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Status of Side Impact Dummy Developments in Europe

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Working Group 12

Abstract
This document reviews the status of side impact dummy developments in Europe. Side impact harmonisation, new restraint systems and higher levels of required occupant protection in side impact are the incentive for intensified research and development work in this area. For the present, new hardware options and certification procedures for the EUROSID-1 have been developed. This document gives some background and evidence for the modifications. Also, recommendations for further research are given.

1. INTRODUCTION

With the introduction of the European Directive 96/27/EC "protection of occupants of motor vehicles in the event of a side impact", the European Union set an important step in reducing the injury problem in road traffic. The current adult side impact dummy EUROSID-1, which will be used in the test procedure of the new European Directive, has been developed during the eighties by five research organisations within the European Experimental Vehicles Committee (EEVC). Its biofidelity has been assessed by comparing its performances to the available biomechanical data. Further tests confirmed its durability, reproducibility and repeatability so that the "Specification of the EEVC side impact dummy EUROSID-1" were approved and published in 1989. Since then, car manufacturers and research laboratories in Europe gained experience in the use of the EUROSID-1 dummy which was recognised as incorporating important features and measurement tools.

Since the development of the EUROSID-1, discussions and research on side impact protection have continued on a world-wide level, especially concerning the crash test dummies used in side impact compliance testing. These -ongoing- discussions concentrate on the following issues:

- The need to harmonise side impact dummies world-wide in order to reduce the development efforts and costs required by manufacturers of cars and restraint systems to comply with different standards specified in different areas of the world;
- The level of biofidelity, i.e. the resemblance of a crash dummy to actual human impact response data, of existing side impact dummies and the biomechanical data used to evaluate their biofidelity;
- Current dummy design enhancements and the appropriateness of dummy designs to evaluate recently introduced restraint systems, such as side airbags, or future restraints;
- The transition from dummy responses in crash tests to the reduction in injury risk, hence specifying the protection performance of cars and restraints.

To this background a number of activities have been initiated in Europe that will be discussed in this document. The objective is to map out Europe's current involvement in improving the assessment of side impact protection (as far as crash test dummies are concerned) and to identify the role of the European Ehanced Vehicle safety Committee.

2. EUROPEAN SIDE IMPACT DUMMY (EUROSID-1) DEVELOPMENTS

EUROSID is the EURopean Side Impact dummy and has been developed in four European countries under auspices of the former EEVC WG 9. EUROSID-1 is the production version of the dummy and the successor to the prototype dummies manufactured during 1987/9. The EUROSID-1 is essentially the same as the production prototype apart from some minor design and biofidelity enhancements. The European Directive 96/27/EC on side impact that has gone into effect on October 1st, 1998, specifies the EUROSID-1 dummy as the injury assessment device to be used in the test procedure.

The design and performance of the EUROSID-1 dummy has in principle not been changed since September 1990. The time has come, however, to review the original specifications of the dummy in the light of the level of side impact protection assessment required for the year 2000 and beyond. Specific reasons for this are:

- The criticisms made of the EUROSID-1 dummy expressed by its day-to-day users over the years on the design and/or performance of a number of parts of the dummy;
- The introduction of new restraint systems on the market such as side airbags, which existence was not taken into account when developing the EUROSID-1 but will be widely used in cars in the near future;
- The improved biomechanical knowledge available compared to that at the time when the EUROSID-1 was developed, both in terms of biofidelity as real-world accident data, and
- The ambition to use the EUROSID-1 dummy as the European development platform for the development of a single world-wide harmonised side impact dummy, and/or as an intermediate harmonised side dummy.

With the expansion of the EEVC WG12 mandate to cover all adult crash test dummies, it is this Working Group's responsibility to ensure that the crash dummy specified in the European Directive of the future will meet the required level of assessment of side impact protection. It is therefore WG12 that initiates and guides research to reach this objective.

The following gives a brief overview of the current development and research programme concerning the EUROSID-1 dummy.

