THE DEVELOPMENT OF A EURO NCAP FAR SIDE OCCUPANT TEST AND ASSESSMENT PROCEDURE

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Paper Number 19-0278

ABSTRACT

The European New Car Assessment Programme (Euro NCAP) has been evaluating side impact protection since 1997. The original side impact test procedure utilised the EuroSID anthropometric test device (ATD) and Multi 2000 barrier face. In the year 2000, the side impact assessment was expanded to incorporate the perpendicular pole impact test. Both procedures were upgraded in 2003 to use the ES-2 ATD and Advanced 2000 barrier face in the side barrier impact. The most recent update to the side impact test procedures saw the adoption of the WorldSID 50th male ATD and the Advanced European Mobile Deformable Barrier face (AE-MDB) along with the oblique pole impact in 2015. To date, the adult side impact assessments have focussed on struck-side impact protection with the use of a driver dummy only and two child occupants in the rear.

A number of European research projects have interrogated accident databases to establish the nature and magnitude of the risks to far-side occupants. In 2015, the Euro NCAP Board of Directors agreed that the level of side impact protection offered to drivers and front seat passengers should be improved and the Euro NCAP Side Impact Working Group (SIWG) was tasked with addressing far-side occupant protection. The group was asked to draft an updated far-side impact procedure that could be incorporated into the existing assessment regime without significantly increasing the test burden. The focus of the new procedure is on passengers seated in the front row and will evaluate excursion and contact injury risk. The new assessment is sled based rather than being a full-scale test, allowing for a wider coverage of real-world scenarios and offering a method for the development of countermeasures in the most effective and efficient way.

This paper details the group’s work in the development of a far-side occupant test procedure. The outcome of real-world accident analyses from numerous European databases has been summarised along with a review of existing work already undertaken for far-side occupants. This data allowed for boundary conditions to be established, which were evaluated by the group with the use of physical and CAE testing. The outcome of this research has been used to develop a Euro NCAP assessment procedure for non-struck side front seat occupants.

BACKGROUND

In 2009, Euro NCAP identified that the side impact test procedures should be more reflective of the high number of deaths and seriously injured occupants that are seen on the road [1]. Euro NCAP subsequently updated the front and side impact test procedures in 2015. The changes were aimed at promoting restraint systems that were more advanced and more robust for the driver and all passengers. Further updates to the front and side impact procedures will also be applied in 2020 as front and side crashes will continue to dominate traffic accidents in terms of the killed and seriously injured [2]. Advanced avoidance technologies are emerging that can mitigate typical head-on and crossing scenarios, but the requirements are technically very challenging. Crash protection remains essential and Euro NCAP continues to promote excellent structural and restraint system performance, even where advanced driver assistance systems are offered.

Euro NCAP's overall goal is to incrementally improve the assessment of crash protection so that it can continue to reward those vehicles that provide the best possible protection against serious and fatal injuries. An in-depth analysis of crashes in Europe performed by ADAC for Euro NCAP highlighted several areas where vehicle manufacturers might improve general vehicle design. One key area was the protection of car occupants in far-side crashes. In 2016, Euro NCAP created a group dedicated to developing a far-side test and assessment procedure. The membership of the group consists of Euro NCAP members, official test laboratories and industry representatives from ACEA and CLEPA.

PREVIOUS RESEARCH

The first step taken by the group was to review existing data on far-side impacts. There have been a number of studies published over the years on far-side occupants, yet side impact test procedures and the resulting protection offered by vehicles still focus on the struck-side occupants.

A study performed by Fields et al identified the high risk to far-side occupants from head contacts with vehicle structures on the struck-side [3]. In 2006, the European 6th framework project for Advanced Protection Systems (APROSYS) published a methodology to address non-struck side injuries [4]. This project reviewed real-world far-side crashes that were contained in several accident databases including CCIS, GIDAS and ZEDATU. The accident data indicated that the head and torso suffered AIS3+ injuries three times more frequently than any other body region. As with the study from Fields et al, the side structure, belt/buckle and adjacent occupants were the most injurious hazards. An examination of the impact characteristics indicated that, in most cases, the direction of force was perpendicular to the vehicle centreline. Regarding velocity, in order to address 50% of all non-struck side occupants with MAIS2+ injuries, a delta V of 41km/h would be required. In 2008, the European Enhanced Vehicle-safety Committee (EEVC) Working groups 13 and 21 produced an overview of side impacts using data from the United Kingdom, France, Germany and Sweden [5]. Of all the occupants in single side impacts analysed, 55% of occupants were on the far-side, leaving 45% on the non-struck side. A study of NASS data examined the characteristics of belted occupants with MAIS3+ injuries from far-side impacts [6]. The analysis found that 79% of drivers sustained MAIS3+ injuries with the head and chest being the most commonly injured body regions. The mean impact severity was a lateral delta V of 36km/h. The most frequent impact direction was found to be between 60 and 90 degrees.

ACCIDENT DATA REVIEW

In addition to the accident data in published literature, the group undertook additional analyses of accident data in 2016. The databases used were NASS, GIDAS, Volvo, BAAC, LAB, CCIS and ADAC. Further details of the accident data samples are contained in Appendix I. The databases contained differing injury severity levels, for example, the LAB data was known to contain higher severity impacts compared to GIDAS due a smaller vehicle fleet. As a result, the data was combined to establish general trends rather than specific conditions.

The databases were interrogated for occupants that met the following criteria:
Belted drivers and front seat passengers above the age of 10 years that suffered at least MAIS2+ and MAIS3+ injuries.

Impact conditions

The data showed that for MAIS2+ injuries the impact opponent was another vehicle in 70-86% of cases. Narrow object (pole) impacts were also represented in all databases and this condition was subsequently considered by the group. Figure 1 shows the impact opponent distribution average across all databases.

Although vehicle to vehicle impacts were more prevalent, data from EEVC Working Group 21 report indicated that the significance of pole impacts increases for MAIS3+ injuries and fatalities [5].

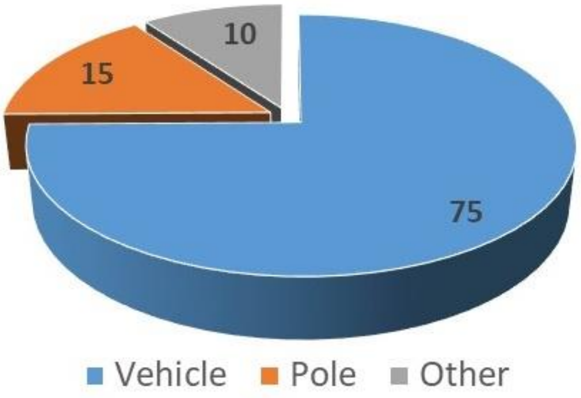


Figure 1: Impact Opponent - MAIS2+ injuries %

The impact location on the target vehicle was mostly on the occupant compartment i.e. the structures rearward of the A-pillar and forward of the C-pillar. This was the case in 64-70% of the impacts across the databases and is shown in Figure 2.

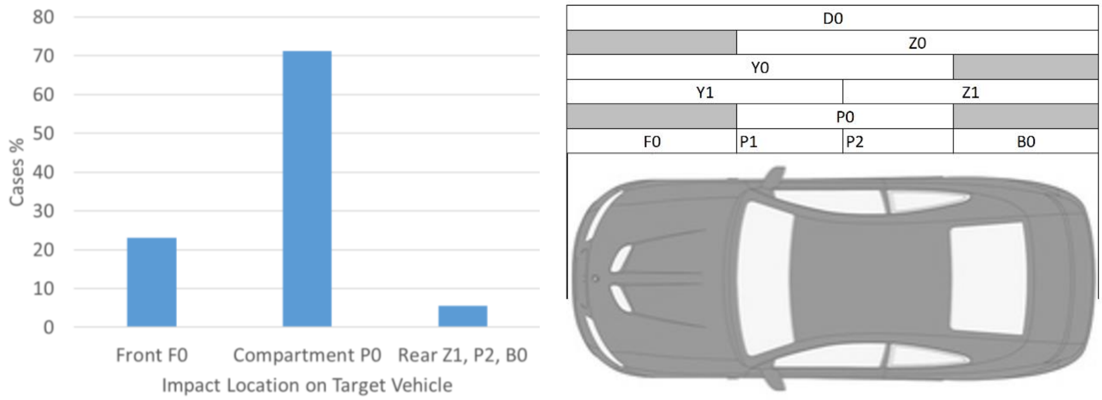


Figure 2: Impact location – MAIS2+ injuries %

Using the clock notation method, impact directions of 5 to 7 o'clock and 11 to 1 o'clock were not considered as side impacts and subsequently excluded. Of the remaining data, the mean impact angles ranged from 71 to 85 degrees. This data was similar to that reported by APROSYS (83 degrees) [2]. The impact angles should be treated with caution due to limits in the accuracy of defining impact angles. The distribution is shown in Figure 3.

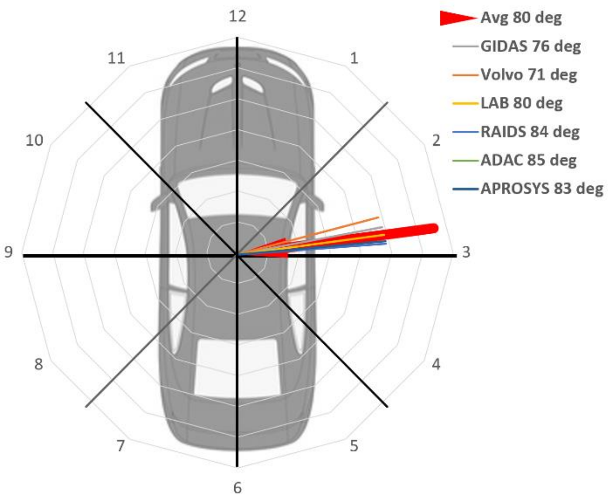


Figure 3: Impact angle

Intrusion levels showed a median level of 190mm for MAIS2+ injuries and 450mm for MAIS3+. As mentioned previously, LAB data contains more severe impacts and smaller vehicles resulting in higher intrusion levels compared to GIDAS data, see Figure 4. ADAC and NASS data indicated similar findings where the intrusion, recorded as a Collision Deformation Classification (CDC) of 3.5, covered between 50-75% MAIS2+ injuries.

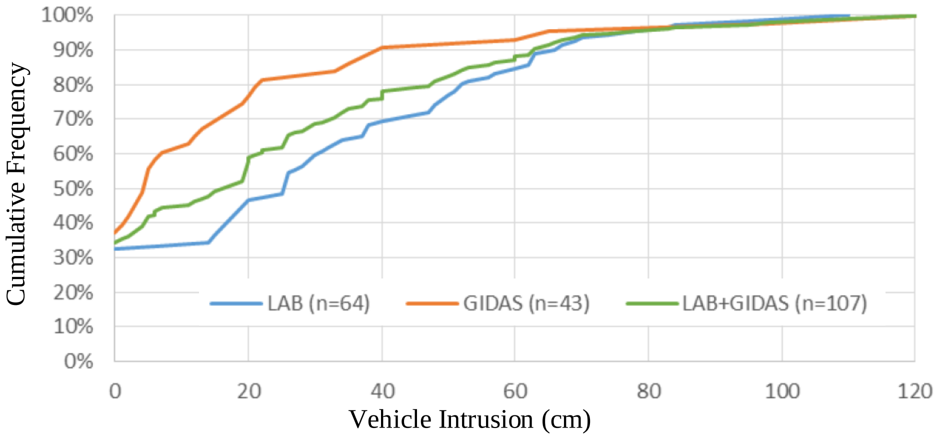


Figure 4: Occupant compartment intrusion MAIS2+

Velocity

There were some discrepancies in delta V between data sets. The accident studies reported a median equivalent energy speed (EES) for MAIS2+ of 37km/h, approximating this to a delta V of 41km/h would cover 37% of LAB data, 84% of GIDAS data and 54% of RAID-CCIS data. As there were eight databases contained in the APROSYS analysis, the report indicated that a delta V of 41km/h would address 40 to 75% of MAIS2+ injuries.

Injuries

Far-side occupants were involved in almost half of the accident cases, the data was broken down further as follows:

Far-Side: Driver, single occupancy

The injured body regions in decreasing frequency were the head, thorax and abdomen. Head injuries were mainly caused by the struck side interior and roof; the thoracic and abdominal injuries were generally caused by the seat belt system and struck side interior.

Far-Side: Driver and front seat passenger occupants

The injured body regions in decreasing frequency were the thorax followed by the head and then the abdomen, a different order to single occupancy. Head injuries were mainly caused by the struck side interior and the other occupant. As with a driver only, the thoracic injuries were caused by the seat belt system and adjacent seat.

It should be noted that the incidences of two front seat occupants were lower than those of single occupant impacts. However, the data did show that when occupant to occupant contact did occur, it was potentially life threatening. A study of NASS-CDS data indicated that in 35% of cases, head injuries were caused as a result of contact with the adjacent occupant, Thomas et al [7]. This research also conducted a sled test with two occupants (ES2-re & Bio-SID) showing that the passenger dummy recorded values multiple times higher than the established head injury criteria as a result of the far-side dummy head impacting the driver's shoulder. Further testing also showed that the head injury risk could be greatly reduced with an airbag that deployed between the occupants.

BOUNDARY CONDITIONS

The findings of the accident analyses were used to establish a set of boundary conditions upon which a test procedure could be based. Two aspects of far-side protection were identified as necessary assessments: head excursion and occupant loading. A sled-based test was chosen over a full-scale test as this offered greater flexibility in the scenarios that could be assessed along with a more cost-efficient means of doing so. Euro NCAP already requires four vehicles to be tested destructively and adding an additional full-scale test would increase the test burden beyond what could reasonably be expected. Adoption of a sled procedure would allow for testing of multiple impact scenarios at an early stage in the vehicle development process.

