# SIDE IMPACT SAFETY: ASSESSMENT OF HIGH SPEED ADVANCED EUROPEAN MOBILE DEFORMABLE BARRIER (AE-MDB) TEST AND WORLDSID WITH 'RIBEYE'

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## ABSTRACT

In 2009, 2,222 people were killed and 24,690 were seriously injured in road traffic accidents in Great Britain (GB). About half the people killed were car occupants and just over one third of these were killed in side impacts.

Over the past ten years, since the introduction of the side impact regulation in Europe, much research work has been performed internationally to develop new and modified test procedures to improve the level of occupant protection offered by vehicles in side impacts. In Europe, this research has been co-ordinated by the European Enhanced Vehicle safety Committee (EEVC) and focused on contributing to the development of WorldSID and three test procedures. These are an Advanced European Deformable Barrier (AE-MDB) test, a pole test and an interior headform test.

This paper describes work performed by TRL on behalf of the UK Department for Transport to inform UK policy regarding side impact protection and provide the UK contribution to EEVC activities. The work described consisted of two parts.

For the first part, three full-scale crash tests were performed with Euro NCAP 5 star rated cars to investigate the implications of an AE-MDB test at a higher test speed than the current 50 km/h, in particular how much the occupant protection level in a current vehicle would have to be improved to meet the requirements of such a test and how representative the AE MDB is of a car at these higher speeds. The tests performed indicated that the safety level of a current Euro NCAP 5 star rated car is close to being able to meet the current UNECE Regulation 95 requirements in a 60 km/h AE-MDB test, but would need substantial modifications for higher speeds. Also, several issues were highlighted which need to be considered further. These included (1) the suitability of the current barrier face, because it was very close to bottoming out in the test performed, and (2) the appropriateness of the ES-2 dummy, because of the particularly high T12 spine loads recorded, which indicated that it may not have behaved in a biofidelic manner in the test performed.

For the second part, component level pendulum tests were performed with a WorldSID to assess the RibEye system, in particular to compare the RibEye measured deflection with the deflections that would be obtained using a 1D or 2D IR-Tracc sensor and to gain information on the best position for the two off-axis LEDs used with RibEye. In addition, a 60 km/h AE-MDB test was performed with a WorldSID 50th percentile driver and 5th percentile rear passenger to compare the performance of the WorldSID with the ES-2 dummy and to provide a further assessment of the RibEye system. It was found that the RibEye system was integrated well into the WorldSID and, in general, worked well. However, a potential issue was identified with the shoulder rib deflection measurement. This and other findings are discussed further in the paper.

## INTRODUCTION

Over the past ten years, since the introduction of the side impact regulation in Europe, much research work has been performed internationally to develop new and modified test procedures to improve the level of occupant protection offered by vehicles in side impacts. This has included the development of a new anthropometric dummy test tool, namely the WorldSID. This work has been co-ordinated in Europe by the European Enhanced Vehicle safety Committee (EEVC) and worldwide via *ad hoc* working groups set up by interested governments (e.g. the International Harmonization of Research Activities (IHRA) working groups, which were active until 2005) and groups formed by standard committees (e.g. ISO). In Europe the focus has been on the development of WorldSID and three test procedures. These are:

- An Advanced European Mobile Deformable Barrier (AE-MDB) test, the aim of which is to improve occupant protection in car-to-car impacts.
- A pole test, the aim of which is to improve occupant protection, especially for head injury, in car to 'narrow object' impacts. Examples of narrow objects are poles and trees. It should also help to improve head protection in other side impact configurations through the introduction of 'Head Protection Systems' such as side curtain airbags.
- An interior headform test, the aim of which is to improve head protection by improvement of the

padding on stiff vehicle interior structures that the head is likely to strike.

Much of the recent work in Europe to develop these test procedures and the WorldSID 5th percentile female dummy was performed by a large integrated European Commission 6th Framework project called APROSYS [1].

This paper describes work performed by TRL on behalf of the UK Department for Transport to inform UK policy regarding side impact protection and provide the UK contribution to EEVC activities. The work described consisted of two parts: the first an assessment of an AE-MDB test with a higher test speed and the second an assessment of WorldSID, in particular the 'RibEye' system for the measurement of rib deflection. This work is described in further detail below.

## ASSESSMENT OF AE-MDB TEST WITH HIGHER TEST SPEED

In 2006 the EEVC WG13 (side impact) was tasked by the EEVC steering committee to perform a review of the need to change the side impact regulation (UNECE Regulation 95) and, if necessary, bring forward appropriate proposals. The first part of this review, an analysis of accident databases to determine the magnitude and nature of side impact accidents, was performed by WG21 (accident studies) [2]. This analysis identified the most significant injuries and their mechanisms and also provided information to help define appropriate test configurations, especially for the AE-MDB test. However, the issue of the test speed was not answered fully. The only accident data available to help set the test speed, the UK CCIS accident data, indicated that an AE-MDB test speed of around 65 km/h may be more appropriate than the current test speed of 50 km/h, assuming that the aim is to address a substantial (about 50%) proportion of MAIS 3+ injured casualties [Figure 1].

The two red lines on the graph show the delta-v expected in Regulation 95 (barrier mass 950 kg) and AE-MDB (barrier mass 1500 kg) tests with a car of mass 1250 kg and a test speed of 50 km/h. It is seen that to address 50% of MAIS 3+ casualties the AE-MDB test speed would have to be raised to give a delta-v of 35 km/h, which for a 1250 kg car would equate to a test speed of about 65 km/h.

The objective of the work performed was to determine the implications of an AE-MDB test with a higher test speed, in particular how much the occupant protection level in a current vehicle would have to be improved to meet the requirements of such a test and how representative the AE-MDB is of a striking car at these higher speeds.

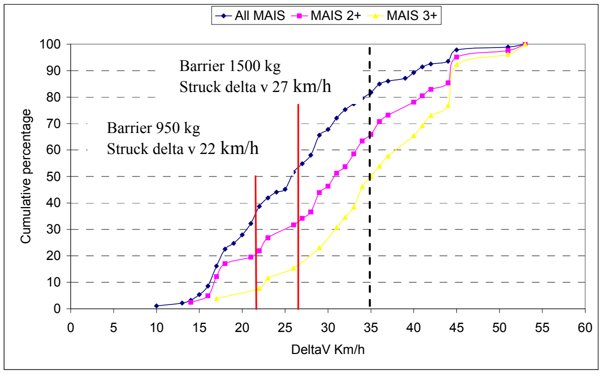


**Figure 1. Cumulative percentage of delta-v for all MAIS, MAIS 2+ and MAIS 3+ from analysis of UK CCIS data.**

### Approach

Three full-scale crash tests (highlighted in Table 1) were performed to obtain the maximum amount of information from a limited number of tests and the test data already available from the APROSYS project, EEVC WG13 members and Euro NCAP.