2.1. EUROSID-1 MODIFICATIONS BASED ON USER CONCERNS

The TNO Crash-Safety Research Centre as co-developers and manufactures of the EUROSID-1 dummy have compiled a lists of dummy concerns, based on feed-back from users in European, Japanese and the US markets. This list includes the items expressed by the American Automotive Manufactures Association, dealing with dummy design and calibration procedures, as part of their petition to NHTSA to adopt FMVSS 214. The following issues were presented at the 14th EEVC WG12 meeting in October 1997:

1. Mechanical issues:
   - 'Flat tops' at the peak of rib deflection data curves i.e. suspected rib binding;
   - Projecting backplate grabbing into seatback;
   - Bending of "flexible" plastic ilium of the pelvis;
   - Upper femur contact with pubic load cell hardware;
   - Clavicle binding in the shoulder assembly;
   - Lumbar spine ringing, and
   - Spikes in pubic symphysis readings attributed to knee to knee contact.
2. Instrumentation issues:
   - Abdominal load cell update.
3. Certification issues:
   - Severity of abdominal certification test (too high);
   - Severity of pelvis certification test (too low), and
   - Input and output requirements for lumbar (and neck) certification tests.

In 1997 TNO started an extensive research programme to investigate most of the above concerns. As part of the programme a number of hardware parts have been re-designed, built, and validated in order to upgrade the EUROSID-1 dummy. The upgraded EUROSID-1 dummy does not necessarily fulfil the requirements of European Directive 96/27/EC or EC Regulation 95/0. Hence, awaiting possible update of the regulation, the dummy can only be used for research purposes. To emphasise this fact, the modified parts are referred to as "EUROSID-1 Research Tools". In addition, the certification of abdomen, pelvis and lumbar spine have been subject of investigation leading to proposed new procedures for these body parts.

2.2. EUROSID-1 RESEARCH TOOLS

The complete research tools kit consists of the following three parts:

1. Modified shoulder assembly, including new shoulder foam cap, new arm to shoulder-cam-clavicle attachment bolts and new elastic cord holder;
2. New torso backplate assembly, including separate torso backplate body, connector plate and optional 4-axis DENTON load cell;
3. Modified pelvis assembly, including re-designed upper femur, new H-point foam block, back plate and iliac wings.

The items will be discussed separately in the remaining part of this section.

Shoulder Assembly - The current 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, nor should the clavicle be damaged in this situation. The research tool shoulder assembly has an increased radius at the top and bottom plate ends in order to prevent the 'locking' of the shoulder (Figure 1). Moreover this limits the wear of the shoulder cam clavicles at the sliding interface with the top- and bottom plates. The reduction of this wear improves the durability of assembly.

