APPLYING SIDE IMPACT CUSHION TECHNOLOGY TO CHILD RESTRAINT SYSTEMS

Farid Bendjellal
Britax Childcare Group
Germany
Godfrey Scicluna
Britax Childcare Pty Ltd
Australia
Richard Frank
Michael Grohspietsch
Andy Whiteway
Britax Europe
Germany/United Kingdom
William Flood
Ron Marsilio
Britax Child Safety Inc.
USA
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ABSTRACT

Side impact was and is still a challenge in automotive safety. In the real world 1 out of 4 crashes are side impacts. According to an NHTSA investigation involving accidents with 28 children, direct contacts with vehicle interior are responsible for 45 % of injuries. The majority of the observed injuries were to the head. Therefore when considering children restrained in child seats, the key safety objective is: Provide energy absorption for the whole body and avoid head contact, with for instance the intruding door. To reach this objective countermeasures have to be developed in terms of child restraint construction.

A project aiming at developing side impact countermeasures was launched at Britax some years ago. System basic requirements were: 1) Anticipate child seat to door contact, and 2) Absorb as much as energy possible “outside” the occupant zone. Another aspect of the specification was to ensure it is transposable to different testing environments or regulations.

This paper deals with applications aiming at implementing side air cushion technology to child restraint systems. The first part summarizes some development efforts to improve head containment on a booster seat. The second part deals with the technology basics as well as its application to a US-type convertible seat and to an EU-type booster seat. In the absence of established regulatory test procedure, internal methods were developed. These methods are described in the paper; they are based on deceleration sled system and a fixed door. Anthropomorphic Test Devices (ATDs) used were the 3year old Hybrid III and Q3. An additional method corresponding to the EU Draft Regulation –moving sled, fixed door - was also used.

The third part of the paper discusses the performance of the side air cushion. Performance was judged utilizing measurements of head, chest and pelvic accelerations and neck loads in the case of the Q3. In both test configurations the side air cushion allowed to reduce significantly dummy responses.

The findings, as detailed in the paper, allow considering the side air cushion approach as a viable and tangible countermeasure to address the challenges posed by side impact.

INTRODUCTION – BACKGROUND AND IMPORTANCE OF SIDE IMPACT

Side Impact is one of the most leading causes of severe injuries to children involved in lateral collisions. According to NHTSA study (Louden, Sullivan, 2008 [1]) side impact represent 60% of AIS 3+ injuries for children aged between 3 and 10 years (see Figure 1).

The study shows also that the head is the most frequently injured body region; for near side occupants the corresponding frequency of injury is twice of that of the torso. Similarly, in the European CHILD Program, the accident review presented in 2006 by Philippe Lesire, Véronique Herve and Alan Kirk [2], highlights the high exposure of the head in this type of impact: 75% of the injuries (all severities) were to the head as shown in Figure 2.

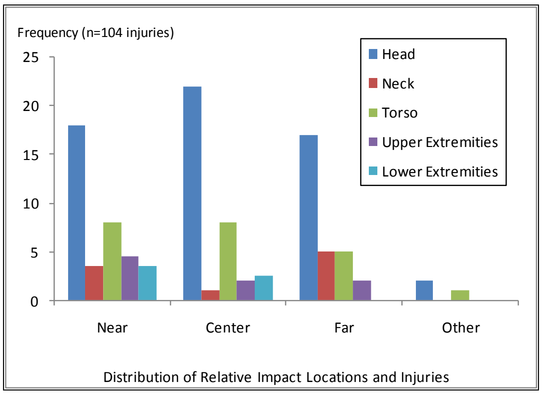


Figure 1. Frequency of injuries to various body regions, as a function of occupant sitting position [1].

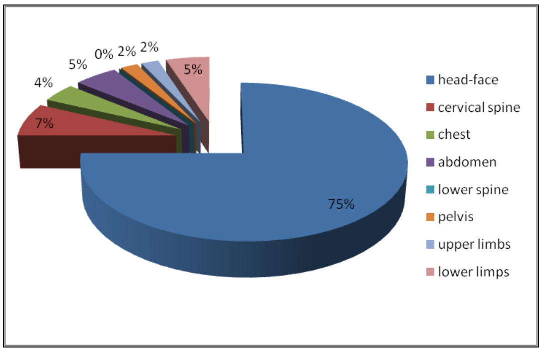


Figure 2. ¾ of injuries to the head and face (seat group 0 to 1); 50 children sustaining 140 injuries (all severities) [2].

