PROTECTION SYSTEM FOR FAR-SIDE OCCUPANTS IN LATERAL CRASHES

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ABSTRACT

Although modern vehicles are equipped with multiple restraint systems such as airbags and seatbelts, there would be a further possibility to reduce occupant injury in even the best-pick category vehicles. The protection systems are mainly designed for occupants that are positioned closest to the intrusion. However, side-impact field data show approximately one-quarter to one-third of severely injured occupants sit on the far-side of the vehicle, furthest from the intrusion.

This study presents a novel protection system which is placed between the two front passengers to protect them from injuries caused by far-side impacts. The fixation of the performance-added-airbag to the seat is designed in a pivot-like method to ensure a laterally stiff protection element, minimizing the excursion of the occupant's torso and head. The concept is designed to incorporate only minimal changes to existing seat and seatbelt designs. With reference to field data accidents, different impact angles have been sled tested under LINCAP conditions.

Results show a high benefit of the proposed Mid-Mount Bag. Keeping the occupants on their own side of the vehicle as much as possible can mitigate many injuries caused by the vis-à-vis interior or by other occupants. The total torso excursion could be reduced by 45% compared to scenarios without adequate far-side protection.

With regard to the field data, approx. 70% of MAIS3+ far-side injuries can be avoided by the Mid-Mount Bag. Although installing additional airbag systems will have a cost impact, this impact is balanced by potentially saving numerous lives. The Mid-Mount Bag brings us closer to our dream of having zero victims due to traffic accidents.

INTRODUCTION

Throughout the past decades, major advances in automotive safety have been achieved. Today, the human toll due to road accidents is decreasing in nearly all developed countries [7]. Active safety which seems nowadays to take most of the attention is making good progress by putting new safety systems on the road in order prevent an immanent crash or support and guide the driver. Nevertheless, there are still further advances needed in passive safety. Looking at various safety rating schemes you will find listings which show the safest cars available. However, it is to be remembered that those ratings are focusing on standardized testing protocols. In the real world there are frequent accident scenarios which are only partially or not at all addressed by those rating schemes. In this paper, we consider lateral crashes in which an occupant is seated at the far side of the impact, i.e. the occupant is located at the non-stuck side of the vehicle.

MOTIVATION

An objective of this study was to examine injury patterns for belted far-side front seated occupants in lateral collisions. Concluding the results, various crash tests were conducted to better understand the occupant kinematics that cause the most frequent injuries as well as developing countermeasures in terms of a protection system to significantly reduce these injuries.

Roughly half of all car accident casualties are involved in side collisions. Throughout the literature, it is a well-know fact that this accident type causes severe injuries to the passengers. Especially those occupants who are seated on the non-struck or far side of the collision experience injuries that account for about one-third of all side collision caused injuries [1],[4]. Further field data activities dealt with a closer analysis on the causation of far-side injuries and occupant kinematics. This was done in order to identify the method to protect far-side occupants by means of a protection system.

ANALYSES OF FAR-SIDE INJURIES BASED ON NASS/CDS

In a NASS/CDS query from 1998-2005, far-side occupants were defined as front left passenger with right side damage and principle direction of force (PDOF) 90° ±50° or front right passenger with left side damage and PDOF 270° ±50°.

The following boundary conditions were set: only the MAIS 3+ respectively AIS 3+ filter was applied; unbelted occupants as well as rollover were excluded from the analysis. The resulting data contained a total number of 216 cases, whereby 163 cases were the front left passenger and 53 were the front right passenger.

On the injury level, it resulted in a total of 245 injuries to the front left passenger and 75 injuries to the front right passenger. Table 1 shows the

distribution of body regions by passenger seating position.