Angle

As the accident data suggested a range of impact angles, it was decided that, in order to simplify the test set-up, an angle of 75 degrees would be appropriate for both pulses. It is worth noting that although the AE-MDB test is perpendicular, the barrier face design was intended to represent the most frequent impact angle observed in moving car to moving car side impact accidents [13].

Intrusion

Occupant excursion beyond the seat centreline towards the intrusion line represents a significant risk of injury. ADAC estimated that, based on a size study of 291 vehicles in seven size groups, a CDC of 3 is around 450mm of intrusion and in the area of the seat centreline. CDC was considered as an assessment measure, but it was decided that the actual vehicle intrusion recorded in the AE-MDB and pole tests would be used.

Pulse

A delta V of 41km/h would cover the majority of MAIS 2+ cases. Much consideration was given to the shape of pulse, both in terms of the accident situation and relevance in a simplified test/assessment scenario. The initial intention was to use a single generic pulse for the assessment, for example the APROSYS pulse or a combination of AE-MDB and pole impact pulses. After taking into account the variation between the AE-MDB and pole test pulses, it was decided that two vehicle specific pulses would be necessary to account for the range of vehicle masses. The group acknowledged that, depending on the vehicle size or weight, the worst-case scenario could be either the AE-MDB pulse or the pole pulse.

A simple analysis of the vehicles tested by Euro NCAP in 2015 showed that for heavier vehicles, the difference in delta V between the AE-MDB and pole impact pulses is greater than that for smaller vehicles, Figure 5. In general, heavier vehicles have a pole impact pulse that is more severe than that of the AE-MDB impact. For smaller vehicles, this difference is not so marked.

In 2020, the Euro NCAP AE-MDB test speed will increase from 50km/h to 60km/h with a trolley mass increase from 1300kg to 1400kg. An analysis of GIDAS data by BASt indicated that the current AE-MDB test speed of 50km/h only covers 20% of MAIS3+ injuries.

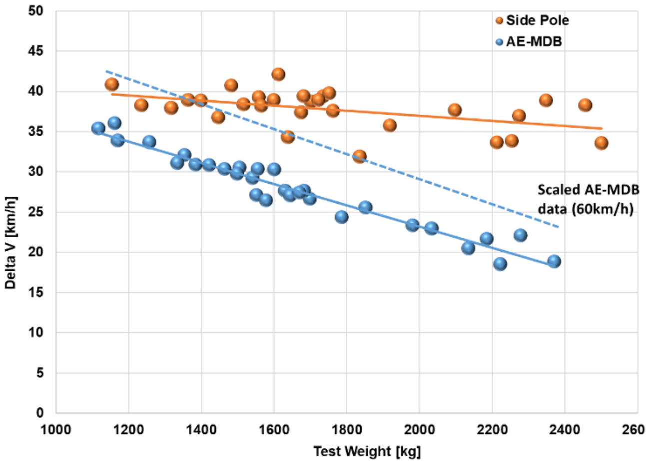


Figure 5: Delta V for vehicles tested in 2015

A speed of 60km/h would be appropriate to cover 50% of MAIS3+ injuries. The trolley mass was increased by only a small amount to be more reflective of the vehicles that Euro NCAP has tested in recent years. ACEA established, with the use of numerical simulations, that to achieve a minimum delta V of 41km/h, the AE-MDB pulse must be scaled up by a factor of 1.255 for small vehicles and 2.096 for large vehicles. For small vehicles, the scaling results in a delta V slightly above that of the pole impact but also closer to the target of 41km/h identified in the accident data. No combination of worst-case factors (e.g. AE-MDB pulse and pole intrusion) would reflect the worst-case for all vehicle sizes. Adoption of a single generic pulse test would require too many compromises that would have questionable relevance to the real-world situation. This made it necessary to consider both the AE-MDB and pole impact pulses for use in the procedure.

The AE-MDB (60km/h) and oblique pole test pulses were chosen for the procedure, Figure 6. Note, the AE-MDB pulse shown is at 50km/h. A scaling factor of 1.035 is applied to both pulses to translate to the 75 degree angle of the sled. It was acknowledged that the shape of the pole impact pulse has less relevance to real-world data compared to the AE-MDB test, but in addition to the pulse and delta V, the intrusion of the target vehicle was identified as an important factor. Higher levels of intrusion were observed in narrow object impacts when compared to vehicle to vehicle impacts. The intrusion from each impact scenario would be applied to the respective test.

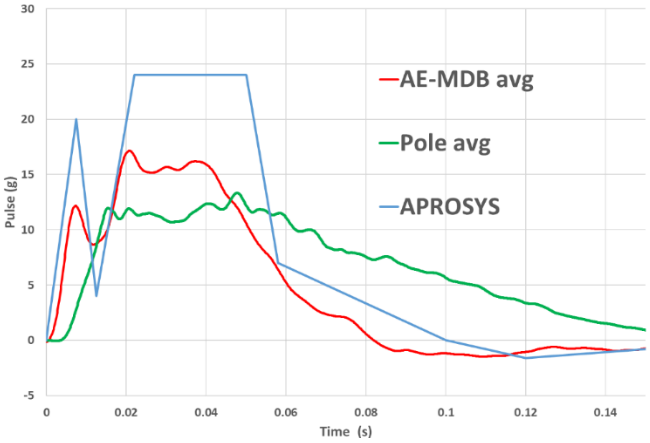


Figure 6: 2015 Average pulses and APROSYS pulse

Occupancy

A greater proportion of single occupants were injured compared to those with an adjacent occupant, 60% to 40%. To limit the complexity of the test setup, a single occupant was chosen for the test. A comparison of five different side impact dummies and post mortem human subjects (PMHS) performed by Fields et al indicated that although all of the dummies had limitations in far-side impacts, the WorldSID 50th male ATD seemed to offer improved performance compared to the others [3]. The work of the SIWG was conducted when availability of the WorldSID 5th female was very limited. The adoption of the WorldSID 50th male by Euro NCAP in 2015 and its availability across the official laboratories meant that this ATD was an obvious choice for the far-side procedure. All further references to WorldSID in this report are to the 50th male stature.

PRELIMINARY SIMULATIONS

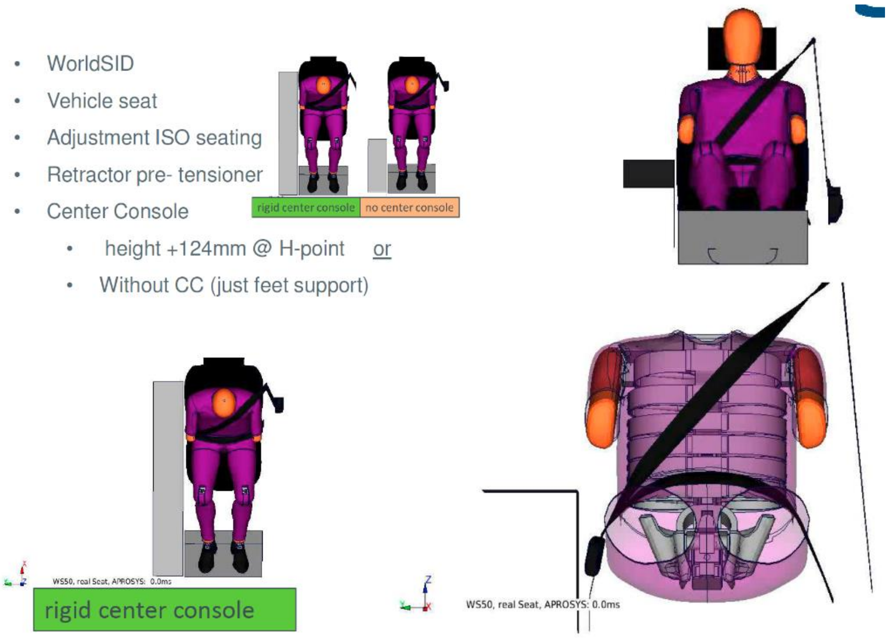
In order to gain a basic understanding of the loading and excursion the WorldSID would be subjected to under the conditions identified by the group, a series of generic sled tests and equivalent simulations were performed. Simulation work began with the sled tests to validate the CAE model. Details of the set-up are contained in Figure

7 and Appendix II. Apart from a small amount of additional excursion in the CAE model compared to the dummy, the simulation of the WorldSID gave an adequate representation of the dummy kinematics. A further series of ten simulations was performed with a combination of the three pulses detailed in Figure 8, two impact angles and different centre consoles (rigid and none) were also used. The configurations used were as follows:

Pulse	**Angle**	**Centre console structure**
APROSYS pulse	90 deg & 80 deg	Rigid & none
Average AE-MDB 2015	90 deg & 80 deg	Rigid & none
Average Pole pulse 2015	75 deg	Rigid & none

The belt pretensioners were fired in all simulations

Figure 7: Sled and CAE



- WorldSID
- Vehicle seat
- Adjustment ISO seating
- Retractor pre- tensioner
- Center Console
  - height +124mm @ H-point or
  - Without CC (just feet support)

Figure 8: Simulation set-up

As this work was only intended to provide a basic level of information of how the WorldSID performed under the aforementioned conditions, the results were limited to the influence of a centre console and an analysis of head excursion. Only a limited amount of information is available in this paper regarding dummy outputs. The APROSYS and pole impact pulses generally have a higher delta V than the AE-MDB at 50km/h, even for smaller vehicles. Where there was no centre console, the head excursion increased in the lateral and downwards directions compared to when a centre console was present. The thorax and abdominal rib deflections were highest with the centre console and higher delta V. However, they were well below the Euro NCAP higher performance limits (28mm and 47mm respectively) and not at a level shown in the accident analyses. Pure belt loading was observed in the cases without a centre console but with low values (<6mm), again well below what was seen in the accident analyses. The impact angle only had a slight influence on the rib deflections.

The evaluations with the generic sled were extended to the human model developed by the Global Human Body Model Consortium (GHBMC). The simulations were limited to the APROSYS pulse only. Results of this work are available in Appendix III and further details can be found in the work of Hallbauer et al [12].

Pulse	Angle	Centre console structure
APROSYS pulse	90 deg & 75 deg	Rigid & none

The belt pretensioners were fired in all simulations

Where the centre console was present the lateral travel of the head, T4 and pelvis was reduced in both the 90 and 75 degree impacts when compared to no centre console. The reductions were small for the head (5-14%) and approximately 31-34% for the pelvis. As was the case for the WorldSID simulations, there was little difference in excursion between the two impact angles. A comparison of the kinematics between the GHBMC and WorldSID models indicated that the dummy model gave slightly more lateral and forwards excursion compared to the human body model. This lower excursion (70mm) can be explained by the stiffer spine in the WorldSID.

One final comparison made between the HBM and WorldSID models was the influence on the kinematics of the outboard elbow joint ‘hooking’ around the diagonal belt. The WorldSID was modelled with the standard half arm assembly only, whereas the HBM had full arms. Where the steering wheel was not modelled, the HBM showed there was hooking on the belt. The HBM simulation was repeated to allow the elbow to pass through the diagonal belt, which gave no difference in the lateral displacement of the head, T4 and pelvis when compared to when the elbow engaged with the belt. This aspect was highlighted as something that should be verified with the use of the WorldSID dummy.

PHYSICAL TESTING

Having established the boundary conditions with the use of accident data, it was then necessary to perform a series of tests to evaluate the feasibility of a sled based approach and to check the correlation between the physical tests and simulations. A supermini was chosen for the series. The vehicle had a low centre console and no far-side protection countermeasures. As the arm to belt interaction was highlighted as an area that should be examined during the physical testing, Transport Canada kindly provided Euro NCAP with the WorldSID full arm. The physical testing performed by the group consisted of two full-scale pole impacts and fourteen sled tests.

Full-scale pole tests

Two full-scale oblique pole tests were performed to establish the delta V for the vehicle and provide a comparison with the APROSYS pulse. The dummy positioning was in line with the Euro NCAP pole impact protocol, i.e. with a WorldSID on the driver’s seat, but the pole impacted the passenger’s side of the vehicle. The standard test speed of 32km/h resulted in a delta V of 38.8km/h. As this was below the target of 41km/h a second oblique pole test was performed at 36km/h giving a delta V of 42.4km/h. A higher test speed was not considered feasible due to the risk of structural failures in the vehicle body.

A comparison of the pulses from the chosen supermini are shown in Figure 9. The data provided is from the 32km/h and 36km/h tests along with APROSYS and the official Euro NCAP pulses recorded in the AE-MDB and oblique pole impacts.

