SENIOR IMPACT PROTECTION SYSTEMS
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ABSTRACT
To assess elderly occupant protection in frontal as well as near-side impacts two restraint systems were designed to reduce loading of the chest and thereby reduce the risk of rib fractures which are common among the elderly population. The frontal protection system is called the split buckle (SB) system, and the side impact protection system is a pre-crash dual airbag (Pre-Crash SAB).

The split buckle system comprised a separated diagonal and lap portion of the belt with the aim to add more load to the upper part of the body such as the clavicle and hence reduce the load on the lower part of the chest. The system was evaluated using a 50% THOR and PMHS tests in a generic sled test setup at 35 km/h.

The side airbag system comprised a dual bag design mounted in the seat. One pre-crash airbag with 10l volume triggered at -25ms pre-crash and one standard side airbag with 22l volume triggered at +3ms. The dual bag system was evaluated in a Euro NCAP and a high speed IIHS side impact sled configuration (64km/h, IIHS+) with the 50%-ile WorldSID.

For the split buckle system in frontal crash significant reductions in chest deflections was obtained compared to a state of the art belt system used in vehicles on the market today. Peak resultant chest deflection for the 50%-ile THOR dummy was reduced from 46mm to 32mm. Peak diagonal force with the reference belt was 4000N and for the SB system it was 5200N. For a 65 year old 46mm chest deflection corresponds to 77% and 32mm corresponds to 24% risk for an AIS3+ chest injury.

For the pre-crash dual airbag system in the lateral crash configuration significant reductions in rib deflection was obtained. For the WorldSID 50%ile dummy the peak chest deflection was reduced from 34mm to 12mm in the Euro NCAP configuration. In the IIHS+ from 52mm to 29mm. For WorldSID 52mm chest deflection corresponds to 86% risk for an AIS 3+ chest injury for a 65-year-old occupant, while 29mm chest deflection corresponds to 7%.

Using crash test dummies with a large measurement range, and assessing injury with age appropriate risk functions, show the need for improved restraint systems. The two systems evaluated in this study show good potential for addressing the issue with the fragility and frailty of the elderly population while maintaining good protection also for the younger population.

KEY WORDS
Elderly, Seat Belt, Split Buckle, Side Airbag, Frontal Impact, Side Impact
INTRODUCTION

Life expectancy in Europe was increased by eight years between 1960 and 2006, which means that the average age of car buyers/drivers in Europe also increased (Roser 2016). Due to the higher exposure of the elderly age group, the proportion of elderly fatalities have increased during the last 10 years. Elderly drivers and passengers have a higher crash involvement rate and frequently sustain more severe injuries than the general population (Youn 2013). It is also a fact the increased frailty and fragility are associated with aging (Kent et al. 2009). This also contributes to that seniors are overrepresented in regard to injuries sustained in both frontal and side impacts (Ridella et al. 2012). An evaluation of the US Crash Injury Research and Engineering Network (CIREN) database found that chest injuries are the most frequently occurring injuries among elderly automobile collision fatalities in the US (Kent et al., 2005). Injuries to the chest consists most frequently of rib fractures, sternum fractures and lung contusions. Rib fractures after a car crash are not necessarily life threatening. However, an elderly occupant ending up in hospital after a car crash may die from only a few rib fractures (Kent et al. 2008).

The primary restraint system for frontal crash is the three point belt. The belt system is generally accepted, and an effective way to restrain vehicle occupants in a frontal impact. The overall lifesaving effectiveness was estimated to 61% (Cummings et al. 2003). Despite that, the performance can be improved. Pre-tensioned and force-limiting seatbelts in combination with airbags was shown to significantly reduce thoracic loading and consequently thorax injuries for a driver (Kent 2001; Walz 2004). However, in a force limiter evaluation with the Jama Human Body Model (Antona-Makoshi et al. 2015) it was found that force limiter values of 4kn or higher regardless of body size and airbag settings resulted in a large number of rib fractures for elderly (Antona-Makoshi et al. 2016). The rib fractures occurred along the belt path and prior to airbag contact. These findings are in agreement with findings by Shaw et al. (2009) who in tests with post mortem human subject (PMHS) found sternum fractures at belt forces below 4 kn. Therefore there is a potential to improve the performance of the 3-pt belt system, in particular for the elderly population.