A similar trend was found by K. Arbogast et Al. [3] in 2008. They have investigated 62 crashes in the US, where they looked into the number of AIS2+ injuries to different body areas for nearside, center and farside occupants (see Figure 3). The data show that 70% of the injuries concern the head and face areas (118/170) and 7% (13/170) are related to the thorax.

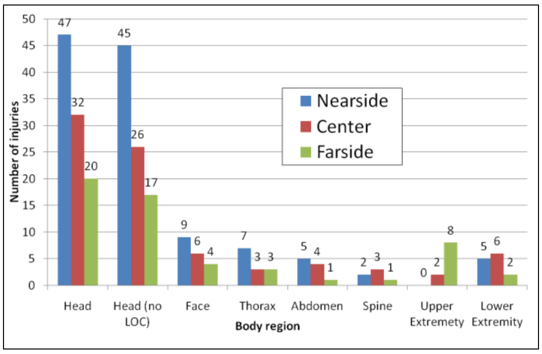


Figure 3. Numbers of AIS 2+ injuries to body regions in side impact crashes (total number of injuries 170) [3].

According to these studies it is clear that the occupant's head is the key body area to protect as a priority 1 in side impact involving children. Technical solutions were developed in the past, consisting of larger side wings with the aim to contain the child's head within a safe zone. Examples of such solutions and their evolution as developed by Britax over the past 6 years are illustrated in Figure 4 and 5. Key was to provide energy absorption by improving the side wings design – chest containment – and to re-think the head restraint construction.

Figure 4. Side Impact Protection – Head restraint structure and energy absorbing elements in a Group 2/3 (15-36kg)

Figure 5. KID Booster Seat – Evolution of side impact countermeasures [4].

If we consider Figure 5 in details, then we can observe that the side wing of 2006 solution does reach the shoulder height of the occupant in comparison to the 2004 earlier solution. The rationale behind the 2006 construction was to improve further impact force distribution over an extended CRS side surface. That means that concentrating only on the head area only by head containment may not be sufficient in severe crashes. Hence the need for a bigger perspective to address side impact in the CRS domain. In order to make a significant progress we looked at the innovations that were developed in the automotive industry. The particular physics of side impact has led the automakers to develop countermeasures combining a certain occupant kinematic with inflatable airbags. That led to the development of energy absorbing (EA) elements in the vehicle door combined with side inflatable airbags mounted in the vehicle seat, and structural improvement of the vehicle body. If we consider the inflatable airbags we can observe that their response time is in line with the shortness of the side impact duration: that means the airbag must deploy within the first ten milliseconds after the initiation of the impact to be effective and constitute an energy absorbing element between the intruding door and the occupant. Therefore any countermeasure to improve side impact protection for children should also anticipate that contact.

THE PHYSICS OF SIDE IMPACT

The side impact collision includes key events which can be summarized as follows:

1. The near side door is impacted by the bullet vehicle and commences intruding laterally into the passenger compartment.

2. Once the bullet vehicle engages with the door sill, the whole vehicle will be subjected to a lateral movement as a result of being pushed by the bullet vehicle. During this phase, the occupant tends to move against the intruding structure.

3. The combination of the movement of the occupant towards the intruding structure and the continued intrusion of the door will result in a contact between the occupant and the intruding structure.

4. Intruding door usually interacts with the lower part of the occupant’s body, for instance, the pelvis and thorax, forcing the head to rotate towards the struck side of the vehicle.

Figure 6 illustrates typical time-histories of impacting vehicle and struck vehicle velocities, and relative velocities door/vehicle and occupant/door.

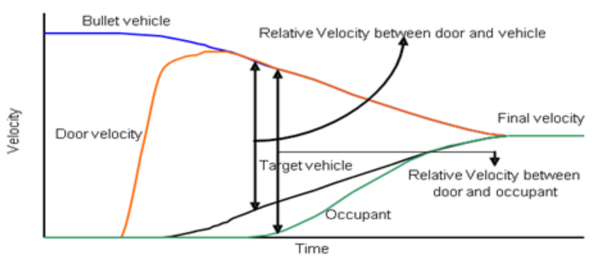


Figure 6. Physics of side impact – Schematic velocities of bullet car, target car, door and occupant. The parameter to address in CRS domain is the “Relative Velocity between door and occupant’.

RATIONAL AND OBJECTIVES

The key objective of the present study was to translate the learning from auto industry to child restraint system taking into account the physics of side impact described earlier. The principles of our approach were the following:

1. Anticipate the contact between the seat and the door as soon as possible during the crash event.

2. Absorb as much as energy possible by a system located outside the occupant area.

3. Using passive restraint technology rather than active restraint technology (such as inflatable systems).

4. To have a technology that is adaptable to CRS and available quickly on products, even in the absence of mandatory side impact test, specifically in EU and US.

