INVESTIGATION INTO A RESTRAINT SYSTEM DEVICE ADDRESSING DIFFERENT OCCUPANT SEATING POSITIONS AND REAL WORLD ACCIDENT SCENARIOS

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ABSTRACT

The development of occupant restraint systems continues to evolve in response to new government regulations and consumer demand. Traditional seatbelt and airbag designs are giving way to more complex and intelligent systems that respond to crash and occupant conditions. In regulated vehicle compliance safety tests, restraint performance is usually judged against injury criteria that differ with respect to occupant size. On the basis of NASS/CDS accident data investigations, it can be observed that vehicle occupants on the passenger side sit predominantly on neutral to most-rear seat position. This paper discusses the approach of a multi-surface passenger airbag devised to enhance the protection of passenger occupants under different frontal collision scenarios in a range of varying occupant seating positions and occupant sizes. A wide range of experiments was carried out that adjusted parameters of the restraint system including seatbelt load limits, inflator outputs and various airbag shapes. This paper documents a new approach to a restraint system component as it looks behind specific test requirements to real world accident scenario comparisons.

Keywords: Airbag, Seating position, Adaptive

INTRODUCTION

Modern restraint systems for passenger cars are developed to protect occupants in the vehicle that is involved in an accident. A frontal protection system mainly consists of the seatbelt, the belt pretensioner, the load limiter and the airbag. This system is developed to address low loads to the occupants under different accident conditions. Corresponding to the different occupant sizes, the restraint system is designed to AF05 seated in frontal position, AM50 seated in neutral position and finally rear position of AM95 dummies. But do these regulated seating positions reflect actual passenger seating positions in the real world?

NASS/CDS (National Automotive Sampling System / Crashworthiness Data System) accident data supplies information about the seating position of passengers during accidents. Based on the size of the occupant which has been defined by the body weight, the seating position can be allocated. A classification of occupant sizes has been made as follows: small-size occupants of 31 to 60 kg representing AF05 dummies, mid-size occupants with a body mass of 61 to 90 kg representing AM50 dummies and finally those occupants with a weight above 90 kg representing AM95 dummies. The seating positions were defined by the possible seat notches on the passenger seat: front-most, neutral and rear-most as well as both front-most/neutral and neutral/rear-most positions.

From the data evaluated it can be seen that many occupants on the passenger side do not sit in the position for which the restraint system was designed. More than 80 % of small passengers sit in the neutral to rear-most position, while more than 60 % of large occupants do not sit in the rear-most position for which the seatbelt and passenger airbag were designed. In the following Figure 1, the seating positions of the different occupant sizes are shown as derived from NASS/CDS data. The investigation is based on 12,733 accidents in which passengers were injured between 1995 and 2004. Accidents involving busses, medium and heavy trucks have not been considered for this evaluation.

Figure 1. Seating position of occupants on the passenger side in real world

When evaluating NASS/CDS [1] accident data according to the injury area and injury levels on the passenger side, the following Figure 2 can be derived. The chart is based on 1,316 accident cases between 1995 and 2005 in which belted passengers were injured. Chest, head, lower and upper extremities are the most frequently injured body parts when evaluating the accident data according to AIS2+ injury level. The data also demonstrates that chest, head and abdomen injuries are most severe. Injuries of AIS4+ level occur.

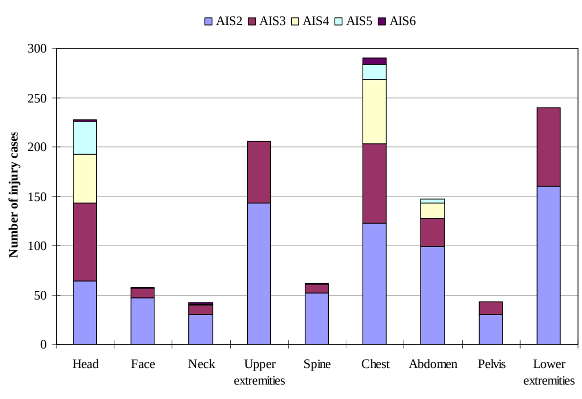


Figure 2. Injured body parts of front-seat passengers and their injury levels according to the abbreviated injury system ASI

When evaluating the same accident data, the cause of abdomen injuries of front-seat passengers can be derived. The data clearly shows that the lap belt affects AIS2+ injuries disproportionately highly compared to armrest, instrument panel or passenger airbag. Figure 3 presents the derived accident data.