**Table 1.**

**Test matrix. Note: tests highlighted in green performed within this study. Other tests performed by APROSYS project, EEVC WG13 members and Euro NCAP.**

| No. | Target | Bullet | Speed (km/h) | Comment |
|---|---|---|---|---|
| 1 | Golf V | AE-MDB v3.10 | 50 | Target car stationary; Impact centre 250 mm rear of R-point* |
| 2 | Golf V | AE-MDB v3.10 | 60 | Impact centre 250 mm rear of R-point |
| 3 | Golf V | Golf V | 48 | Target car moving at 24 km/h; Impact centre R-point |
| 4 | Golf V | Golf V | 65 | Target car stationary; Impact centre 250 mm rear of R-point |
| 5 | Fiesta (MY 2009) | Golf V | 65 | Target car stationary; Impact centre 250 mm rear of R-point |
| 6 | Golf V | R95 MDB | 50 | Target car stationary; Impact centre R-point |

*Note: Impact centre 250 mm rearwards of R-point is the standard AE-MDB test configuration to allow loading of rear seated dummy and reproduce conditions of car-to-car impact with both cars moving.

The VW Golf Mk V was chosen as the target car for all of the tests except one because it was representative of a Euro NCAP 5 star rated car and other test data were available for comparison purposes. A test with a Ford Fiesta was performed to check that the performance of the Golf V was typical of other Euro NCAP 5 star rated cars. The AE-MDB v3.10 was used because it was the latest version of the barrier and fell within the

AE-MDB force deflection performance corridors derived by EEVC WG13 for definition of the barrier stiffness [3]. Car-to-car tests were performed at 65 km/h rather than AE-MDB tests because in the 60 km/h AE-MDB test the barrier was close to 'bottoming out' and hence may not have been representative of a car in a 65 km/h impact.

**Results**

Figure 2 and Figure 3 illustrate the approximate alignment of the AE-MDB (coloured in green) and Golf bullet car lower rails and bumper crossbeam (coloured in brown) with Golf V and Fiesta target cars, respectively, to help understand the dummy injury criteria values. The amount the AE-MDB overlaps the rear wheel should be noted because in the 60 km/h AE-MDB to Golf V test the barrier nearly bottomed out on the wheel, so bottoming out may occur in tests at higher speeds and/or with cars with shorter wheel bases such as the Fiesta.

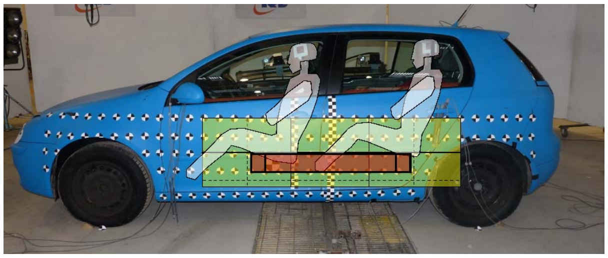


**Figure 2. Approximate alignment of AE-MDB and bullet car lower rails with Golf V target car and ES-2 dummies.**

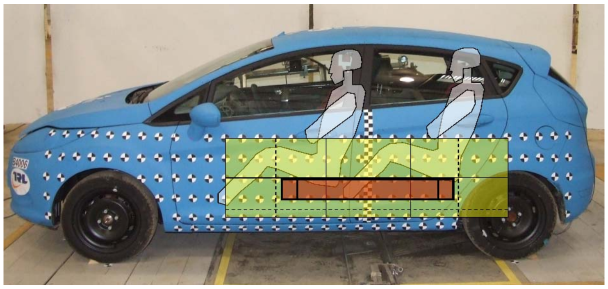


**Figure 3. Approximate alignment of AE-MDB and bullet car lower rails with Fiesta target car and ES-2 dummies.**

There were some issues noted for each of the tests but it is not thought that they affected the test results significantly. For example, in the AE-MDB vs Golf 60 km/h test there was an incorrect curtain airbag deployment. Specifically, interaction between the bag and the B-pillar and seat belt upper anchorage point prevented the bag unfolding and deploying correctly. Also, the rear door fully unlatched and opened during the test.

The driver dummy injury criteria values and accelerations are compared in Figure 4 and Figure 5 respectively.

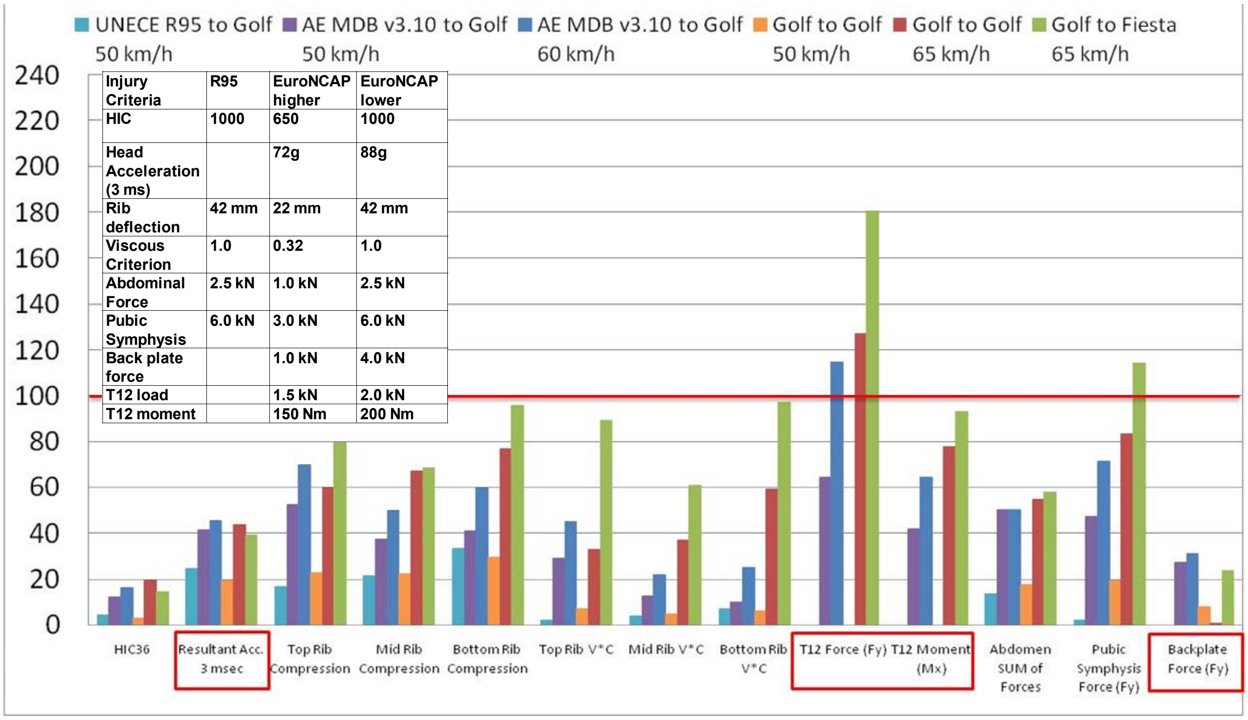
For the driver dummy it is seen that, for the Golf 60 km/h AE-MDB and 65 km/h car-to-car tests, all injury criteria values were less than about 80% of the legislative performance limits. This indicates that the Golf offered a good level of protection, even at the higher impact speeds. However, the spine T12 loads were high (greater than the Euro NCAP lower limit for a full modifier) in particular the Fy force, which indicates possible unloading of the thorax. This is an issue caused by the lack of biofidelity of the ES-2 dummy lumbar spine. It is much stiffer than a human lumbar spine and hence it can transmit greater loads than a human spine. The outcome of this is that when the ES 2 dummy pelvis is subjected to large loads the lumbar spine will transmit unrealistically large loads to the thorax. This can help displace the thorax sideways and hence reduce thorax loading via other load paths, such as through the ribs, and in turn reduce the associated injury criteria values. It is expected that this problem has been resolved with the WorldSID because it has a more flexible lumbar spine which should not transmit unrealistically large loads.