Table 1
MAIS 3+ injury distribution for belted occupants in far-side crashes by body region only one injury counted per body part

Front Left Passenger AIS 3+

Body Region	No.	Percentage
Chest	85	35%
Head/Neck	77	31%
Abdomen	26	11%
Pelvis	21	9%
Upper X	18	7%
Lower X	12	5%
Other	6	2%
Total	245	100%

Front Right Passenger AIS 3+

Body Region	No.	Percentage
Chest	26	35%
Head/Neck/Face	28	37%
Abdomen	6	8%
Pelvis	4	5%
Upper X	4	5%
Lower X	4	5%
Other	3	4%
Total	75	100%

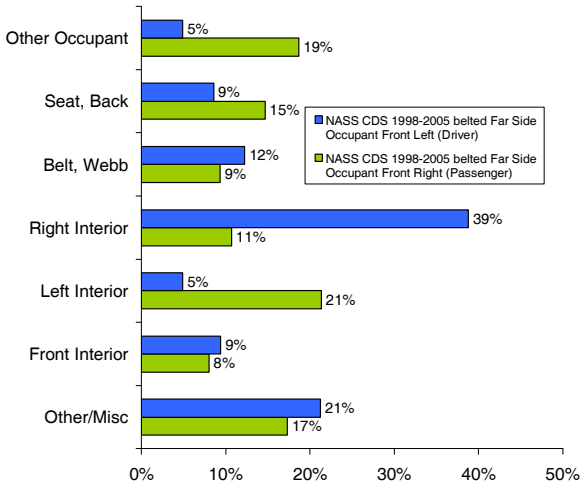
Digges et al. also investigated injuries to restrained occupants in far-side crashes [2] in NASS/CDS data set. Herein it was concluded that the most frequent injuries in the case of a far-side accidents are head and torso injuries.

The injury mechanisms and kinematics of chest and abdominal injuries in far-side crashes have been researched in detail by Fildes et al. [5]. As a result from this paper, the head, chest and abdominal injuries are also the top three injuries associated with far-side crashes. Charles [6] highlights the head and thorax injuries as the top injuries as well.

Diagram 1 shows the distribution of AIS 3+ injuries by the injuring contacts. The blue bars are related to the front left passenger contacts. The green bars are related to the front right passenger contacts. The categories 'Seat/Back', 'Belt/Webb', 'Front Interior', 'Other/Misc' are somehow distributed equally between front left and right side passengers. At least there are no significant recognizable discrepancies.

The unequally distributed category 'Other Occupant' roots back to the fact that a front left side passenger is always seated in the vehicle, whereas not always is a passenger seated in the right front seat of the vehicle. It is a trivial fact that the category Right Interior addresses the front left passenger in a far-side crash, whereas the category Left Interior addresses the front right passenger in a far-side crash.

Diagram 1
Distribution of injuring contacts for AIS3+ injuries of front left and front right passengers



Charles [6] did a comparison of mortality, injury severity and injury patterns between near and far-side occupants in side collisions. He also showed two single cases where large deformations of the side structure of the vehicle are visible. Thereby injury sources such as vis-à-vis side interiors become evident.

All these field data define the requirements and boundary conditions for a restraint system. From the analyzed body regions it is obvious that an optimally designed restraint system needs to have both a protection zone for the head as well as for the thorax, respectively the chest. The results from the analysis of the injuring contacts concluded that a protection system, too, needs to protect against perpendicular contacts as well as oblique contacts from a view of a far-side seated occupant.

CONCEPTUAL CONSIDERATIONS

Altogether, the field data and injury pattern show that the following categories need to be addressed for maximum protection:

- Protect the far-side occupant not only for perpendicular impact but also for oblique impact.
- Limit the potential interaction with the vehicle interior as much as possible.
- Develop a protection system not only beneficial for dummies but also for humans.

Figure 1
Far-side dummy kinematics in a far-side lateral impact

Figure 1 shows the dummy excursion in a possible far-side condition. It is to be considered that current dummies have a fairly stiff spine (no bending, no stretching). Digges [3] shows the fundamental differences between a dummy and a human in a far-side condition. In a real crash the far-side occupant is well supported at the pelvis by means of the middle console and the lap belt. However, the shoulder belt typically slips off and hence the upper torso and head will rotate about the pelvis towards the intruding side wall. Significant bending and stretching of the spine of the far-side occupant is seen. The result is a much larger excursion of the head and upper torso when comparing those two measures with a dummy. As shown in Diagram 1, there are not only injuries from contact to interior parts but also from the belt and webbing. In consequence, the likelihood of severe injuries becomes much higher for humans than for dummies. But it is only true if the occupant is actually allowed the higher excursion. If we can avoid the occupant excursion we may also avoid the injuries.