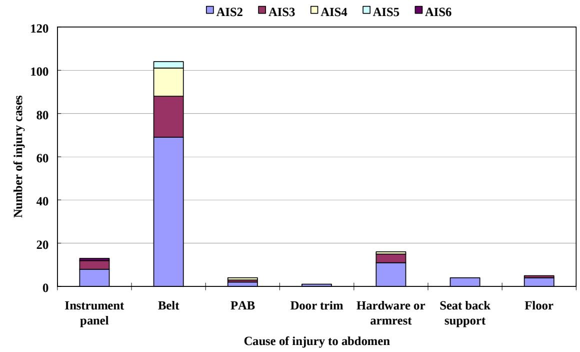


Figure 3. Cause of abdomen injuries of front-seat passengers and their injury levels according to the abbreviated injury system ASI

DESIGN CONCEPT

Nowadays, most passenger airbag cushion designs are of a simple 3-D triangular shape. In interaction with the seatbelt, they represent state-of-the-art technology for protecting passengers in both regulation and consumer test scenarios. Head and neck loads of AF05 and AM50 hybrid dummies are the scales used to determine the performance of such a restraint system, whereby the contact area between the dummy and the airbag front is characterised by the nose and chin as well as the concentrated contact load on the chest.

Based on the above information, it was decided that the development process for the multi-surface passenger airbag (MSA) would first be designed to address a low injury level of the AM50 dummy. If the injury levels in the head and neck area were too high, the loads would then be partly distributed to the chest area by a suitable change to the airbag design. It was recognised that in some cases, this change in airbag cushion design might lead to an increase of the head and neck injury level of AM50 dummies. To prevent these phenomena, a compromise between AM50 dummy head restraint performance and AF05 dummy neck injury level would have to be made.

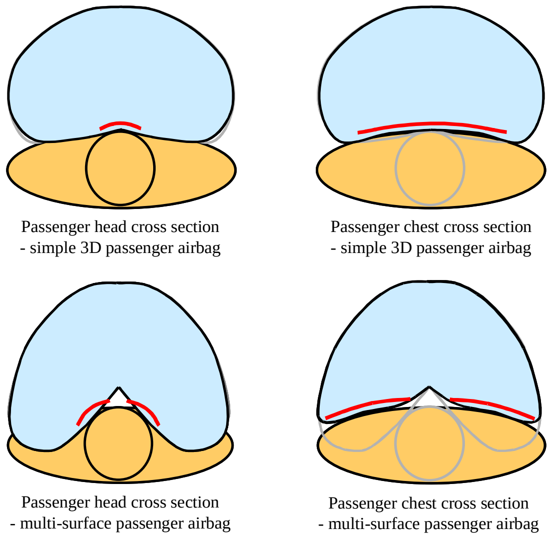


Figure 4. Comparison between simple 3-D passenger airbag and multi-surface airbag concept concerning contact force areas

Fortunately, multi-surface passenger airbags can be used to avoid the necessity of such a compromise and to counteract increased AF05 head and neck loads. In contrast to the simpler 3-D triangular cushion shape, this new airbag design technology provides distributed contact loads in the head and chest areas during the restraint phase. By causing the cushion to bulge out in two separate and specific contact zones to support the left and right areas of the chest, the resulting dent between the zones provides lateral contact of the head with the bag and supports longitudinal head movement during intrusion into the airbag, while also preventing the head from making direct contact with other hard points of the car, such as the A-pillar. The above Figure 4 shows the main differences in airbag cushion design between simple 3-D triangular shape and multi-surface airbags.

In a previous study [2], the occupant injury levels in frontal crashes with simple 3-D triangular and multi-surface passenger airbags were investigated. By using multi-body simulations with Madymo and performing sled tests, the effect on restraint performance of the different airbag design concepts was evaluated. In addition, simulations with the human simulation model THUMS were performed to analyse more deeply the protection effect of this safety device on loads experienced by the fifty percentile male. The study demonstrates that both airbag concepts, simple 3-D and multi-surface airbag, have an overall similar restraint performance which was confirmed by performing validated numerical simulations and conducting sled tests. Furthermore, the study of the multi-surface passenger airbag showed that there is a potential increase in restraint performance for the AF05 dummy under unbelted conditions. Neck loads described by the normalised neck injury value can be reduced significantly. Reasons for this potential restraint improvement are, on one hand, the wide support of the upper torso and head during intrusion of the dummy into the airbag cushion and, on the other hand, the lateral stabilisation of the dummy head by the two dents of the cushion.