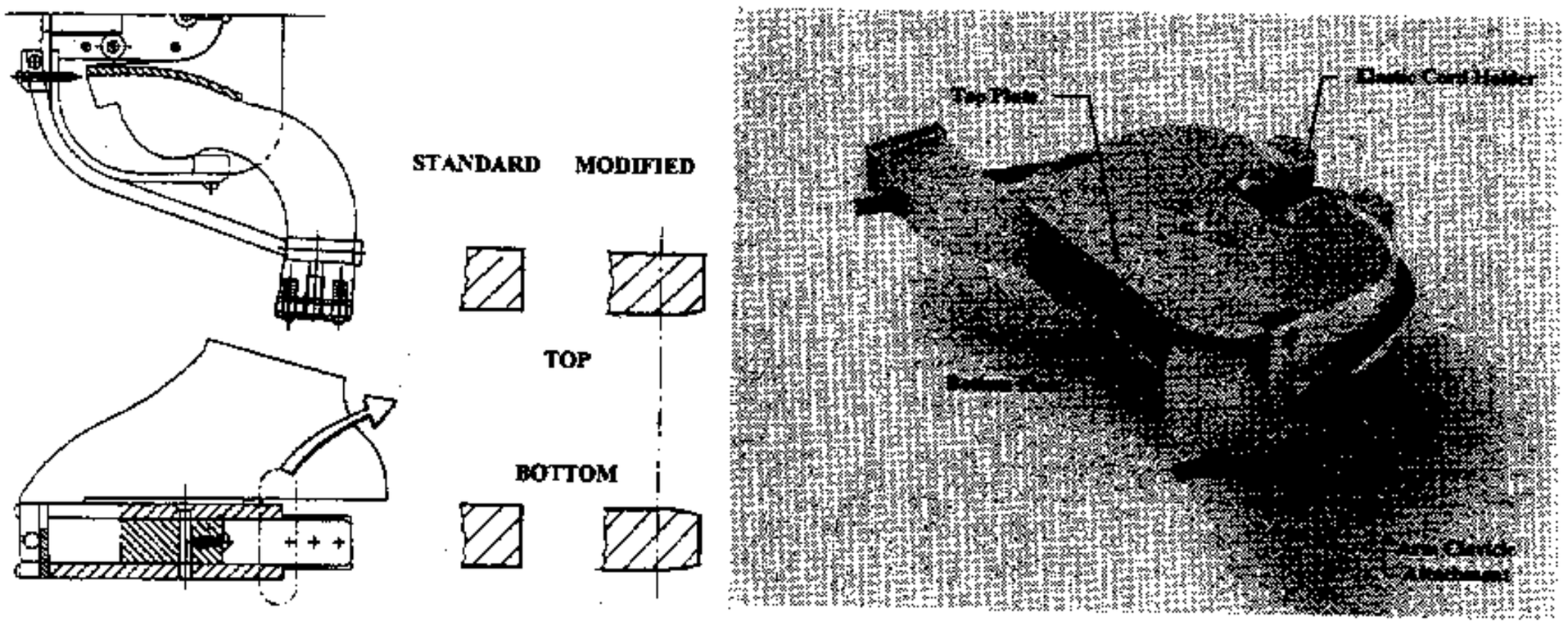

Figure 2: *Left: Shoulder top and bottom plate modification; Right: Research Tool Shoulder Assembly (new elastic cord holder, self locking bolt and shoulder foam cap not shown).*

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. The shoulder foam cap has been modified to prevent damage due to handling at the neck recess and to prevent wear due to interference with the arm during the arm inwards stroke travel at the outward foam cap ends. The new arm to shoulder-cam-clavicle attachment screw has a self-locking feature and the elastic cord attachment has been redesigned to improve handling and the durability of the cord. Except for minor evaluations on a component level, the new shoulder assembly has not been tested yet. The merits of the dummy modifications will have to be demonstrated by evaluating the upgraded EUROSID-1 in actual crash conditions.

Torso Backplate Assembly - The current 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 spin box and determines the interface of the EUROSID-1 with the seat. The existing backplate is known to grab into the seat during a crash test, which may result unrealistic dummy kinematics. The new torso back plate (Figure 4) has got a curvature in the XY-plane based on human anthropometric data. Apart from the curved shape, the back plate has