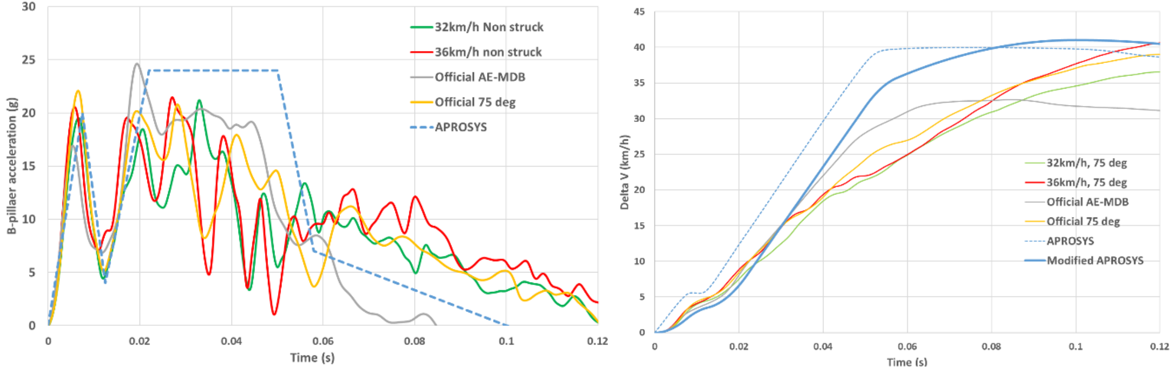


Figure 9: Supermini test vehicle pulses and delta V

The data from the 32km/h test showed all dummy outputs to be well below the WorldSID higher performance thresholds used in the Euro NCAP rating scheme. There was also no contact between the head and vehicle interior. In the 36km/h test, there were no structural issues with the bodyshell but there was a head contact with the far-side door (HIC3305), all other dummy outputs were below the higher performance thresholds, see Figure 10. The reason for the low torso outputs was a high level of rotation preventing the thoracic and abdominal ribs from being loaded in the expected manner. The rotation induced high loading in the neck and lumbar spine (forces and moments). This highlighted the need for both a kinematic and numerical assessment.

Figure 10: Oblique pole impact - 36km/h

Sled tests

Following the full-scale tests, two series of sled tests were performed. The sled tests were to be performed with the APROSYS pulse, which was chosen instead of the vehicle pulse because the intention was to examine the feasibility of the test procedure and not to perform an assessment of the vehicle. However, upon closer examination of the APROSYS pulse, it was discovered that the pulse did not have a delta V of 41km/h, the calculated value being 42.7km/h. As a result, the pulse was modified to match the target delta V of 41km/h. The initial peak of the pulse at 10ms was reduced from 20g to 14g to be more representative of the average peak seen in recent Euro NCAP AE-MDB tests on superminis. The plateau of the peak was also reduced from 24.0g to 23.8g to achieve the target delta V of 41km/h. For the purposes of this paper, this new pulse is termed the ‘modified APROSYS’ pulse and was used in the sled testing along with the 32km/h and 36km/h pulses.

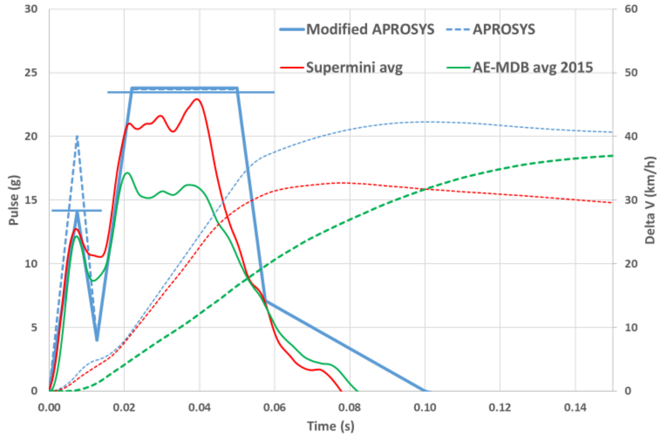


Figure 11: Pulse and delta V comparison

A comparison of pulse and delta V from APROSYS, six superminis in AE-MDB impacts and the average fleet of vehicles assessed by Euro NCAP in 2015 is shown in Figure 11. The pulse is shown on the primary y-axis and delta V on the secondary y-axis.

Test set-up for series 1

Based on the findings of the of the aforementioned publications and discussion of the various practical considerations with sled-based testing, a simplified setup was chosen for the sled tests as follows:

- Vehicle body in white
- No representation of struck-side intruding structures. Simulations showed that peak intrusion occurred before peak head excursion and a static marking would be sufficient.

- Body in white mounted at 75 degrees
- Modified APROSYS pulse & vehicle specific pulses
- One WorldSID 50th male driver, sleeved suit, in the standard pole impact seating position
- Full standard facia assembly including centre tunnel trim
- All first row seats
- The belt pretensioner was not fired in any of the tests as this would not occur in a far-side impact on the road with the vehicle chosen

Lines were marked on the buck to offer a comparison of head excursion. The blue line was placed on the vehicle centreline, yellow line on the struck-side seat centreline and the red line was marked at the location of the maximum static intrusion of the interior trim observed in the 32km/h pole or AE-MDB impact, see Figure 12.

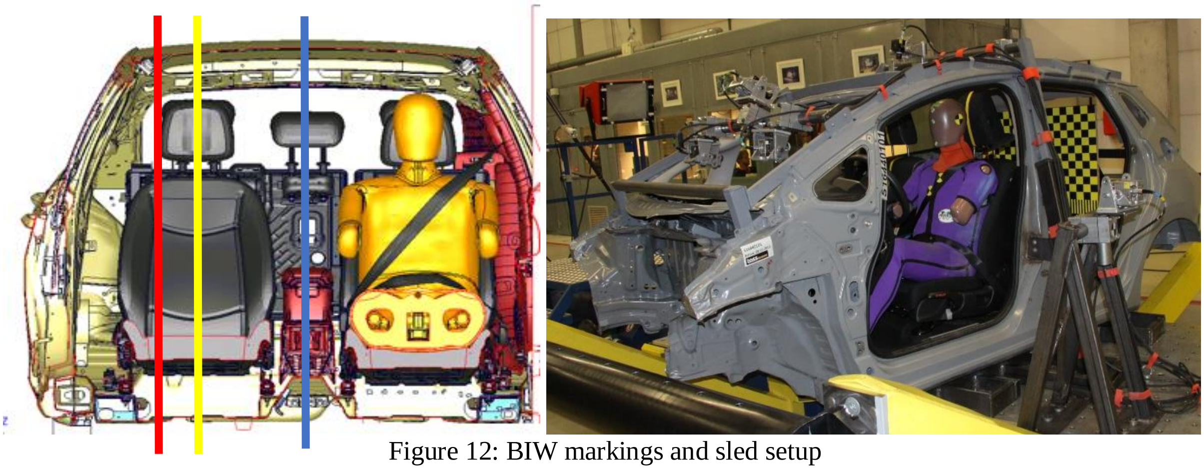


Figure 12: BIW markings and sled setup

Sled test series 1
Repeatability tests
The test matrix detailing the test numbers referenced in this report can be found in Appendix IV. Please note that the test numbers in the images differ from those in the test matrix. The first three sled tests were aimed at establishing repeatability of the sled and dummy setup, tests #1, #2 and #3. The struck-side airbags were fired only in the first test to identify any interaction with the dummy. As no interaction was observed, these airbags were not fired for the remaining sled tests. However, there was a difference observed in the seat kinematics due to the deployment of the side airbag in the first test filling the gap between the seat and vehicle structure.

The peak head excursion in the first test was approximately 50mm lower than of the other two tests and approximately 9ms earlier. This was caused by interaction between the WorldSID shoulder/jacket (with sleeves) and seatbelt, see Figure 13 and Figure 14. The belt slid into the gap between the shoulder and arm for a longer amount of time in the first test and subsequently increased the level of restraint up to the point where the belt began to slide down the dummy arm. It was found that the shoulder pad was incorrectly positioned in the shoulder rib prior to test. However, this interaction occurred in a number of the tests to a greater or lesser extent and was not considered top have influenced the results. In the third test, the interaction was such that the zip on the jacket was pulled open.

It was thought that the interaction would be reduced with the use of the sleeveless WorldSID suit and triggering of the seat belt pretensioner. The sleeveless suit was already implemented in the Euro NCAP AE-MDB and pole tests.

The full table of dummy outputs can be found in Appendix V. The dummy head and shoulder values were comparable and below the existing AE-MDB higher performance limits (HPL). In test #1, where the belt interaction was greatest, the thoracic rib deflections (TR) were all relatively low. In test #2 and #3, only one rib was close to the higher performance limit. In test #2, this was TR2 and in test #3 TR3, the difference being dependent on how the dummy was aligned with the loading structures (belt and/or centre console). All other dummy parameters were comparable and well below the HPL.

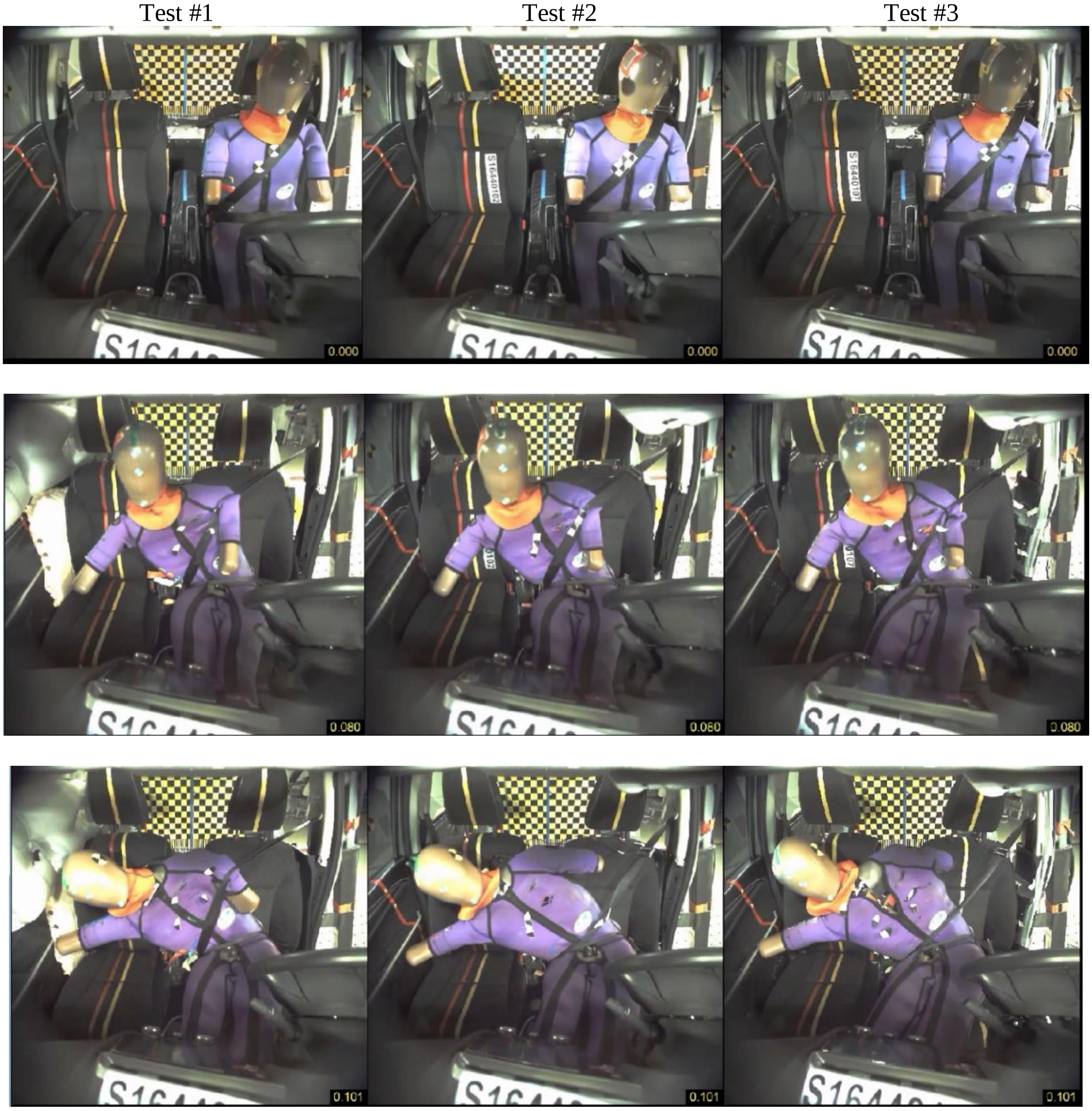


Figure 13: Repeatability test - belt interaction

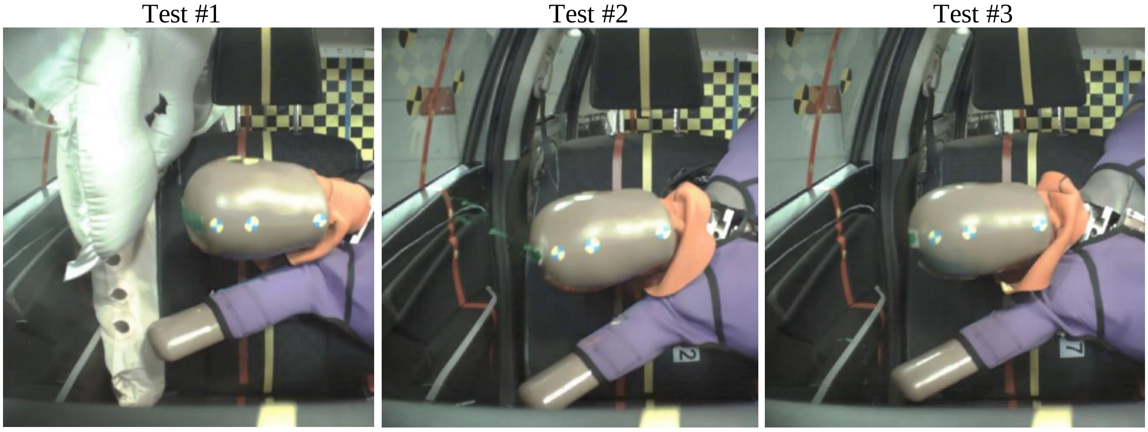


Figure 14: Repeatability test - max head excursion

WorldSID full arm, test #4

The second of the repeatability tests (#2) was chosen as the best baseline scenario for comparison with other tests due to the least amount of shoulder/belt interaction. A test was performed with the prototype full arm assembly attached to the driver's outboard arm, #4. It was used to provide a comparison with the HBM simulations that suggested the elbow hooking on the diagonal belt would not have a significant influence on the results. Having observed the shoulder to belt interaction in the first tests, the full arm tests were subsequently performed with a modified shoulder pad from the THOR dummy to limit the likelihood of the belt sliding into the shoulder gap. The full arm assembly and shoulder pad are shown in Figure 15.