EXISTING TEST PROCEDURES – DEFINING AN INTERNAL APPROACH

When this project started the situation of side impact regulatory requirements for CRS was as follows:

- Australia: Test method, anthropomorphic test dummy and performance criteria established since 2004.
- Europe: No mandatory test procedure, only consumer test (Stiftung Warentest/ADAC) with a BIW (body in white) sled test, 80° angle, Q-dummies (except for booster seat where P10 is used) and with demanding performance criteria.
- USA: No mandatory test, no consumer test.

It was then necessary to build an internal side impact test procedure based on the known state of the art at that time. The method that seemed to correspond to that objective was the initial ADAC fixed door on a deceleration sled. Based on that a test procedure was established with the corresponding key parameters, as illustrated in Figure 7 and 8.

- Simple, repeatable and adaptable on existing test rigs at Britax US and Europe.
- Fixed door as per ADAC specifications, 500mm height and 330mm horizontally from child seat center line.
- Sled orientation with 80° angle in order to have a longitudinal component in the loading of the CRS and occupant.
- Using existing test devices such as P-dummies for Europe and Hybrid III 3y for

the US development. Later the EU internal test procedure has been updated to include the Q3 dummy. Since it was decided to consider the head protection as the top priority we have then chosen the head containment as the key performance indicator. Head and chest accelerations were used as design targets for the design of the system.

Figure 7. EU internal test method Fixed door on a R44 rig

Figure 8. US internal test method Fixed door on a FMVSS 213 rig

The SICT was developed using this internal testing approach as well as math simulations and pendulum tests. Its principal elements are detailed in the next section.

In addition to these sled-bench tests, the ADAC-Stiftung Warentest [5] test configuration was used. It is based on Body in White set-up, with an Opel Astra body attached to a deceleration sled. The child seat is tested in the rear seat at the nearside position and the door is fixed and covered with a specific padding, Figure 9 illustrates the setup.

Figure 9. Internal reproduction of the ADAC-Stiftung Warentest side impact BIW test procedure

As intruding door based methods are being developed on both sides of the Atlantic, the system was tested also using the draft side impact test procedure, the so-called “moving sled - fixed door“ that was defined by the GRSP Informal Group on CRS [6]. Figure 10 shows an overview of the setup. The door, covered with a 35 mm rubber cell and a 20 mm Styrodur foam, is vertical and attached to the wall, i.e. the door is fixed. The test bench, oriented 90° with respect to the sled, is mounted on a platform that can move laterally. The aim here is to reproduce in a simple way the door relative velocity between the door and the struck vehicle, as shown in Figure 11.

Figure 10. Illustration of EU draft side impact test procedure, moving sled-fixed door

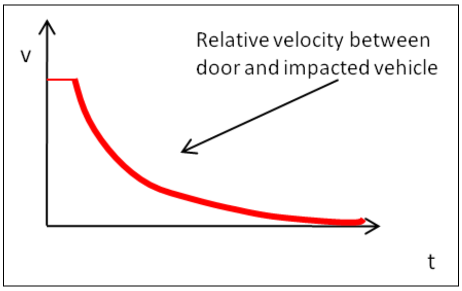


Figure 11. Relative velocity-time relationship of the door in the impacted vehicle. Part of the curve shown in the figure is to be reproduced in the EU draft test procedure.

SIDE IMPACT CUSHION TECHNOLOGY – DESCRIPTION AND PERFORMANCE

The system consists of an air filled cushion, blow-molded, attached to both wings of the child restraint system. The principle is to use this cushion as an interface between the door and the CRS and absorb as much as possible the impact energy with the compression of the cushion and the release of the air from the cushion. The physical parameters of the cushion were established using math simulation, sub-system tests as well as full sled tests as described above. One of the challenging performance criteria was to ensure the head containment of the dummy's head. This was achieved by ensuring the SICT is working together with the other features of the seat such as its shell as well as the head restraint. Figures 12 and 13 illustrate Side Air Cushion Technology as developed on a US convertible and EU booster restraints.

