EEVC - WORKING GROUP 12 ADULT CRASH DUMMIES

ES-2 DUMMY: REVIEW OF OICA COMMENTS

DRAFT TECHNICAL DOCUMENT FOR DISCUSSION

OCTOBER 2002

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INTRODUCTION

In August 2001, the EEVC completed its work on the development and evaluation of the improved side impact dummy EUROSID-2 (ES-2). The final report, entitled “Development and Evaluation of the ES-2 Dummy” [1], summarises the main results from the ES-2 prototype evaluation in Europe, carried out on behalf of the EEVC WG12. Furthermore, the report addresses in detail the comments and concerns of the European vehicle manufacturers organisation ACEA based on its experience with the dummy [2] .

The ES-2 dummy is an improved EUROSID-1 dummy with increased injury assessment and measurement capabilities that addresses the main concerns expressed with the EUROSID-1. The dummy biofidelity with respect to EEVC criteria is maintained as intended and repeatability, sensitivity durability and handling properties are all equivalent or improved compared to the EUROSID-1. Full-scale test results show that values for ES-2 are sometimes higher than EUROSID-1, for the thorax in particular. This is being 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. The EEVC has concluded that the ES-2 dummy is a suitable replacement for the EUROSID-1.

Following the recommendation of the EEVC, appropriate steps have been taken to put forward the ES-2 dummy for use in European regulatory test procedure. It is at this stage, that the International Organisation of Car Manufacturers, OICA, has asked for further investigations into parts of the ES-2 dummy performance [3]. The points raised by OICA are similar to the concerns expressed earlier by industry and rely mostly on the same test evidence. Nevertheless, an appropriate reply from EEVC is anticipated.

This report responds to the issues raised by OICA in Informal Document N 14 of the 31st GRSP meeting, held 13-17 May 2002 [3]. The report comprises an extended analysis on available data of EEVC and others. In addition, new tests have been performed to produce further evidence.

CONCERNS REGARDING THE RESPONSE OF THE ES-2 DUMMY

The OICA report asks for further investigations into the following items (taken from [3]):

1. Variation of performance criteria between EUROSID-1 and ES-2: the EEVC report explains that ES-2 has lower criteria than EUROSID-1 in biofidelity tests. According to OICA, this depends on the test conditions, and too much data are missing from the test results to make a complete analysis possible: additional sled tests should be performed.
2. Directional sensitivity: OICA has observed higher rib deflections at rearward angle impacts. Some hypotheses are given to explain this phenomenon in the EEVC report, unfortunately, no data exist on the production EUROSID-1, so it is not possible to compare the responses.
3. Inter-rib homogeneity: the evolution of responses between EUROSID-1 and ES-2 are not continuous. This aspect is not addressed and would have a greater influence on maximum deflection and V*C values for individual ribs than on the average values for the three ribs highlighted in the EEVC report.
4. Thorax damping characteristics and stiffness: friction is eliminated in ES-2 and compensated by increasing the tuning spring stiffness. This leads to a stiffer thorax with less overall damping. According to the OCA report, this way of decreasing friction in rib modules doesn't seem appropriate and should be investigated more in depth.
5. Interaction between body segments: apart from the thorax, other changes were performed on ES-2, in particular to the pelvis segment. OICA suggests their effects on thorax loading need to be investigated and biomechanical reasons have to be given.

These issues will be addressed below.

VARIATION OF PERFORMANCE CRITERIA BETWEEN EUROSID-1 AND ES-2

In the OICA report [3], the authors express concern that there is a variation in the injury criteria responses between EUROSID-1 and ES-2 in the biofidelity tests (Appendix B of the EEVC report on ES-2 [1]) and that the relative responses depend on test conditions.

One of the objectives in the improvement to EUROSID-1 was to keep the biofidelity, as defined by EEVC WG9, the same. It is unfortunate that the basic biomechanical testing of cadavers in the pendulum impact tests and in the Heidelberg sled tests provided responses in terms of the forces generated by the cadavers onto load cells and in terms of acceleration seen by the cadaver spine. The responses of those parameters currently used for injury criteria i.e. rib deflections and V*C, were not measured in those tests. Thus it is only possible to judge the biofidelity of the dummy in terms of parameters measured in the cadaver tests. The EEVC report [1] provides these measures and shows that the biofidelity of ES-2 is equivalent to that of EUROSID-1.

It may be true that the responses of the injury criteria do vary. Some will be lower with ES-2 and some may be higher. However, it is important to realise that it is not possible to say which of these is correct or which is more biofidelic in that respect since the cadaver responses under these test conditions are unknown.

It is proposed by OICA that sled test are performed at lower impact speed so that the relative chest deflections can be compared in cases other than maximum deflection [3]. However, EEVC WG12 considers that this cannot be justified since firstly the impact speeds selected by EEVC were the appropriate ones taking into account the sled rebound in the original Heidelberg tests (the ISO impact speeds are incorrect since the sled rebound was ignored) and secondly, even if they were performed and differences measured, again it is not possible to say which results are correct.

In Annex A, some drop rig test results are presented for EUROSID-1 and ES-2 ribs. The data enable an evaluation of the V*C parameter in a pure lateral condition. The test results show slight V*C increases only. The large variation observed in car crashes is therefore more likely explained by the fact that the friction generated by off-axis loading or moments in the guide system in these test conditions is generally much larger for EUROSID-1 than for ES-2.

In conclusion, the EEVC recognises that the responses of the injury criteria between EUROSID-1 and ES-2 may vary in full-scale tests. This does not mean, however, that the EUROSID-1 values are more appropriate than those of ES-2 as the biomechanical basis does not justify such conclusion.

DIRECTIONAL SENSITIVITY

In the OICA report [3], the authors draw the attention to the thorax performance of the ES-2 dummy in off-axis loading. This case is believed to be important since in full scale testing the loads to which the dummy is exposed often include off-axis components. During the EEVC evaluation program, the ES-2 dummy was subjected to pendulum impacts at -20°, -10° (rearward), 0° (perpendicular), +10° and +20° (forward) angles. As the ES-2 rib guide system and point of displacement measurement are different from the EUROSID-1, the objective was to study the effect on the directional sensitivity of the dummy (see Annex D of the EEVC report [1]). The authors are surprised that ES-2 produces higher measured deflections at rearward oblique than at lateral impacts and claim that no data exist on the production EUROSID-1 to make a proper comparison.