Although the addition of the shoulder pad prevented the belt from interacting with the shoulder, the belt was caught by the top of the bicep resulting in a higher level of restraint than occurred with the half arm assembly. The bicep of the full arm has a flat upper surface and is of a different shape to that of the half arm assembly. This led to approximately 40mm less excursion with the full arm, see Figure 16. The torso and pelvis were unaffected by the different engagement. It was suspected that the arm hooked on the shoulder belt but a direct comparison of the kinematics with the HBM simulations could not be made due to the different belt interaction. Given the status and availability of the full arm, implementation into a test protocol was not realistic. The full arm was subsequently given no further consideration for use the test protocol. The dummy outputs are detailed Appendix V, but this part of the work focussed on the kinematic differences observed with the full arm.

Figure 15: WorldSID full arm and THOR shoulder pad

Test #2 Test #4

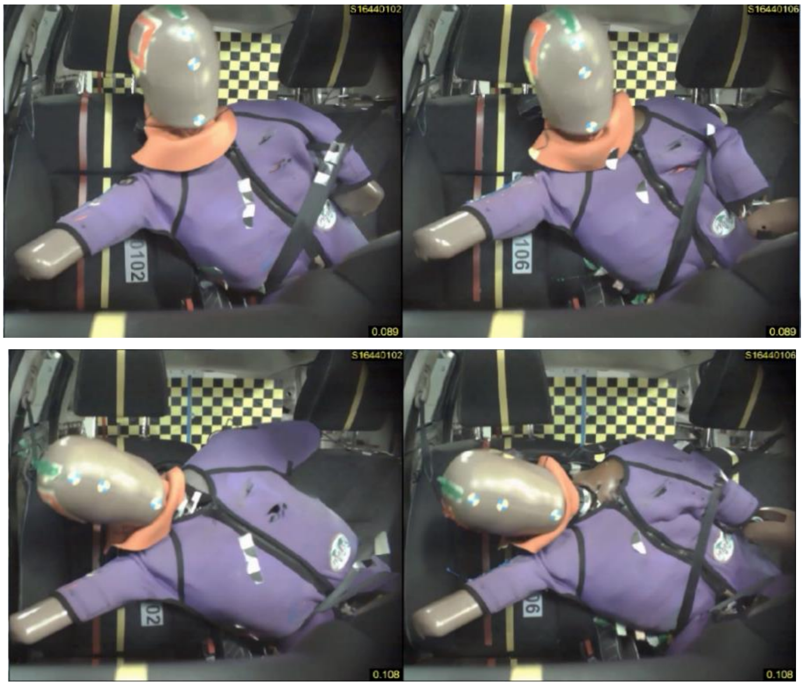


Figure 16: Half arm and full arm belt interaction - max excursion

Large centre console, test #5

Previous research indicated that the WorldSID might be suitable for use in far-side impacts [1]. A test was performed with a high centre console to see how well the dummy could detect the presence of such structures. A structure was fabricated out of stiff foam covered with sheet metal that was 180mm above the dummy H-point and approximately 60mm taller than the standard console. As expected, the presence of the large center console reduced the lateral head excursion by approximately 115mm, but also resulted in 42% greater neck My loading. The additional neck loading was caused by further rotation of the head. The outboard arm rotated rearwards around its fixing and contacted the head after the time of peak excursion. Although this was not detrimental to the kinematics or dummy outputs, the performance was not biofidelic. The torso loading was focused on the abdominal ribs (AR): AR 1, 46mm and AR2, 31mm, posing an additional risk of abdominal injury. The test with the standard console had maximum loading in the thoracic ribs, (TR): TR2 28mm and TR3 14mm. See Figure 17.

Test #2 Test #5

Figure 17: With and without centre console max excursion

Vehicle pulse tests #6 & #7
Two sled tests were performed with vehicle specific pulses (#6 & #7) obtained from the two full-scale pole tests at 36km/h and 32km/h. Tests #6 and #7 were compared with the modified APROSYS pulse (#2). The characteristics of the pulses and delta V is shown in Figure 9. Although the delta V of the 36km/h test was similar to that of the modified APROSYS pulse (41km/h), the profile was different.

When comparing the 36km/h pulse (#6) with the modified APROSYS pulse (#2), the more severe modified pulse between 25ms and 120ms led to an earlier max head excursion (118ms vs 135ms). However, the maximum excursion was approximately 20mm greater with the vehicle pulse. The thoracic rib loading was higher in the 36km/h pulse compared to the modified pulse, whereas the abdominal ribs were higher in the modified pulse. However, the only limit that was exceeded was TR3 in the 36km/h pulse, being 128% of the HPL. See Figure 18.

The pulse characteristic of the modified APROSYS pulse (#2) was significantly different to that of the 32km/h vehicle pulse (#7), with a delta V of 41km/h vs 38km/h. As mentioned above, the initial phase of the test influenced the dummy kinematics in a similar way. Due to the lower severity, the head excursion in the 32km/h tests was 20mm below that of the modified pulse. None of the HPL were exceeded in the 32km/h test.


Test # 2 Test #6 Test #7

Figure 18: Modified APROSYS pulse vs 36km/h pulse vs 32km/h pulse - max head excursion

Comparing the tests using the two vehicle specific pulses (#6 & #7) shows a higher head excursion in the 36km/h pulse of approximately 40mm. This was to be expected given the higher delta V. The dummy thoracic loading showed a slight difference between these tests; in test #7 TR2 was highest, whereas in test #6, TR3 was highest. There was visibly more bending of the torso in test #6. Only the compression from TR3 in test #6 exceeded the HPL (128%). The abdominal loadings were all below 33% of the HPL. It is worth reaffirming that the intrusion line in both of these tests was based on the 32km/h test; in a 36km/h impact there would be approximately 70mm of additional intrusion.

The final comparison made was between the two vehicle specific sled pulses and the respective full-scale pole test. Unfortunately, the onboard cameras on the 32km/h full-scale pole tests failed so no detailed comparison of the dummy kinematics could be made. As there was no intrusion simulated in the sled tests, the kinematics differed to those of the full-scale test after the head contacted the intruding door in the full-scale test at 36km/h, see Figure 19. The head acceleration trace shows that although the curtain airbag deployed in the full-scale tests, it was not able to prevent the head from contacting the top of the door panel at approximately 115ms. Up to that point, there were only slight kinematic differences found in the head rotation between the full-scale and sled tests. There was no head contact with the intruding door in the 32km/h test. Replication of the pole intrusion was out of the test scope for this first series of testing. As the intention was to evaluate the feasibility of a sled procedure, reproducing intrusion was considered an unnecessary complication.

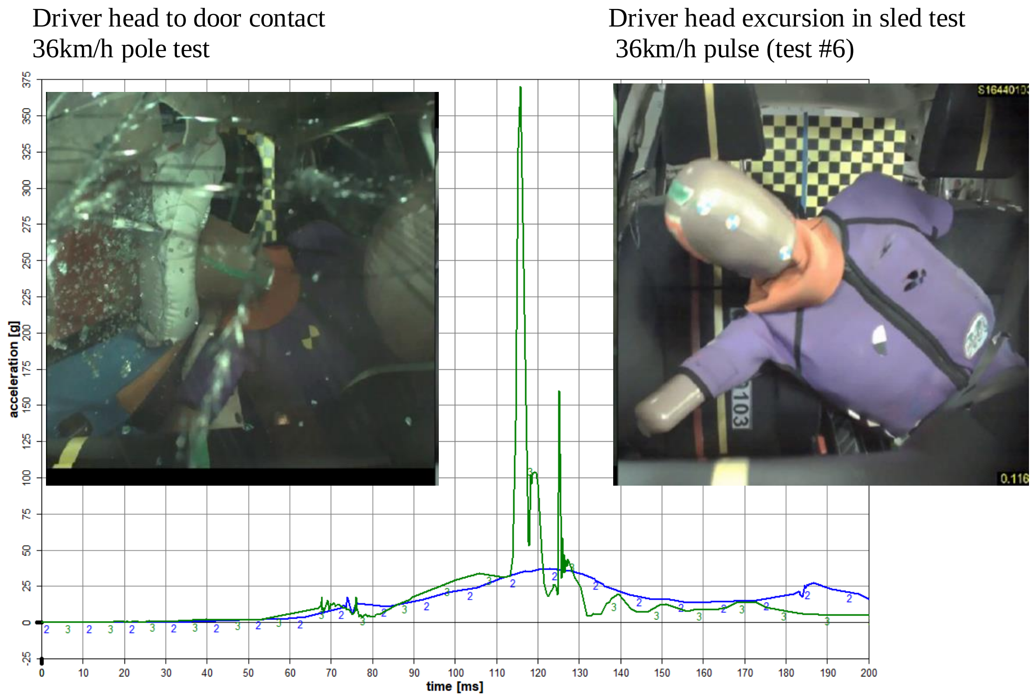


Figure 19: Driver head resultant accelerations - sled and full-scale test comparison

Summary of sled test series 1

In the full-scale tests the deploying struck-side airbag bridged the gap between the seat and intruding vehicle structure. This bridging effect was not replicated in the first series of tests, but it was thought that supporting the seat with foam spacers would offer a simplified way of simulating the presence of the airbag.

The influence of the full arm was not considered significant enough to require the full arm to be used in all sled tests. The THOR shoulder pad could not prevent belt interaction with the upper arm and a subsequent reduction in head excursion. Unfortunately, the effect of the elbow hooking on the diagonal belt could not be fully established or compared directly with the HBM data due to an incorrect test setup.

The baseline tests (#1, #2 & #3) were all influenced by shoulder to belt interaction. The greater the interaction, the smaller the excursion and the spread of max head excursion was approximately 80mm across the three tests. It was thought that this interaction could be reduced with the use of the sleeveless suit and the deployment of the belt pretensioner.

The fabrication of a large centre console resulted in head to arm contact and increased neck loading. The arm kinematics were not representative of a human. The large centre console did reduce lateral excursion by approximately 115mm, although it introduced an additional risk of abdominal injury. However, none of the HPL were exceeded.

Three different pulses were used in the first test series: 32km/h and 36km/h vehicle specific pole impact pulses and the generic modified APROSYS pulse. The 36km/h pulse and modified pulse had a similar delta V of approximately 41km/h and the 32km/h pulse had a delta V of approximately 37km/h. Delta V was not the only factor influencing occupant kinematics, the shape and duration of the pulses also having a significant effect.

Almost all of the dummy outputs resulted in readings below the established higher performance limits. The head excursion in all tests was beyond the (red) intrusion line and the seat centreline.

Sled test series 2

The outcome of the first seven sled tests was used to plan the second series of seven sled test series. Again, the modified APROSYS pulse was used along with the vehicle specific pulses. The test matrix detailing the variables is in Appendix VI and a table of dummy outputs can be found in Appendix VII. It should be noted that the camera locations differ slightly between the two series of tests and the lines superimposed on the images differ from the seat centreline due to movement of the seat during the tests.

The considerations for the second series tests were:

Sleeveless suit (all series 2 tests)
Belt pretensioning
Near-side seat support
Large centre console
Spacers between seat and vehicle structure

Sleeveless suit, test #8

The first test performed in series 2 (test #8) was a repetition of the repeatability tests with the use of the sleeveless WorldSID suit, test #1. There was no interaction between the belt and sleeveless suit, the more close fitting sleeveless suit had less material which prevented the bunching of material that was observed with the sleeved suit, see Figure 20. The maximum head excursion was approximately 80mm greater with the sleeveless suit.

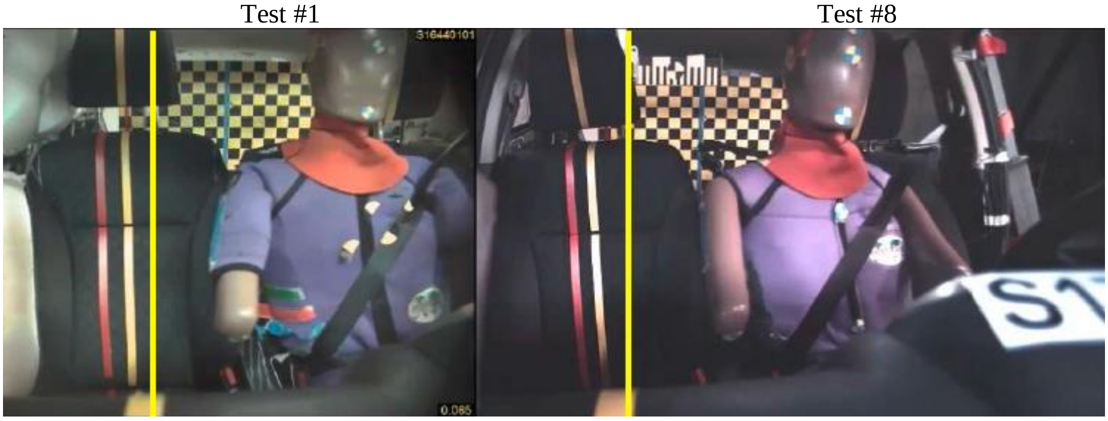

Test #1
Test #8

Figure 20: Sleeved vs sleeveless WorldSID suit – belt to shoulder interaction

Pretensioners, test #9

Test #9 was similar to that of test #8 but the belt pretensioner was fired. Unfortunately, the analysis of the pretensioner effects was hindered by a different arm adjustment and a different upper belt anchorage position prior to test. In test #9, the arms were set closer to the torso and the belt anchorage lower than in test #8. The lower anchorage increased the shoulder rearward movement up to 50ms and resulted in less interaction with the arm below the shoulder joint, see Figure 21. The pretensioning limited the rotation of the torso and pelvis, leading to a shift from the even TR2/TR3 load distribution of test #8 to a higher load on TR2.