In the future, vehicle innovations will lead to an increase in information available both before and during collision, for instance the size and velocity of the obstacle, the direction of the crash, the characteristics and size of the passenger-side occupant and more details about the occupant's seating position. Based on this information, the restraint performance for real-life scenarios could be advanced if the restraint device can be controlled. This new information would in the future allow adaptation of restraint performance of safety devices to whichever occupant might be seated inside the car at any given moment.

Nowadays, it is possible to detect the position in which the occupant is sitting. Thus, it would be possible to adapt the performance of the passenger airbag to offer the best protection to the occupant in any seating position.

A bag shape optimised for one seating position would not be the best option for all possible positions. If information about where the occupant is sitting were available, it would be possible to adapt the shape of the multi-surface airbag – using variable bag technology – to offer the best protection to the occupant in a wider range of incidents [3].

The concept to adapt the multi-surface passenger airbag (adaptive multi-surface airbag – AMSA) is based on the ability to adjust the length of the airbag tethers during bag deployment, maintaining the concave frontal surface. By adjusting the length of the airbag tethers initially, three shapes of the airbag, i.e. A-shape, B-shape and C-shape, can be generated. The shapes correspond to the passenger seat positions. Respectively for the front-most seat position, the airbag will deploy in A-shape, for the neutral seat position in B-shape and for the rear-most seat position in C-shape. The superimposition of the three different airbag deployment shapes of the adaptive multi-surface airbag is indicated in Figure 5 as outlines.

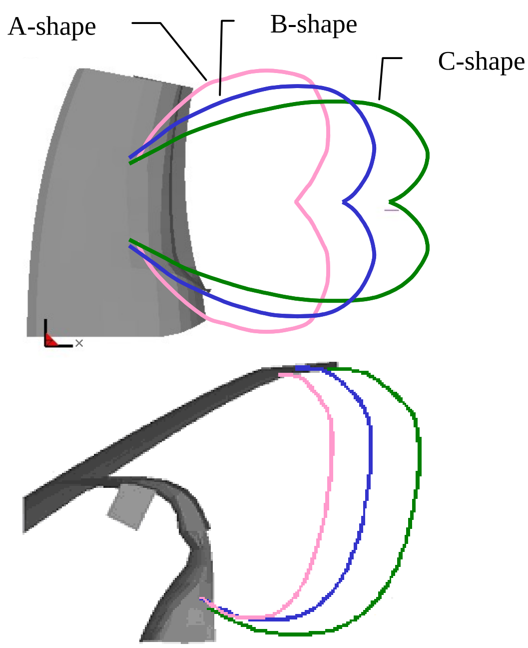


Figure 5. Superimposition of three different deployment shapes in cross-section of the adaptive multi-surface airbag for different seating positions on the passenger side; top – top view; bottom – side view

Selectable inflator gas output and variable vents complement the advanced airbag concept to supply the optimum airbag inner pressure for any occupant seating position.

NUMERICAL SIMULATION

The aim of the investigation was to assess the potential passenger restraint improvement by the application of an adaptive multi-surface airbag under the belt conditions of US-NCAP test procedure.

During the study, several multi-body simulations with Madymo [4] and tests, based on frontal crash scenarios with seatbelts and using an adaptive multi-surface passenger airbag, allowed us to evaluate the kinematics and injury level of the occupant sitting on the passenger side of the car. In addition, three different seating positions, front-most, neutral and rear-most for AF05, AM50 and AM95 dummies were investigated. To compare the restraint performance, a multi-surface passenger airbag with a volume of 130 litres and two constant vent holes each of 60 mm in diameter was selected as baseline technology. Also, a constant seatbelt force limit of 4 kN was applied. One of the variable parameters of the AMSA concept was the bag volume, which varies between 120 and 150 litres. Another parameter was the variable venting corresponding to the dummy size and seating position. The effectiveness of this airbag system was complemented by a seatbelt system that is able to adjust a belt force of 3, 4 and 5 kN. The varied parameters of the adaptive multi-surface passenger airbag are shown in Tables 1 and 2.

