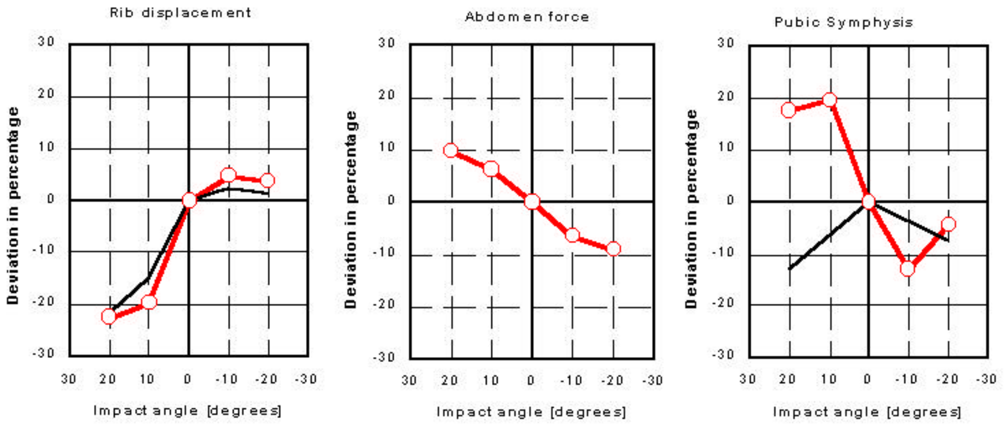

Figure 6: ES-2 (-o-) and EUROSID-1 sensitivity to impact angle in pendulum tests.

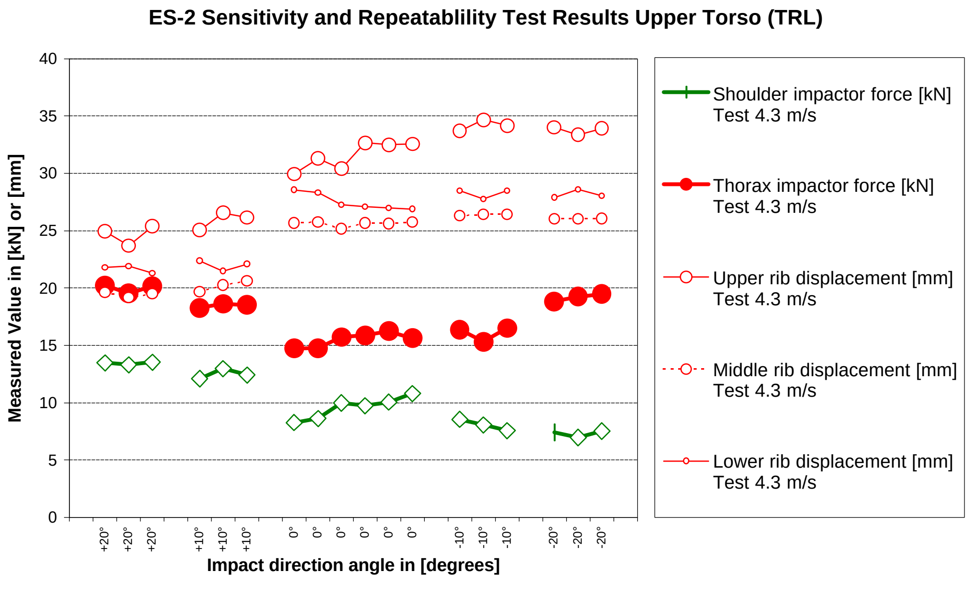

Figure 7: ES-2 upper torso sensitivity and repeatability test results.

The ES-2 shoulder was found to be sensitive to changes in impact angle. This is an expected result of the design of the shoulder mechanism that is not changed with respect to EUROSID-1. The ES-2 rib deflection as measured by the transducer gave results below those for pure lateral impacts for the forward oblique condition, whilst rearward oblique tests gave slightly higher results. The effect was similar to that seen in tests with the prototype EUROSID [D1]. On EUROSID-1 rib displacement was measured at a point on the rib between the piston and the damper, whilst on ES-2 the displacement transducer is positioned on the rib to the rear of the piston. It seems likely that the change in position of the rib displacement point of measurement can have an effect on the measured values of the displacement when oblique loading components are present.