Figure 12. SICT on a booster seat (Britax Römer KID)

Figure 13. SICT on a convertible seat (Britax US Advocate)

TEST RESULTS

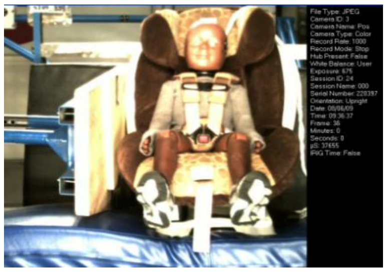
We will limit the presentation of the test results to those obtained in sled configurations. To better understand the function of the SICT system in Figure 12 and 13, three principle sequences during the loading phase of the child seat and the dummy were reproduced in Figure 14, 15 and 16. These are:

a) Contact at T0
b) First contact of the SICT with the door
c) End of loading phase, head fully contained within the head restraint

As can be seen the system and its characteristics helped to achieve head containment using the Hybrid III 3-year-old dummy in the US procedure and with the Q3 in the European procedure as well.

a)

b)



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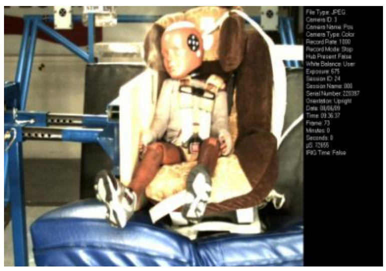


Figure 14. Principle sequences during a side impact sled test, head is contained through the entire duration of the impact, in a sled test with fixed door (US internal test procedure)

a)

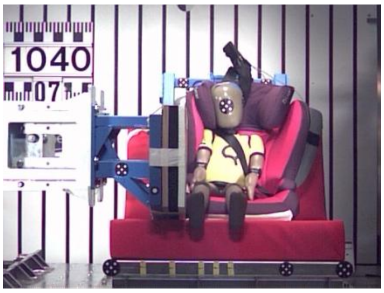
b)

c)

Figure 15. Principle sequences during a side impact sled test, head is contained through the entire duration of the impact, in a Body In White side impact sled test with a Q3 dummy.

a)

b)



c)

Figure 16. Principle sequences during a side impact sled test, head is contained through the entire duration of the impact, in a side impact sled test with a Q3 dummy, according to the draft EU side impact test procedure, moving sled-fixed door.

One of the key criteria of this development was to compare the relative effectiveness of the SICT. This was established in comparative sled tests using the same CRS with and without the system. Figures 17 and 18 illustrate the head and chest resultant acceleration time-histories obtained from US and EU sled tests with and without SICT. The same parameters are illustrated in Figure 19 for the tests conducted according to the EU draft test method. Peak to peak comparison shows a reduction of approx. 17% of max. head acceleration and 30% of max. chest acceleration in the US fixed tests. In the EU fixed tests, performance indicators similar to those used by Stiftung Warentest/ADAC were considered. These are the HIC, head, chest and pelvic accelerations, head lateral displacement and neck loads. On average the SICT allows to reach 25% reduction across all these parameters, suggesting that SICT system does a remarkable job. In particular maximum head and chest acceleration in the EU tests were reduced resp. by 21% and 40%. Considering the results from the EU draft test method it can be seen that the contact between the system and the door takes place even earlier compared to previous test methods. It should be noted that the CRS tested here is a booster that was attached to the test bench by the Isofix system with the occupant secured with a 3-point-belt. Film analysis shows that the head is contained during the entire motion. Head maximum 3ms acceleration with SICT was reduced by 5% while the chest acceleration showed 30% reduction with SICT. These results are considered satisfactory given the fact that the EU test method is more severe than the other ones discussed here.

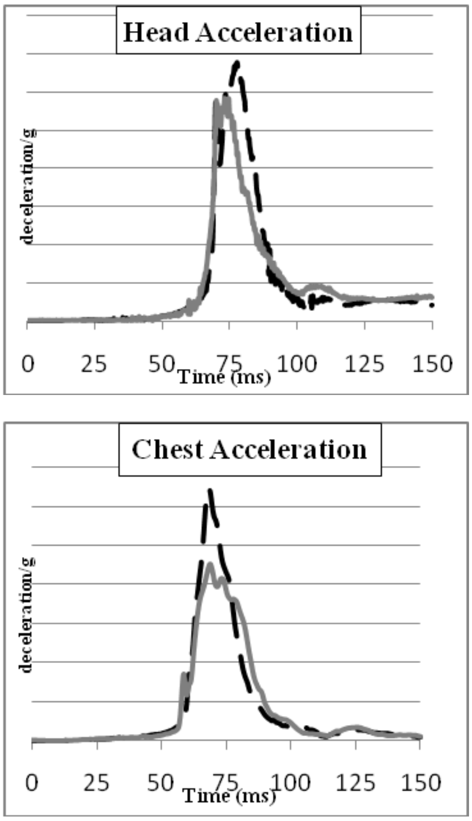


Figure 17. Head and chest Acceleration in US sled test @ 27 km/h with a convertible seat. Doted lines represent baseline CRS, solid lines illustrate the same CRS with SICT