Table 1. AMSA parameters

	MSA	AMSA
Bag volume	130 litres	120 to150 litres
Inflator	dual stage	dual stage
Vent size	Constant	Variable
Belt force limiter	4 kN	3, 4 and 5 kN

Table 2. Seat position versus AMSA shape

Front-most position	Neutral position	Rear-most position
A-shape	B-shape	C-shape

When evaluating the simulation results of the AF05 dummy, presented in the following Figure 6 as a normalised value, it is obvious that the adaptive multi-surface airbag is able to enhance the head loads compared to the MSA passenger airbag in its regulated seating position. In fact, a reduction of the head injury criteria (HIC_{36}) by 31 % was achieved. Even under the same crash scenario but seated in the neutral or rear-most position, the protection of the head through the adaptable bag technology with its variable vent was significant, improving the HIC value by 34 to 41 %. The advancement of chest acceleration $a_{3\,ms}$ by 11 to 19 % and chest deflection by 17 to 26 % can be ascribed to the concurrence of the AMSA and the adapted belt force limit.

The results of the study indicate that the optimisations of passenger airbag shape and seatbelt force limiters are viable measures for injury reduction of the occupant. Among them, the AF05 dummy representing small adults showed significant injury mitigation on its chest.

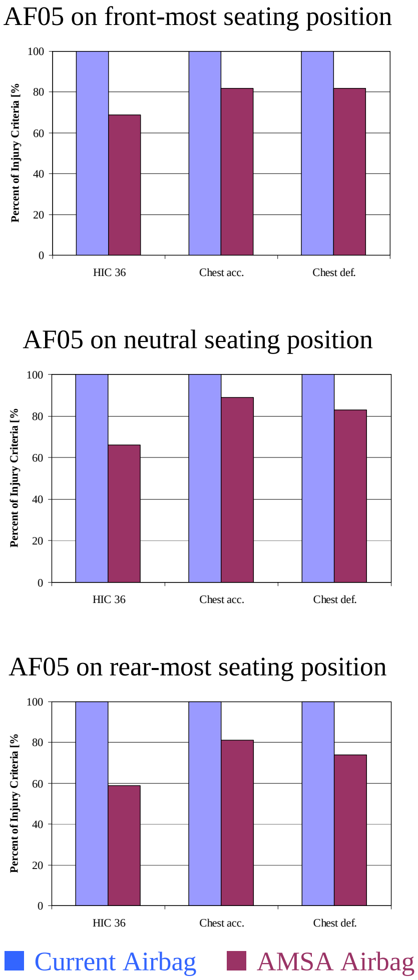


Figure 6. Simulation results – comparison of injury levels of AF05 dummy standard versus AMSA in different seating positions

The results of head and chest loads, obtained from multi-body simulations with the three different dummy sizes and three different seating positions, are indicated in Table 3. It can be clearly seen that the loads were reduced for AM50 and AM95 dummies as well. It should be noted that the injury level of seating positions for which the MSA passenger airbag is not designed was substantially reduced.

Table 3. Simulation results – comparison of all injury levels of AF05, AM50 and AM95 dummies with MSA airbag versus AMSA in different seating positions

		Improvement [%]		
		Front-most	Neutral	Rear-most
AF05	HIC_{36}	**31***	34	41
	Chest a_{3ms}	**18***	11	19
	Chest def.	**18***	17	26
AM50	HIC_{36}	39	**29***	37
	Chest a_{3ms}	8	**9***	8
	Chest def.	12	**5***	19
AM95	HIC_{36}	31	32	**34***
	Chest a_{3ms}	6	7	**4***
	Chest def.	4	9	**5***

*: Dummy in regulated seating position

The superimposition of the three AMSA shapes and the AF05 dummy in front-most and neutral and rear-most seating positions is shown in Figure 7.

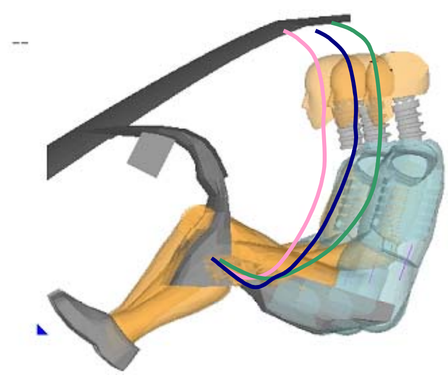


Figure 7. Superimposition of AF05 front-most/neutral/rear-most simulation model

Depending on the seating position, the response of the head acceleration under MSA and adaptive multi-surface airbag is presented in the following Figure 8 as normalised value plots for the AF05 dummy. In the design case for the small female dummy, which represents a tough requirement for the restraint system, the head acceleration response in front-most seating position is well pronounced. By applying the

AMSA, the limited forward displacement space of the occupant can be utilised to lower the head acceleration peak value under the same conditions. Airbag and seatbelt can be adjusted more gently. The effect of the adaptive multi-surface airbag under the remaining two seating positions is similar. By means of early contact between the head and the cushion during the restraint phase, the load level of the head can be kept much lower compared to the level experienced with the base airbag.