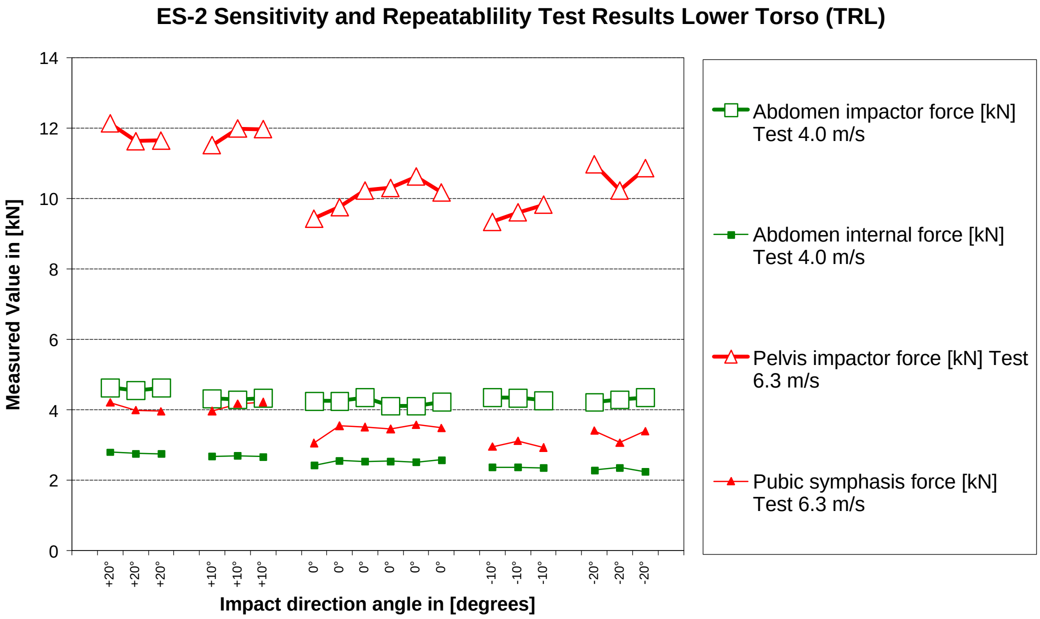

Figure 8: ES-2 lower torso sensitivity and repeatability test results.

The ES-2 abdomen exhibited a low sensitivity to changes in impact angle over the range of angles tested. The ES-2 pelvis had a low sensitivity to changes in impact angle for the rearward oblique and pure lateral tests. The tests in the frontal oblique condition resulted in higher pubic force. This may be caused by interference of the modified upper leg with the impactor and/or more concentrated loading due to the change in contact profile of the impactor for forward oblique loading.

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ANNEX E: REPEATABILITY TEST RESULTS

The peak responses of repeated tests are examined to assess the repeatability of the ES-2 dummy. For this, the results of the biofidelity "Heidelberg" sled tests and the sensitivity tests were used (Annex B and D). The level of repeatability of dummy responses is expressed in the coefficient of variation. A coefficient of variation of 10% is generally considered to be acceptable. The purely lateral pendulum tests on the shoulder, thorax abdomen and pelvis at TRL were repeated six times, giving a firm base for a repeatability analysis. From the "Heidelberg" sled tests only a limited number of samples is available, however, comparable data are available from the tests performed on the first production EUROSID-1 in 1991 [E1].

Table 9: ES-2 Coefficients of variation of not normalised peak values in lateral pendulum tests.

	Speed (m/s)	**Mean (n=6)**	**SD**	**CV (%)**
Shoulder				
Impactor Force, kN	4.3	9.58	0.96	10.0
Thorax				
Impactor Force, kN	4.3	15.49	0.61	4.0
Upper rib deflection, mm		31.55	1.20	3.8
Middle rib deflection, mm		25.60	0.22	0.9
Lower rib deflection, mm		27.52	0.73	2.7
Abdomen				
Impactor force, kN	4.0	4.22	0.09	2.2
Internal force, kN		2.53	0.05	2.1
Pelvis				
Impactor force, kN	6.3	10.09	0.42	4.2
Pubic force, kN		3.44	0.19	5.6

Table 10: Repeatability of EUROSID-1 and ES-2 in the Heidelberg sled tests (normalised peak values).

	Coefficient of Variation CV (%)	
	EUROSID-1†	**ES-2**
Thorax wall force		
7.6 m/s Rigid Wall	4.7 (1.2)	0.5
10.3 m/s Rigid Wall	14.0 (7.2)	3.1
10.3 m/s Padded Wall	1.3 (5.6)	1.0
Pelvis wall force		
7.6 m/s Rigid Wall	1.0 (1.0)	1.0
10.3 m/s Rigid Wall	3.4 (4.6)	1.9
10.3 m/s Padded Wall	1.0 (3.0)	2.1
Pelvis lateral acceleration		
7.6 m/s Rigid Wall	35.8 (4.5)	0.9
10.3 m/s Rigid Wall	0.2 (9.8)	1.5
10.3 m/s Padded Wall	26.8 (1.8)	4.1

† Values between brackets are for the first EUROSID-1 tested in 1991 [2].