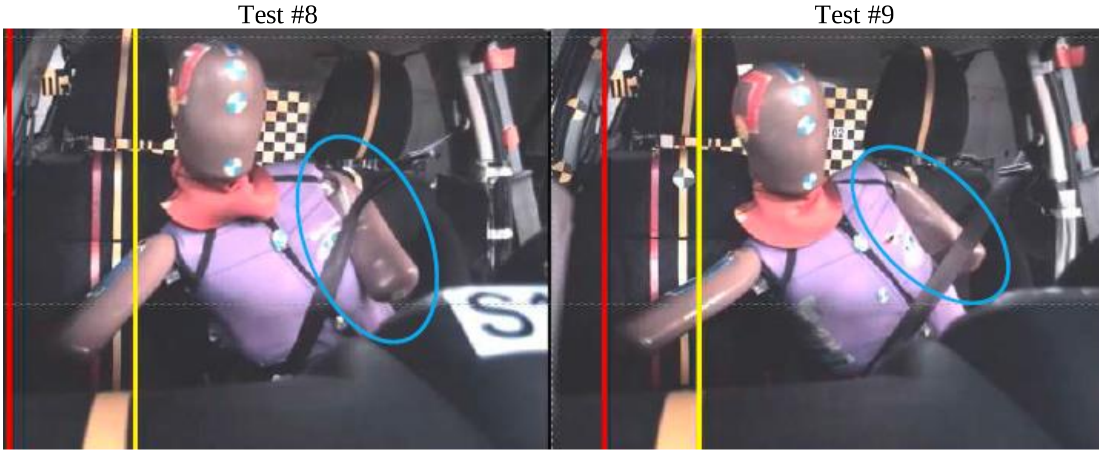

Test #8
Test #9

Figure 21: With and without pretensioning – belt to arm interaction

Spacers, test #10

The movement of the seats due to airbag deployment and, in the real-world, intrusion was identified in series 1. The seat was seen to move inboard, bridging the gap to the centre console. In order to replicate this, a test (#10) was performed with stiff foam spacers bridging the gaps on both sides of the unoccupied seat. The belt pretensioner was fired meaning a comparison with test #9 was necessary. Bearing in mind the incorrect setting of the dummy arms and belt anchorage in test #9, a comparison was made of tests with and without spacers. There was slightly more torso rotation without the spacers (with higher belt anchorage position) but only a small difference in max head excursion (20mm). The neck loading was uninfluenced but there were slightly higher lumbar moments (Mx) and lower torso rotation. It was thought that the spacers supported the centre console as it was loaded by the dummy.

Test #9 Test #10

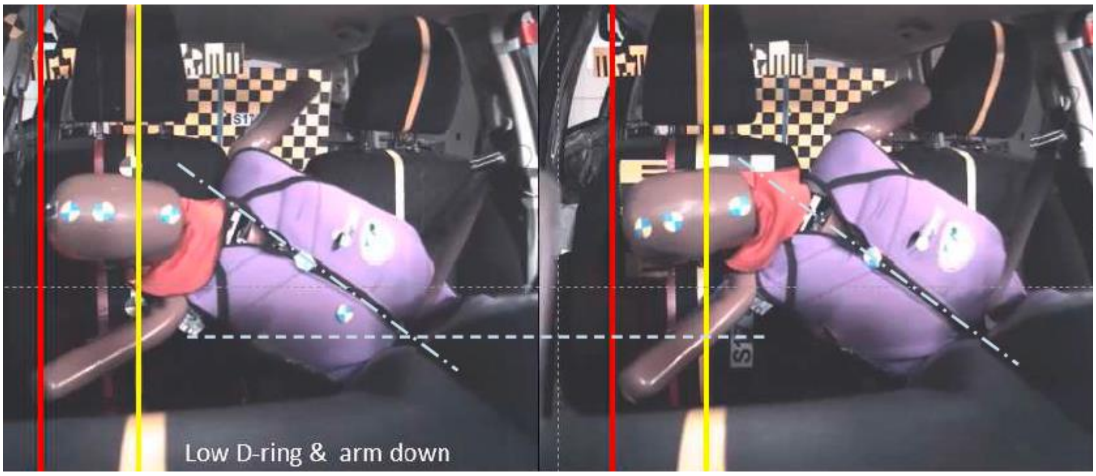


Figure 22: With and without spacers – max head excursion

Pretensioning and spacers, test #8 & #10

A comparison of test #8 and #10 was made to examine the influence of pretensioning and spacers. Without the spacers the centre console was seen to move laterally from about 42ms. With pretensioning and the addition of the spacers the max head excursion was reduced by approximately 20mm. The rib loading shifted from TR2 and TR3, to TR3 with AR2 loading significantly reduced, lumbar My increased by about 44%.

Test #8 Test #10

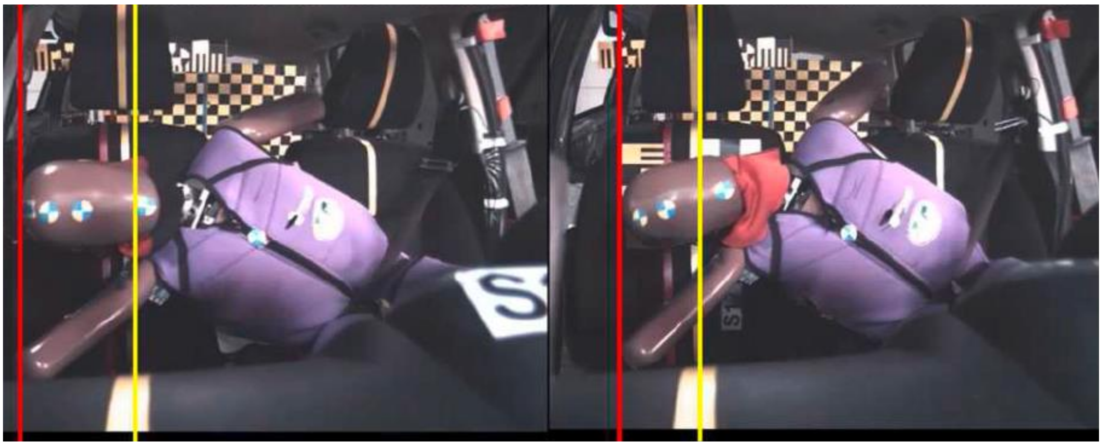


Figure 23: With and without pretension and spacers – max head excursion

Large centre console, test #11
As was the case in series 1, the presence of a large centre console was examined. The outcome was similar to that of the first series where the lateral head excursion was reduced and the abdominal rib loading increased, but still below the higher performance criteria, See Figure 24.

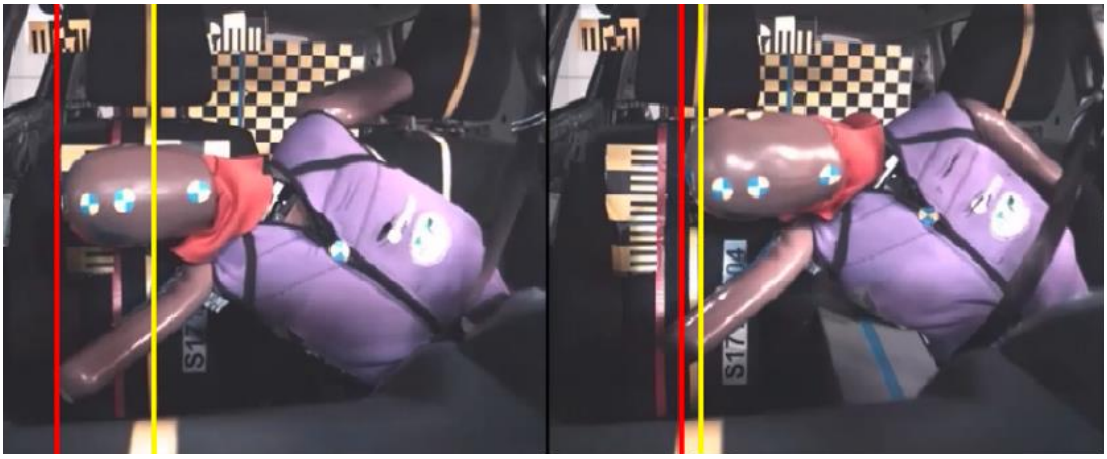

Test #10 Test #11

Figure 24: With and without large console – max head excursion

The presence of the centre console was compared between the test from series 1 (no pretensioning and sleeved suit) and series 2 (with pretensioning and spacers). The dummy outputs were very similar as was the max head excursion. See Figure 25.


Test #5 Test #11

Figure 25: With and without sleeveless suit pretension and spacers – max head excursion

Pretensioning, spacers and jacket
The pretensioning, spacer and jacket effects were compared using the vehicle specific pulses at 32km/h (Figure 26) and 36km/h (Figure 27). These comparisons gave similar results to those above (#8 and #10) with the modified APROSYS pulse. There was slightly lower lateral head excursion and some Z axis rotation in the test with pretensioning, spacers and sleeveless suit. There was no significant influence on the dummy outputs. The greatest head excursion and dummy outputs were seen in the 36km/h tests followed by the modified APROSYS pulse and then the 32km/h pulse.


Test #7 Test #12

Figure 26: With and without sleeveless suit pretension and spacers – max head excursion


Test #6 Test #14

Figure 27: With and without sleeveless suit pretension and spacers – max head excursion

Vehicle specific pulses, #12, #13 & #14
The presence of the large centre console was evaluated with the vehicle specific 32km/h pulse. The findings of this comparison were similar to those of the previous comparison with tests #10 and #11 that used the modified APROSYS pulse, see Figure 28.

The final comparison was between the two vehicle specific pulses at 32km/h and 36km/h. As expected, the higher pulse gave more lateral head excursion (50mm) and a shift of loading from the TR2 to TR3. The other dummy outputs were comparable.

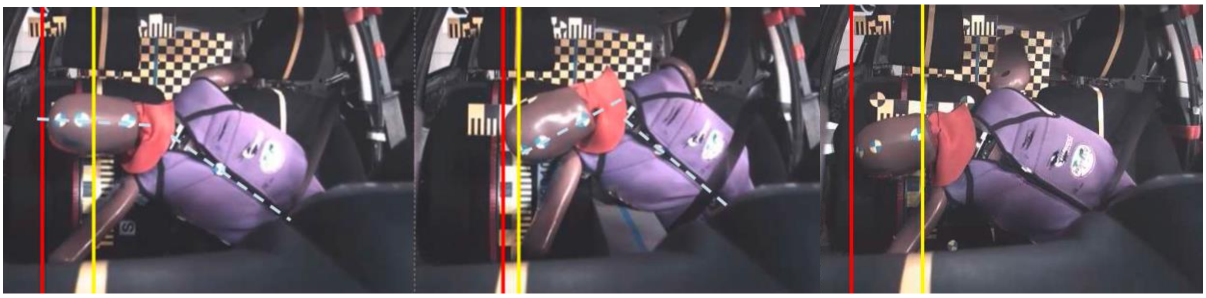

Test #12 Test #13 Test #14

Figure 28: With and without large console

Summary of series 2

One of the major issues highlighted in series 1 was the interaction between the shoulder belt and sleeved WorldSID dummy jacket. This interaction was successfully reduced by the adoption of the sleeveless jacket and pretensioning of the belt. There were no instances of shoulder to belt interaction observed in series 2.

The effect of ‘spacers’ between the B-pillar, seat and centre console was examined. Spacers were added to replicate the effects of intrusion during an impact that closes the gap between the vehicle and seat. This was achieved in the undeformed sled setup, albeit in a simplified manner, by fitting rigid foam blocks to support the seat frame with the surrounding structures. The dummy outputs were seen to increase slightly in the neck and lumbar body regions, but it was thought that the effect of deformation must be represented in vehicle between the struck-side seat and BIW. The spacers also help to limit the movement of the centre console. It was not necessary to trigger seat mounted side airbags as their influence on bridging the gap between the vehicle and seat would be represented by the spacers. In the event that there is a far-side occupant countermeasure, e.g. larger side airbags, then this can be accommodated by the test procedure.

The modified APROSYS pulse and 36km/h pole impact pulses had similar delta Vs, both higher than that of the 32km/h pulse. However, it was not just a higher delta V that resulted in greater head excursion and dummy readings. The shape of the pulse can also determine the amount of dummy loading. The dummy readings from the modified APROSYS test were higher than both of the vehicle specific pulses, for which the results were similar.

The greatest influence on the lateral head (top) excursion was due to the presence of the large centre console, which was present in tests #11 & #13. This reduced the excursion in these two tests to approximately 0.65m, whereas the excursion in all other tests (with standard centre console) was 0.77m to 0.86m. See Figure 29.