Firstly, reference is made to EEVC pendulum tests performed by Friedel et al. [4] on the EUROSID prototype which, according to the authors, show the prototype EUROSID was insensitive to impact angles. Figure 1 below (left), reproduced from Friedel et al. [4] shows angular sensitivity of the EUROSID prototype with deflection values getting larger as the angle of impact increase from 70° and constant values for 90° to 110° (Note: the definition used in Friedel et al. being: 0° for front, 90° for side and 180° for rear impact). This plateau effect is typical for the EUROSID prototype which had an optical system that measured deflection directly on the piston. Later on, this design was changed and a potentiometer was placed between the piston and damper (slightly more forward of the optical system) for the production version EUROSID-1. This change has affected the directional sensitivity of EUROSID-1 compared to the original EUROSID prototype.

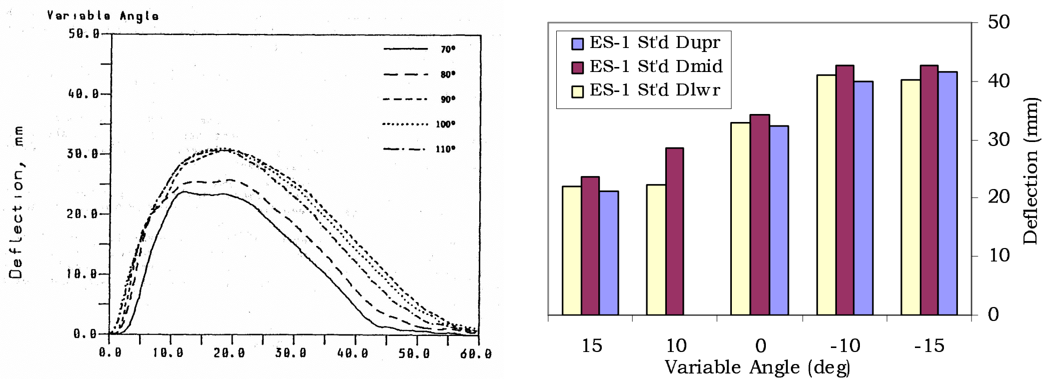

Figure 1: Left: Time histories of rib deflection for five impact angles of the EUROSID prototype (Friedel et al. [4]). Right: Peak rib deflection for five impact angles in high-mass impacts on the EUROSID-1 production version (Maltese et al. [5])

Directional impact data on EUROSID-1 production dummy have been published in 1999 by Maltese et al. [5]. This NHTSA study into the response of the EUROSID-1 thorax to lateral impact, uses a high-mass Part 581 bumper testing pendulum to load the dummy at discrete angles ranging from frontal oblique to rearward oblique. Figure 1 (right) shows the peak rib deflections as a function of impact angle for upper, mid and lower ribs. This figure shows higher deflection values for rearward oblique impact angles, as is the case for ES-2. It should be noted that “flat-tops” occurred in the frontal oblique conditions, both in the original EUROSID prototype tests as during the NHTSA tests with EUROSID-1.

In conclusion, EUROSID prototype, EUROSID-1 and ES-2 show a very similar trend regarding oblique loading i.e. lower readings in forward oblique and higher readings in rearward oblique impacts. This is explained by the design of the rib structure and location of actual measurement point. Changes in directional sensitivity between EUROSID-1 and ES-2 are caused by changes in rib friction and a small shift in point of measurement as explained in the EEVC report [1]. In general, the (change of) sensitivity of the parameters studied is found to be acceptable.

INTER-RIB HOMOGENEITY

*In the OICA report [3], the authors have noticed a lack of inter-rib homogeneity in the rib responses reported by EEVC. In sled tests, for instance, it is noted that not all ribs follow the same pattern suggested by the calculated average deflection and V*C, instead individual ribs may deviate from each other. Reference is made to Friedel et al. [4] which data suggest a continuous evolution from lower to upper rib for the EUROSID prototype. For comparison, mean peak rib are included in the OICA report [3], taken from the TRL test report (Figure 2, right).*

The question to answer is whether it is justified to assume inter-rib homogeneity? The reference data on the EUROSID prototype that the authors refer to, are shown in Figure 2 (left) below. Indeed, this figure suggests a continuos evolution from upper to lower rib, except for the pure lateral case. It should be noted, however, that the data for frontal oblique tests are suspect as there is clear evidence for flat tops in these (see Figure 1, left). Evidence on the EUROSID-1 production version can be found in the NHTSA data [5] (Figure 1, right) that show discontinuity of upper, mid and lower ribs instead.

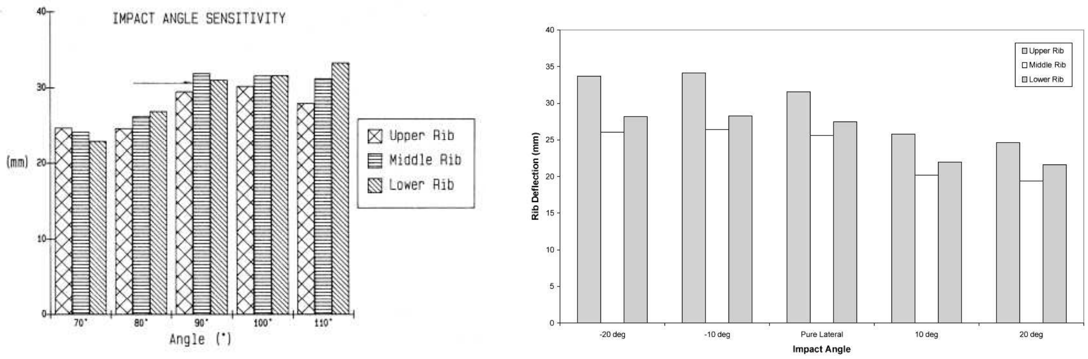

Figure 2: Left: Comparison of peak rib deflection for five impact angles of EUROSID prototype (Friedel et al. [4]); Right: Mean peak rib deflection for each impact angle from TRL ES-2 prototype evaluation, showing the effect of permanent deformation of two tuning springs [3].