It was found that in side impact drivers age 75 or older were 13 times more likely to die than drivers ages 30–59 (Li et al. 2001). By comparison, the oldest drivers were about 6–7 times more likely to die in frontal or rear impact crashes per vehicle mile of travel than 30–59-year-old drivers.

The primary restraint systems to mitigate injuries in side crashes are side- and curtain airbags. The overall lifesaving effectiveness was estimated to approximately 30% for a side airbag system protecting head and thorax (Kahane 2014; MacCart and Kyryschenko 2007). However, the effectiveness has been questioned for elderly occupants who might even sustain injuries from the side airbag (Griffin et al. 2012). Rib fractures are the most frequent injury in side crashes as well as in frontal crashes (Sunnevång et al. 2015). Rib fractures in particular are sustained at lower severities for senior compared to non-senior occupants (Augenstein et al. 2005; Kent et al. 2005) Rib fractures also correlates with the likelihood of life-threatening injuries such as lungs perforation, pneumothorax and flail chest, for both side and frontal impacts (Kuppa et al., 2003; Kent at al., 2004).

One way of increasing the protection level of the side airbag, especially for senior occupants, is to use pre-crash information to deploy side airbags or to move the seat before time of impact. An investigation of innovative side impact restraint by Luzan-Narro et al. (2014) showed that thoracic injury risk decreased from 23% to 0% for a
45-year-old occupant represented by the EuroSID2-re. In a simulation study presented by Hierlinger et al (2016) a pre-crash triggered side impact protection systems for a small electric vehicle showed an overall 20% injury risk reduction also using the EuroSID2-re. However, there are no injury risk functions for a senior occupant available for the EuroSID2-re.

Due to the prevalence of rib fractures in frontal and side crashes, given the existing trend of a growing proportion of elderly road users, it is mandatory to recognize their physiological differences and to incorporate their peculiarities into the design of more effective restraints. The aim of the study is to evaluate the potential injury reducing benefits for elderly of advanced seat belt for frontal impact and airbag systems for side impact.

**METHODS**

**Frontal Impact**

A generic test rig was used as the basis for the development of the fixture to be used in the evaluation of the seat belt systems (Lopez-Valdes et al. 2015; Pipkorn et al. 2015) (Figure 1). The generic fixture (the so called Gold Standard) consisted of a rigid metallic frame mimicking the basic geometry of a standard seating position in a passenger car while allowing direct visualization of the kinematics of the occupant. This test fixture was designed to provide reasonable approximation of real world frontal crash loading of a belted occupant while providing repeatable and reproducible test conditions. The fixture was used in a study of ATD biofidelity and in development of thoracic injury criteria (Shaw et al. 2009; Lopez-Valdes et al. 2010). In these tests, the knee bar previously used in the aforementioned references was removed from the fixture. The rigid seat was considered to be a worst case scenario for the occupant due to the fact that no anti-submarining system was included. However, due to the fact that pelvis pretensioners were used the risk for the occupant to submarine in the tests was limited.

![Figure 1. Split buckle](image)

Two different three-point seat belt systems were evaluated: a pretensioned (shoulder retractor and lap) force-limiting seat belt (reference seat belt) and a new prototype belt system in which the shoulder band and the lap band were split (split buckle seat belt) (Figure 1). The lab belt and diagonal belt are independent from one another. The reference belt system comprised a shoulder (1.5kN) and lap (2kN) pretensioned, force-limiting (4kN) belt (PT+FL) seatbelt. In the mechanical tests the belt was replaced after each test. The split buckle seat belt system incorporated pretensioners at the shoulder retractor, and at the lap buckle and anchor (bilaterally on the lap band). For the split buckle system the lower anchor point of the shoulder band was moved 150 mm
forward of the lap anchor point (Figure 1). The shoulder belt force was measured at an intermediate position between the shoulder of the occupant and the D-ring. By splitting the belt system and moving the lower attachment point of the diagonal belt forward in the vehicle the loading from the belt is reduced on the lower part of the thorax and increased in the upper part (clavicle) of the thorax leading to reduced chest deflection.