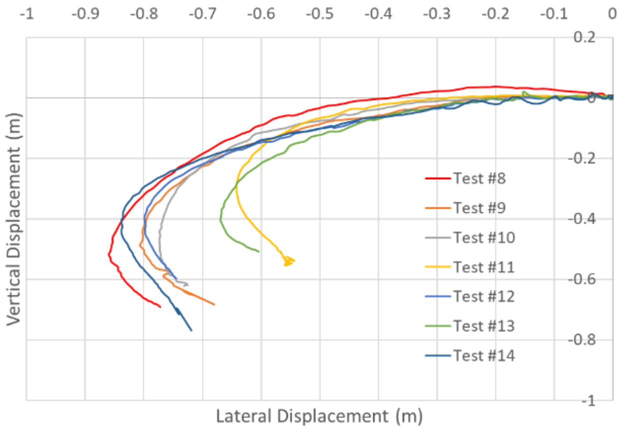


Figure 29: Series 2 head top film tracking

DUMMY DURABILITY ISSUES

One of the first issues highlighted in the sled tests was the WorldSID jacket being cut above the outboard abdominal ribs. As the dummy moved inboard and slid beneath the seatbelt, the upper edge of the first thoracic rib cut through the suit. The damage to the jacket did not influence results in any of the sled tests. Solutions to this damage were discussed with a dummy manufacturer. Enlarged and reinforced Kevlar patches on the inside and outside of the jacket were thought capable of preventing such suit damage.

Under certain conditions, the sternum plate holes have been known to tear at the shoulder rib connection. It is assumed that this component was originally designed for compression loading only (near-side testing) and the far-side testing subjects it to tensile loading. The holes for the shoulder rib, the only area where damage has been found, were closer to the material edge than the other ribs, increasing the likelihood of failure. A modified sternum plate has been developed with additional material outboard of the holes along with a fabric overlay, either as additional strengthening or an interim solution, that strengthens the sternum plate holes under tensile loading but has no influence on the compressive stiffness. It is believed that this issue has been presented to the ISO group. See Figure 30.

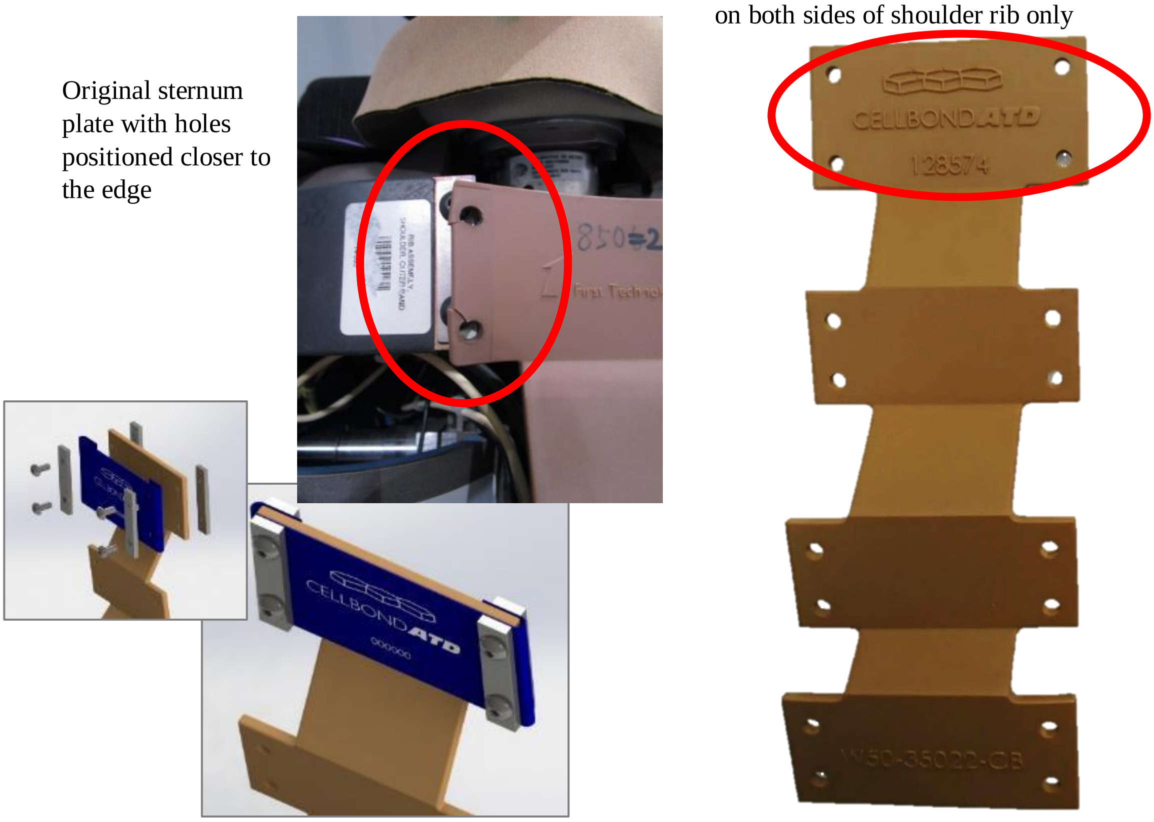


Figure 30: Sternum modifications

The WorldSID arm kinematics observed in some of the tests was not biofidelic. The use of the full arm was not thought necessary and, given the prototype status, cannot be implemented in the far-side procedure in the foreseeable future. It was necessary to continue drafting the procedure with the half arm assembly, even though its biofidelity is limited. Care should also be taken to ensure that ATDs with umbilicals have their cables routed in a way that does not influence the movement of the dummy and limits interaction between the cables and vehicle interior.

The far-side testing appears to be applying greater loads to the WorldSID lumbar spine than the near-side testing. An investigation by JAMA highlighted an incidence where the lumbar spine mount contacted the abdominal rib, resulting in a spike in the lumbar traces. The abdominal rib has also been known to contact the pelvis flesh. It should be noted that no such occurrences were identified in the SIWG tests or the 2018 assessments from Euro NCAP. The lumbar rubber is not a certified component and may not lend itself to a reliable certification test. At this stage, it is questionable as to how much of an influence this may have on the head excursion, particularly where a vehicle offers good control of the dummy kinematics by limiting the inboard movement. The relevance and need for a test will be examined in the future along with how such a corridor might be established.

ASSESSMENT CRITERIA

Euro NCAP has highlighted the protection of far-side occupants as an area of vehicle design that should be improved. The objective of the assessment is to reward vehicles that offer control of occupant kinematics, thus limiting head and torso excursion and reducing the risk of contacts with the struck-side interior and other occupants. Euro NCAP would like to encourage countermeasures that have been specifically designed for far-side impact scenarios which would prevent occupant to occupant contact while also ensuring that there are no additional risks presented to the occupants. The assessment of far-side protection focuses on two areas, dummy head excursion and evaluation of the dummy outputs. The accident data indicated that reduced lateral excursion of the occupant potentially reduces interaction with the vehicle and subsequently reduces the risk of injury not just to the head, but also the torso [8] [9].

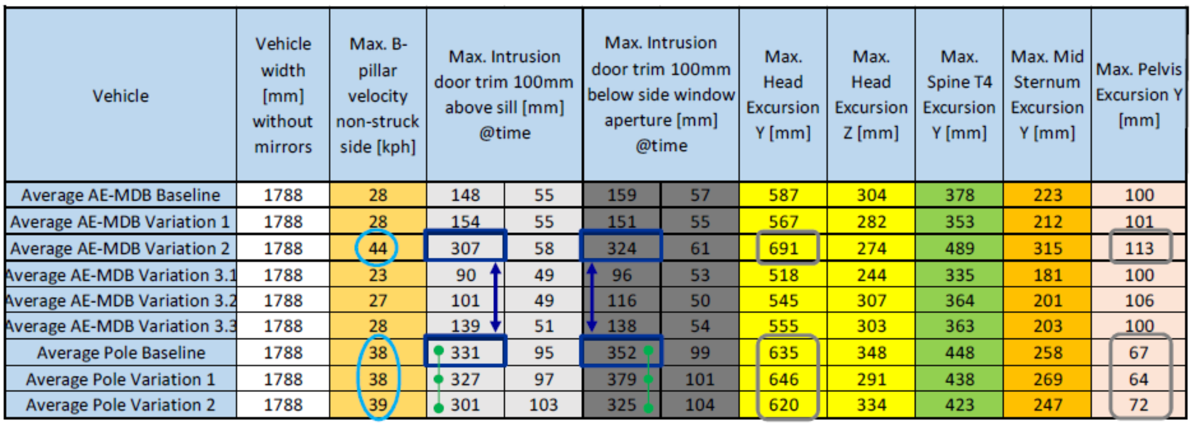
Excursion lines were established at the location of peak vehicle intrusion and the seat centreline. The position of the intrusion line would be based upon that seen in the official Euro NCAP test, or an equivalent in-house test if testing is performed early in the vehicle development. Where an in-house test is used, the pulses and intrusion will be cross checked with the official Euro NCAP tests. The intrusion is measured at the most inboard point of the vehicle interior. As mentioned previously, peak intrusion occurs before the maximum head excursion, so there was no need to reproduce the dynamic intrusion in the test procedure, see Table 1.

An occupant to occupant interaction limit was specified at the inboard edge of the far-side seat. This area of interaction was identified in a series of numerical simulations performed by ACEA, AE-MDB tests with two occupants showed head to shoulder contact in this region. The simulation showed there was significantly more rebound of the driver in the pole impact scenario compared to the AE-MDB.

The simulations were performed with the WorldSID model and were based on a number of the vehicles tested by Euro NCAP in 2015. The head contacts were mostly on the door trim (armrest) and therefore too low to be covered by the curtain airbag.

- 2 Small family cars
- 1 Supermini
- 1 Large Family Car
- 2 Small MPVs

Table 1: Vehicle simulations



Vehicle	Vehicle width [mm] without mirrors	Max. B-pillar velocity non-struck side [kph]	Max. Intrusion door trim 100mm above sill [mm] @time		Max. Intrusion door trim 100mm below side window aperture [mm] @time		Max. Head Excursion Y [mm]	Max. Head Excursion Z [mm]	Max. Spine T4 Excursion Y [mm]	Max. Mid Sternum Excursion Y [mm]	Max. Pelvis Excursion Y [mm]
Average AE-MDB Baseline	1788	28	148	55	159	57	587	304	378	223	100
Average AE-MDB Variation 1	1788	28	154	55	151	55	567	282	353	212	101
Average AE-MDB Variation 2	1788	44	307	58	324	61	691	274	489	315	113
Average AE-MDB Variation 3.1	1788	23	90	49	96	53	518	244	335	181	100
Average AE-MDB Variation 3.2	1788	27	101	49	116	50	545	307	364	201	106
Average AE-MDB Variation 3.3	1788	28	139	51	138	54	555	303	363	203	100
Average Pole Baseline	1788	38	331	95	352	99	635	348	448	258	67
Average Pole Variation 1	1788	38	327	97	379	101	646	291	438	269	64
Average Pole Variation 2	1788	39	301	103	325	104	620	334	423	247	72

The other part of the far-side assessment is dummy criteria. Existing criteria were adopted where possible, e.g. the head, rib compression, pubic symphysis etc, but additional criteria were also included. Some criteria for brain injury risk are also being monitored for possible future adoption. The thoracic rib compression limit of 28mm is based on the skeletal risk, whereas abdominal rib compression (47mm) is based on the soft tissue risk. Nevertheless, even with the presence of a large, ‘rigid’ centre console the maximum abdominal rib compression in the two series of tests was 45mm.

The accident data showed cases of cervical spine injury, Forman et al [10]. GIDAS data also showed that impacts with a lower delta V (16 & 34km/h) than the target of 41km/h can result in C2 vertebrae fractures (AIS 3). Unfortunately, biomechanical criteria for the neck and lumbar regions is limited, so the decision was taken to specify pragmatic limits that prevent unreasonably high values. As there is no WorldSID transfer function for neck tension (Fz) and little reliable data for moments, the limits were adopted as pass/fail criteria only. This was also the case for the lumbar, where data showed disc breaking in the region of 2.84kN [11].

A rating was developed based upon three body regions with four points being awarded to each body region, a maximum of 12 points is available for each impact scenario, see Table 2. A penalty is applied to the overall score of a test where the lumbar loads exceed the prescribed limit. The head excursion assessment is then applied to the dummy score of each scenario. Where the head passes the seat centreline, zero points are awarded for the head, and if it passes the intrusion line, no points will be awarded for that scenario. Finally, where the occupant interaction line is passed, the score for that scenario will be halved. The scores for each scenario are then combined and scaled down from 24 points to four.

Further details of the assessment are contained in the Euro NCAP Far-Side Test and Assessment Protocol v1.1.

Table 2: Assessment criteria

	Criteria	**Performance limits**			**Points**
		Higher	**Lower**	**Capping**	
Head	HIC_{15} (with hard contact)	500	700	700	4 points
	Resultant 3ms acceleration	72g	80g	80g	
	SUFEHM/BrIC	monitoring			
Neck	Tension Fz		3.74kN		4 points
	Lateral flexion MxOC		50Nm		
	Extension negative MyOC		50Nm		
Chest & Abdomen	Chest lateral compression	28mm	50mm	50mm	4 points
	Abdomen lateral compression	47mm	65mm	65mm	
Pelvis & Lumbar	Pubic symphysis	2.8kN			-4 points
	Lumbar Fy	2.0kN			
	Lumbar Fz	2.84kN			
	Lumbar Mx	100Nm			

2018 RESULTS

It was initially planned for the far-side assessment to be implemented in 2018. However, as the development of the procedure took longer than anticipated this was delayed until 2020. A draft protocol was made available in 2017, with 2018 and 2019 designated as a period of monitoring and protocol ‘fine tuning’. During the monitoring phase, far-side data was required by Euro NCAP but not considered in the vehicle rating.