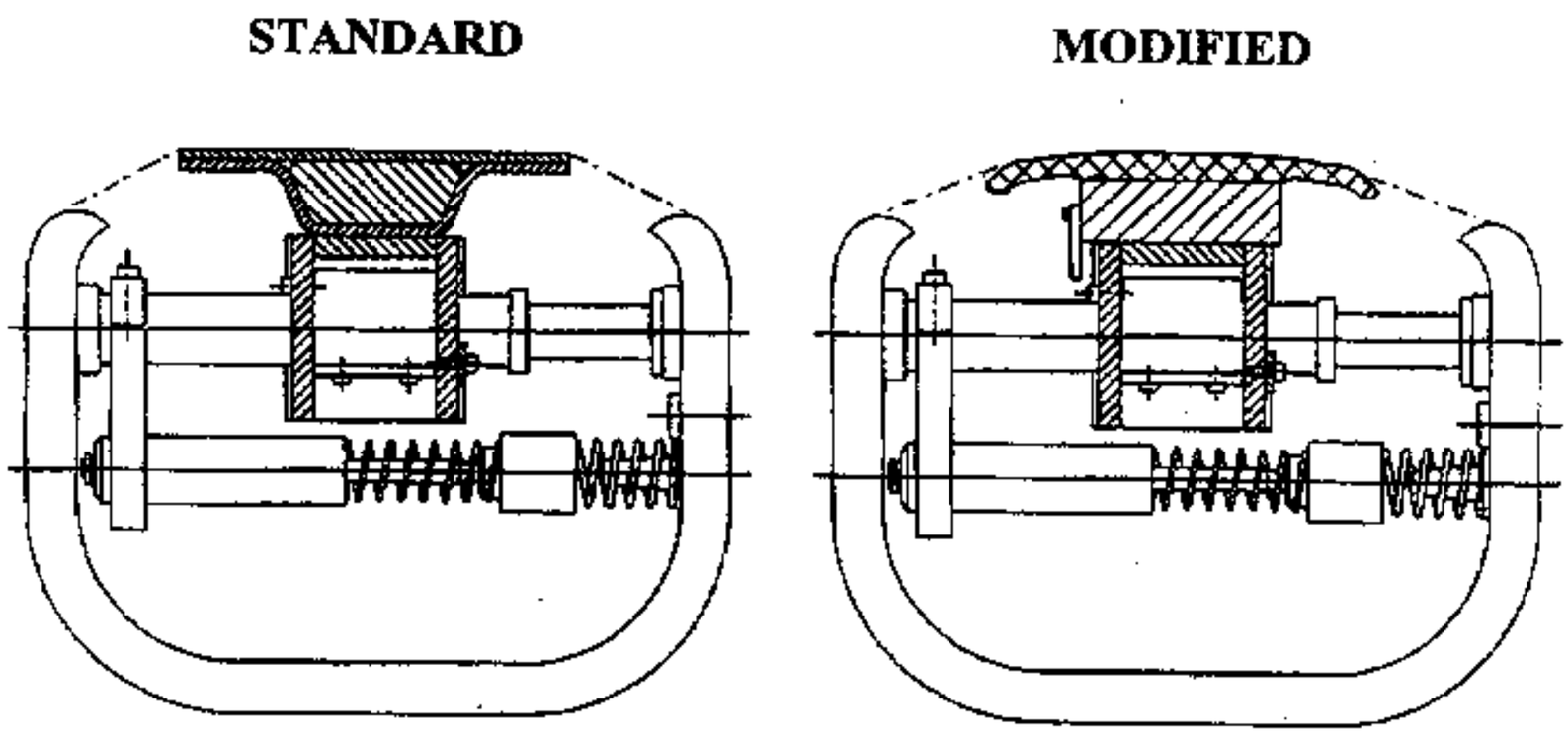

Figure 3: *Torso backplate modification*

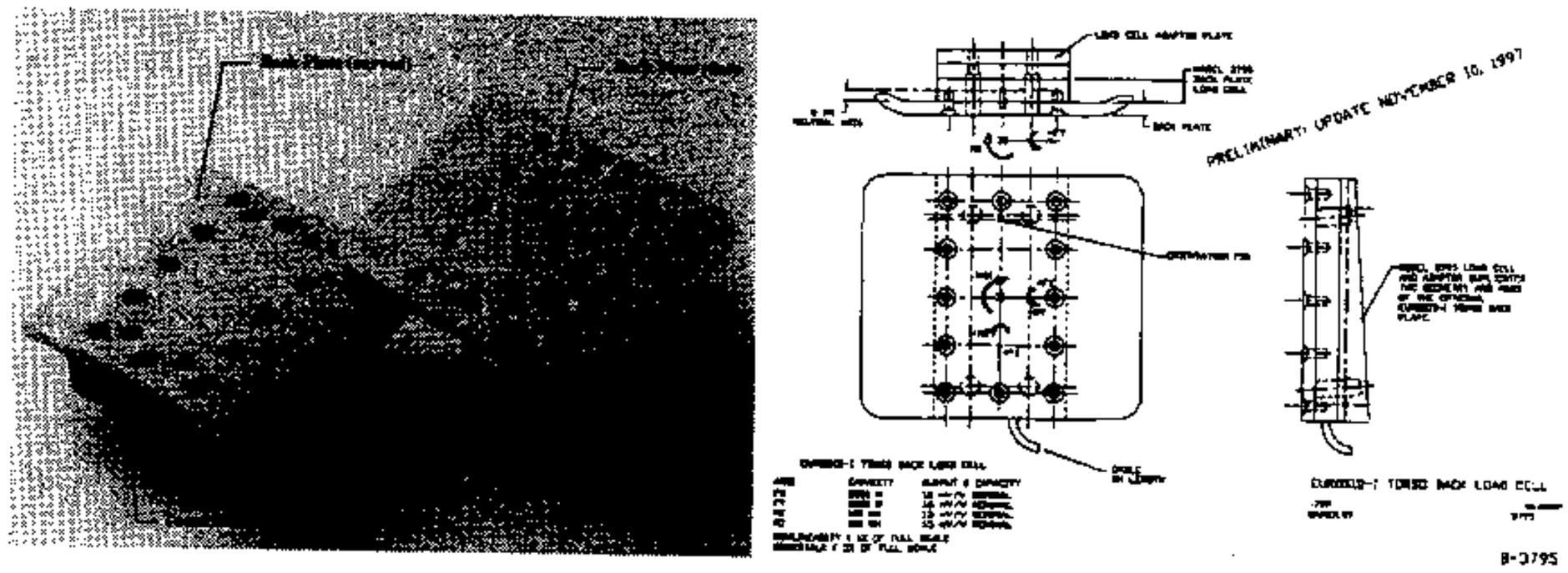

Figure 5: *Left: Research Tool Torso Back Plate Assembly (Connector Base Plate not shown). Right: EUROSID-1 Torso Back Plate Load Cell (Denton model: B-3795).*

