Preliminary Study of Roof Airbag Protecting Rear-Seat Occupants in Frontal Impact

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ABSTRACT

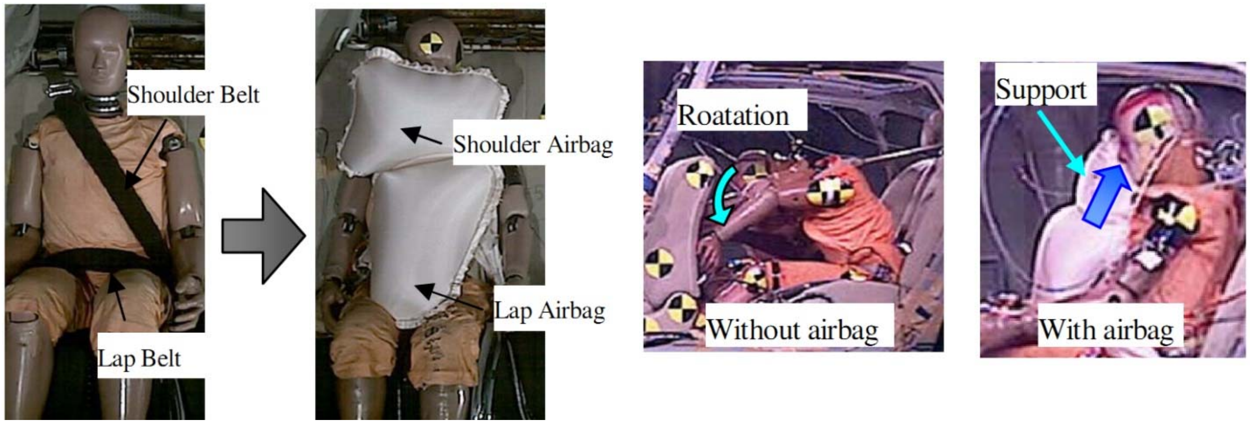
A kind of innovative Airbag, Roof Airbag (RAB), with external straps is studied via virtual engineering, which provide protection to rear-seat occupants in frontal impact. Frontal sled model with AF05 female dummy is generated in LS-DYNA, which is well correlated with full vehicle frontal crash tests in terms of the kinetics and injuries of the dummy. In addition, it is adapted for AF50 and AF95. Based on above models, different configurations of restraint system are studied, different levels of load limiter, belt with or w/o pretensioner, with or w/o RAB for instance. It can be summarized that roof airbag with low level of belt load limiter and pretensioner could provide protection to most size of rear-seat adult occupants as good as that of front-seat occupants in frontal impact.

0 INTRODUCTIONS

Frontal Airbag, Driver Airbag (DAB) and Passenger Airbag (PAB), has been fitted in most of the vehicles as standard safety restraints, which provide inevitable protection to drivers and passengers in frontal accidents. This is benefitted from the requirements of regulations and consumer metric protocols, such as NCAP. It is reported that 40% fatal and serious injuries is caused by frontal accidents for rear-seat occupants [4]. However, for rear seat occupants, such helpful restraint equipments are not fitted in any commercial vehicle, yet. Anyway, the protection to rear seat occupants in frontal impact has been paid more attentions since last decay. NHTSA funded Rear Seat Occupant Protection Research Program. In 2005, Kuppa[1] and etc. reported that protection performance of rear-seat occupants is related with the age of the occupants in frontal impact. For the children and young adult people, age below 50, it is safer seated in rear seats than in the frontal-row seats, which is opposite for older people. It may be caused by misuse of frontal airbag. In 2007, Richard Kent[2] and etc. revealed that newer vehicle models, after 1999, with better restraints has improve the benefit to occupants younger than 50 seated in frontal seats compared with vehicle models before 1999, which is similar to those seated in rear seats. Meanwhile, Koji Mizuno[3] and etc. carried out couples of full vehicle frontal impact tests at 50km/h, which emphasis the necessaries of using seatbelt to avoiding fatal injuries during frontal impact for adults and children. Lotta Jakobsson and her partners have introduced integrated booster cushion with progressive torsion bar of seatbelt to provide protection for growing Children in frontal accidents[5]. Katarina Bohman and etc. has studied the rear seat child protection due to different type of seatbelt retractors, which shown that seatbelt with load limiter and pretensioner can not only constrained the occupants well to avoiding secondary impact but also reduce the injuries by 10% to 40%[6]. Above development and research work has consolidated current vehicle fitments for protection to rear seat occupants in frontal impact.