REFERENCES

E1. Roberts, A.K. et al., The Biofidelity of the Production Version of the European Side Impact Dummy, EEVC-WG9, ESV paper 91-S8-O-02

ANNEX F: REVIEW OF ACEA ES-2 TEST RESULTS

A summary of measurements found by ACEA is given in Table 12 at the end of this Annex. The findings of the ACEA test program indicate that the following issues must still be addressed:

- Further consideration of dummy responses and injury criteria is needed (especially V*C, TTI, rib deflection and abdomen force) given that most values of the ES-2 in full-scale tests are higher than those of the EUROSID-1;
- Review of "damping" characteristics of the rib modules in view of high frequency rib acceleration results and oscillatory behaviour in loading and unloading phase;
- Further analysis is needed to see if some recorded back-plate loads with ES-2 are reasonable or acceptable;
- Reproducibility and repeatability of head position prior to impact must ensured.

These issues will be addressed below.

REVIEW OF DUMMY RESPONSES AND CRITERIA

ACEA performed six (6) EURONCAP, three (3) ECE R95, two (2) FMVSS 214 tests and one (1) FMVSS 201 (pole) test with various vehicles from different manufacturers. It was noted that in general "flat-tops" on rib responses had disappeared, back-plate loads were reduced and knee interaction was less severe. In order to investigate how the differences in response between the ES-2 prototype and the EUROSID-1 have influenced the overall dummy criteria, the ACEA TF.D has carried out a statistical analysis on their main results. The findings have been presented at the 23rd EEVC WG12 meeting. To get a handle on the effect on the criteria in relation to the existing regulatory limit, the average normalised percentage of change in key measurements was calculated, as follows

$$\frac{\sum \frac{(ES2 - ES1)}{IC}}{NoT},$$

in which *ES2* and *ES1* stand for the measured values for ES-2 and EUROSID-1, respectively, *IC* for the injury criterion limit value (EEVC/EuroNCAP), and *NoT* for the number of tests. This average normalised percentage was determined for HIC, upper/middle/lower rib deflection and V*C, abdomen and pubic load. The figure below shows the outcome.

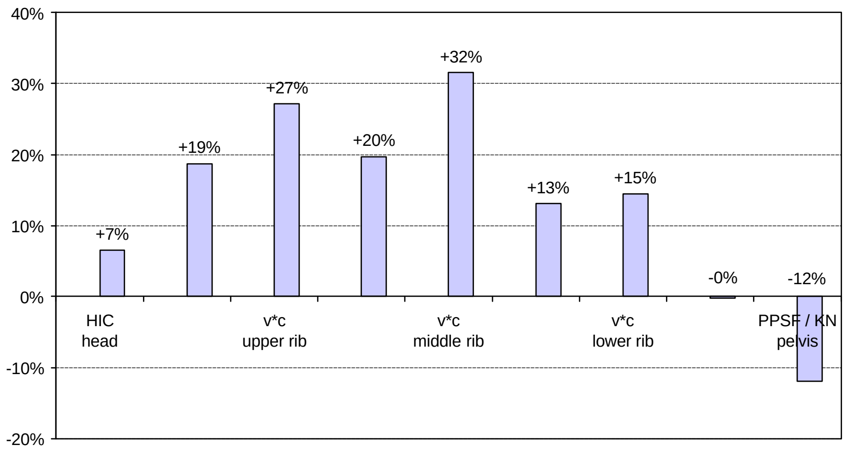

Figure 9: Average normalised percentage of change in key measurements between ES-2 and EUROSID-1 (ACEA results, EuroNCAP/ECE tests only).

Over all cars tested by ACEA, normalised rib deflections have gone up by 17% (on average over three ribs) and normalised V*C by 25%. Higher rib deflections have been anticipated due to the elimination of rib binding. The reduced friction in the guide system of ES-2 makes the thorax more sensitive to impact velocity. Rib response details not detected with EUROSID-1 are revealed with ES-2. On the other hand, normalised pubic loads have decreased by 12%, probably due to a more realistic leg interaction.

In particular for the thorax, it should be noted that the (purely lateral) Heidelberg biofidelity sled tests do not indicate an increase of measured values for the ES-2 prototype [F1]. The figure below gives the average normalised[1] percentage of change in key measurements based on the EEVC biofidelity tests (thorax pendulum and Heidelberg sled tests [F2]). The figure shows that normalised results on average are smaller for ES-2 than EUROSID-1.