Three mechanical sled tests for each restraint condition with the 50%-ile THOR dummy were performed at 35km/h with a peak acceleration of 16-19g and a duration of approximately 80ms (Table 1). A similar crash pulse was used in a study by Forman in PMHS sled tests in far-side oblique impacts (Forman et al. 2013). The crash pulse from these frontal impacts was selected for this study because the tests included here were part of a larger scope project aiming to compare the performance of the same restraint systems in frontal and oblique impacts.

Table 1. Test Matrix Frontal Impact

<table>
<thead>
<tr>
<th>Occupant type</th>
<th>Restraint</th>
<th>Speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>THOR (3 runs) mech test</td>
<td>SB</td>
<td>34.8±0.2</td>
</tr>
<tr>
<td>THOR (3 runs) mech test</td>
<td>PT+FL</td>
<td>34.7±0.0</td>
</tr>
</tbody>
</table>

The THOR dummy used in this study was one of the demonstrator dummies developed within the EC Seventh Framework project THORAX (EU-THORAX). In EU-THORAX the THOR-NT dummy was upgraded with a new thorax and shoulder (Lemmen et al. 2012, Lemmen et al. 2013). The upgraded THOR is comparable to the NHTSA THOR Mod Kit dummy with an SD3 shoulder (Mod-Kit_SD3) and the design was then used as the basis for building the THOR-M. The difference between THOR Mod-Kit SD3 and THOR-M is that the Mod-Kit is an upgrade from THOR-NT and the THOR-M is built from scratch using metric fasteners. A biofidelity evaluation performed by NHTSA showed improved biofidelity of the THOR Mod Kit with an SD3 shoulder compared to previous versions of the THOR dummy, and also similar to the THOR-M (Parent et al. 2013).

The injury risk was evaluated by means of risk curves. The injury risk was evaluated for both resultant chest deflection (Eq. 1) (Saunders 2015) and PCA Score (Eq. 2) (NHTSA 2015).

\[
P(AIS \geq 3 | age, R_{\text{max}}) = 1 - \exp\left(-\frac{R_{\text{max}}}{\exp(4.4853 - 0.0113age)}\right)^{5.03996}
\]

Eq. (1)

\[
P_{\text{PCAScore}} = 0.485\left(\frac{u_{p_{\text{tot}}}}{17.509}\right) + 0.499\left(\frac{lower_{\text{tot}}}{15.526}\right) + 0.493\left(\frac{u_{p_{\text{dif}}}}{10.479}\right) + 0.522\left(\frac{lower_{\text{dif}}}{11.996}\right)
\]

Eq. (2)

**Side Impact**
The Pre-Crash SAB system consists of two airbags. One 22 liter standard seat mounted side airbag covering shoulder, thorax and pelvis of the 50th percentile male, and one 10 liter Pre-Crash airbag (3D design) mounted inboard of the seat frame according to Figure 1.

Figure 1. Standard SAB and Pre-Crash SAB mounted in the seat.

The Pre-Crash SAB system was evaluated in a sled test representing a Euro NCAP moving deformable barrier test for a mid-size sedan. The 50th percentile male WorldSID dummy (build level E, thorax upgraded to F) was seated according to the Euro NCAP seating protocol, in a Volvo S80 driver seat and impacted by a generic door panel mounted (50 mm Ethafoam 220) on a rigid vertical structure (Figure 2).

Figure 2. Sled test setup.

Two severities were evaluated; one generic Euro NCAP MDB pulse with peak door velocity X m/s, and one IIHS high MDB in 64 km/h (IIHS+) with peak door velocity X m/s. In the Euro NCAP sled test the standard SAB was deployed at +6ms. For the Pre-Crash SAB system the Pre-Crash SAB was deployed -25ms and the standard SAB at +6ms. In the IIHS+ the standard SAB was deployed at +3ms and for the Pre-Crash SAB system the Pre-Crash bag was deployed at -25ms and then the standard SAB at +3ms. The tests were captured using four high-speed cameras and the WorldSID was instrumented in the head (acceleration), shoulder (force and deflection), thorax/abdomen (deflection and VC), and pelvis (acceleration, pubic and iliac wing force). Dummy and sled (base and door) acceleration data was filtered according to SAE J211.