For the Fiesta 65 km/h car-to-car test the injury criteria values, in general, were higher than for the Golf, but still below the legislative limits with the exception of the pubic symphysis force. However, as for the Golf the spine T12 loads were high which again indicates possible unloading of the thorax.

Figure 5 shows that the driver dummy accelerations are substantially increased for the higher speed tests, in particular in the pelvis and lower spine areas. These are the areas of the dummy that are more closely aligned with the barrier and bullet car.

The rear passenger dummy injury criteria values and accelerations are compared in Figure 6 and Figure 7 respectively.

For the rear passenger dummy it is seen that for the Golf 60 km/h AE-MDB test the injury criteria were below the legislative limits. However, spine T12 loads and backplate forces were high indicating possible unloading of the thorax. For the Golf car-to-car test at 65 km/h the dummy injury criteria exceeded the legislative limits for the pubic symphysis. The high pelvis loading was exacerbated by the alignment of the main rail of the bullet Golf with the bottom of the dummy pelvis [Figure 2]. Again, spine T12 loads were



| Injury Criteria | R95 | EuroNCAP higher | EuroNCAP lower |
|---|---|---|---|
| HIC | 1000 | 650 | 1000 |
| Head Acceleration (3 ms) | | 72g | 88g |
| Rib deflection | 42 mm | 22 mm | 42 mm |
| Viscous Criterion | 1.0 | 0.32 | 1.0 |
| Abdominal Force | 2.5 kN | 1.0 kN | 2.5 kN |
| Pubic Symphysis | 6.0 kN | 3.0 kN | 6.0 kN |
| Back plate force | | 1.0 kN | 4.0 kN |
| T12 load | | 1.5 kN | 2.0 kN |
| T12 moment | | 150 Nm | 200 Nm |

**Figure 4. Driver injury performance as a percentage of legislative or Euro NCAP lower limits. Notes: Criteria not used in legislation are indicated with red boxes. In 50 km/h Golf vs Golf test target car was also moving at 24 km/h.**