Still, the ES-2 data presented by OICA [3] give reason for further analysis. Firstly, it is observed in Figure 2 (right) that the mid rib deflection is always lower than upper and lower rib deflection. This may still be as it should be, if the peak values occur at different moment in time due to the overall dummy kinematics. Still, going back to the original data and test set-up, it appears that the ES-2 ribs at TRL had a slight off-set with respect to each other, caused by permanent deformation of the tuning spring of two ribs. Annex B of this report further investigates this concern and reports on additional impactor tests to study inter-rib homogeneity. These new tests clearly demonstrate a good overall correlation between EUROSID-1 and ES-2 dummies and confirms that both exhibit identical individual rib response in laboratory test conditions.

THORAX DAMPING CHARACTERISTICS AND STIFFNESS

Probably the most pertinent of the issues raised by OICA is the thorax damping characteristics and stiffness. The authors are concerned that the reduced friction damping and increased tuning spring stiffness in ES-2 have resulted in less appropriate humanlike thorax behaviour and an oscillatory response.

Regarding the elastic rebound, it is argued that although ES-2 is meeting the corridor better, this doesn't mean the it is more biofidelic as it seems the way to achieve this is not "appropriate". This statement seems questionable in itself. Researchers world-wide have discussed biofidelity requirements at great length and an accepted well-defined set of criteria is not achieved overnight. Once a test condition is included and accepted, dummies are simply designed to best meet the corridors. Apparently, the authors now have additional, unsupported requirements on what is and what isn't the appropriate technique to meet the corridors. This makes the argument therefore subjective.

Furthermore, the authors claim oscillations observed in some vehicle tests (most notably the Renault Megane test) are a consequence of elastic rebound of the thorax, governed by the natural frequency of the rib module. While no evidence is presented to support this statement, it renounces the analysis of eigenfrequency included in the EEVC report [1] (which does include the stiffness of the rib itself, see Annex F, page 29 and further). No attempts are made to investigate the most plausible cause of this phenomenon put forward by EEVC, i.e. the occurrence of multiple loading applied to the thorax.

Annex C of this report describes additional rib tests carried out to study and compare the characteristics of the ES-2 and EUROSID-1 ribs. While differences between ES-2 and EUROSID-1 are noted, no evidence was found that would give credit to anything else than the rationale already put forward in the EEVC report.

INTERACTIONS BETWEEN BODY SEGMENTS

Some concerns about the interaction between body segments are raised, in particular the effect of changes in the pelvis region on the thorax loading. According the authors of the OICA report [3], a decrease of pelvis and abdomen loading results in a greater rib loading, a phenomenon, which, judging the Heidelberg sled test results, is likely to occur with ES-2.

In the Heidelberg tests not only the pelvis forces (EEVC report [1], figure 5[1]) are recorded but also the thorax forces (EEVC report [1], figure 3). The EUROSID-1 and ES-2 show identical thorax results. In these tests, the changes of the pelvis performance has not affected the thorax performance.

It is important to recall that no major changes have been implemented in the ES-2 dummy pelvis, lumbar spine and abdomen that could affect the direct performance of these parts. This is confirmed by the certification test results on these ES-2 parts, using the EUROSID-1 and ES-2 calibration procedures. The change in performance of the lower body region observed is a result of modifications of the upper leg flesh and (indeed) the interaction with the modified thorax. The rationale behind the upper leg modification is explained in detail in the EEVC report [1].

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[1] *The label of the y-axis of figure 5 in EEVC report [1] should be "Normalised Pelvis Force (kN)" instead of "Normalised Thorax Force (kN)". The title of the graphs and the caption of figure 5 are nevertheless correct.*

The overall effect is that ES-2 slightly better meets the specified sled test corridors. Following the arguments put forward earlier, it is not possible to say which dummy response would be more correct, due to the limitations of the test conditions. Clearly, the new upper leg mass distribution better corresponds to the actual human being and moreover addresses the "unrealistic" high peaks in the pubic symphysis response seen in EUROSID-1.

A final remark can be made on the sensitivity of the pelvis, which seems to have changed in particular for frontal oblique impacts. Possible explanations are given in the EEVC report ([1], Annex D, page 25). The relevance in full-scale test, however, will be small: full-scale data show that the pubic force has dropped on average by 10% (percentage normalised to current tolerance value), indicating that the more dominant spikes in the pubic signal have been omitted [1].

CONCLUSIONS

In this report, a number of concerns raised by OICA on the performance of ES-2 in relation to EUROSID-1 has been addressed. An effort has been made to re-examine and analyse the evidence that form the basis for these concerns and new tests have been carried out on the thorax and ribs to give new insight.

Regarding the performance differences between EUROSID-1 and ES-2, it may be true that the responses of the injury criteria do vary, however, it is important to realise that it is not possible to say which of these is correct or which is more biofidelic in that respect since the cadaver responses under these test conditions are unknown.

Older as well as more recent data on the thorax directional sensitivity demonstrate that the ES-2 dummy does not exhibit entirely different behaviour as the EUROSID-1 dummy. The differences that do exist, are caused by changes in rib friction and a small shift in point of measurement. The change of sensitivity of the thorax is found to be acceptable.

The inter-rib homogeneity has been studied in more detail and new data have analysed and presented. Full-body pendulum data on EUROSID-1 and ES-2 show similar trends in the individual rib responses and only small differences between the two dummies.

The oscillatory behaviour of the ES-2 thorax observed in some full-scale tests have been investigated in depth, supported by a new series of laboratory rib drop tests. The test set up was designed to generate overshoot on rib deflection, that depends on the rib characteristics only and would likely reveal oscillatory behaviour if present. Both EUROSID-1 and ES-2 have been tested in the same set-up at several speed mass combinations of the impactor. No evidence was found that could support the eigenfrequency theory as put forward by OICA. This gives more credibility to the rationale put forward earlier by EEVC.