Table 2. Test Matrix Side Impact

<table>
<thead>
<tr>
<th>Occupant type</th>
<th>Restraint</th>
<th>Trig time (ms)</th>
<th>Door velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WorldSID (1 run) mech test</td>
<td>Standard SAB</td>
<td>+6</td>
<td>8</td>
</tr>
<tr>
<td>WorldSID (1 run) mech test</td>
<td>Pre-Crash SAB System</td>
<td>-25 and +6</td>
<td>8</td>
</tr>
<tr>
<td>WorldSID (1 run) mech test</td>
<td>Standard SAB</td>
<td>+3</td>
<td>15</td>
</tr>
<tr>
<td>WorldSID (1 run) mech test</td>
<td>Pre-Crash SAB System</td>
<td>-25 and +3</td>
<td>15</td>
</tr>
</tbody>
</table>

Peak chest deflection (Cd), measured by the IR-Tracc (2D) was used as injury criteria for assessing AIS3+ thoracic injury risk, in terms of rib fractures, to the near-side seated 50th percentile WorldSID dummy. Injury
risk was calculated for a 45 and 67-year-old occupant using the IRC derived by Petitjean et al. (2012). All ribs, thoracic and abdominal, were treated as thoracic ribs and evaluated using the same risk curve.

\[
Risk_{\text{ATT},t} = \frac{1}{1 + \exp\left(-\frac{\ln(Cd) - \left(1.6699 \times 791 + \text{age} \times -0.01457179\right)}{\exp(-2.59449585)}\right)}
\]

\text{Eq. (1)}

RESULTS

Frontal Impact

Figure 4 shows the time history plot of the belt tension measured at the upper shoulder belt location in the THOR sled tests. Red solid lines correspond to the split buckle seatbelt while blue solid lines are the forces measured in the PT+FL belt tests. Apart from the greater pretensioner force of the split buckle seatbelt, two out of the three tests with the split buckle seatbelt resulted in a higher peak force than in the case of the PT+FL seatbelt (PT+FL: 5465.7 ± 212.7 N; 2B: 6124.7 ± 706.6 N). Figure 4 also shows that the split buckle seatbelt induced a bimodal force curve on the ATD with the first and higher peak occurring at around 100 ms followed by a smaller peak at approximately 135 ms. The second maximum observed when the split buckle seatbelt was used contributed to the longer interaction between the occupant and the restraint: while the time traces of the PT+FL force are almost negligible at t=120 ms, the curves corresponding to the split buckle seatbelt indicate that the occupant was still being restrained by the seatbelt up to t=150 ms.

![Figure 4. Time history of the upper shoulder belt force measured in the dummy tests](image)

The peak chest deflection in the local x-direction (initially aligned with the motion of the sled) was measured at the lower left IRTRACC when the PT+FL seatbelt was used while it occurred at the location of the upper left IRTRACC with the 2B due to the higher forces applied to the shoulder of the occupant. In addition, the peak deflection was greater with the PT+FL seatbelt (35.9 ± 5.6 mm vs. 25.2 ± 0.8 mm). When the three components of the deflection were combined into the calculation of the peak resultant deflection, still the PT+FL seatbelt resulted in a greater magnitude (46.2 ± 3.4 mm vs. 32.7 ± 1.1 mm). However, the resultant peak deflection was
measured at the lower left chest location regardless of the restraint used for all configuration but the split buckle x-direction measurement.

Figure 5. Peak Chest deflection for mechanical THOR dummy. Error bars correspond to the standard deviation measured in the three repeats of mechanical THOR tests.

For the mechanical THOR dummy the greatest chest deflections, in both resultant and x-direction, were measured in the PT+FL belt system (Figure 5). Smaller chest deflection were observed for the split buckle system than for the PT+FL belt system. For the mechanical THOR dummy peak chest deflection was obtained with the lower left IR-TRACC for all configurations except for the split buckle configuration in the x-direction, in which the maximum x-deflection was measured at the upper left location.