Assuming the dummy/occupant is actually kept well within its seat (by a to-be-installed protection system); we can expect their lateral motion pattern of both the dummy and the occupant to be the same. This is a fair assumption because the difference in spine bending and stretching will not occur.

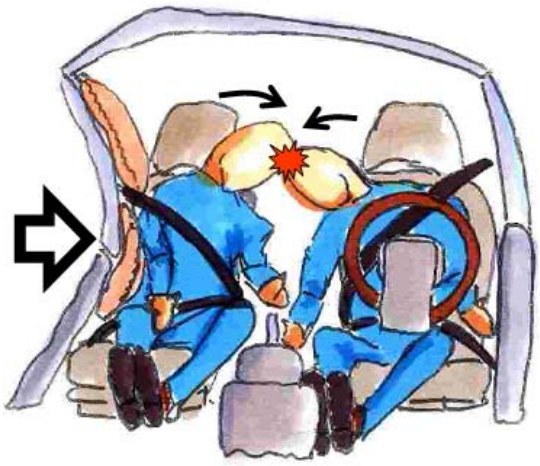


Figure 2
Both dummies are at risk for interaction

In case of two occupants in one seating row (driver and passenger next to each other) there is the further injury risk of interaction. This is shown in Figure 2. Calculations from t_1 (t_1 = triggering of restraint devices) show we want to focus on 50ms at which point the two occupants have the following status:

- Near-side occupant: Intrusion of the side structure is in full progress; the Head-Side Airbag and Thorax Airbag are fully engaged; the occupant is under its highest loading and the rebound is about to start.
- Far-side occupant: The propagation of the crash pulse throughout the vehicle structure is somewhat delayed and has just arrived at the far-side seat. Hence, the far-side occupant starts to move towards the middle of the vehicle and beyond.

As a result, the two occupants now move towards each other and there is a significant injury risk from potential occupant interaction. To prevent injuries in such a scenario a protection system is needed to keep the two occupants apart from each other.

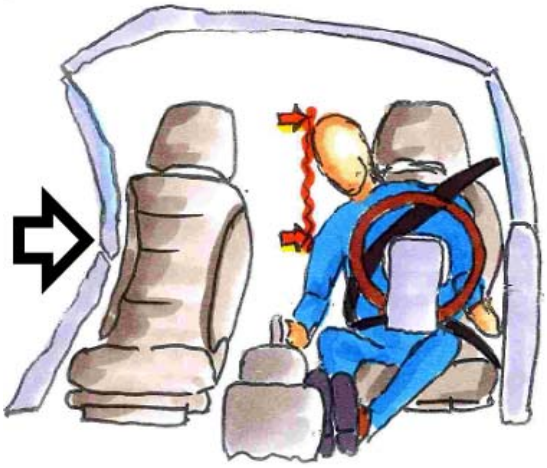


Figure 3
The far-side dummy/occupant needs to be kept as much as possible in its seat (smallest possible excursion)

Figure 3 illustrates the specification of the far-side protection device in terms of limiting the occupant excursion towards the middle of the vehicle. In summary, the following specification is postulated:

- Limit the occupant excursion towards the middle of the vehicle as much as possible, i.e. the CoG of the far-side occupant/dummy head should not cross the geometrical middle line of the vehicle.
- Cover various impact angles, e.g. 60° and 90° lateral impact (60° = 2 o'clock; 90° = 3 o'clock).
- The crash pulse should be equivalent to a standard side impact pulse e.g. LINCAP (max. acceleration at far-side seat: 20g).
- The integration of such new protection device should require minimum modifications to an existing vehicle design.
- Cost, package and weight need to be as low as possible.
- The comfort of the occupant should not be reduced by an additional protection device for the far-side condition.