REFERENCES

1. Development and Evaluation of the ES-2 Dummy , EEVC WG12 report, August 2001
2. ACEA EUROSID-2 Testing, Final Report, T.F.D. ACEA, September 2000
3. Concerns regarding the thoracic response of the ES-2 side impact dummy, Informal document N14 , 31st GRSP 13-17 May 2002
4. Friedel (ed.), The European side-impact dummy 'Eurosid", Proceedings of the seminar held in Brussels, 11 December 1986
5. Maltese, Radwan Samaha, Eppinger, Strassburg, Response of the Eurosid-1 Thorax to Lateral Impact, SAE 1999-01-0709

ANNEX A: VARIATION OF PERFORMANCE CRITERION V*C

In Figure 1 of the OICA report [3], the variation of deflection and V*C for pendulum tests on EUROSID-1 and ES-2 is shown. The parameter that increases the most is V*C. The figure suggests that the variation between the two dummies becomes smaller as the impact velocity increases. This observation is further investigated here.

In order to compare the ES-2 and EUROSID-1 V*C rib responses, data from the rib drop tests are compared. The test set-up is the standard rib certification drop rig, shown in Figure 3.

Drop tests on EUROSID-1 and ES-2 ribs have been performed at three velocity - impactor mass combinations:

- 4.0 m/s with 7.78 kg rib impactor;
- 6.5 m/s with 3.10 kg rib impactor;
- 8.0 m/s with 1.40 kg rib impactor.

During the tests, the following measurements were taken:

- Rib displacement with the rib potentiometer,
- Rib acceleration with an accelerometer at the standard location on the rib bow near the piston for EUROSID-1, and the piston itself for ES-2.

The V*C values are calculated with the rib displacement and the velocity obtained from integrating acceleration. The table below shows the results of the drop test on a single EUROSID-1 and ES-2 rib.

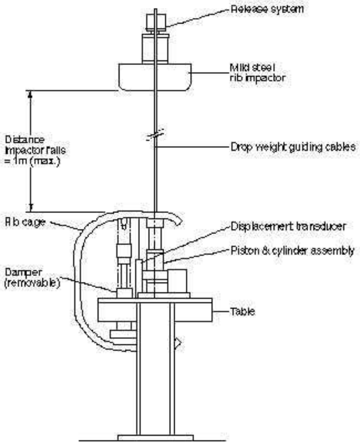

Figure 3: Rib drop rig.

*Table 1: Rib drop rig test V*C values*

Speed m/s	**Mass** kg	**Energy** Nm	**EUROSID-1** m/s	**ES-2** m/s	**Variation** %
4.0	7.78	62.2	0.54	0.59	10.9
6.5	3.10	65.5	0.67	0.71	7.0
8.0	1.40	44.8	0.52	0.49	-5.5

The certification drop test is a very straightforward test that loads the rib purely lateral. The impactor is aligned with the rib guide system, so off-axis loading and moments on the rib guide system can only be generated by bending of the rib bow. Consequently, friction generated in the bearings of the guide system is minimal. However, reduced friction due to the new bearing system applied in ES-2 has resulted in the need to apply a stiffer tuning spring to comply with certification requirements. The tuning spring stiffness has increased from 9.6 to 19 N/mm. The transfer from dissipated friction energy in EUROSID-1 to elastic spring energy in ES-2 results in higher V*C values. This effect has been observed in car tests.

The drop rig test results presented above show small V*C increases: from 11% for 4.0 m/s impacts to -6% for 8.0 m/s. This supports the impression that the V*C increase effect is larger for smaller impact speeds. The large variation observed in car crashes is likely explained by the fact that the friction generated by off-axis loading or moments in the guide system is generally much larger in those tests. In those cases the decrease of the friction in the ES-2 ribs exposes the effect that was masked by EUROSID-1.

ANNEX B: INTER-RIB HOMOGENEITY

The thorax assembly used at TRL for the sensitivity evaluation suffered from some permanent deformation of the tuning springs as a result of over-loading at earlier tests. Figure 4 shows a picture of ES-2 Prototype –004 before testing at TRL: the upper rib appears to be on nominal position. Both other ribs show a permanent set of 3 mm and 2 mm for middle and lower rib, respectively. Figure 2 in the OICA report showing the mean peak rib deflection for each impact angle therefore includes the effect of this permanent set.

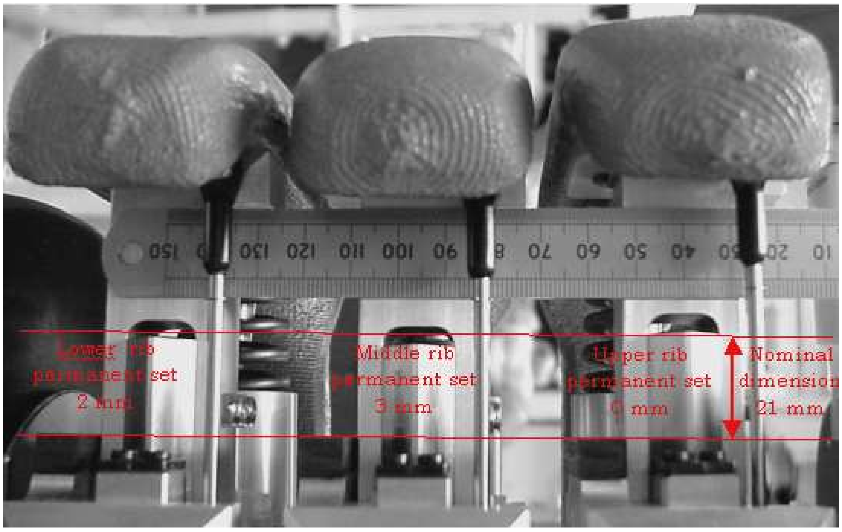

Figure 4: Aft view of thorax left to right: Lower rib 2 mm permanent deformation, middle rib 3 mm permanent deformation and upper rib on the nominal position.

Additional thorax impactor tests have been performed on ES-2 and EUROSID-1 dummies to reproduce (in part) Figure 2 in the OICA report with a calibrated ES-2 dummy and to compare the performance with the standard EUROSID-1. Full body pendulum tests are performed at 4.3 m/s, 5.7 m/s and 6.7 m/s at 0° and 4.3 m/s at 30° forward oblique. Figure 5 shows the results for 4.3 m/s tests on ES-2 and EUROSID-1. The figure shows good overall correlation between the two dummies and confirms that both exhibit identical individual rib response in laboratory test conditions.