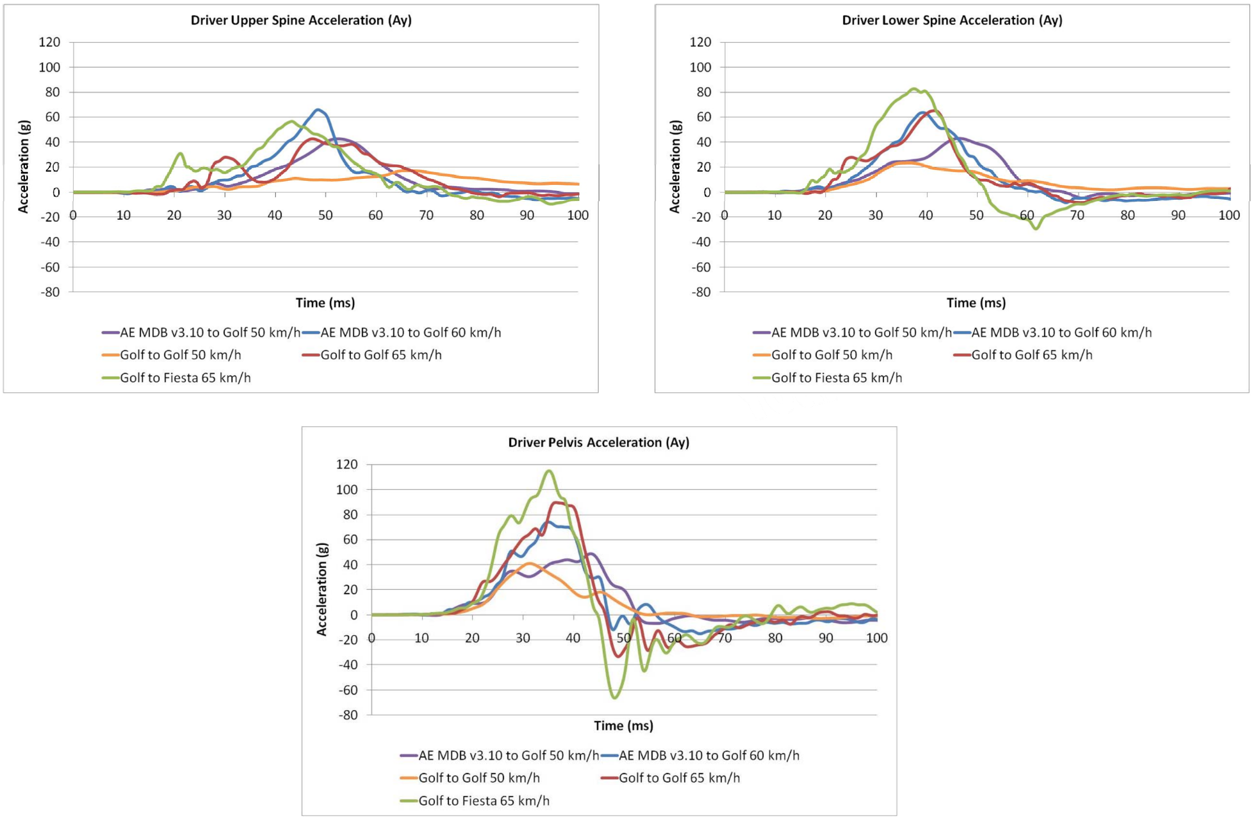


**Figure 5. Driver upper spine, lower spine and pelvis accelerations. Note: R95 results not available.**

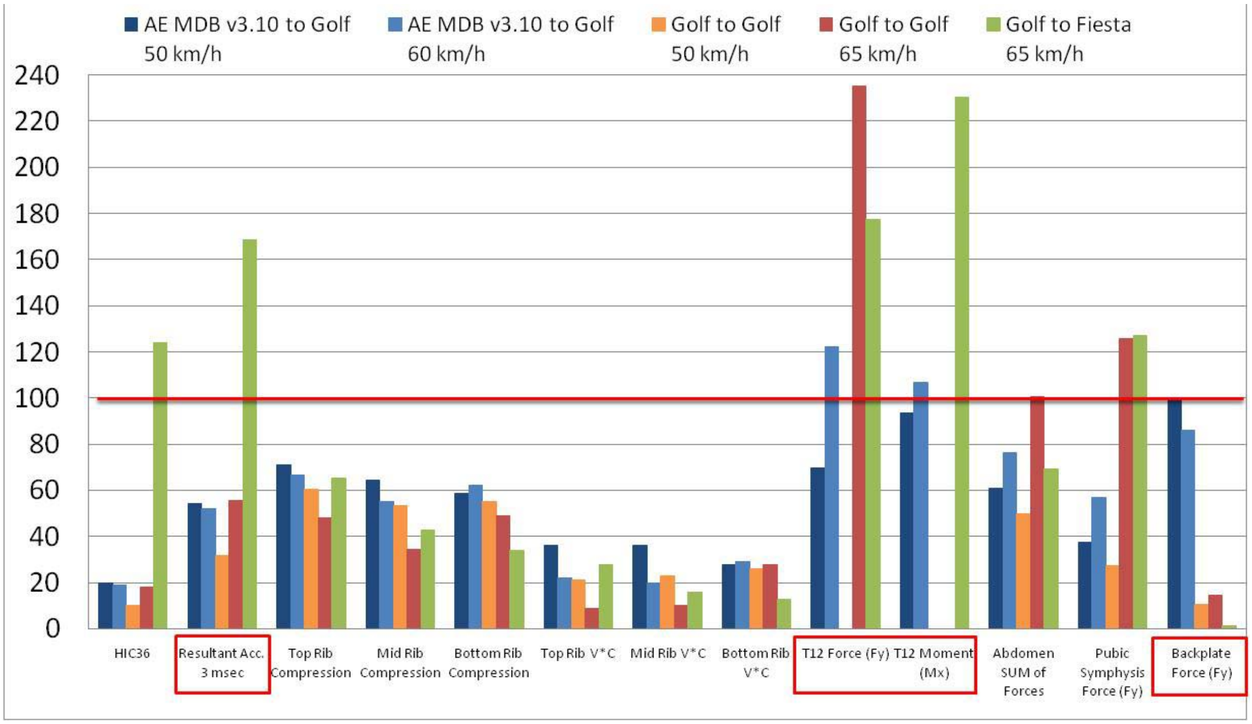


**Figure 6. Rear seat passenger injury performance as a percentage of legislative or Euro NCAP lower limits.**

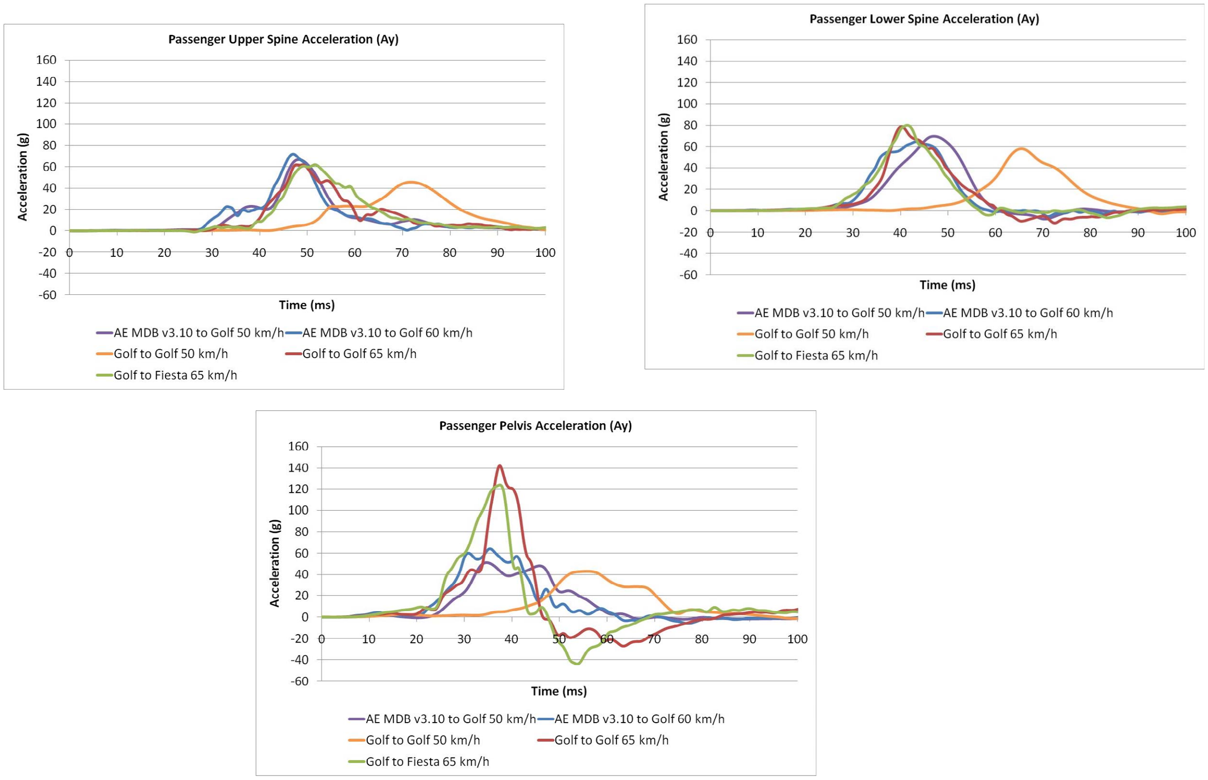


**Figure 7. Rear seat passenger upper spine, lower spine and pelvis accelerations.**

high indicating possible unloading of the thorax. For the Fiesta car-to-car test the dummy injury criteria exceeded the legislative limits for the pubic symphysis and the head. The high head injury criteria were a result of the head impacting the C-pillar. This vehicle was not fitted with a curtain airbag which probably would have prevented this. As for the Golf, spine T12 loads were high.

For the rear passenger dummy accelerations [Figure 7] two interesting observations were made. The first was the delay in the acceleration of the dummy in the Golf-to-Golf 50 km/h test compared to the other tests. This is a result of the different test configuration for this test, in particular that the target car was moving at 24 km/h and the barrier impact point on the car was 250 mm forward compared to the other tests. The result of this was that the barrier moved into alignment with the dummy later in the impact than in the other tests. The other observation is the much larger pelvis accelerations for the 65 km/h car-to-car tests. This was a result of the alignment of the main longitudinal member of the bullet car with the bottom of the dummy pelvis in these tests, which increased the dummy loading. It should be noted that the AE-MDB uses six areas which have different stiffnesses to represent the stiffness profile of a car. Hence, it does not represent precisely the highly localised stiffness of a car's longitudinal member.

Figure 8 shows the measured deformations of the target cars. It is seen for the tests with the Golf car that the deformation was substantially larger in the higher speed tests at mid-door and waist rail levels and in particular for the Golf to Golf tests at 65 km/h. The deformation in the Golf to Fiesta 65 km/h test was larger than for the Golf to Golf test and also a different shape. In the Fiesta test the B-pillar was deformed more than in the Golf test with the result that the Fiesta had more of a C-shaped deformation profile compared to the Golf's M-shaped profile. It should be noted that there was little localised penetration of the target car in the car-to-car tests due to the good performance of the bumper crossbeam on the bullet Golf car.

Figure 9 shows the deformation of the barrier in the 60 km/h AE-MDB to Golf test. It is seen that the AE-MDB was close to 'bottoming out' near its bottom right hand corner due to interaction with the Golf's rear wheel and C-pillar. This indicates that bottoming out may occur in tests at higher speeds and/or with cars with shorter wheel bases such as the Fiesta.