the same size as that of the existing back plate. The body of the new configuration is made of steel (instead of lead) to obtain the required mass. This steel body can be replaced by 4-axis load cell, developed at Robert Denton Incorporation (Denton model 3795). With the installation of a flat plate the old configuration can effectively be restored on the new body or load cell. This allows usage of the optional load cell in the original configuration.
At both sides of the steel body, an aluminium base plate for connectors can be attached. The connector base plate must be mounted at the non-impacted side of the dummy.

Pelvis Assembly - 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 produce metal- to metal contact. The new H-joint configuration has an increased size bearing allowing 19° of upper leg abduction (Figure 6). 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. Moreover, the H-point back plate has an indication of the position of the H-point of the manikin and the attachment bolt type has been changed from countersunk- to hex-head to ease the disassembly and assembly. The H-point foam block was changed leaving out the centre hole to improve the handling durability. Additionally, the following changes are made to the pubic symphysis load transducer attachment structure:

- The torque head 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.
- The pubic symphysis load transducer spacers have been changed to prevent the possibility of mis-orientation of the bellville washers during assembly. The bellville washers and the spacer are integrated in one part and the structure is made symmetrical at both sides of the transducer.

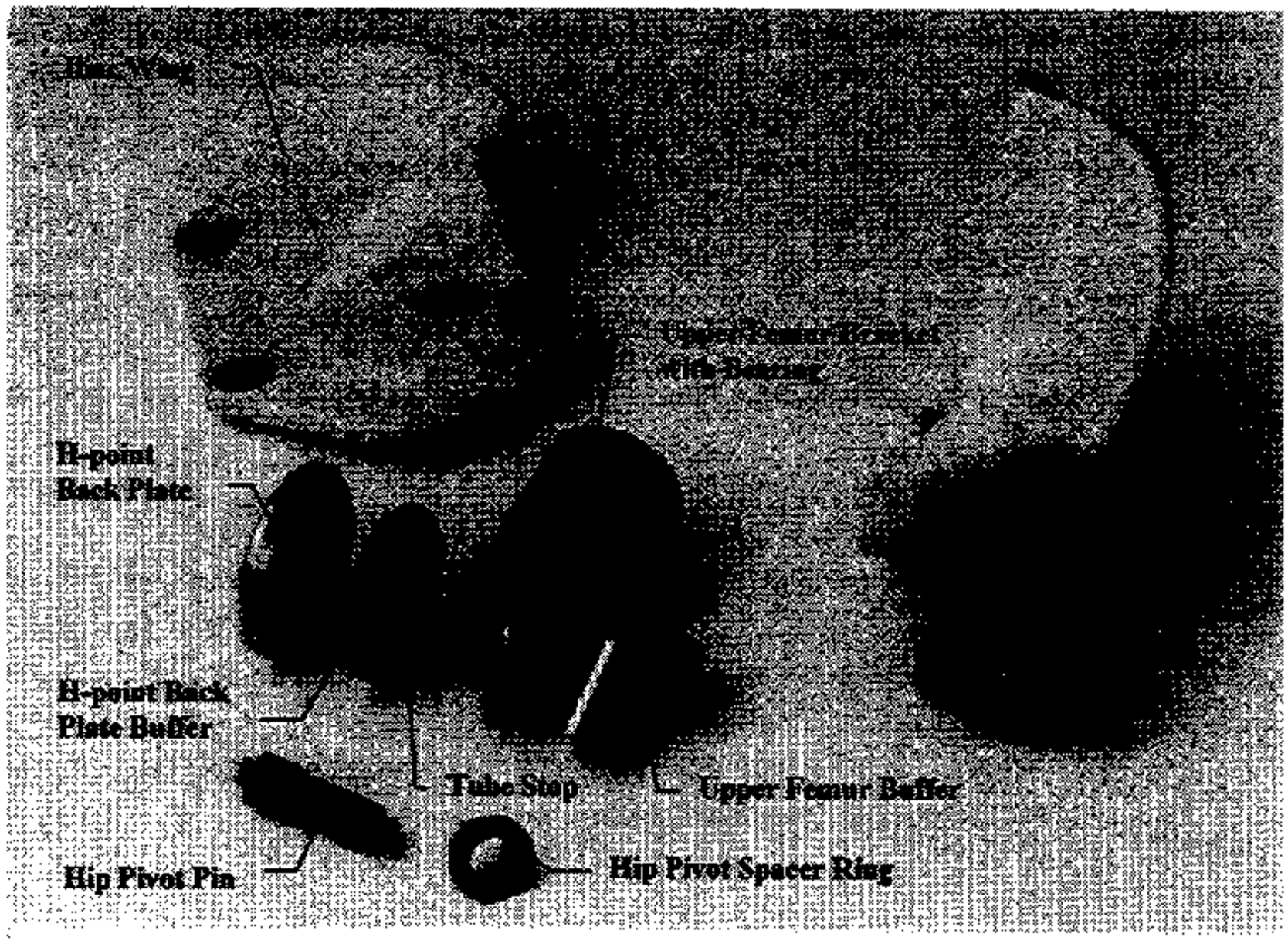

Figure 7: Research Tool Pelvis Assembly (H-Point Foam Blocks and Transducer bush and spacer not shown)

The evaluation of the effiency of the new pelvis assembly has been evaluated on a component level. Like for the shoulder assembly and torso back plate, the value of the pelvis modification will have to be further demonstrated by evaluating the upgraded EUROSID-1 in actual crash conditions.

2.3. CERTIFICATION PROCEDURES