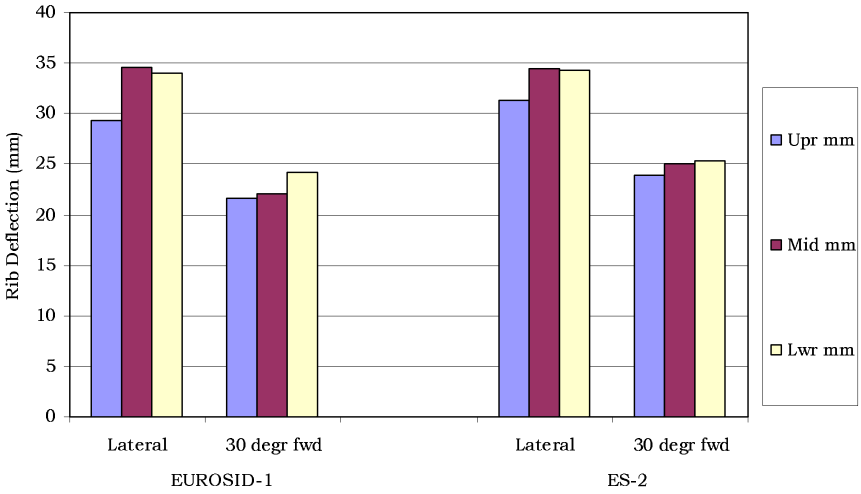

Figure 5: Mean peak rib deflection for 4.3 m/s thorax pendulum impacts at pure lateral and 30 degrees forward angles.

ANNEX C: THORAX DAMPING CHARACTERISTICS

The concern on the thorax damping brought up by OICA relates to a certain aspect of the full scale results, which is most clearly illustrated by the Renault Megane test. The EEVC report on ES-2 includes the figure below, taken from the ACEA test report [2] that shows double peaks of the deflection responses. Analysis of these signals shows that the rib speed in the first loading curve on average are approximately 1.8 m/s (upper), 2.5 m/s (middle) and 3.0 m/s (lower) respectively, and 1.3 m/s (upper) 1.8 m/s (middle) and 1.8 m/s (lower) in the second loading curve. The authors suggest that the double peak is due to rib system oscillation (in this case at frequency of approximate 50 Hz).

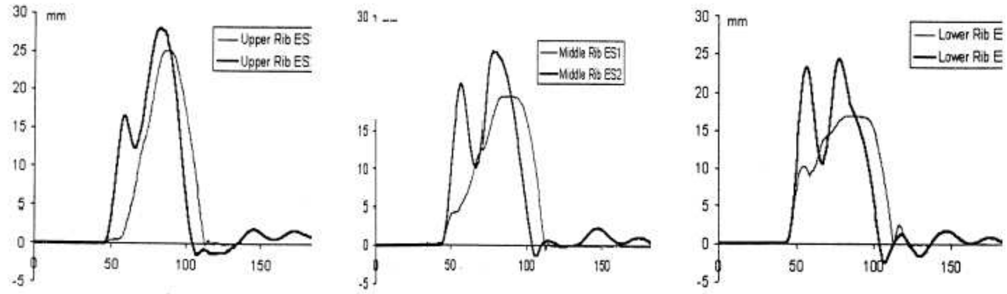

Figure 6: Renault Megane rib deflection signals [2]

In order to investigate the rib oscillation, tests with the standard rib certification drop rig are performed. Different from the standard certification test, the impactor is stopped after a certain travel of the rib. Consequently, the rib will show a displacement overshoot without contact between the impactor and the rib. This overshoot depends on the rib characteristics only and would likely reveal oscillatory behaviour if present. Both EUROSID-1 and ES-2 are tested in the same set-up at several speed mass combinations of the impactor.

The test set-up used is the standard rib certification drop rig as shown in Figure 3. The impactor mass was stopped after approximately 20, 10 an 5 mm of rib displacement. The stopping of the impactor was realised by the application on wooden blocks on both sides of the rib, as illustrated in the pictures below. The stop distances of 20, 10 and 5 mm rib

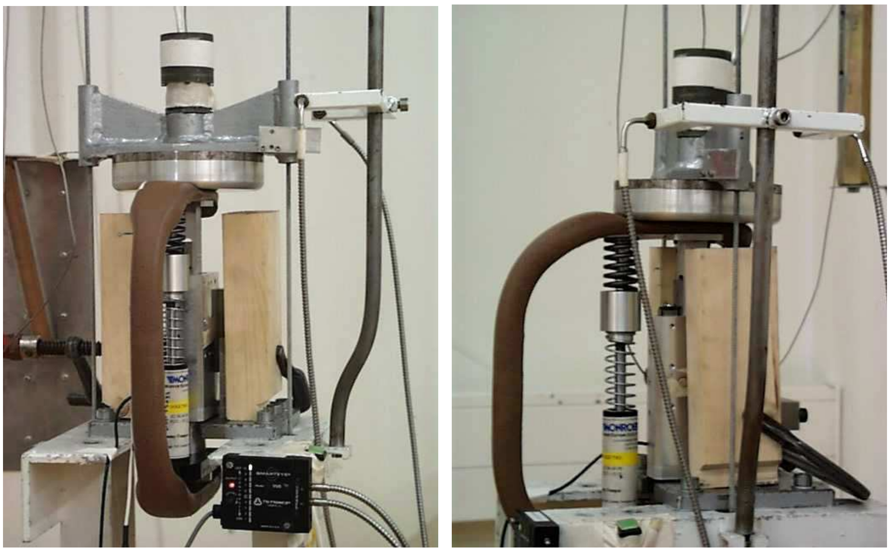

Figure 7: ES-2 rib in certification drop rig with wooden stop blocks. Gap between impactor mass and wooden stop blocks 20 mm nominal (rib foam compressed). Impactor mass 3.1 kg.

displacement are nominal values, as it was difficult to position the wooden stop blocks accurately relative to the rib in both test series with EUROSID-1 and ES-2. The realised position was determined later on with help of the signals measured. Within series of tests for EUROSID-1 and ES-2 the rib position remained the same for each test. The gap between the impactor and the wooden blocks is changed to 10 mm and 5 mm by application of an additional shims package under the blocks of 10 or 15 mm.