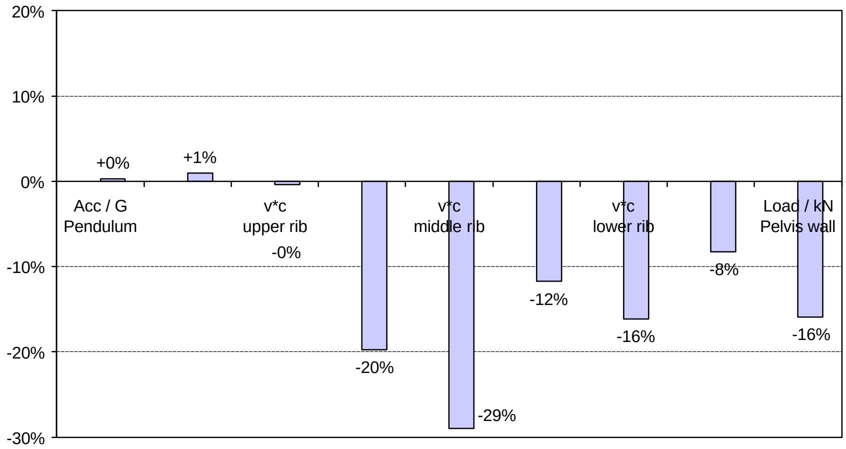

Figure 10: Average normalised percentage of change in key measurements between ES-2 and EUROSID-1 in biofidelity tests (thorax pendulum and Heidelberg sled tests).

Finally, the effect of dummy changes on the thorax criterion TTI has not been investigated. This criterion has never been considered for EUROSID-1, is currently not used in ECE Regulation 95 nor does any justification exist to start using it for ES-2.

REVIEW OF DAMPING CHARACTERISTICS OF THE RIB MODULES

Oscillatory behaviour of the rib module and high frequency rib acceleration signals are observed in the loading and unloading phase during full scale testing and certification. ACEA attributes this to "unrealistic" damping characteristics of the rib modules.

Oscillations in the unloading part of the rib signal

The oscillation in the unloading part of the rib displacement signal is observed in full-scale and certification tests. The phenomenon occurs when the rib has returned to its initial position.

These rib displacement oscillations are the result of the introduction of end stop buffers that replace the rigid end stop of the EUROSID-1. These buffers are introduced to reduce the spiking acceleration peaks found with EUROSID-1 and, consequently, preserve accelerometer hardware and the guide bearing assembly. The maximum buffer compression is 3.5 mm. The mass that oscillates is 0.72 kg per rib module. This is small with respect to the mass of the complete thorax (22.4 kg). Review of T1 and T12 acceleration responses show that the energy involved does not affect the dummy kinematics.

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[1] For parameters that do not have biomechanical limits such as load wall force and pendulum acceleration, values are normalised to the mean peak value indicated by the EEVC corridors.

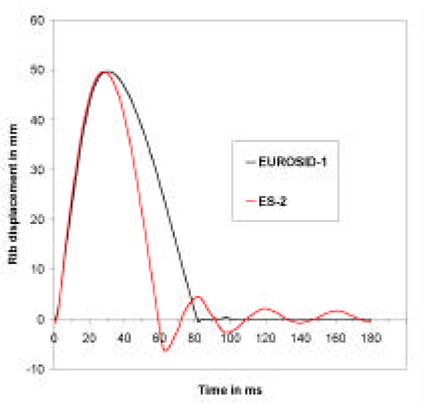

Figure 11: EUROSID-1 and ES-2 rib certification responses

Oscillations in the loading part of the rib signal

Oscillations in the loading phase of the displacement rib signals have been observed to a greater or less extent in several tests. The test, which seems to most extremely show the effect is that of the Renault Megane (with lateral seat-head airbag) in EuroNCAP test condition[2]. This test shows a pronounced alternation in the displacement signal of all three ribs in the loading curves (see Figure below). The displacement oscillations and dips correlate with peaks in the rib acceleration and rib V*C signals. In the report, ACEA suggests this behaviour may be caused "from a first impact, followed by a repeated loading and unloading of the rib module from the impacted door, which may have been caused due to unrealistic damping

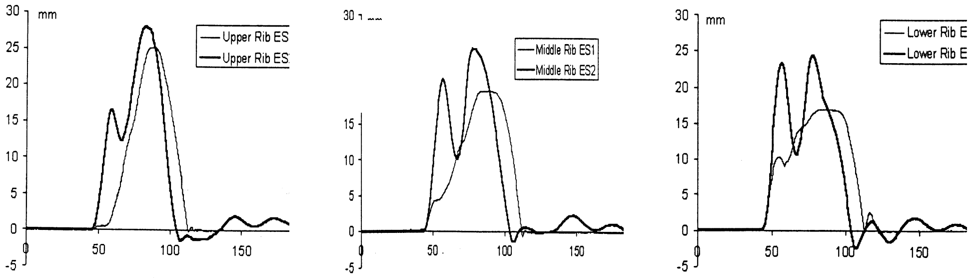

Figure 12: ES-2 Rib displacements in Renault Megane test [1]

characteristics of the rib modules".