Abdomen - The EUROSID-1 abdomen certification test is derived from the original biomechanical tests, which were performed by APR [1]. These tests, which have been included in the ISO document [2] involved dropping cadavers from 1 and 2 meter drop heights onto a hard surface. This surface was not flat, but had a representation of the armrest of the car door. A series of 11 tests were performed, of which 8 were considered to be suitable for further analysis. From these tests, it was concluded that the tolerance level for the abdomen in lateral impacts (AIS 3) was 39 mm deflection and 4.5 kN external impact force[1].
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 with a length of 150 mm, a 70 mm width, and a 60 mm minimum height, 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

[1] Pendulum impact tests showed that the impact force measured by the impactor lies a factor approximately 1.5 higher than the internal forces . The value of external 4.5 kN force was chosen to match 2.5 kN internal force.

impact tests. Actual measurement values of the EUROSID-1 are available from a database of test results, the data of which was used in a paper by Beusenberg et al [3]. The database, set up with data of tests performed at the TNO Crash-Safety Research Centre, shows that the average measured force level lies 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 a lower speed, resulting in loading values closer to those experienced in actual crash tests. The proposed certification requirement is:

Test set-up:	No changes (as described in EUROSID-1 Assembly and Certification Procedures)
Pendulum speed:	**4.0 ± 0.1 m/s** (was 6.3 m/s)
Acceptance corridors:	
Peak abdomen force (internal):	**2.45 ± 0.25 kN**; occurring between 10.0 and 12.3 ms
Peak impactor force (external):	**4.4 ± 0.4 kN**; occurring between 10.6 and 13.0 ms

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 and 152.4 ± 0.25 kg mm diameter. The impactor is suspended by 8 wires to allow a free swing onto the pelvis with an impact speed of 4.3 ± 0.1 m/s. The pelvis certification test is based on test originally performed by INRETS [4]. This test involved impactor human cadavers with a spherical impactor. The striking surface of this impactor has a radius of 175 mm and an outer diameter of 120 mm. The mass of the impactor was 17.3 kg. The test were carried out at velocities between 6 and 10 m/s. The spherical impactor was later replaced by the part 572 impactor. This was probably done for practical reasons as it was already available for use with the US Dummies such as the Hybrid-III.