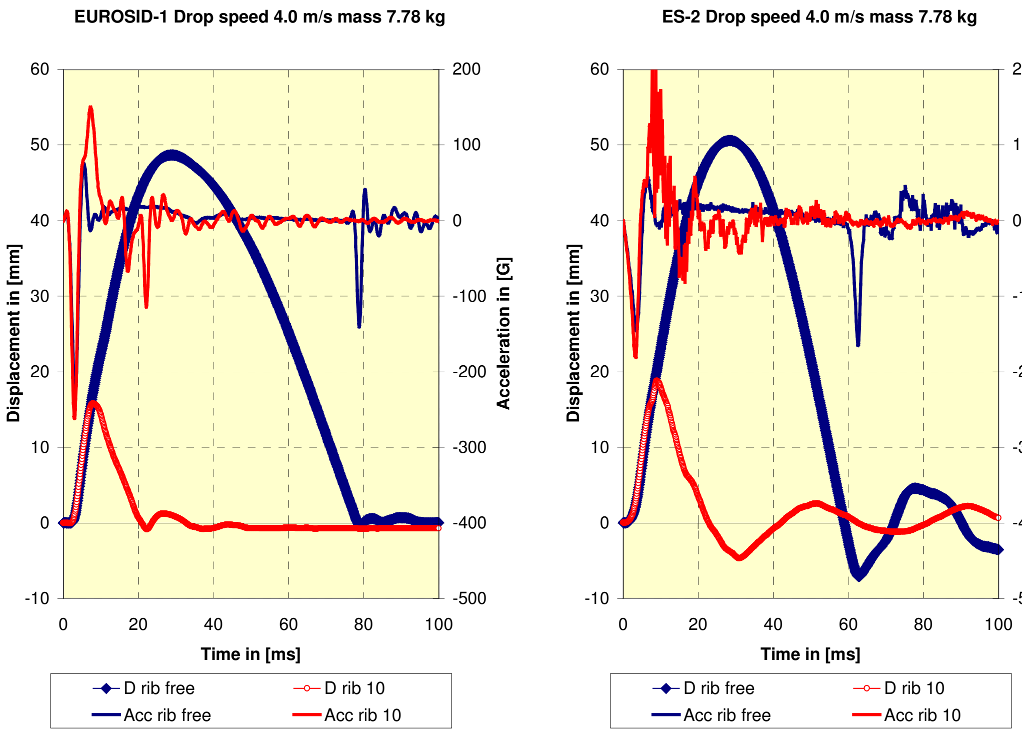

Figure 8: Measured rib displacement and acceleration with impactor free to fall and impactor stopped after approximately 10 mm rib displacement. Impactor speed 4.0 m/s mass 7.78 kg.

The total number of test done for EUROSID-1 and ES-2 each is 12. The tests were done with 3 impactor mass-speed combinations. For each mass-speed combination one test without stopping the impactor is used as the reference test (similar to certification test). For each mass-speed combination, the impactor was stopped after approximately 5 mm, 10mm and 20 mm rib of displacement, respectively. A summary of the test matrix is given in Table 2.

Table 2:Summary of test matrix for EUROSID-1 and ES-2 each.

Speed [m/s]	Mass [kg]	**No stop** Reference test	**Impactor stop at 20 mm (nominal)**	**Impactor stop an 10 mm (nominal)** Close to max. rib speed	**Impactor stop at 5 mm (nominal)** At about max. rib speed
4.0	7.78	X	X	X	X
6.5	3.10	X	X	X	X
8.0	1.40	X	X	X	X

To explain how the data were analysed, the test with the impactor speed-mass combination of 4.0 m/s-7.78 kg, stopped after 10 mm rib displacement, is taken as an example. The following steps are made in the data analysis:

Measure signals - The signals measured are rib displacement and rib acceleration. The signals are put on the same time scale with time zero at the first significant increase of rib acceleration. The signals are shown in Figure 8.