Based on the resultant chest deflection the PT+FL system resulted in 38% risk of AIS3+ thoracic injury for a 45 year old occupant. Corresponding risk for a 65 year old occupant was 77%. With the split buckle system the injury risk was reduced to 9% for a 45 year old occupant and 24% for a 65 year old occupant.

Based on the PCA score using the PT+FL system resulted in a 13% risk of an AIS3+ thoracic injury for a 45 year old occupant. Corresponding risk for a 65 year old occupant was 37%. With the split buckle system the injury risk was reduced to 2% for a 45 year old and 6% for a 65 year old occupant.

Table 3. Injury Risk

<table>
<thead>
<tr>
<th></th>
<th>AIS 3+ Injury Risk</th>
<th>PCA Score</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Resultant Deflection</td>
<td>45 year old</td>
<td>65 Year Old</td>
<td>45 year old</td>
</tr>
<tr>
<td>Reference Belt</td>
<td>38%</td>
<td>77%</td>
<td>13%</td>
<td>37%</td>
</tr>
<tr>
<td>Split Buckle</td>
<td>9%</td>
<td>24%</td>
<td>2%</td>
<td>6%</td>
</tr>
</tbody>
</table>
Side Impact

Sled base and door velocities for the two severity levels are shown in 6. For the EuroNCAP tests the door peak velocity was 8 m/s and in the IIHS+ 15 m/s.

Figure 6. Door and sled base velocity for the EuroNCAP and IIHS+ sled tests.

For the standard SAB peak chest deflection occurred at the first thoracic rib and was measured to 34mm in the EuroNCAP test and 52mm in the IIHS+ test. For the Pre-Crash SAB system the peak chest deflection occurred at the second thoracic rib in the Euro NCAP test (12mm), while peak deflection was measured at the first abdominal rib in the IIHS+ (29mm). Time history plots of chest deflection is presented in Figure 7 for the EuroNCAP tests and Figure 8 for the IIHS+ tests.

Figure 7. Chest deflection over time for EuroNCAP sled tests. Left: With the standard SAB. Right: With the Pre-Crash SAB system.

Figure 8. Chest deflection over time for IIHS+ sled tests. Left: With the standard SAB. Right: With the Pre-Crash SAB system.
The AIS3+ thoracic injury risk for a 45 and 65-year-old occupant is shown in Table 4. For the 45-year-old the standard SAB resulted in 2% for in the Euro NCAP test while at higher severity, IIHS+, the injury risk was 37%. For the 65-year-old occupant the AIS3+ injury risk was 20% in the Euro NCAP test compared to 86% in the IIHS+ test. The Pre-Crash SAB concept resulted in very low risk of injury in both severities.

Table 4. Thoracic injury risk for a 45 and 65-year-old occupant protected by standard SAB and Pre-Crash SAB System.

<table>
<thead>
<tr>
<th>AIS 3+ Injury Risk</th>
<th>EuroNCAP</th>
<th>IIHS+</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45-year-old</td>
<td>65-year-old</td>
</tr>
<tr>
<td>Reference SAB</td>
<td>2%</td>
<td>17%</td>
</tr>
<tr>
<td>Pre-Crash SAB System</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

An overview of all dummy measurements are presented in Table 5. In the Euro NCAP test with standard SAB the shoulder IR-Tracc was damaged, and in the IIHS+ tests the pubic force load sensor failed.

Table 5. WorldSID measurements for all tests.

<table>
<thead>
<tr>
<th></th>
<th>Euro NCAP MDB Sled Test</th>
<th>IIHS+ MDB Sled Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard SAB</td>
<td>Pre-Crash SAB Concept</td>
</tr>
<tr>
<td>Head Acc, Res (g)</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>Shoulder Fy (kN)</td>
<td>1.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Shoulder defl (mm)</td>
<td>54</td>
<td>N/A</td>
</tr>
<tr>
<td>Thorax Rib 1 (mm)</td>
<td>34</td>
<td>10</td>
</tr>
<tr>
<td>Thorax Rib 2 (mm)</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Thorax Rib 3 (mm)</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Abdomen Rib 1 (mm)</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>Abdomen Rib 2 (mm)</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>Pelvis Acc, Res (g)</td>
<td>41</td>
<td>37</td>
</tr>
<tr>
<td>Pubic Force (kN)</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>LH Iliac Fy (kN)</td>
<td>1.7</td>
<td>1.3</td>
</tr>
<tr>
<td>RH Iliac, Fy (kN)</td>
<td>1.1</td>
<td>0.9</td>
</tr>
</tbody>
</table>