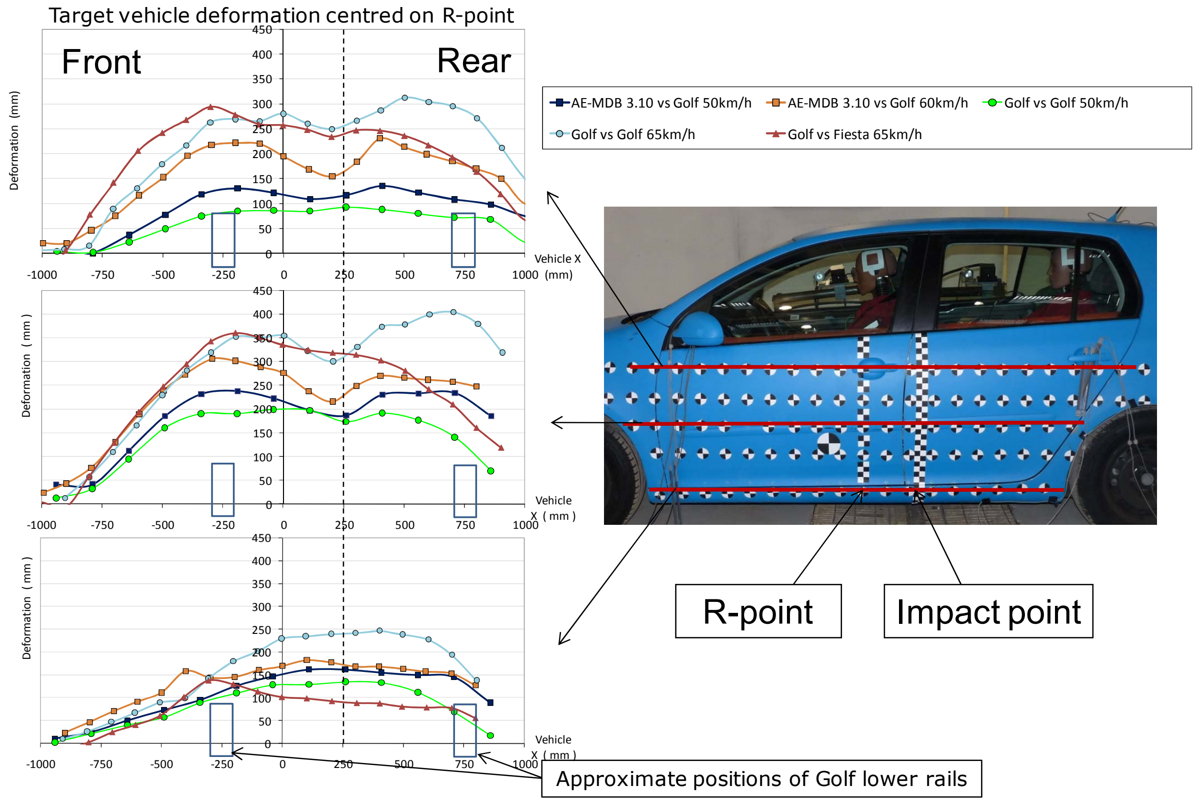


Figure 8. Vehicle deformation measurements at sill, mid-door and waist rail levels.

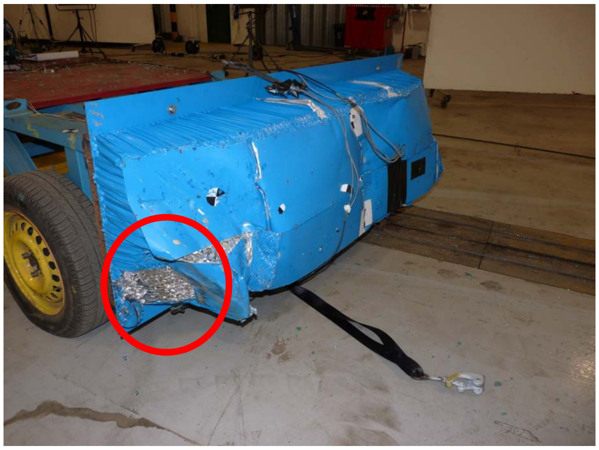


**Figure 9. AE-MDB from 60 km/h Golf test showing that barrier was close to 'bottoming out'.**

### Conclusions

- Both the driver and passenger dummy injury criteria values were less than 80 percent of the regulatory limits in the 60 km/h AE-MDB test with the Golf V. However, during the test the door unlatched which would have failed the legislative requirement that no door opens during the test. In addition, issues were noted with the deployment of the curtain airbag and that spine T12 loads were high, which is an indication of possible unloading of the thorax. Also, the barrier was close to bottoming out in the test.

- In the 65 km/h car-to-car tests, for at least one body region, either the driver or passenger dummy injury criteria values or both exceeded the legislative limits in both tests, although by less than about 25 percent. Furthermore, the spine T12 loads were particularly high in these tests, (up to 230 percent of the Euro NCAP lower limit for application of a modifier) which is an indication of possible unloading of the thorax.

- In summary, the tests performed indicated that the safety level of a current Euro NCAP 5 star rated car is close to being able to meet the requirements of a 60 km/h AE-MDB test but would need substantial modifications for higher speeds. In addition, issues regarding a higher speed test were highlighted, in particular the suitability of the current barrier because it was close to bottoming out and the suitability of the ES-2 dummy because of the particularly high T12 spine loads which indicate that the dummy may be behaving in an non-biofidelic manner. It is expected that the more flexible lumbar spine of the WorldSID would help to resolve this issue.

## ASSESSMENT OF WORLDSID

The assessment of WorldSID consisted of two main parts. The first part was a series of component level pendulum tests to assess the new RibEye™ Multi-Point Deflection Measurement System (from here on referred to as 'RibEye') for measuring the deflection of the WorldSID shoulder, thorax and abdominal ribs. The main objective was to compare the output from the RibEye optical rib deflection measurement system with the more conventional measurements that would be obtained with a one dimensional (1D) or two dimensional (2D) IR-Tracc sensor.

The second part consisted of a 60 km/h AE-MDB full-scale crash test to compare the performance of the WorldSID dummy with the ES-2 dummy and to provide a further assessment of the RibEye system.

### The 'RibEye' Deflection Measurement System

It is generally accepted that the WorldSID dummy is superior in thorax biofidelity to other side impact dummies [4]. Until the introduction of WorldSID, little consideration was given to the biofidelity of side impact dummies for oblique loading, because the older dummies were designed to be sensitive in the lateral axis only. A feature of the WorldSID is that oblique and off-axis chest deformations are possible. A consequence of this is that measurement of the chest deflection needs to take into account oblique and off-axis deformations.

When it was introduced, the WorldSID 50th percentile male dummy was instrumented with a 1D IR-Tracc sensor on each rib to measure the deflection. Unfortunately, these dummies displayed a reduced sensitivity of the rib deflection measurement system to oblique and offset impact as any rotation of the IR-Tracc was not taken into account. This limitation was shown in testing conducted at TRL [5] as part of the EC 5th Framework SIBER project and in various other studies.

Figure 10 illustrates this problem. Under lateral impact the forward component in rib displacement introduces extension of the rib deflection measurement system (indicated by the red dotted line). This reduces the compression output of the measurement system. Under rearward oblique impact [Figure 10(c)], there is more forward rib deformation. This leads to an even greater underestimate of the lateral rib compression and therefore of the risk of injury, if based on a single axis lateral deflection measure.

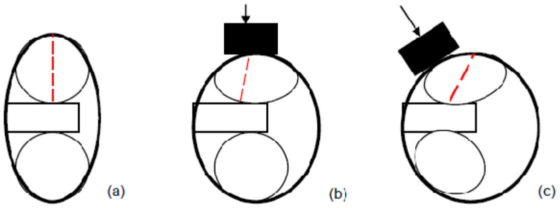


**Figure 10. WorldSID rib schematic top view undeformed (a), deformation under lateral impact (b), and deformation under rearward oblique impact (c).**

The APROSYS project [6] developed and tested two-dimensional (2D) IR-Traccs with potentiometers at their base to improve the sensitivity of the WorldSID thorax to oblique impact. The 2D IR-Traccs showed improved sensitivity to off-axis deformations, but some error in the measurements was still seen when compared with the true, peak deflection.