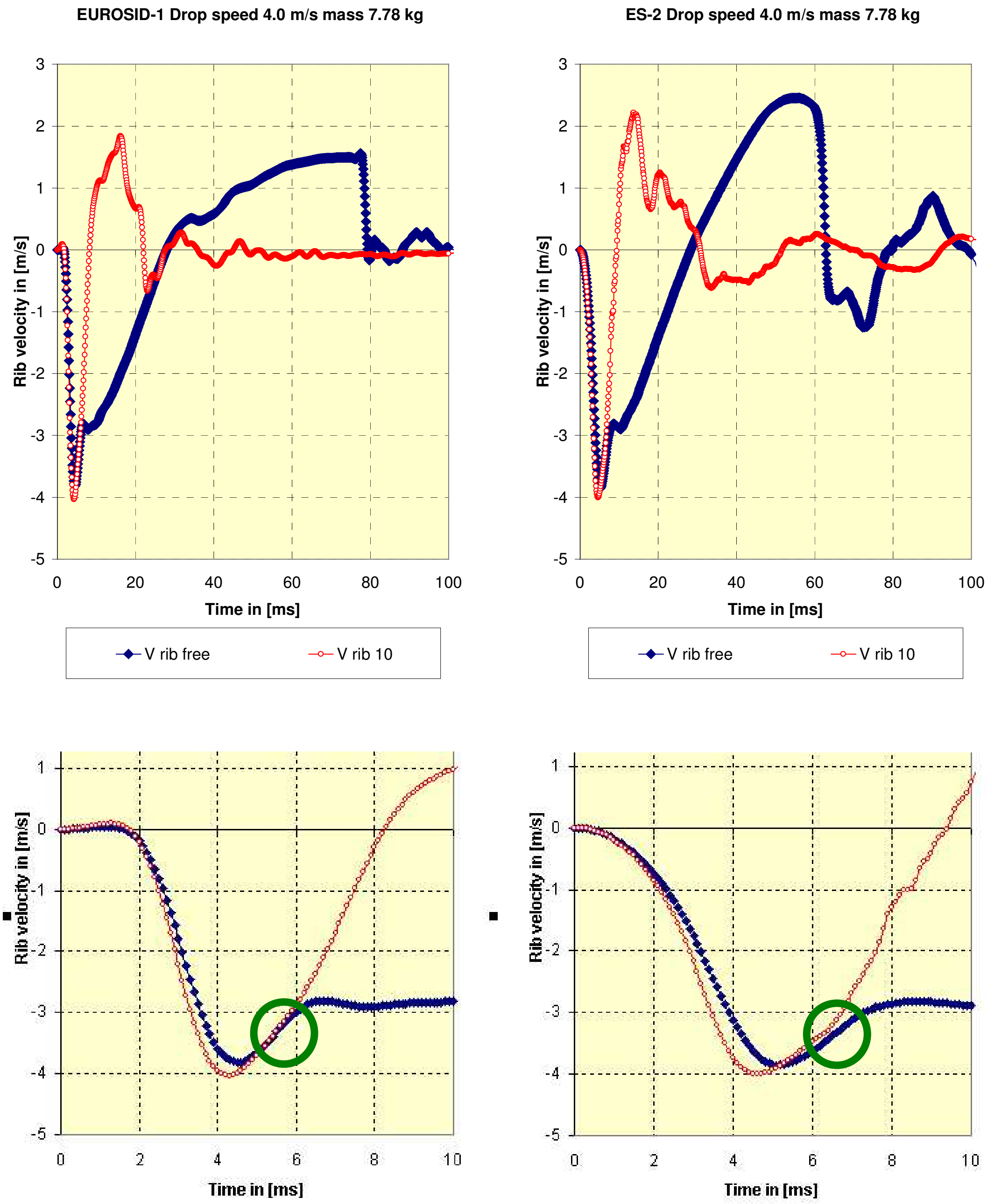

Figure 9: Calculated rib velocities with impactor free to fall and impactor stopped after approximately 10 mm rib displacement. Left for EUROSID-1 and right for ES-2. Impactor speed 4.0 m/s mass 7.78 kg. At the bottom, the same graphs with the time scale enlarged.

Rib velocity calculation - For further analysis, the measured rib acceleration signal is integrated to obtain the rib velocity and double integrated to check the displacement accuracy of the analysis. The integration quality was found good as the deviation shows only 1 mm difference on the maximum rib displacement of about 50 mm being 2% after 30 ms. Consequently, the velocity obtained by single integration in the time-domain up to 10 ms will have an accuracy smaller than 0.1%. In Figure 11, the rib velocities are shown.

Determination of true stopping distance - To establish consistent stopping distances for the test series, the moment of contact with the impactor stops is determined by velocity profile comparison. At the time that the rib velocity signals of the test with the stopped impactor start deviating from the free impactor test response, the rib displacement is established. In Figure 11, the exact time this occurs is indicated with a circle. Table 4 summaries the main test parameters for the impactor test at 4.0 m/s and 7.78 kg mass. This procedure is followed for all the test performed on a fixed rig configuration. From these results, the actual position of the stop blocks is determined by averaging the nine tests per rib configuration. In Table 4 the results of this exercise, the "true" stopping distances, are presented.

Table 3: Test results parameters for impactor speed 4.0 and mass 7.78 kg

	EUROSID-1		**ES-2**	
	Free	**Stopped at 10 mm (nom.)**	**Free**	**Stopped at 10 mm (nom.)**
Maximum displacement [mm]	48.7	15.8	50.6	18.8
Displacement at velocity profile change [mm]		11.0		13.8
Maximum velocity [m/s]	3.82	4.03	3.86	4.00
Velocity at impactor stop		3.39		3.29

Table 4: True stopping distances in the rib drop tests

Nominal stop distance [mm]	**EUROSID-1 tests Actual stop distance [mm]**	**ES-2 tests Actual stop distance [mm]**
20	20.4	21.8
10	10.4	11.8
5	5.4	6.8

Determination of (relative) overshoot - After the impactor has stopped, the accelerated rib continues and shows an overshoot. During this overshoot, the rib is not in direct contact with the impactor, thus the overshoot is the response of the rib system only. The overshoot is defined as:

$$\text{Overshoot} = D_{\text{blocked}} - \text{Stop Distance},$$

according to the definitions in Figure 10. A relative overshoot can be calculated as a fraction of the cut off displacement:

$$\text{Relative overshoot} = \text{Overshoot} \; / \; \text{Cut off displacement}$$

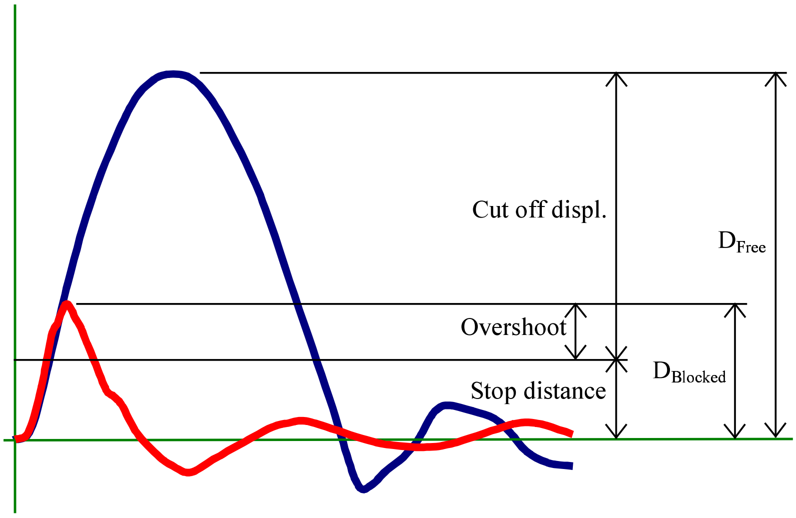

Figure 10: Definition of geometric parameters

The consolidated results for all tests conditions are given in Table 5. A graphic summary of the overshoot and the relative overshoot is given in Figure 11. The overshoot and relative overshoot for ES-2 are in all but two cases higher than EUROSID-1. The differences between ES-2 and EUROSID-1 are all within 33% relative to EUROSID-1.