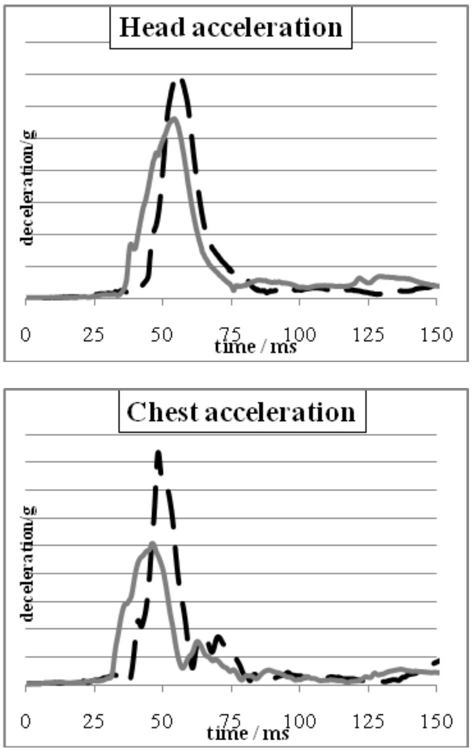


Figure 18. Head and Chest acceleration in EU BIW sled test @ 27 km/h with a booster seat (belted). Doted lines represent baseline CRS; solid lines illustrate the same CRS with SICT

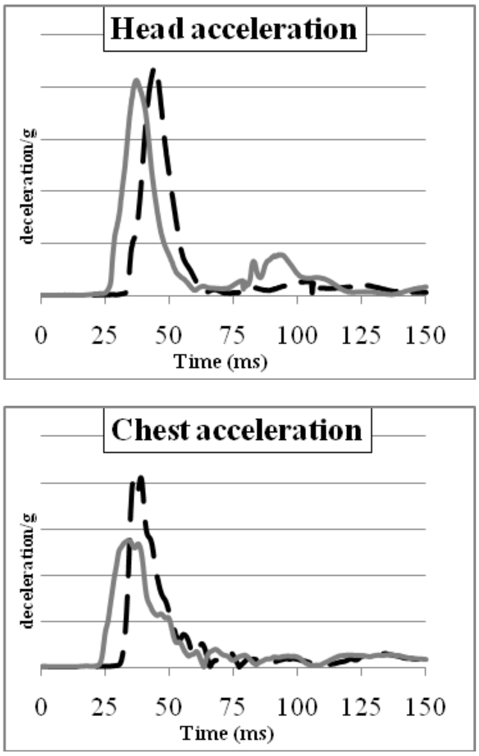


Figure 19. Head and Chest acceleration in the EU draft test procedure (moving sled-fixed door) @ 27 km/h with a booster seat with Isofix anchorages. Doted lines represent baseline CRS; solid lines illustrate the same CRS with SICT

SUMMARY AND PERSPECTIVES

This study has demonstrated that improving CRS for a better protection of children is an ongoing process. It has started a decade ago at Britax with first structural CRS enhancement of the CRS side wings and head restraints. A further step was taken by the introduction of larger side wings in 2006 with the aim to improve load distributions. Today's introduction of Side Air Cushion Technology is a logical continuation of that effort. The key was to use the SICT to anticipate the contact between the door and the CRS and absorb as much as energy outside the occupant zone. Internal test results in various test configurations have proven that the approach is valid in terms of controlling the head containment, a critical parameter aimed at reducing the head exposure in real world. In terms of energy absorption substantial reductions of head and chest accelerations were obtained on both US and EU restraints to which this technology was applied. The system was also tested using the draft test procedure that is aimed at approving CRSs under the new EU regulation. First tests that were carried out show a similar trend of the SICT despite the severity of the test method: 1/ head is contained during the entire test duration, 2/ the system allows to have an earlier contact with the door, and 3/ head and chest acceleration were reduced.

On a more general scale it is essential that CRS developments such as this one are accompanied with structural enhancement of vehicles such as reducing intrusion into occupant compartment, and improvement of restraint in cars – such as side airbag curtains with sizes compatible with child anthropometry, and or providing energy absorption in the passenger compartment elements, susceptible to be contacted by the occupant (see Figure 20).

Figure 20. Examples of vehicle rear seat compartment where energy absorption might be needed for child protection

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