In 2018, a total of 20 vehicles were assessed by Euro NCAP and it is worth noting that none of these vehicles were superminis. Vehicle manufacturers provided sled data with vehicle specific pulses for AE-MDB (60km/h) and oblique pole impacts. Two vehicles were not equipped with side curtain airbags and were not subjected to the pole tests, so no far-side data was provided for these vehicles.

In all cases, the peak head excursion was beyond the occupant interaction limit. In four cases, the head exceeded the seat centreline; in a further three cases the head excursion exceeded the intrusion line. Head excursion was higher in the pole impact for 13 of the cars, and in the AE-MDB for three. In the remaining cases the excursion was so similar an accurate determination could not be made. In many cases, although the excursion was deemed highest in the pole test, there was not a large difference compared to that observed in the AE-MDB test. There were no hard contacts with any part of the vehicle interior or any notable interaction with the far-side seat, as was to be expected given that intrusion was not replicated.

In three of the tests the thoracic rib higher performance limit (28mm) was exceeded, all on the lower rib. One of these tests was the AE-MDB pulse and the remaining two were pole pulses, the largest value recorded being

31mm. The soft tissue abdominal rib HPL (47mm) was not exceeded in any of the tests. Application of the skeletal risk limit (28mm) would result in only three tests above this limit (max 31mm).

The neck Mx limit was exceeded in 12 tests; the My limit was exceeded in one test only. The lumbar Fz limit was exceeded in one test, Fz and Mz were exceeded in five and four of the tests respectively. As mentioned previously, biomechanical criteria for the neck and lumbar regions is limited, so pragmatic limits were set to prevent unreasonably high values. There was no correlation between exceeding the neck limits and head excursion, the lumbar Mx limit was only exceeded in cases where the head excursion approached the seat centreline.

Given the frequency of far-side injuries in accident data and the results of the monitoring phase, it appeared that the WorldSID may not be predicting thoracic or abdominal injury risk as originally anticipated. The assessment of head excursion would seem to offer the best evaluation of far-side occupant protection as the kinematics of the dummy are sufficiently representative of those of a human. Further consideration of the assessment limits will be made by the group in the future.

FUTURE WORK

Due to the limited capabilities of the WorldSID, the focus of the assessment must be on excursion of the head and torso. The working group is discussing ways to be more discriminative of the vehicles assessed and to ensure that the procedure encourages the fitment of countermeasures that reduce excursion and offer protection against occupant to occupant contact. At the time of writing, the details of this assessment are still to be finalised, but one possible option is with the use of an additional excursion line, see Figure 31. Proof of sufficient protection for vehicles with an occupant to occupant countermeasure is also under discussion. The current proposal is for a second WorldSID to be included in the official oblique pole impact to enable a demonstration of the efficacy of such countermeasures. The feasibility of such a test is still under consideration by the group.

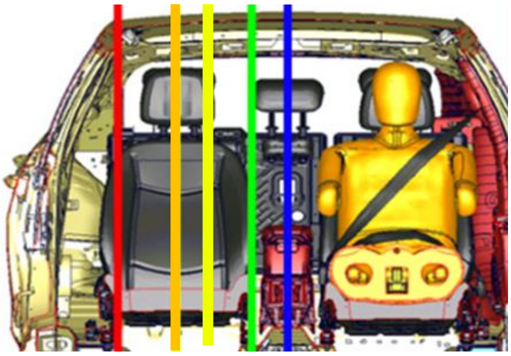


Figure 31: Draft assessment update

CONCLUSION

The development of the Euro NCAP far-side procedure began with accident data analyses. Previous accident research was combined with new analyses to establish the parameters that could be applied to a sled-based test procedure. In additional to the accident research, various numerical simulation studies were performed along with fourteen sled tests to investigate the factors affecting far-side protection.

The procedure aims to encourage vehicles to limit occupant excursion and mitigation of occupant to occupant interaction. A single ‘generic’ pulse was considered but this was found to be too limited given the variation in mass of the vehicle fleet and the increasing prevalence of electric vehicles. Two impact scenarios are therefore used to evaluate each vehicle model: a barrier to car impact and a pole impact, and both tests use vehicle-specific pulses. The sled setup is a simplified body in white that does not replicate struck-side intrusion as this was considered an unnecessary complication.

Results from the 2018 monitoring phase show that the WorldSID dummy has limited capability in predicting thoracic and abdominal injury risk. None of the dummy outputs exceeded the established injury criteria. However, in a number of cases the pragmatic neck and lumbar spine limits were exceeded. The kinematic assessment is appropriate and a simple method for assessing the head excursion has been adopted. This method is still under discussion and subject to change in favour of a more discriminating method. The far-side assessment will become part of the Euro NCAP rating from 2020. At the time of writing, the latest version of the procedure is version 1.1, November 2018 and is available at www.euroncap.com.

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ACKNOWLEDGEMENTS

The working group and authors would like to thank F Ochiai from Honda for his technical contributions and S Tylko from Transport Canada for the use of the WorldSID full arm.

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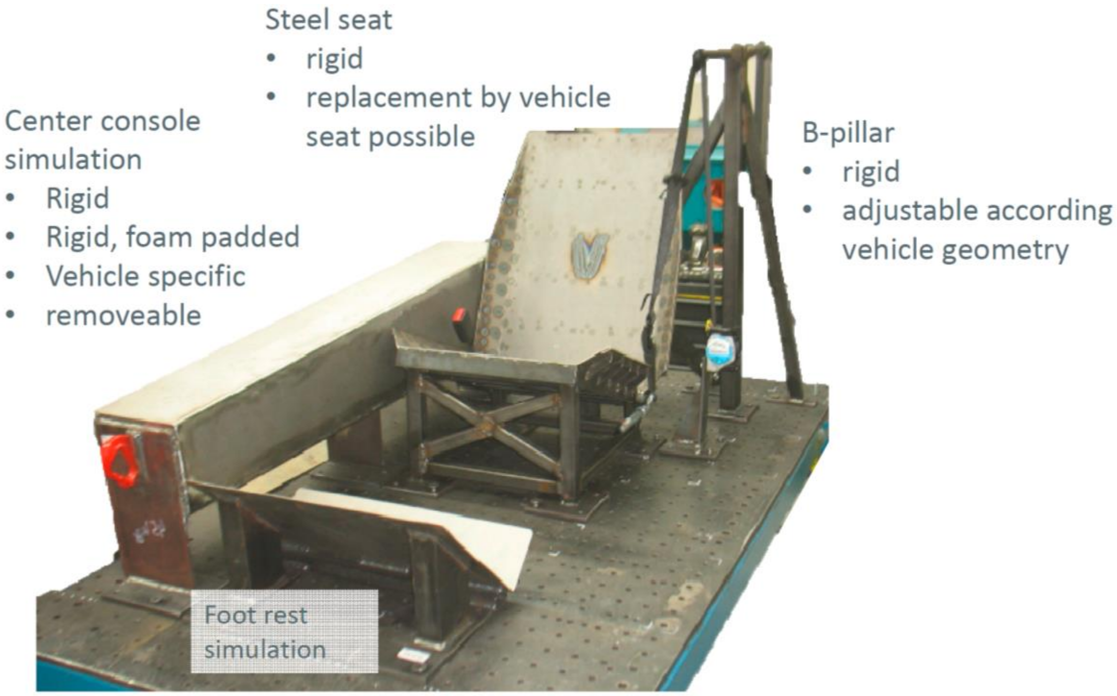
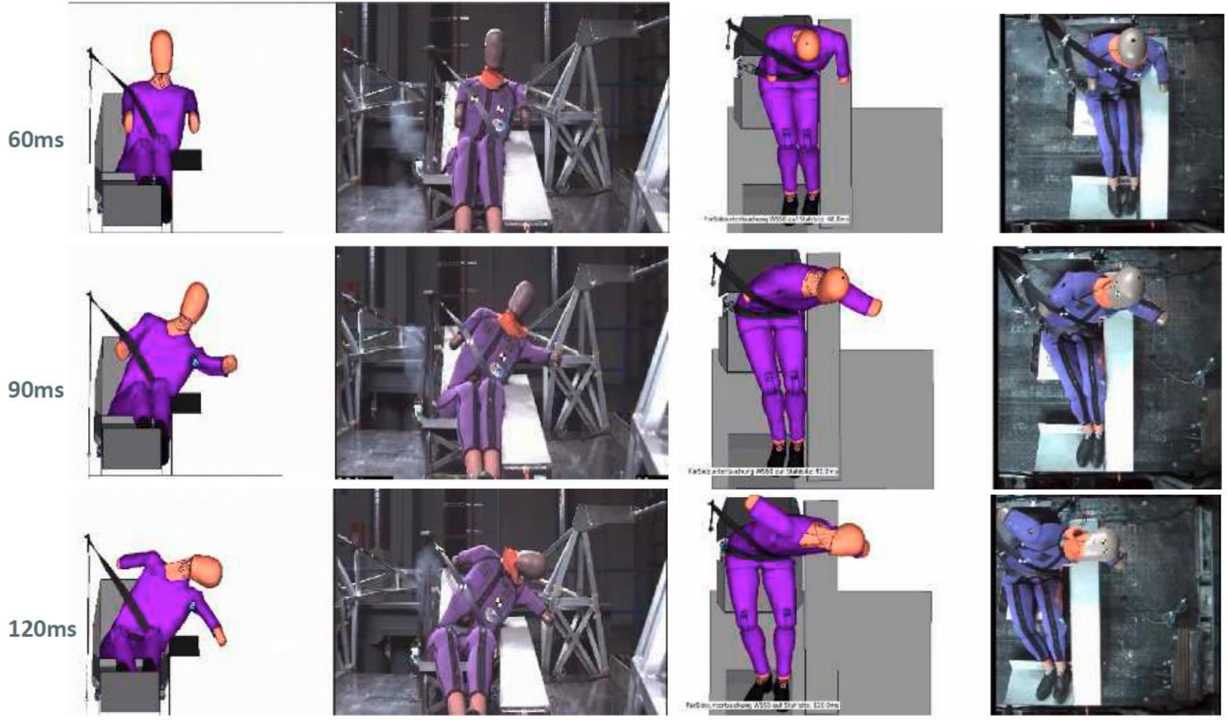
Appendix I
Accident data summary

	GIDAS	**Volvo Cars Traffic Accident Database**	**BAAC French National Database**	**LAB (weighted data)**	**ADAC**	**RAIDS-CCIS**	**APROSYS**
Accidents	2005 – 2014 Germany Injured accidents No P or 2W	2002 – 2013 Sweden High repair costs	2010-2013 France Injured+ accidents (under reporting) No P or 2W	2005 – 2014 France Injured+ accidents No P or 2W	2005 – 2014 NO P OR 2W	1998 - 2010	ZEDATU CCIS PENDANT HIT GIDAS TNO DIANA BASC-CCIS
Impacts	Lateral						
Vehicles	Cars Reg. 2000+	Volvo cars MY 98+	Cars Reg. 2000+	Cars Reg. 2000+	Cars Reg. 2000+	1998-2010	1995+
Occupants	Belted drivers and front seat passengers						
Ages	10+	14+	10+	10+	10+	12+	
Sample	1,719 (804/915)	2,852 (1,295/1,557)	14,775 (6,801/7,974)	432 (199/233)	899 (374/525)	2108 (962/1146)	
MAIS 2+	99 (43/56)	41 (14/27)		172 (64/108)	538 (211/327)	585 (219/366)	
MAIS 3+	34 (9/27)	10 (1/9)		89 (34/55)	191 (74/117)	391 (141/250)	
Fatal & Seriously Injured			3,433 (1,391/2,042)				