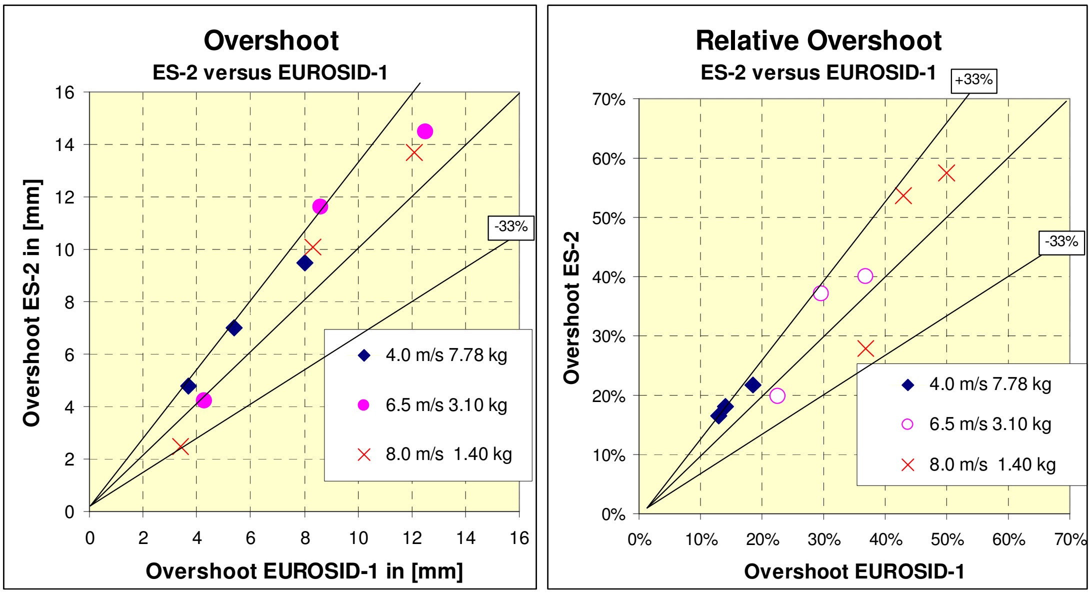

Figure 11: Overshoot and relative overshoot of ES-2 versus EUROSID-1

In summary, with regards to the rib oscillation seen in the Renault Megane full-scale test result, the following conclusions can be drawn from this study:

- The rib velocities in the full scale Renault Megane test are approximately: 1.8 m/s (upper) 2.5 m/s (middle) and 3.0 m/s (lower) in the first loading curve, and 1.3 m/s (upper) 1.8 m/s (middle) and 1.8 m/s (lower) in the second loading curve; the tests velocities in this programme vary from 4.0 to 8.0 m/s and are therefore close to the maximum velocity and higher.
- The ES-2 rib assembly does not show any rib oscillation of the magnitude seen in the full-scale test during the overshoot phase. It is far more likely that a second loading curve is a direct result of a second impact;
- The overshoot found in the stopped impactor tests with ES-2 show the same characteristic as the found for EUROSID-1, however, is up to 33% higher than those found with EUROSID-1 in the same test condition.

It must be noted that the smaller oscillation of the ES-2 rib at the end of the rebound is caused by the rubber end stop integrated in ES-2. The end stop has been implemented to prevent damage to the rib unit and its instrumentation as such damage was occasionally reported for EUROSID-1.

Table 5: Test result comparison EUROSID-1 versus ES-2 true stop distances in the rib drop tests

	EUROSID-1 tests			**ES-2 tests**		
Impact speed [m/s]	**4.0**	**6.5**	**8.0**	**4.0**	**6.5**	**8.0**
Impact mass [kg]	**7.78**	**3.1**	**1.4**	**7.78**	**3.1**	**1.4**
Impact energy [Nm]	**62.2**	**65.5**	**44.8**	**62.2**	**65.5**	**44.8**
Free impactor						
Maximum displacement [mm]	48.7	39.3	29.6	50.6	43.0	30.6
Maximum velocity [m/s]	3.82	5.81	5.86	3.86	6.14	6.11
Impactor stopped at 20 mm (nominal)						
Impactor stopping distance [mm]	20.4			21.8		
Maximum displacement [mm]	24.1	24.7	23.8	26.6	26.0	24.3
Overshoot after stop [mm]	**3.7**	**4.3**	**3.4**	**4.8**	**4.2**	**2.5**
(relative to cut off displacement)	(13%)	(23%)	(37%)	(17%)	(20%)	(28%)
Velocity at impactor stop [m/s]	2.9	3.9	3.4	2.9	3.4	2.7
Maximum velocity [m/s]	3.82	5.72	5.68	3.93	6.18	6.23
Impactor stopped at 10 mm (nominal)						
Impactor stopping distance [mm]	10.4			11.8		
Maximum displacement [mm]	15.8	19	18.7	18.8	23.4	21.9
Overshoot after stop [mm]	**5.4**	**8.6**	**8.2**	**7.0**	**11.6**	**10.1**
(relative to cut off displacement)	(14%)	(23%)	(43%)	(18%)	(37%)	(54%)
Velocity at impactor stop [m/s]	3.3	5.1	5.1	3.6	5.7	5.3
Maximum velocity [m/s]	4.03	5.84	5.60	4.00	6.23	6.22
Impactor stopped at 5 mm (nominal)						
Impactor stopping distance [mm]	5.4			6.8		
Maximum displacement [mm]	13.4	17.9	17.5	16.3	21.3	20.5
Overshoot after stop [mm]	**8.0**	**12.5**	**12.1**	**9.5**	**14.5**	**13.7**
(relative to cut off displacement)	(18%)	(37%)	(50%)	(22%)	(40%)	(57%)
Velocity at impactor stop [m/s]	4.0	5.7	5.7	4.0	6.0	5.9
Maximum velocity [m/s]	3.97	5.73	5.76	3.93	6.07	6.23