To understand what may cause this behaviour, the design of the rib modules was studied in more detail. The EUROSID rib module is a complex mass-spring-damper-system that has different characteristics for loading and unloading. The guide system mass and tuning spring are active during loading and unloading. During loading, the spring-loaded oil damper is active. After reaching its maximum deflection, the rib is pushed back by the stiff damper spring. The damper is not connected to the rib in the unloading phase and therefore does not influence the rib response in this phase. From the moment that the spring damper spring reaches it zero length, only rib guide system mass and the tuning spring remain active.

The change in the guide system from linear journal bearing (EUROSID-1) to linear needle bearings (ES-2) has eliminated the friction almost entirely. At the same time, the mass of the moving rib parts increased from 610 to 720 gram. To restore the rib performance on EUROSID-1 certification levels, the tuning spring stiffness for ES-2 had to be increased

[2] The pronounced loading curve oscillation is observed in only one of the 11 tests performed by ACEA. Other tests either do not show it or exhibit slight dips only near the maximum displacement.

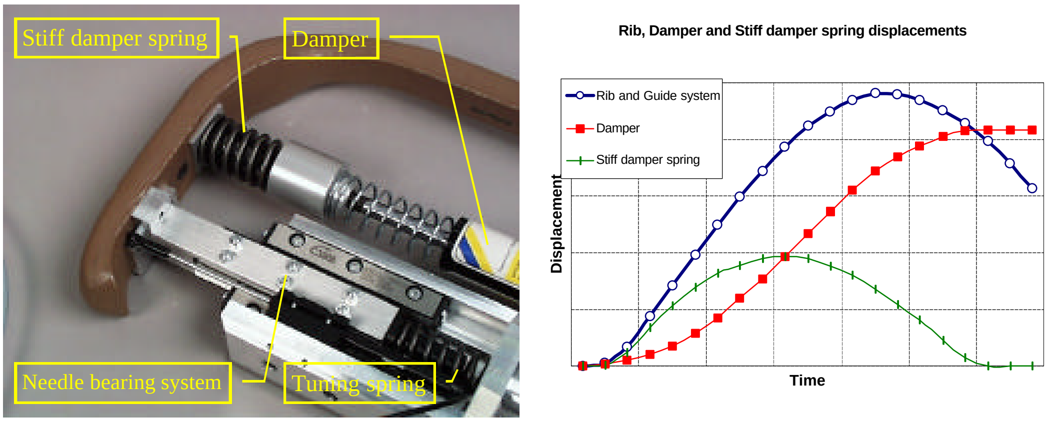

Figure 13: Left: ES-2 Needle bearing rib design. Right: rib and damper displacements and stiff damper spring compression in a standard rib certification test.

considerably. The stiff damper spring, however, remained unchanged. EEVC tests showed that these changes did not affect the biofidelity of the rib module.

The natural frequencies of the rib module depend on the damper velocity, as the stiff damper spring contributes depending on damper stroke. As the rib displacement is the sum of stiff damper spring compression and damper displacement, the natural frequency of the rib module will change during rib compression. Natural frequencies are defined by:

$$f_n = \frac{1}{2p}\sqrt{\frac{k_1 + k_2}{m}}\ ,$$

where *k1* is rib bow plus tuning spring stiffness, *k2* the stiff damper spring stiffness (as far as effective) and *m* the mass of the moving parts. The Table below gives a theoretical estimate of the natural frequencies of the rib module of EUROSID-1 and ES-2.

Table 11. Estimation of theoretical eigenfrequencies of the rib modules.

	EUROSID-1	**EUROSID-1**	**ES-2**
Moving mass	0.610 kg	0.610 kg	0.720 kg
Stiff damper spring stiffness	72000 N/m	72000 N/m	72000 N/m
Rib bow + Tuning spring stiffness	13000 N/m	18600 N/m	28000 N/m
Theoretical value with full effective damper spring	59 Hz	61 Hz	59 Hz
With 75% effective damper spring	53 Hz	55 Hz	54 Hz
With 50% effective damper spring	45 Hz	48 Hz	47 Hz
With 25% effective damper spring	36 Hz	39 Hz	40 Hz
Unloading phase (tuning spring only)	23 Hz	28 Hz	31 Hz

The change in rib module design effectively alters the frequency response in the unloading phase only. If the rib would oscillate in its natural frequency, it must not be in contact with an intruding surface. The observed frequency in the Renault Megane test is approx. 50 Hz, hence it is more likely that an external source has governed this oscillation. This is supported by the fact that the first peaks in the rib displacements take place approx. at the same time for all three ribs (lower rib at 56 ms, middle rib at 57 ms and the upper rib at 59 ms).