In parallel, but on a longer timeframe, an optical rib deflection measurement system was developed, the RibEye. The differences between the RibEye and 2D systems are that the RibEye measures vertical displacements as well as lateral and fore-aft, and the deflections are assessed at three different positions around the rib. This is achieved by using sensors mounted on the spine box which optically track three LEDs on each rib in three dimensions throughout the impact [Figure 11]. Using the data obtained from the forward, middle, and rearward LED positions, more complicated deformation patterns of the ribs can be measured than would be possible based on a single point measurement system.

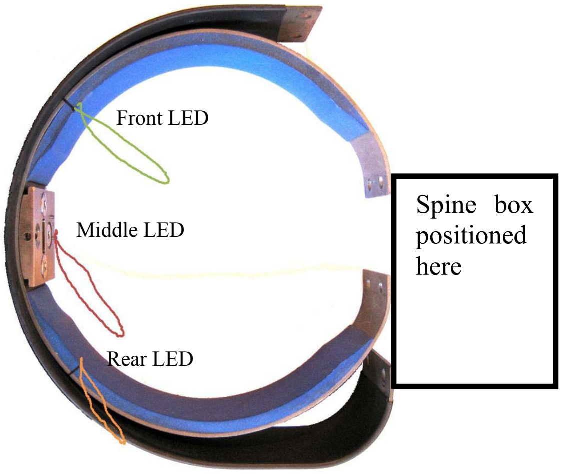


**Figure 11. Example of RibEye resultant deflection measurements at the front, middle, and rear LED positions with forward oblique loading.**

## Assessment of WorldSID 'RibEye' using Pendulum Tests

Forty pendulum impactor tests were performed on a WorldSID 50th percentile male (50M) in broadly two regimes, namely oblique and offset [Figure 12], for two different postures of the WorldSID. These were either suspended in a seated position until the moment of impact (without any other support) or reclined on the WorldSID's certification bench.

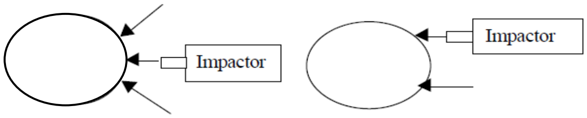


**Figure 12. Oblique impact (left) and offset impact (right), schematic overhead views.**

The tests were configured to evaluate the RibEye deflection measurement system with respect to the existing 1D and 2D IR-Tracc measurement systems. Equivalent ID and 2D IR-Tracc measurements were calculated from the RibEye measurements. It should be noted that the tests were set up to minimise vertical rib displacements and hence were not suitable to evaluate the importance of the vertical measurement that RibEye offers.

For a 1D IR-Tracc measurement it was found that even for purely lateral impacts, there was a slight underestimate of the rib deflection. For the oblique and offset impacts this under-estimate increased substantially. Table **2** shows the measurements from the offset tests in which the WorldSID was suspended. It is seen that the 1D IR-Tracc deflection measurement under-estimates were greatest when the loading was most offset, only 61 percent of the 2D resultant deflection for 75 mm offset impact.

**Table 2.**
**Rib deflections for offset tests with WorldSID suspended (all values in mm)**

| Impact offset | 1-D IR-Tracc equivalent | 2-D calculated lateral disp. | 2-D resultant deflection | RibEye middle LED resultant | RibEye front LED resultant |
|---|---|---|---|---|---|
| -75 | 23.0 | 26.7 | 37.5 | 37.5 | 36.1 |
| -50 | 27.8 | 30.4 | 39.4 | 39.5 | 34.1 |
| -25 | 28.4 | 29.2 | 31.8 | 31.8 | 27.8 |
| 0 | 24.3 | 24.4 | 24.8 | 24.8 | 25.2 |
| 25 | 22.3 | 22.4 | 23.0 | 23.1 | 23.0 |
| 50 | 18.3 | 18.7 | 20.7 | 21.0 | 23.9 |

This is because with offset impacts a greater component of the rib deformation comes from x-axis displacement than in lateral tests. This is evident from comparison of the difference between the 2-D lateral and resultant measurements, which are closer for the tests with the smallest offset.

For RibEye measurement of lateral displacement it was found that the forward of lateral rib measurement LED position provided greater peak lateral displacement values than the middle LED. This indicates that the forward position could provide useful additional information, if assessing risk of injury based on lateral rib displacement. This should represent an advantage to considering the middle LED position alone, as in a 2D IR-Tracc system.

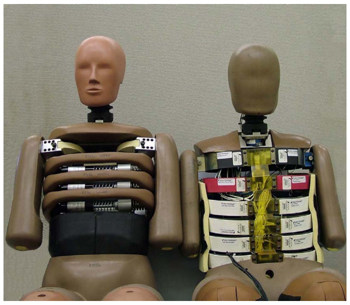
For measurement of resultant displacement it was found that the resultant deflection was rarely greater at the forward LED position than at the middle position. From this it can be inferred that the front position was not picking up a particularly greater aspect of the overall rib loading. Hence, if the resultant deflection was considered as the key criterion, it seems as though alternative rib deflection assessment positions would be useful only when there is localised loading. To assess this further it is recommended that the relative measurements from the LEDs be considered in loading expected to cause localised deflections of the rib cage. For instance, one might consider testing the thorax when tightly constrained by a seat-belt and when loaded with a non-flat impact surface.

### Assessment of WorldSID in 60 km/h AE-MDB Test

A full-scale side impact crash test was performed between a Volkswagen Golf and an AE-MDB v3.10 at 60 km/h using a WorldSID 50M driver and a WorldSID 5F rear passenger. The WorldSID 50M was fitted with RibEye and hence equivalent measurements for 1D and 2D IR-Tracc systems could be calculated. The WorldSID 5F was fitted with a 2D IR-Tracc system. The main aim of the test was to compare the performance of the WorldSID dummies with the performance of ES-2 driver and rear passenger dummies which were tested as part of the investigation of increased test speed reported previously. A further aim of the test was to compare the different rib deflection measurement systems used in the WorldSID dummies, namely the 1D IR-Tracc, 2D IR-Tracc and RibEye in a full-scale test.

In order to undertake a comparison of the relative performance of the WorldSID and ES-2 dummies, it was necessary to check that the performance of the vehicles in both tests was similar. The vehicle accelerations and deformations in each of the tests were compared and judged to be similar enough to allow comparison of the dummies. However, it should be noted that the head curtain airbag did not deploy correctly in either test. The central section of the airbag appeared to be caught on the top of the B-pillar trim or seatbelt anchorage which prevented the central section from fully deploying. In addition, in the WorldSID test the airbag did not fully unfurl next to the driver dummy's head. However, these issues did not have a detrimental effect on the dummy results and the driver's head was still protected by the airbag in both tests.