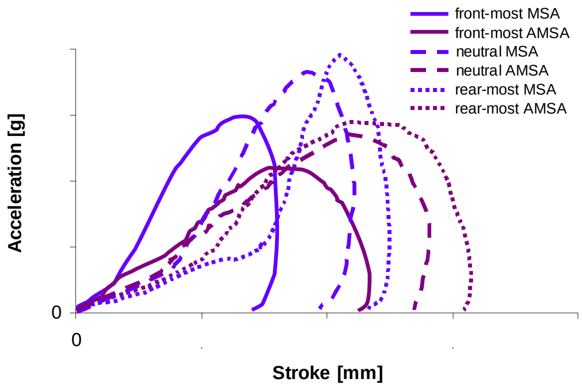


Figure 8. Head acceleration plot of AF05 in front-most, neutral and rear-most seating position with MSA and AMSA technology

Three different effects mitigating the injury criteria can be derived from these simulation results.

As already demonstrated in a previous study [1], the specific shaped passenger airbag is able to reduce dummy loads in the head and chest area due to the distributed contact forces between the dummy and the airbag. When this multi-surface airbag adapts to the seating position occupied by the dummy, earlier restraint is achieved. The loads on the human body can be reduced. – First effect.

During the restraint phase of the dummy, its kinetic energy will be absorbed mainly by belt elongation, by the force limiter of the seatbelt system and the venting of the airbag. Variable vent holes are able to adjust the damping behaviour by changing the inner pressure of the cushion, shaped according to the dummy size and its seating position and thus, forward displacement can be optimised. – Second effect.

The third effect attributed to the AMSA is the possibility to introduce a variable seatbelt force limiter to manage the different dummy sizes in their various seating positions and thus to optimise the load acting on the occupant's chest.

THE EFFECT ON ABDOMEN INJURY MITIGATION

As confirmed by the multi-body simulation, the AMSA for the passenger side could reduce the loads on head and chest, accounting for the early restraint of the dummy during the crash and for the ability to adapt energy absorption. But when reviewing the results of the evaluation in Figure 8, the protection potential for the abdomen using AMSA also needs to be validated.

Dummies like Hybrid III are not the appropriate measures for valuing and judging the injuries of the abdomen which often turn into higher AIS injury levels subsequently.

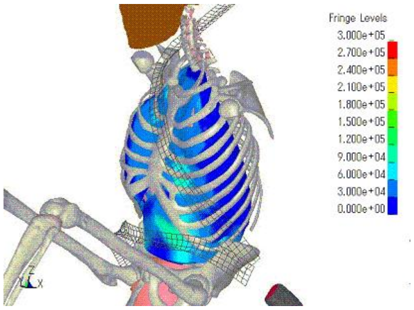
A dummy's dimensions are based on statistical and biomechanical values and are used to evaluate the performance of a restraint system according to defined injury limits. These measurements are an essential tool for the development process of a restraint system. However, numerical simulation with the human simulation model THUMS can be performed in order to assess the restraint performance concerning local loads on the human body.

The THUMS is a family of human models created by Toyota Central R&D Labs that represent a fifty percentile male. The THUMS LS-Dyna model has been validated by four different test scenarios [5] and [6]: thoracic frontal impact [7] and [8], thoracic side impact [9], pelvic side impact [9] and abdominal frontal impact [10].

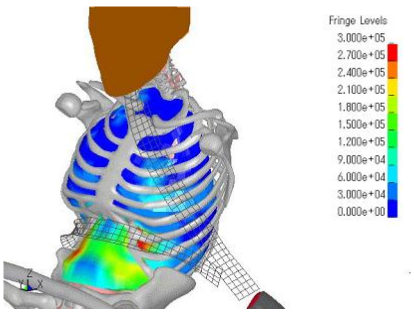
Using the fifty percentile male human model THUMS, a sled test simulation model was created in LS-Dyna based on the same vehicle environment parameters as in Madymo. The restraint components are the same as the validated components used in the multi-body simulations. The analysis was based on the same crash scenario: 56 km/h US-NCAP crash specification under belted conditions.