The elimination of the friction in the guide system makes the ES-2 thorax more discriminating against different types of loading. Rib displacement details not seen with EUROSID-1 are brought to light by ES-2 because of increased sensitivity to changes in loading environment. In circumstances such as a dummy subsequently interacting with door, seat and airbag, the ES-2 rib module may demonstrate rapid alternations in the displacement signals.

Report obtained from the EEVC web site www.eevc.org

Changing the stiff damper spring and damper combination as suggested by ACEA will not address the responses found, nor will it influence the high frequency rib acceleration responses. In general, the rib acceleration response is inherent to the design of the EUROSID rib and is no different for ES-2 as it is for EUROSID-1.

REVIEW OF BACKPLATE LOADS

With respect to the back-plate issue, contradictory results were found by ACEA. A majority of results showed lower back-plate forces (average of 37% decrease of lateral force Fy, see figure below) and moments but still some cases of high loads were recorded. Further analysis was asked for to see if some recorded back-plate loads with ES-2 are reasonable and acceptable.

The benefits of the new torso back plate have been solely questioned on the basis of two Ford Focus tests, in which torso back plate load values increase with a factor 4.4 (on Fy) to 13.6 (on Mz) compared to loads obtained with EUROSID-1 [1]. Of all vehicles tested with ES-2, however, these are the only tests for which the loads actually have increased[3]. This suggests that the cause may be more vehicle- than dummy-related. Still, the event seems not very significant because no discontinuities in the rib displacement or V*C signals can be observed. The EUROSID-1 values for the Ford Focus are very small (Fx = 350 N, Fy = 310 N, My = 15 Nm and Mz = 7 Nm). Factors on such small load values can easily be relatively large.

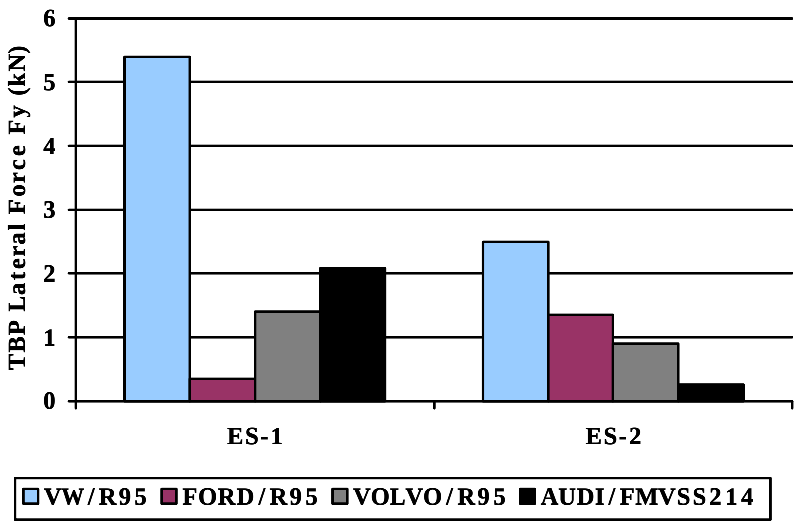

Figure 14: Comparative back-plate data available for 4 vehicles in ECE R95 and FMVSS 214 conditions.

In general, ACEA results indicate that the modified back plate implemented in the ES-2 prototype reduces back plate loads. Also, ACEA noticed that belt pre-tension may increase the back plate loads. .

HEAD POSITION PRIOR TO IMPACT

ACEA noticed that horizontal positioning of the ES-2 dummy prototype's head was difficult. This may impair the test repeatability.

The ES-2 prototype circular buffers in the neck have been produced in the specified tolerance whereas the EUROSID-1 circular buffers were slightly oversized. This has resulted in reduced pre-tensioning of the buffers and the observed "looseness" in head positioning. This issue has been resolved by restoring the pre-tensioning of the EUROSID-1 buffers in the ES-2 production version.

[3] Excluding the Focus tests, the average decrease of the lateral back-plate load is 59%.

Table 12. Overview of measurements in the ACEA test programme: comparison of dummy criteria found with EUROSID-1 (ES-1) and ES-2 in similar test conditions. Values include test and car variability.