**A comparison of the WorldSID and ES-2 dummy performances** is reported below for the driver and passenger dummies. The WorldSID and ES-2 dummies have significant differences in their anthropometries [Figure 13]. The top rib of the ES-2 dummy approximately aligns with the shoulder of the WorldSID dummy. Also the WorldSID and ES-2 dummies have different seating position procedures. As a result of these differences the initial positions of WorldSID 50M and ES-2 dummies in the tests were significantly different, e.g. the head to roof measurement was 74 mm for the ES-2 compared to 119 mm for WorldSID 50M.



| | ES-2 (mm) | WorldSID (mm) |
|---|---|---|
| **Shoulder width** | 485 | 480 |
| **Pelvis width** | 355 | 410 |
| **Sitting height** (neck/torso interface) | 660 | 600 |
| **Sitting height** (erect) | 920 | 870 |

**Figure 13. Comparison of anthropometry of ES-2 and WorldSID.**

The injury parameter outputs for the ES-2 and WorldSID dummies in the tests are shown in Table **3**.

The main points of interest are the peak force levels recorded for the WorldSID 50M shoulder, which is significantly higher than the ES-2 driver, and the pubic symphysis, which is significantly lower than the ES-2.

Table 3.
ES-2 and WorldSID injury parameter outputs

| | Parameter | ES-2 driver | ES-2 passenger | WorldSID 50M driver | WorldSID 5F passenger |
|---|---|---|---|---|---|
| Head | $\text{HIC}_{36}$ | 163.47 | 188.22 | 137.7 | 201.3 |
| | Peak resultant accel (g) | 42.38 | 48.00 | 42.14 | 49.55 |
| | 3ms exceedence (g) | 40.12 | 45.92 | 40.67 | 46.79 |
| Shoulder | Force y (kN) | 0.65 | 1.87 | 3.21 | -**** |
| | Deflection (mm) | - | - | > 40*** | 49.11 |
| Thorax | Top rib deflection (mm) | 29.36 | 28.07 | 18.39* | 25.55** |
| | Middle rib deflection (mm) | 21.01 | 23.11 | 22.31* | 13.20** |
| | Bottom rib deflection (mm) | 25.06 | 26.12 | 27.64* | 18.85** |
| | Top rib V*C (m/s) | 0.45 | 0.22 | 0.22* | 0.40** |
| | Middle rib V*C (m/s) | 0.22 | 0.20 | 0.27* | 0.14** |
| | Bottom rib V*C (m/s) | 0.25 | 0.29 | 0.27* | 0.31** |
| Abdomen | Abdomen Force summation (kN) | 1.26 | 1.91 | - | - |
| | Abdomen Rib 1 deflection (mm) | - | - | 32.01* | 23.93** |
| | Abdomen Rib 2 deflection (mm) | - | - | 35.44* | 35.59** |
| | Abdomen Rib 1 V*C (m/s) | - | - | 0.47* | 0.49** |
| | Abdomen Rib 2 V*C (m/s) | - | - | 0.51* | 1.00** |
| | T12 acceleration Y (g) | 63.75 | 64.50 | 54.41 | 101.32 |
| Pelvis | Pubic symphysis force (kN) | 4.28 | 3.41 | 0.99 | 1.07 |
| | Pelvis accel Y (g) | 74.32 | 64.28 | 80.22 | 74.35 |

*Based on equivalent 1D IR-TRACC measurement
**Based on equivalent calculated lateral component from 2D IR-TRACC
***Value taken prior to channel failures. Estimated peak value approximately 50-60 mm, based on curve fitting to equivalent 1D IR-TRACC measurements before and after channel measurement range exceeded.
****Shoulder load cell not fitted to dummy

**Figure 14. Comparison of driver dummy kinematics (ES-2 left, WorldSID 50M right), showing ES-2 shoulder moving forward away from ribs (shrugging).**

Considering the difference in shoulder loads, comparison of the driver dummy kinematics showed that the dummies' shoulders interacted with the door differently. The ES-2 dummy's shoulder was pushed forward and rotated away from the ribs during the impact, whilst the WorldSID 50M shoulder did not rotate and was directly loaded by the door structure [Figure 14]. Likely contributory factors to this were (1) the significant structural differences in the design of the shoulder between the two dummies and (2). the difference in alignment of dummies' shoulders with the door structure; the WorldSID 50M shoulder aligned directly with the door structure due to the dummy's lower initial position compared to the ES-2.

Considering the difference in pubic symphysis loading, both the driver dummies showed significant pelvis movement away from the door which was consistent with the high pelvis accelerations observed for both dummies (approximately 80 *g*). However, this did not explain the significant difference in pubic symphysis load, where the ES-2 experienced much higher loading than the WorldSID 50M. The differences in dummy design probably contributed to some of this difference. However, it is also possible that the WorldSID pelvis was loaded through a different load path, perhaps at the rear of the pelvis where the load would not have been picked up by the pubic symphysis load cell. The WorldSID 50M can have a sacrum load cell fitted at the rear of the pelvis which may have provided this information. However the dummy used in this test did not have this instrumentation fitted.

The WorldSID 5F rear passenger kinematics showed that the head curtain airbag did not protect the dummy's head during the impact. Despite initial contact with the lower part of the airbag, the dummy's head was not prevented from contacting the door [Figure 15].

**Figure 15. WorldSID 5F rear passenger showing head contact with door - head not protected by airbag.**

However, the values for HIC and 3ms exceedence recorded by the dummy indicated that this head contact was not significant in terms of injury risk. A similar phenomenon was seen for the WorldSID 5F in a test performed by APROSYS [7].

In the test with the ES-2, as reported previously, high levels of T12 loading were recorded possibly due to the poor biofidelity of the ES-2 spine in this area. This may have unloaded the ribs. The WorldSID is a more biofidelic dummy than the ES-2, and as such it was expected that loading through T12 would not be as high and hence any unloading of the ribs would not be as great. As such, higher rib deflections were expected to be observed for the WorldSID 50M than the ES-2. However, this was not the case. A possible reason for this result was the increased loading of the WorldSID 50M shoulder in the test which may have unloaded the ribs. It should be noted that the WorldSID is not fitted with a T12 load cell, and as such it was not possible to make any conclusions about whether the improved biofidelity of the WorldSID lumbar spine reduced the T12 loads.

In order to compare the performances of the WorldSID and ES-2 dummies, a calculation of the estimated injury risk for each dummy's body region was made using known injury risk functions. Injury risk functions were not available for the ES-2, so ES-1 risk curves were used. The injury risks for the WorldSID 50M dummy were calculated using the risk functions developed by Petitjean *et al.* [8]. The injury risks for the WorldSID 5F dummy were calculated using the risk functions developed within the APROSYS project [9]. It should be noted that the only injury risk functions available for the WorldSID 50M rib outputs were based on the 1D IR-Tracc measurements, whilst risk functions were available for the WorldSID 5F using 1D and 2D IR-Tracc outputs. Therefore, for the purposes of this comparison, the rib outputs for the WorldSID 50M were based on the equivalent 1D IR-Tracc measurements calculated from the RibEye outputs, whilst the rib outputs for the WorldSID 5F were based on the 2D IR-Tracc calculated lateral displacement measure.

The calculated injury risks are shown in Table **4**. Comparison of the injury risks between the ES-2 and WorldSID dummies showed that the ES-2 driver predicted a significantly higher injury risk than the WorldSID 50M driver for the thorax and abdomen, with a similar injury risk for the pelvis based on acceleration. However, the WorldSID 50M had a very high risk of AIS2+ shoulder injury which cannot be compared to the ES-2 because no risk function was available.