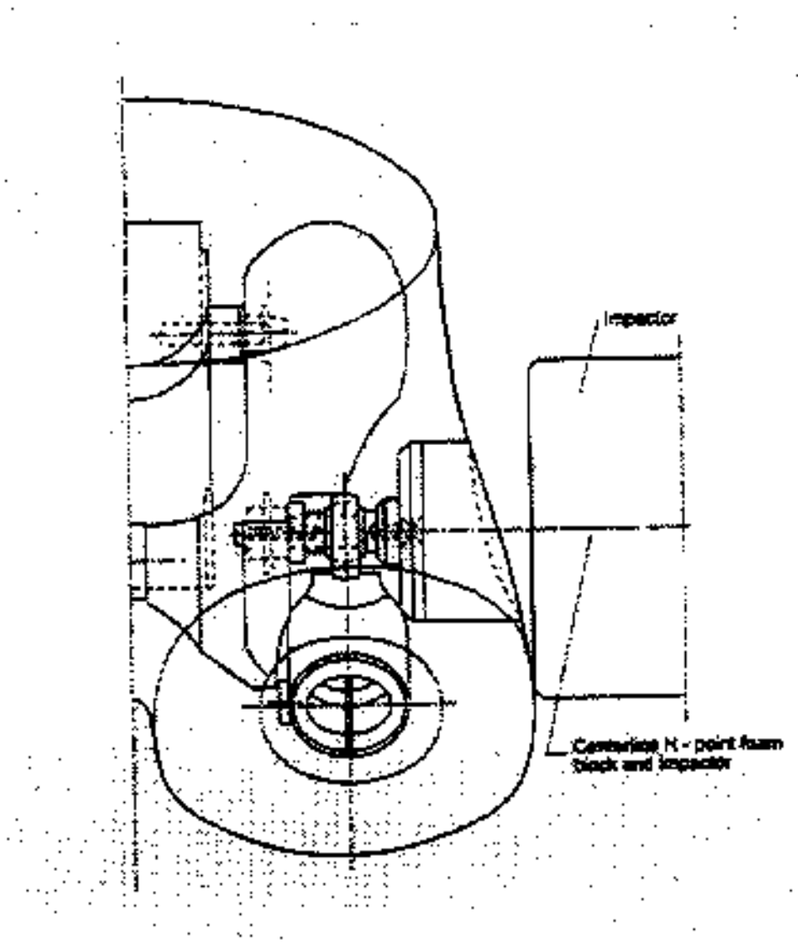

Figure 8: EUROSID-1 Pelvis Certification Impact.

The certification requires an impactor force of 4.9 ± 0.5 kN between 10.3 and 15.5 msec after impact and a pubic symphysis load of 1.34 kN ± 0.30 kN between 9 and 15.9 msec after impact. Actual (full scale) measurement values of the EUROSID-1 are available from a database of test results, the data of which was used in a paper by Beusenberg et al [3]. The database shows that the maximum pubic symphysis force measured was 6.6 kN, and the average value was 3.4 kN. This is significantly higher than values measured in the certification.

The impact severity of the pelvis tests should be increased, but the impact level should not be adjusted in a way that results in exceeding of the biomechanical corridors. As an alternative for the pelvis certification process described in the manual EUROSID-1 Assembly and Certification Procedures, the following procedure has been developed. The objective of this development was to define a certification test with generates an output signal more close to the performance criterion for the pubic load signal (6 kN). The following changes are proposed:

Test set-up:	No changes (as described in EUROSID-1 Assembly and Certification Procedures)
Pendulum speed:	**6.3 ± 0.1 m/s** (was 4.3 m/s)
Acceptance corridors	
Peak impact force:	**11.0 ± 1.2 kN**; occurring between 9.5 and 12.5 ms
Peak pubic compression force:	**3.05 ± 0.35 kN**; occurring between 10.0 and 13.0 ms

Lumbar Spine - The prototype EUROSID lumbar spine certification was certified in a dynamic test with Part 572 neck pendulum with a head mounted on the spine. Lateral and vertical displacements of the head were measured with high speed film which proved to be very expensive and time consuming. For the EUROSID-1, an alternative for the film was developed using a special head form 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 were used as input for an algorithm which calculated the two dimensional head form [5]. Criteria were determined for the maximum head(form) flexion angle (the sum of fore angle and top angle) and the head (form) lateral and vertical displacements (Y and Z) as well as the time of occurrence of these three maxima.
Still, the new procedure caused problems because the algorithm was over sensitive to small variations in the measured potentiometer angles. Alternatively, it was decided to define the criteria directly for the measured potentiometer angles, instead of the lateral and vertical displacements. These angle based output criteria were accepted and form the basis for the current lumbar spine certification procedure defined in chapter 5 paragraph 10 of the "EUROSID-1 Assembly and Certification Procedures" manual [6].
Nevertheless, 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, an re-evaluation of the current lumbar spine certification procedure is 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 (Table 1).