Test condition / vehicle model	THORAX - UPPER RIB Deflection (mm)		THORAX - UPPER RIB V*C		THORAX - MIDDLE RIB Deflection (mm)		THORAX - MIDDLE RIB V*C		THORAX - LOWER RIB Deflection (mm)		THORAX - LOWER RIB V*C	
	ES 1	**ES 2**	**ES 1**	**ES 2**	**ES 1**	**ES 2**	**ES 1**	**ES 2**	**ES 1**	**ES 2**	**ES 1**	**ES 2**
FMVSS 201												
BMW 5	33	39.2	0.34	0.36	33	n.a.	0.39	n.a.	26	34.7	0.51	0.42
FMVSS 214												
BMW 5	n.a.	26.9	n.a.	0.38	n.a.	26.6	n.a.	0.37	n.a.	26.6	n.a.	0.36
AUDI A6	21	29.6	0.2	0.35	26.5	26.7	0.29	0.36	19.9	30.1	0.2	0.37
ECE/NCAP	***** 42 *****		***** 1 *****		***** 42 *****		***** 1 *****		***** 42 *****		***** 1 *****	
Peugeot 406	34.7	39.7	0.59	0.86	37.6	42.4	0.61	0.97	37.5	38.8	0.72	0.89
R Megane	25.1	28	0.18	0.24	19.5	25.3	0.07	0.38	16.9	24.3	0.09	0.33
Mercedes E	26.0	53.0	0.36	<u>1.33</u>	25.0	43.0	0.18	<u>1.09</u>	25.0	34.0	0.29	0.58
VW Lupo	18.2	29.4	0.2	0.44	8.6	22.9	0.09	0.45	26.5	22.2	0.50	0.33
VW Polo	21.4	23.9	0.12	0.21	17.4	21.4	0.10	0.14	14.75	17.9	0.06	0.09
Ford Focus	21.1	25.0	0.16	0.43	15.8	24.2	0.11	0.46	11.2	23.8	0.07	0.43
Ford Focus	19.2	23.6	0.12	0.36	15.7	20.6	0.15	0.31	10.9	19.8	0.1	0.3
Volvo S 80	13	19	0.05	0.08	14	20	0.06	0.09	17	23	0.08	0.12
Volvo S 80	17	n.a.	0.07	n.a.	14	n.a.	0.06	n.a.	16	n.a.	0.08	n.a.

Test condition / vehicle model	HEAD HIC		ABDOMEN APF (KN)		PELVIS PPSF (KN)		B-PLATE Fy (KN)	
	ES 1	**ES 2**	**ES 1**	**ES 2**	**ES 1**	**ES 2**	**ES 1**	**ES 2**
FMVSS 201								
BMW 5	3718	clipped	1.97	3.14	3	2.73	n.a.	0.664
FMVSS 214								
BMW 5	n.a.	240	n.a.	3.145	n.a.	2.73	n.a.	0.658
AUDI A6	n.a.	78.1	1.08	1.28	1.81	1.67	2.08	0.26
ECE/NCAP	***** 1000 *****		***** 2.5 *****		***** 6 *****		*******	
Peugeot 406	75	251	0.67	0.016	0.47	0.126	0.77	0.18
R Megane	116	245	0.39	0.017	2.57	0.11	n.a.	0.19
Mercedes E	102	220	1.25	1.55	1.87	2.80	n.a.	n.a.
VW Lupo	182	180	1.48	1.56	3.96	3.3	5.4	2.5
VW Polo	101	172	0.89	0.86	5.79	2.61	-	-
Ford Focus	81.7	61.9	1.18	1.94	3.47	3.48	0.35	1.54
Ford Focus	40.5	63.5	1.54	1.42	2.72	3.43	n.a.	1.35
Volvo S 80	43	71	0.43	n.a.	1.45	n.a.	n.a.	0.9
Volvo S 80	44	n.a.	0.65	n.a.	1.15	n.a.	1.4	n.a.

REFERENCES

F1. Summary of ES-2 Prototype Evaluation Results, EEVC WG12 document 110, February 2001

ANNEX G: EEVC FULL-SCALE TEST RESULTS

Table 13: TRL and TNO EuroNCAP-type full-scale crash test results for injury parameters.

ORGANISATION		**TRL**			**TNO**		**ECE**
Vehicle type		Mid-size family saloon			Ford Focus		
		ES-2	**EURO-SID-1**	**EURO-SID-1**	**ES-2**	**EURO-SID-1**	**Limit**
HEAD							
Peak acceleration (g)		123.43	48.72	67.08	-	-	
HIC_{36}		303.00	80.70	183.40	100.8	40.5	1000
3 ms exceedence (g)		62.90	33.71	56.40	-	-	
CHEST							
Top Rib							
Compression (mm)		**47.88**	34.59	36.96	32.2	19.2	42
Viscous Criterion (ms^{-1})		1.09	0.51	0.41	0.30	0.12	1.00
Lateral acceleration (g)		202.01	144.00	-	-	-	
Middle Rib							
Compression (mm)		16.30	33.24	33.76	21.4	25.6	42
Viscous Criterion (ms^{-1})		0.15	0.54	0.48	0.15	0.15	1.00
Lateral acceleration (g)		276.80	150	-	-	-	
Bottom Rib							
Compression (mm)		37.62	39.57	36.96	14.0	10.9	42
Viscous Criterion (ms^{-1})		0.69	0.71	0.67	0.12	0.10	1.00
Lateral acceleration (g)		265.91	225	-	-	-	
ABDOMEN							
Peak lateral force (kN)	Front	0.28	0.27	-	-	-	
	Mid	1.43	1.20	-	-	-	
	Rear	1.13	1.09	-	-	-	
	Total	**2.74**	2.40	1.76	1.14	1.54	2.50
PELVIS							
Pubic symphysis force (kN)		2.75	3.30	2.84	2.60	2.72	6.00