Note: Throughout the development of the far-side protection system, it is assumed that the occupant is secured by a standard 3-point seatbelt including a pyrotechnic pretensioner.

Several concepts were considered as possible technical solutions:

- Extended seat side wings at shoulder and/or thorax (Feist [4])
- Improved seatbelt (e.g. X-type or H-type)
- Deployable middle console (e.g. airbag deploys upwards)
- Deployable head-shoulder-thorax support (airbag) in seat side wing

These concepts were compared with the provided specifications shown above. The preferred protection concept is an airbag mounted at the seat side wing. It is deployed by a hybrid or stored gas inflator and designed to be airtight for an extended time to provide protection not only during the first impact but also during a multiple crash scenario or a rollover. Further on this concept shall be called MID-MOUNT BAG.

MID-MOUNT BAG CONCEPT

With a novel protection system which is mounted to the seat frame in a specific way, it is possible to reduce injuries and fatalities in the case of far-side crashes significantly. The cushion is designed to keep the occupant restrained as shown in Figure 3. The specific cushion design and a special way of attachment of the protection system to the seat frame are two of three key factors for the restraint effect.

Figure 4 shows the principle function of the Mid-Mount Bag in a top view. In contrast to ordinary Side-Thorax Airbags, the Mid-Mount Bag is designed to limit the excursion of the occupant by keeping the person in its position as much as possible i.e. it is rather a supporting device than an energy absorbing one. The cushion has no means for venting.

The Mid-Mount Bag is attached and mounted to the seat frame on a lateral portion. The distal ends of the airbag can freely rotate around a lateral connection.

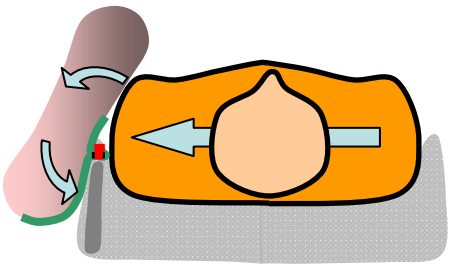


Figure 4
Principle mode of function of the Mid-Mount Bag.

Combining the advantages of the high internal pressure of the Mid-Mount Bag (approx. 200kPa) with a pyrotechnically pretensioned seatbelt, the excursion of the occupant/dummy is reduced significantly. The high pressure is the third key factor of the Mid-Mount Bag. The occupant applies a force on a lateral side of the Mid-Mount Bag, the bag then rotates around its rotational point and distributing the force to the side of the seat frame. This requires a stiff transfer of the force which is established by the internal pressure.

The design of the cushion contains some novel features. Figure 5 shows a side view of the Mid-Mount Bag.

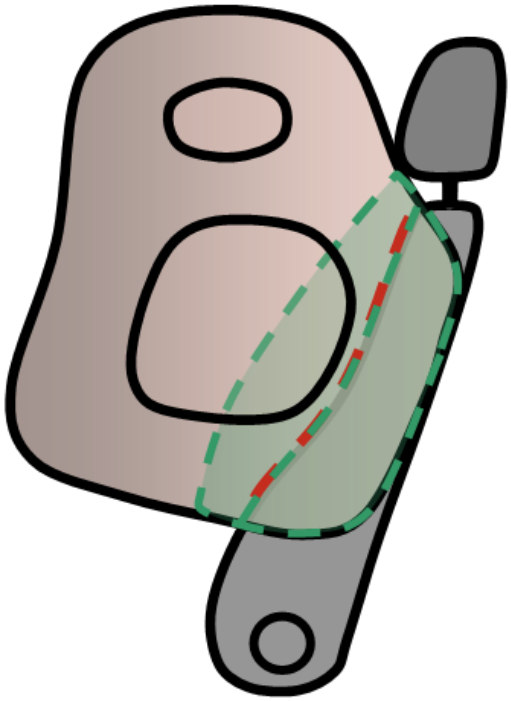


Figure 5
Side view of the Mid-Mount Bag

The cushion has been designed to meet not only perpendicular but also oblique crash types. The two big zero tethers' function is to reduce volume, allowing for a smaller inflator. Combining all those different properties of the Mid-Mount Bag, it was possible to create a protection system that achieves high benefit and improvement in the case of a far-side side collision.