Table 1: Pendulum velocity corridor

Upper Boundary		**Lower Boundary**	
Time [s]	Velocity [m/s]	Time [s]	Velocity [m/s]
0.001	0	0	-0.05
0.0037	-0.2397	0.0027	-0.4251
0.0270	-5.8	0.0245	-6.5
		0.03	-6.5

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. The proposed revised criteria are:

Input criteria: pendulum deceleration		
1	Impact speed	5.95 - 6.15 m/s
2	Velocity change corridor	Table 1
Output criteria: lumbar spine bending		
1	Maximum head form flexion	45.0 - 55.0 degrees
2	Time of maximum head form flexion	39.0 - 53.0 ms
3	Maximum fore angle dQA	31.0 - 35.0 degrees
4	Time of maximum fore angle dQA	44.0 - 52.0 ms (revised)
5	Maximum aft angle dQB between 0.8 * dQA + 4.5 and 0.8 * dQA + 2.0 degrees	(revised)
6	Time of maximum fore angle dQB	44.0 - 52.0 ms (revised)

The effect of the proposed revised input and output criteria on at set of evaluation data provided by 5 different labs was investigated. Application of the proposed revised criteria reduced the failure rate of lumbar spine certifications from 53 to 24 %.

3. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The EUROSID-1 research tools have been made commercially available at the end of the 2nd quarter of 1998. The merits of the dummy modifications will have to be demonstrated by evaluating the upgraded EUROSID-1 in actual crash conditions. Besides the EEVC, contributions are requested from ACEA, NHTSA (US), AAMA (US)/ Transport Canada and JAMA Side Impact Working Group (Japan).

Remaining hardware modifications that need further investigation are:

- the 'flat top' issue: internationally co-ordinated research should lead to a re-design of the EUROSID-1 rib module. Shoulder-arm and backplate are generally associated with the 'flat-top problem' which could lead to additional modifications of these dummy parts.
- the 'knee contact' issue as brought up by Volkswagen AG at the 14th EEVC WG12 meeting in Cologne. The occurrence of spikes in pubic symphysis readings as the result of leg to leg contact has been recently investigated by BASt. Further research efforts are necessary to be able to carry out hardware modifications to the EUROSID-1 legs.

The remaining certification issue is the neck certification procedure and criteria. A similar analysis as presented in this report on the lumbar spine could also be performed for the neck.

All modifications to the EUROSID-1 dummy and certification procedures should be finalised before mid 1999. The proposed EUROSID-1 modifications and calibration procedures should be evaluated in Europe, North America and Japan. Once the modifications have proved to be improvements, it would be beneficial to propose an amendment of the dummy specifications (changing EUROSID-1 into EUROSID-2) in the European directive. This process should have taken place before the year 2000. If internationally accepted, the EUROSID-2 will become the intermediate harmonised side impact dummy.

The WorldSid project is the first step in the long term strategy. Ultimately, one single side impact dummy should be used world-wide in side impact compliance testing. The EC funded SID-2000 project provides the basic knowledge and tools for the definition of such dummy from the European perspective. Following the SID-2000 project, additional research is anticipated, in particular in the prototype evaluation phase of a WorldSid in Europe and the establishment of injury risk functions for the dummy.

REFERENCES

1. Walfisch, G., Fayon, A., Tarriere, C., Rosey, J., Guillon F., Got, C., Patel, A., Stalnaker, R. "Design of a Dummy's Abdomen for Detecting Injuries in Side Impact Collisions". 5th International Conference on the Biomechanics of Impact, IRCOBI secr., France. 1980.
2. ISO TR9790-1 to 6. Jan 1, 1990.
3. Beusenberg, M.C. "5 years of experience with Eurosid-1 in Sled and Car Tests". Proceedings of the 14th ESV Conference, paper 94-S6-O-09. 1994.
4. Cesari, D., Ramet, M., and Bouquet, R. "Tolerance of the Human Pelvis to Fracture and Proposed Pelvic Protection Criteria to be measured in Side Impact Dummies". Proceedings of the 9th ESV Conference. 1982.
5. EUROSID-1 User's Manual, November 1990
6. EUROSID-1 Assembly an Certification Procedures, January 1994