Appendix II
Generic Sled setup

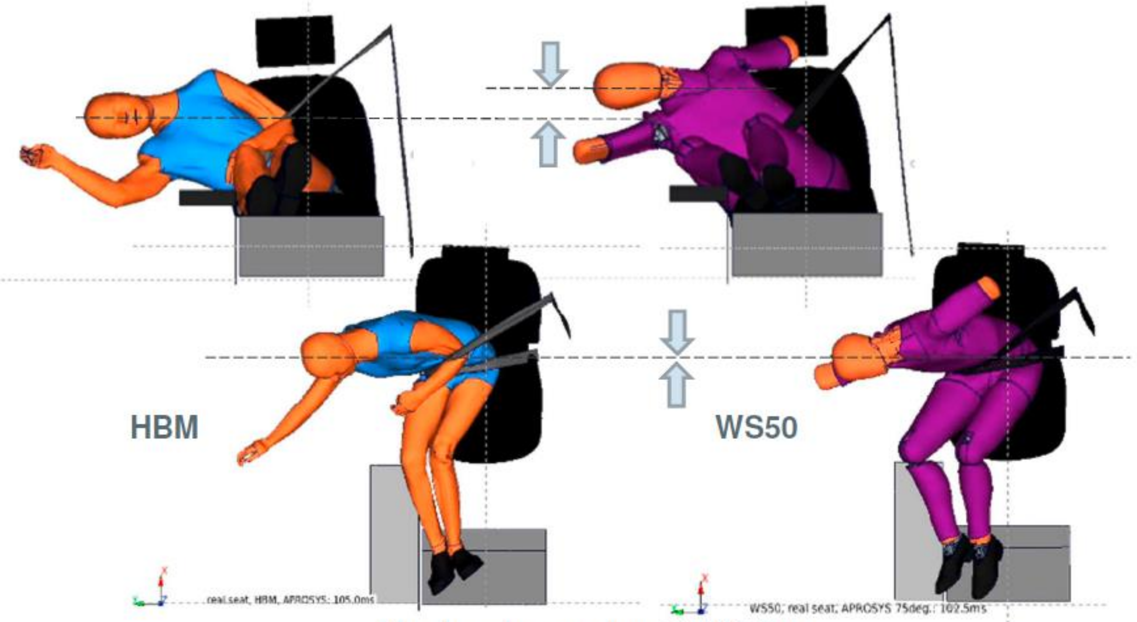


Sled and CAE comparison



HBM SIMULATIONS

Comparison AROSYS pulse 75° without center console HBM and WorldSID



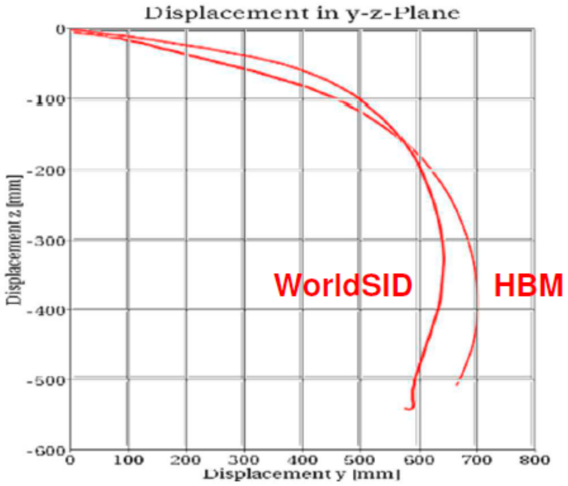
Max head excursion @ 102,5ms

HBM SIMULATIONS

Comparison AROSYS pulse 75° without center console HBM and WorldSID

HEAD

appr. 70mm more lateral Head CoG travel of HBM



Appendix IV
Sled test series 1

Test No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Loadcase	AE-MDB					Pole	
Delta V	41km/h					42.4km/h	38.8km/h
Pulse	Generic modified Aprosys pulse					36 kph-75° Pole F164609	32 kph-75° Pole F164302
Angle of Impact	75°						
Occupant (Driver)	WorldSID half arm			WorldSID full arm	WorldSID half arm	WorldSID half arm	
Centre console present above H-point	Standard (119mm above H-point)				Large & strong foam block with 2mm tin layer (185mm above H-point)	Standard (119mm above H-point)	
Deploy struckside curtain airbag	yes (5,5ms) side glazing closed	No, if no head interaction in first test				No	
Deploy struckside airbag	yes (5,5ms)	No, if no arm/torso interaction in first test				No	
Deploy driver pretensioner	No						
Seat & dummy position	Euro NCAP						
Remark	Baseline	Repeatability		Full arm influence		Baseline	

Appendix V

Series 1 results summary table

Test-Nr.				1	2	3	4	5	6	7
Loadcase				AE-MDB					Pole	
Velocity (Km/hr) / Pulse				41 / Generic Modified Aprosys Pulse					36 / 75° Pole F164609	32 75° Pole F164302
Angle of Impact				75°	75°	75°	75°	75°	75°	75°
Occupant (Driver) WorldSID50				w/o Full Arm			With Full Arm	w/o Full Arm	w/o Full Arm	
Centre console (Xmm above H-point)				Standard (119)				"Big CC" (185)	Standard (119)	
Deploy of struckside SIAB & CAB (TTF, ms)				Yes (5,5)	No					
Deployment of Driver Retractor PT				No*						
Seat & Dummy Position				EuroNCAP						
Head	**HIC15**	**500**	**700**	310.29	227.62	187.92	344.33	501.70	114.51	84.67
	Accn. Res. (g)	**72**	**80**	58.20	50.30	46.45	59.61	74.01	37.03	33.40
Neck Forces - Max; Min	**Fx (kN)**			0.19; -0.24	0.31; -0.24	0.30; -0.21	0.23; -0.27	0.08; -0.36	0.15; -0.18	0.15; -0.19
	Fy (kN)			0.14; -0.50	0.16; -0.41	0.09; -0.38	0.10; -0.50	0.16; -0.68	0.10; -0.39	0.11; -0.39
	Fz (kN)		**3.74**	2.21	1.96	1.80	2.29	2.88	1.45	1.30
Neck Moments - Max; Min	**Mx (Nm)**		**-50**	-60.21	-51.80	-47.65	-57.07	-66.52	-33.84	-36.19
	My (Nm)		**-50**	-33.83	-38.79	-40.48	-38.57	-26.96	-33.93	-34.64
	Mz (Nm)			14.28; -16.75	15.43; -13.07	19.37; -16.18	13.94; -17.63	0.82; -11.82	13.84; -13.50	13.89; -13.77
Neck NIC	**Fx +; - (%)**			6.3; 7.8	14.1; 7.9	14.8; 8.8	7.4; 7.0	2.5; 12.7	6.6; 5.7	7.5; 6.1
	Fz +; - (%)			67.0; 0.1	62.5; 0.1	75.2; 0.1	87.5; 0.1	87.4; 0.1	51.4; 0.1	54.5; 0.1
Chest - Shoulder Force	**Res. Max (kN)**			1.38	1.69	1.55	1.45	1.84	1.44	1.11
	Fy Max (kN)			1.25	1.31	1.34	1.25	1.69	0.85	0.74
Thorax Rib Deflection (mm)	**1**	**-28**	**50**	-13.21	-7.83	-5.05	-4.37	-7.94	-1.06	-3.08
	2	**-28**	**50**	-14.21	-27.75	-6.89	-14.65	-10.74	-9.03	-23.06
	3	**-28**	**50**	-2.38	-13.90	-29.97	-6.09	-19.93	-35.75	-16.30
Abdomen Rib Deflection (mm)	**1**	**-47**	**65**	-1.76	-2.73	-8.86	-7.63	-45.65	-15.33	-1.97
	2	**-47**	**65**	-19.07	-21.29	-17.28	-25.07	-31.40	-2.48	-5.41
Pelvis	**Pubic ForceY (kN)**		**2.8**	-0.92	-0.90	-0.73	-0.68	-1.06	-0.70	-0.63
Lumbar	**Fy (kN)**		**2**							
Lumbar	**Fz (kN)**		**2.84**							
Lumbar	**Mx (Nm)**		**100**							
Remarks				with infl. Restraints shoulder belt trapped in sh joint (sh pad concern)	no top view camera in prel data no lower retractor fixation buckle opend	zipper opened by interaction suit w/ sh belt				

Appendix VI
Sled test series 2

Test No.	8	9	10	11	12	13	14
Loadcase	AE-MDB				Pole		
Main Evaluation Priority							
Delta V	41km/h				38.8km/h	38.8km/h	42.4km/h
Pulse	Generic modified Aprosys pulse				32 kph-75° Pole F164302	32 kph-75° Pole F164302	36 kph-75° Pole F164609
Angle of Impact				75°			
Occupant (Driver)	WorldSID half arm and sleeveless suit						
Centre console present above H-point	*Standard (119mm above H-point)*	*Standard (119mm above H-point)*	*Standard (119mm above H-point)*	*High console*	*Standard (119mm above H-point)*	*High console*	*Standard (119mm above H-point)*
Deploy of struckside curtain airbag	No	No	No	No	No	No	No
Deploy of struckside airbag	No	No	No, with spacer	No, with spacer	No, with spacer	No, with spacer	No, with spacer
Deploy driver pretensioner	No*	Yes;	Yes	Yes	Yes; 10ms	Yes; 10ms	Yes; 10ms
Seat & dummy position	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP
Remark	Record T1 and T4 acceleration Markers for	If pretensioning causes interaction with	Support B-pillar to PASSseat AND PASSseat to	Support B-pillar to PASSseat AND PASSseat to	Support B-pillar to PASSseat AND PASSseat to	Support B-pillar to PASSseat AND PASSseat to	Support B-pillar to PASSseat AND PASSseat to

Appendix VII
Series 2 results summary table

Far Side Occupant Protection - Sled Test Matrix												Crash	
Test No.				**S17120101**	**S17120102**	**S17120103**	**S17120104**	**S17120105**	**S17120106**	**S17120107**		**F164609**	**F164302**
Test No.				**1**	**2**	**3**	**4**	**5**	**6**	**7**		**Pole**	
Loadcase				**AE-MDB**				**Pole**				**Pole**	
Velocity (Km/hr) / Pulse				**41 / Generic Modified Aprosys Pulse**				**32 75° Pole F164302**		**36 / 75° Pole F164609**		**36 / 75° Pole F164609**	**32 75° Pole F164302**
Angle of Impact				75°	75°	75°	75°	75°	75°	75°			
Occupant (Driver) WorldSID50				**WS50 w/o full arm - WITH sleeveless suit**								**w/o Full Arm - WITH sleeved suit**	
Centre console (Xmm above H-point)				**Standard (119)**			**"Big CC" (185)**	**Standard (119)**	**"Big CC" (185)**	**Standard (119)**		**Standard (119)**	
Deploy of struckside CAB - Yes / No (TTF, ms)				**No**								**Yes (5,5)**	
Deploy of struckside SIAB - Yes (TTF, ms)				**No**		**No - Support B-pillar to PASS seat AND PASS seat to centre console**							
Deployment of Driver Retractor PT				**No***	**Yes; 7ms**			**Yes; 10ms**				**No**	
Seat & Dummy Position				**EuroNCAP**								**EuroNCAP**	
Head	**HIC15**	**500**	**700**	**192.00**	**225.20**	**210.60**	**501.90**	**93.80**	**133.70**	**101.60**		**3305.41**	**253.77**
	Accn. Res. (g)	**72**	**80**	**47.00**	**51.60**	**51.00**	**70.50**	**36.00**	**39.20**	**39.10**		**370.98**	**72.84**
Neck Forces - Max; Min	**Fx (kN)**			**0.25 -0.27**	**0.37; -0.30**	**0.17; -0.24**	**0.07; -0.42**	**0.16; -0.18**	**0.05; -0.24**	**0.15; -0.25**		**0.05; -1.55**	**0.10; -0.24**
	Fy (kN)			**0.11; -0.47**	**0.15; -0.45**	**0.08; -0.51**	**0.15; -0.68**	**0.03; -0.48**	**0.09; -0.57**	**0.03; -0.40**		**0.31; -0.80**	**0.20; -0.60**
	Fz (kN)		**3.74**	**1.83**	**2.03**	**2.03**	**2.77**	**1.40**	**1.54**	**1.43**		**1.45**	**1.26**
Neck Moments - Max; Min	**Mx (Nm)**		**-50**	**-46.39**	**-44.64**	**-47.85**	**-56.59**	**-31.52**	**-44.52**	**-28.87**		**-16.31**	**-48.67**
	My (Nm)		**-50**	**-36.33**	**-48.19**	**-37.94**	**-23.41**	**-46.02**	**-32.70**	**-47.01**		**-60.28**	**-37.51**
	Mz (Nm)			**16.00; -17.83**	**19.79; -18.79**	**14.81; -15.84**	**3.34; -11.54**	**17.76; -19.22**	**4.63; -14.52**	**18.61; -19.41**		**4.67; -47.07**	**11.08; -23.93**
Neck NIC	**Fx +; - (%)**			**9.3; 8.6**	**14.4; 9.6**	**6.2; 7.9**	**5.8; 14.4**	**5.3; 10.0**	**1.8; 8.3**	**5.0; 14.0**		**1.5; 50.2**	**9.3; 7.8**
	Fz +; - (%)			**58.3; 0.1**	**61.6; 0.1**	**66.4; 0.1**	**84.0; 0.1**	**47.1; 0.1**	**46.6; 0.1**	**49.5; 0.1**		**44.1; 154.2**	**38.3; 66.5**
Chest - Shoulder Force	**Res. Max (kN)**			**1.68**	**1.55**	**1.58**	**1.78**	**0.97**	**1.19**	**0.95**		**1.35**	**0.92**
	Fy Max (kN)			**1.46**	**1.38**	**1.43**	**1.64**	**0.84**	**1.07**	**0.83**		**0.80**	**0.79**
Thorax Rib Deflection Max (mm)	**1**	**-28**	**50**	**-4.6**	**-7.1**	**-3.4**	**-6**	**-5.1**	**-4.1**	**-3.9**		**0**	**-0.04**
	2	**-28**	**50**	**-22.4**	**-26.1**	**-4.9**	**-9.5**	**-19.4**	**-6.9**	**-8**		**0**	**-0.17**
	3	**-28**	**50**	**-23.1**	**-10.2**	**-18.7**	**-21.6**	**-19.7**	**-21.3**	**-32.3**		**3.22**	**-1.59**
Abdomen Rib Deflection Max (mm)	**1**	**-47**	**65**	**-7.9**	**-3.1**	**-11.2**	**-40.7**	**-7**	**-26.1**	**-14.2**		**-2.66**	**-4.26**
	2	**-47**	**65**	**-24.8**	**-1.9**	**14.4**	**-30.5**	**-5.6**	**-16.2**	**-2.6**		**-5.57**	**-6.93**
Pelvis	**Pubic ForceY (kN)**		**2.8**	**-0.78**	**-0.82**	**-0.77**	**-1.01**	**-0.77**	**-0.7**	**-0.75**		**-0.66**	**-0.69**
			2										
			2.84										
			100										
Remark				Cut in new sleveless suit; no belt interaction with dummy shoulder / jacket	Belt height adjuster in lowest posn. +1 notch instead of up; no belt interaction with dummy shoulder / jacket								