ANNEX H: PELVIS AND LEG PERFORMANCE

Issues with regards to full-scale performance of EUROSID-1 pelvis and lower extremities are particularly related to the pubic symphysis force signal (Annex A):

- The metal to metal contact in the EUROSID-1 hip joint in case of large upper leg abduction (15º) results in a tension peak, superimposed on the pubic symphysis compression;
- Severe knee to knee contact results in a compression peak superimposed on the pubic symphysis compression.

Both effects are considered to be not humanlike.

At BASt in Germany these phenomena are reproduced with oblique (20 degrees forward and 20 degrees aft) sled tests (speed 20 km/h) on to a barrier bar that covers the pelvis, upper leg and knee. Tests have been performed with the ES-2 dummy to find out whether the modified upper legs and hip joints address these problems sufficiently. By impacting the pelvis first (metal to metal contact) or the knee first (knee-to-knee contact), the two problems may be looked at separately.

METAL TO METAL CONTACT

Figure 15 shows the EUROSID-1 (equipped with US-SID legs) during impact and the results for the tests with a 20 degrees aft impact direction. The EUROSID-1 signals show the metal to metal contact that results in a tension peak superimposed on the pubic symphysis compression. For the ES-2 prototype this effect is damped and reduced by 60%.

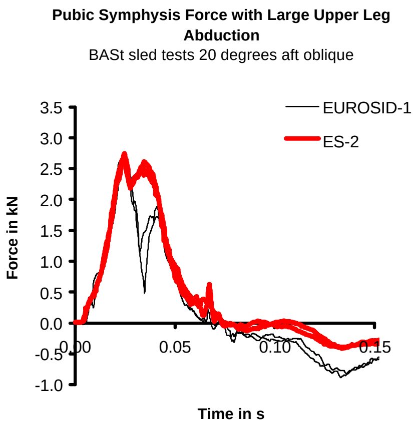

Figure 15: ES-2 prototype and EUROSID-1 in sled tests at BASt, impact speed 20 km/h; impact direction 20 degrees aft (pelvis contact first), Left: EUROSID-1 (equipped with US-SID legs) during impact.

KNEE TO KNEE CONTACT

Figure 16 shows ES-2 prototype in the sled test set-up and the results for the tests with a 20 degrees forward impact direction. The EUROSID-1 signals show the knee to knee contact that results in a compression peak superimposed on the pubic symphysis compression. For the ES-2 prototype this effect is almost entirely eliminated.

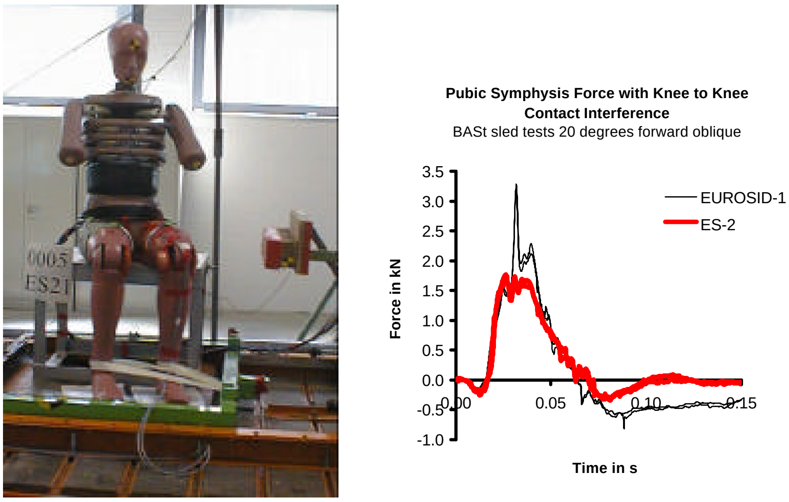

Figure 16: ES-2 prototype and EUROSID-1 in sled tests at BASt. Impact speed 20 km/h; Impact direction 20 degrees forward (knee contact first) , Left: Test set-up. The barrier is a padded bar covering pelvis, upper leg and knee. Right: ES-2 prototype and EUROSID-1