DISCUSSION

The decrease in THOR chest deflection confirmed one of the design goals of the split buckle system. By splitting the belt system and moving the lower attachment point of the diagonal belt forward in the vehicle, while increasing the pretensioning force and adding a lap belt pretensioner peak chest deflection was reduced. Moving the lower attachment point forward, reduced the seat belt loading in the lower part and increased the load in the upper part (clavicle) of the thorax. For the THOR, combining this with increased level of the force limiter, the excursion of the body was similar to the one with the reference belt system while the chest deflection
was reduced. In one of the FL+PT tests the right upper chest deflection in x- and z-direction differed from corresponding measurements in the other 2 tests. However, the resulting right upper chest deflection was similar in all 3 tests. The reason for the difference in the measurements is not clear. However, one explanation can be that the THOR dummy is sensitive to the belt routing over the chest for deflection measurements in the x-, y-, and z-directions.

It was found that belt forces more than 4kN in the shoulder portion of the diagonal belt was associated with sternum and rib fractures (Shaw et al. 2009; Antona-Makoshi et al. 2016). In the tests the force in the shoulder portion of the belt was greater than 4 kN in both the FL+PT and split buckle tests. The intention with the split buckle belt system was to increase the load on the upper part of the thorax to structures such as the clavicle and reduce the load on the ribs in the lower part of the thorax. Therefore the force in the belt may be higher than 4 kN without inducing sternum and rib fractures.

High pretensioning forces were observed for the split buckle system (Figure 4). Higher pretensioning forces for the split buckle system than for the PT+FL system was expected due to the fact that there was no belt webbing transport possible from the chest portion to the lap portion of the belt system. The influence of these high pretensioning forces on the chest deflection of the occupant will be evaluated in future tests.

There were significant differences in the AIS 3+ injury risk predicted by resulting deflection relative to the risk predicted by PCA score. However, both methods predicted injury reduction for 65 for the split buckle belt system. In particular the AIS3+ risk reduction for resulting deflection for 65 year old went from 77% to 24%.

Compared to the standard SAB, the Pre-Crash SAB system resulted in a substantial reduction of the chest deflection, and thereby AIS3+ toracic injury risk, for both a 45 and a 65-year-old occupant. Initiating an inboard motion by the Pre-Crash SAB at 25ms prior to impact increases the distance to the intruding structure, and with two airbags the protection level during the crash phase was increased and injury risk substantially reduced. Even though peak deflection occurred at the same time for the two systems, the Pre-Crash SAB System resulted in a lower peak due to the initial movement of the occupant.

Previous studies have shown reductions in peak chest deflection for pre-crash side airbag/seat concepts using the EuroSID2 dummy. The thoracic injury risk reduction based on the peak deflection was approximately 25% (Luzan-Narro et al. 2014; Hierlinger et al. 2016). Using the WorldSID dummy, the reduction of peak chest deflection was higher and therefore also a greater reduction of injury risk was obtained, especially for an elderly occupant. With the WorldSID, injury risk assessment for a senior occupant is possible, and in the current study high benefit of a Pre-Crash SAB system was shown.

A Pre-Crash SAB system will require further development to ensure robust and reliable pre-crash deployment. Further evaluations are also needed to establish the protection level of the SAB at different pre-crash deployment times. In case of pre-crash failure it is essential that the standard SAB alone can fulfil legal and rating requirements providing the occupant with protection as evaluated today. Hence the deployment times of current SAB systems were used for the standard SAB in this study.

CONCLUSION
A split buckle belt system can reduce the chest deflection and thereby the risk for chest injuries, in particular for elderly.

A Pre-Crash SAB can substantially reduce the chest deflection and thereby the thoracic injury risk for a near-side seated occupant. In particular the elderly occupants would benefit from such a system.

REFERENCES