**Table 4.**
**Comparison of ES-2 and WorldSID injury risks**

| Injury risk comparison | | ES-2 driver | ES-2 passenger | WS50M driver | WS5F passenger |
|---|---|---|---|---|---|
| Shoulder | Deflection | - | - | >2% AIS2+*** | - |
| | Force | - | - | 92% AIS2+ | - |
| Thorax | Top Rib deflection | 12% AIS3+ | 10% AIS3+ | <1% AIS3+* | 21% AIS3+** |
| | Top Rib V*C | 26% AIS3+ | 10% AIS3+ | [4% AIS3+*] | - |
| | Mid Rib deflection | 4% AIS3+ | 5% AIS3+ | <1% AIS3+* | 7% AIS3+** |
| | Mid Rib V*C | 10% AIS3+ | 9% AIS3+ | [6% AIS3+*] | - |
| | Bot Rib deflection | 6% AIS3+ | 7% AIS3+ | <1% AIS3+* | 13% AIS3+** |
| | Bot Rib V*C | 11% AIS3+ | 13% AIS3+ | [6% AIS3+*] | - |
| Abdomen | Force | 15% AIS3+ | 16% AIS3+ | - | - |
| | Abdomen Rib 1 deflection | - | - | <1% AIS3+* | 7% AIS3+** |
| | Abdomen Rib 1 V*C | - | - | [<2% AIS3+*] | - |
| | Abdomen Rib 2 deflection | - | - | <1% AIS3+* | 14% AIS3+** |
| | Abdomen Rib 2 V*C | - | - | [<2% AIS3+*] | - |
| | T12 Acceleration | 46% AIS3+ | 47% AIS3+ | <2% AIS3+ | - |
| Pelvis | Force | 20% AIS2+ | 13% AIS2+ | <1% AIS2+ | <2% AIS2+ |
| | Acceleration | 24% AIS2+ | 21% AIS2+ | 19% AIS2+ | [~35% AIS2+] |

*Based on equivalent 1D IR-TRACC measurement
**Based on calculated lateral component from 2D IR-TRACC
***Based on value recorded prior to channel failure at 32ms, likely to be much higher

It is likely that that the high load on the shoulder reduced the loading on the ribs and therefore contributed to the low injury risk for the thorax. It should be noted that there are concerns regarding the injury risk calculated for rib viscous criterion in the WorldSID 50M, as it is calculated based on the equivalent 1D IR-Tracc rib compression which does not take into account the rotation of the rib and therefore does not necessarily relate to the lateral deflection of the rib. As such these values are shown in square brackets. Also, it should be noted that the shoulder rib front and middle LED measurements dropped out during the test, probably due to the high deflection of the shoulder rib in all three dimensions (lateral, fore/aft and vertical), which in turn probably led to the rib LEDs being positioned such that they could not be seen by the sensors.

The WorldSID 5F rear passenger injury parameters could not be directly compared to the ES-2 rear passenger dummy due to the differences in the sizes of the dummies. However, it could be seen that the WorldSID 5F had generally higher risk of AIS3+ chest injury than the ES-2.

**A comparison of the rib deflection measurement systems** for the WorldSID 50M was made. Using the RibEye middle LED measurements equivalent measurements for 1D and 2D IR-Tracc systems were calculated [Table **5**]. Comparison of the 1D IR-Tracc measurement with the 2D IR-Tracc lateral measurement (EY) shows that the 1D IR-Tracc consistently underestimated the lateral deflection of the ribs. This was due to the fact that it does not take the rib rotation, and therefore fore/aft movement of the rib, into account. The comparison of the 1D IR-Tracc compression with the 2D IR-Tracc calculated resultant deflection (ER) showed an even larger difference. As no injury risk functions were available for the 2D IR-Tracc on the WorldSID 50M dummy, it was not possible to assess the impact that the underestimation of rib deflection by the 1D IR-Tracc would have had on the likelihood of occupant injury.

**Table 5.**
**Comparison of 1D and 2D IR-TRACC equivalent measurements for WorldSID 50M driver**

| | **1D IR-TRACC** Equivalent | **2D IR-TRACC** (Equivalent from Ribeye Middle LED) | | |
|---|---|---|---|---|
| | | EX | EY | ER |
| Shoulder | 32.31* | 31.51* | 50.59* | 59.60* |
| Thorax 1 | 18.05 | 20.47 | 19.3 | 26.51 |
| Thorax 2 | 22.05 | 19.34 | 22.83 | 28.26 |
| Thorax 3 | 26.59 | 17.93 | 29.53 | 34.48 |
| Abdomen 1 | 30.87 | 19.93 | 34.32 | 39.64 |
| Abdomen 2 | 34.00 | 20.68 | 37.91 | 43.00 |

*Values recorded prior to channel measurement range being exceeded

## Conclusions

Assessment of WorldSID 'RibEye' in pendulum tests:

- Even in the purely lateral impacts, there was a slight underestimate in the rib deflection arising from the 1-D IR-Tracc measurement. This increased to 61 % of the resultant, in the case of the 75 mm offset impact test.

- RibEye LED position.
  - The forward of lateral LED position often provided a larger lateral (y-axis) displacement measurement than the middle LED position.
  - Unless the loading is particularly oblique (> ~30 degrees) or offset (~ 50 mm) there is no additional benefit in using the resultant deflection data from the forward of lateral LED position.
  - Only with particularly concentrated loading would it be expected that the rearward of lateral LED position would measure greater rib deflection values than the forward of lateral and middle LED positions.

Assessment of WorldSID in 60 km/h AE-MDB test.

- Dummy kinematics.
  - The WorldSID 50M and ES-2 driver exhibited different behaviour, in particular for the interaction of the shoulder with the car door.
  - The WorldSID 5F head was not protected by head curtain airbag due to a low head position. The head contacted the door at the base of the window. However, the values for HIC and 3ms exceedence indicated that this head contact was not significant in terms of injury risk.

- Injury criteria and risks
  - There was a significantly higher shoulder load for the WorldSID 50M compared to the ES-2. This most likely reduced the loading to the thorax. Likely contributory factors were the different alignment of the dummies with the cars' structures and the different designs of the dummies' shoulders. The different dummy alignment was a result of the difference in the anthropometry of the dummies and the different seating procedures.
  - There was a significantly lower pubic symphysis loading for WorldSID 50M compared to the ES-2 even though both dummies had similar pelvis accelerations. The differences in dummy design probably contributed to some of this difference. However, it is also possible that the WorldSID pelvis was loaded through a different load path, perhaps at the rear of the pelvis where the load would not have been picked up by the pubic symphysis load cell.
  - The injury risk predicted by the WorldSID 50M was generally lower than that predicted by the ES-2 apart from the shoulder. For the WorldSID 50M high shoulder loads and deflections were measured and a high risk of AIS2+ shoulder injury was predicted. For the ES-2 relatively low shoulder loads were measured but an injury risk could not be calculated because a shoulder injury risk function was not available for ES-2. It should be noted that injury risk curves for the WorldSID 50M were only available for 1D IR-Tracc measurements.

- Other
  - A potential issue was identified with WorldSID shoulder and RibEye system
    - The shoulder rib middle and forward LEDs deflected out of range of RibEye sensor causing signal dropout during the test.

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Further information on CCIS can be found at http://www.ukccis.org

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