RESTRAINT PERFORMANCE

Compared to ordinary side airbag applications, the Mid-Mount Bag has a slower deployment. This is due to a longer period of time for the crash pulse to reach the far-side seat/occupant. The deployment criterion was to achieve the pressure level of 200kPa within 40ms.

In Figure 6, the deployment sequence is shown. The deployment pattern must be as close as possible to the occupant in order to avoid the potential for the airbag to be hindered by the neighboring seat or occupant or any other interior part. The two high pressured areas atop and below the shoulder, including the special cushion attachment design to the seat frame, gives enough side support to adequately restrain the occupant.

This can be observed in the dynamic tests which were conducted with two different impact angles, 90deg and 60deg, and a crash pulse similar to the LINCAP test configuration.

Figure 7 shows the maximum excursion of the dummy at different impact angles. It is obvious from the pictures that the Mid-Mount Bag limits the excursion much more effectively.

Figure 6
Sequence of a deployment test

Impact angle: 90deg

Impact angle: 60deg

Figure 7
Maximum torso excursion at two different impact angles

The results of a more objective measurement are shown in Diagram 2. The excursion of the head CoG was measured in both cases with and without the Mid-Mount Bag at the 90deg and 60deg impact angle.

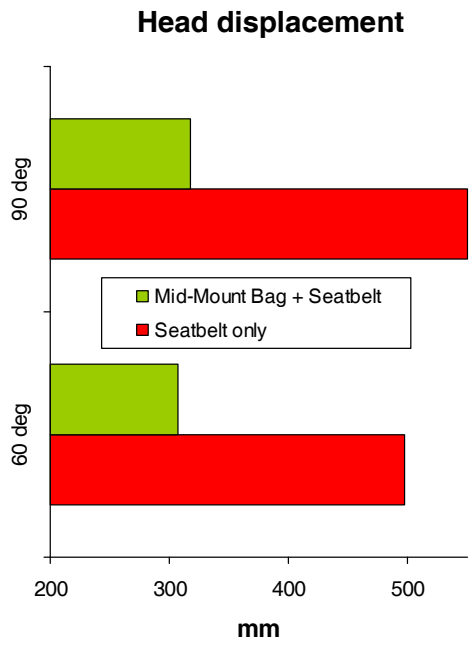


Diagram 2
Maximum head displacement at 60 deg and 90 deg impact angle

In these cases, the Mid-Mount Bag reduces the excursion by 45% in the 90deg impact angle and by 40% in the 60deg impact angle. In both cases, the head CoG did not cross the vehicle center thus fulfilling the previously set target specification.

In summary, the occupant was kept on its own vehicle seat and therefore avoided many of the typical injuries that are likely in today's vehicles without an appropriate far side protection device.

The force retaining the shoulder, which is applied by the seatbelt, is the most important for the restraining benefit. The smaller the impact angle becomes, the higher the effect of the safety belt becomes. Figure 8 shows the difference in the 60deg case with and without pretensioning.

Belt pre-tensioning

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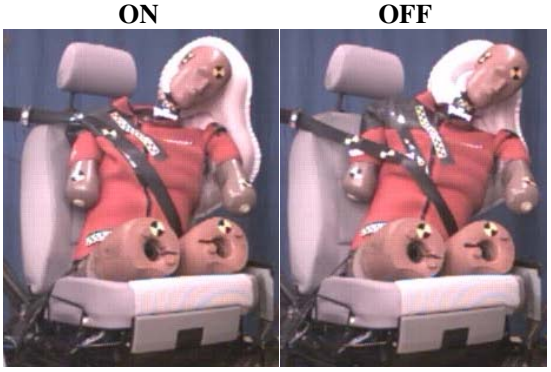

Figure 8
Comparison of torso excursion with and w/out belt pre-tensioning

OUT-OF-POSITION

Tests have been conducted to evaluate the system in OOP tests. In the absence of a defined position for a far-side device, a position according to the TWG was chosen. The most critical one was found to be a rearward facing position. The dummy was placed on the inboard side of the seat kneeling partially on the middle console. Figure 9 illustrates the dummy position. Here, the 3-year-old dummy is leaning with its torso and head directly towards the front of the tear seam through which the Mid-Mount Bag inflates.