By applying the human body simulation model THUMS, the effect on abdomen injuries of the adaptive multi-surface airbag and the corresponding belt force limit was investigated

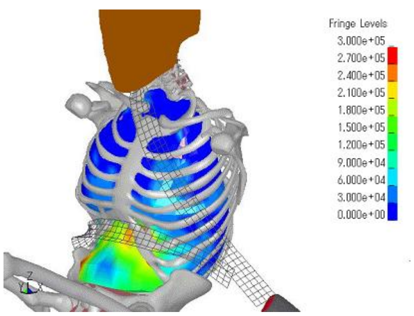
Four scenarios were set up and investigated. The basic set up involves the fifty percentile male human body seated in neutral position with MSA passenger airbag and a backrest inclination regulated per the US-NCAP specification. A second simulation model was set up with the same airbag and seating position but with a flattened backrest. The third scenario featured a flattened backrest and the adaptive multi-surface airbag. The fourth scenario was the sled model with AMSA and knee airbag.



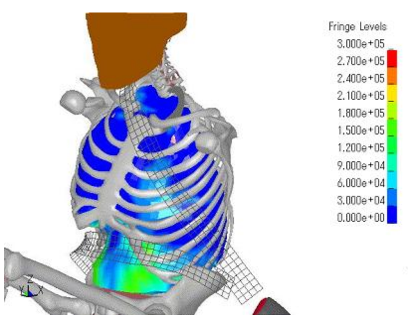
MSA passenger airbag under US-NCAP conditions



MSA passenger airbag with flattened backrest



AMSA with flattened backrest



AMSA and KAB with flattened backrest

Figure 9. Comparison of belt loads on the abdomen under different restraint conditions and backrest inclinations

The analysis of the results in Figure 9 with the MSA passenger airbag showed moderate loads on the abdomen. The results with the same airbag but with the flattened backrest showed an increase of the abdominal loads which can be attributed to the changed occupant kinematics. During the restraint phase of the occupant, the lap belt in the seat belt system slips from the pelvis to the abdomen. This results in a strong forward movement of the occupant’s pelvis and results in increased abdomen loads.

The AMSA allows to set the seat belt load limiter at a lover force level. Thanks to early restraint of the occupant during the restraint phase, there is a slight reduction in pelvis displacement as well as lap belt slippage. Hence, local forces on abdomen can be attenuated. However, slippage of the lap belt off the pelvis sill occurs. The analysis of the results with AMSA airbag in combination with a knee airbag under the same crash conditions indicates an improvement in the occupant kinematics. By introducing the knee airbag, the effect on the occupant’s pelvis displacement is further enforced. Thus, the abdominal loads on the occupants under flattened backrest conditions could be further mitigated. In the following Figure 9, the loads on the abdominal area are presented as normalised contour plots.

CONCLUSION

Simple 3-D passenger airbags are able to prevent the passenger-side occupant from experiencing high injury loads during a head-on collision. This study demonstrates that the adaptive multi-surface passenger airbag concept has an overall improved restraint performance under advantage of seating positions, which was confirmed by performing validated numerical simulations. This study confirms that the adaptive multi-surface airbag is a viable means of reducing occupant injuries in the conditions.

Furthermore, the multi-body simulation of the adaptive multi-surface passenger airbag showed that there is a potential increase in restraint performance for the AF05 dummy under belted conditions seated in different positions. Head loads described by the head injury criteria can be reduced significantly. The reasons for this potential restraint improvement are the early and wide support of the upper torso and head by the shape adaptation to the occupant’s seating position in combination with seatbelt force limits and variable vents.

In addition to numerical development tools with dedicated software, and empirical development tools such as crash and sled tests, simulation with human models complements the development process by allowing a better understanding of the protection mechanism of a restraint device. It also complements the information that is derived from a frontal dummy, making it possible to obtain data about loads on bones and organs. The numerical simulations with the human body model THUMS were also useful for gaining a better understanding of the detailed protection mechanism of the adaptive multi-surface airbag. It was observed that local stress acting on the abdomen could be reduced by a adaptive multi-surface design in combination with the variable force limiter of the seatbelt system. In addition, it was found that the restraint of knees by a knee airbag can add to the reduction of pelvis forward displacement and thus to reduce abdomen loads under backrest flattened conditions.

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