The tests produced good results. None of the dummy values were higher than 60% of the allowed limits.

Other positions have not yet been tested due to the lack of any defined requirements for this specific application. But as soon as there are any direction-giving proposals exist, these positions will be further evaluated.

Figure 9
Dummy position in out-of-position testing

Concluding on the restraint performance the Mid-Mount Bag improves the situation for a far-side occupant in lateral collisions much by establishing an effective support between the both occupants. The Mid-Mount Bag supports the occupant that well that the occupant stays on its own vehicle side and does not cross the vehicle center line which was defined as the limit.

DISCUSSION

Considering the amount of work and resources put into the protection for near-side occupants in a side crash, it can be assumed that industry, regulatory bodies and consumer information institutes are deeply concerned about life endangered by a vehicular side-impact. But side-impact protection is not only near-side occupant protection. As shown in the chapter MOTIVATION, about a third of all side-impact injuries (MAIS 3+) are associated to far-side. However, there is no clearly determined group within the safety community to reduce these risks in daily traffic. Up until now, there have been many research papers explaining the need for a far-side protection system. A few in the industry have chosen to work towards an improvement but no determined actions were taken. This is an unfortunate situation were we clearly have an opportunity to reduce traffic fatalities.

The proposed Mid-Mount Bag concept has demonstrated its effectiveness under various requirements. Without any doubt, this concept can be further improved to produce an even better protection performance. However, there is the saying, ‘A bird in the hand is worth two in the bush’ meaning we need to take small steps in the right direction first instead of bigger steps in possibly the wrong direction.

CONCLUSIONS

The project set out to tackle the issue of occupants which are seated on the non-struck side of the vehicle in a lateral crash. By employing the Mid-Mount Bag, a clear advance in restraint performance is shown. However, no sacrifice was made towards passenger comfort. The concept is a straight forward combination of existing and new technology, offering a solution to a well known issue.

REFERENCES

[1] J. Augenstein, E. Perdeck, P. Martin, J. McKinnon, L. Labiste, J. Stratton, T. Horton, M. Singer (The William Lehmann Injury Research Center), K. Digges and J. Steps (G.W. University). 2000. “Chest/Abdominal Injuries in Side Crashes“. CIREN November 30, 2000

[2] K. Digges, (The Automotive Safety Research Institute), D. Dalmotas (Transport Canada). 2001. “Injuries to Restrained Occupants in Far-Side Crashes”. Paper Number 351. ESV Paper 2001

[3] K. Digges, P. Mohan, B. Alonso (Georg Washington University), H. Gabler (Virginia Polytechnic Institute and State University) 2005. “Characteristics of the Injury Environment in Far-Side Crashes”. AAAM Paper 2005

[4] F. Feist and J. Gugler. 2007. “APROSYS SP11 – Methodology to Address Non Struck Side Injuries”

[5] B. Fildes, M. Fitzharris (Monash University Accident Research Centre, Melbourne Australia), H. C. Gabler (Virginia Tech, Blacksburg, VA), K. Digges (Georg Washington University, VA), S. Smith (GM Holden Innovation). 2007. “Chest and Abdominal Injuries to Occupants in Far-Side Crashes”. ESV Paper 2007

[6] Charles McC. Mathias Jr. 2007. “Comparison of Mortality, Injury Severity and Injury Patterns Between Near Versus Far Occupants of Lateral Crashes”. University of Maryland, Baltimore. CIREN Quarterly Meeting March 2007

[7] OECD, International Transport Forum. “TOWARDS ZERO – Ambitious Road Safety Targets and the Safe System Approach”. 2008.
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