1.0 ROOF AIRBAG WITH EXTERNAL STRAPS

Seiji Aduma[7] and etc. has studied airbag integrated with seat belt via virtual simulation and sled test, which would provide improved protection performance in terms of head and neck, fatal injuries reduced by 30% appropriately. For chest injuries, the protection of the airbag is not mentioned in the paper, which takes 35% of the fatal locations of human body. Seatbelt Airbag has advantages in no requirements of mounting or supporting system in front of occupants, which is different from traditional airbag system, shown as Figure 1. Unfortunately, it has not been implemented to automotive industry to improve frontal protection to rear seat occupants, yet.

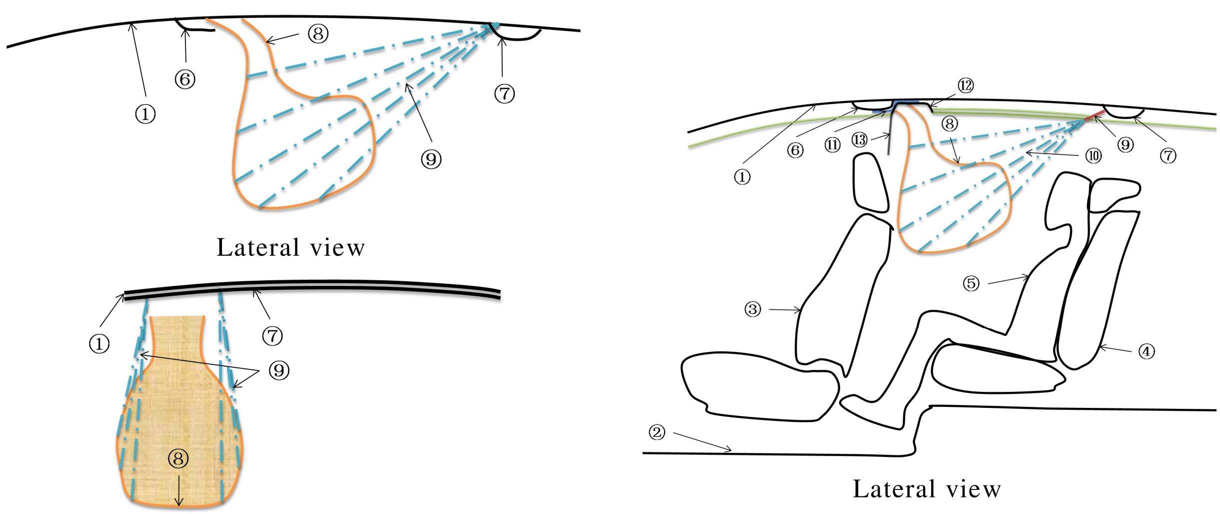


a) Seatbelt Airbag deployments b) Seatbelt Airbag Working Senario

Figure 1 Seatbelt Airbag provides protection to rear-seat occupants in frontal impact. [7]

1.1 DESIGN IDEA

According to the Rating results released by EuroNCAP, some vehicles could achieve merely maximum score, 98.8%, in frontal impact, which could be considered as perfect protection. Frontal airbag, belt load limiter, belt pretensioner and even knee airbag could be used to presuming better protection for front-seat occupants. Due to lacking head restrained, for the rear-seat occupants low level of belt load limiter is not recommended in risk of secondary contact to frontal seats. To absorb energy of the head of occupants, the airbag for rear-seat occupants should be constrained in the front of the occupants. Generally, there are frontal seats for outboard occupants. It has been designed as container of rear-row airbag. The position of frontal seats are not fixed, which cause challenges to restraint system as smart as possible. The system needs to recognize the position of the frontal seats and accordingly the airbag can be scaled to interact with the occupants well. Here, a roof airbag with external straps is studied, shown in figure 2. The housing of airbag is fixed in frontal roof cross member and the cushion attaches to external straps. The rear end of straps is fixed at rear roof cross member. So, the external straps can constrain the airbag when it interacts with rear-seat occupants in frontal impact. The airbag does not need any external support, supported by frontal seat back for instance. It covers the shortage of the head restrained in frontal impact.



a) Roof Airbag deployment b) Roof Airbag Layout

Figure 2 Deployment and layout of Roof Airbag

The influence by add-in the roof airbag to occupant protection is discussed in the following paragraphs via virtual engineering.

2.0 SLED MODEL GENERATION

To carry out virtual engineering of restraint system development, the models should be correlated overally, from materials to parts, subsystem and full models[8]. Regarding rear occupants protection, the sub system including compartment, seats, seat belts, occupants and the roof airbag, shown as figure 3, which is generated within LS-DYNA.

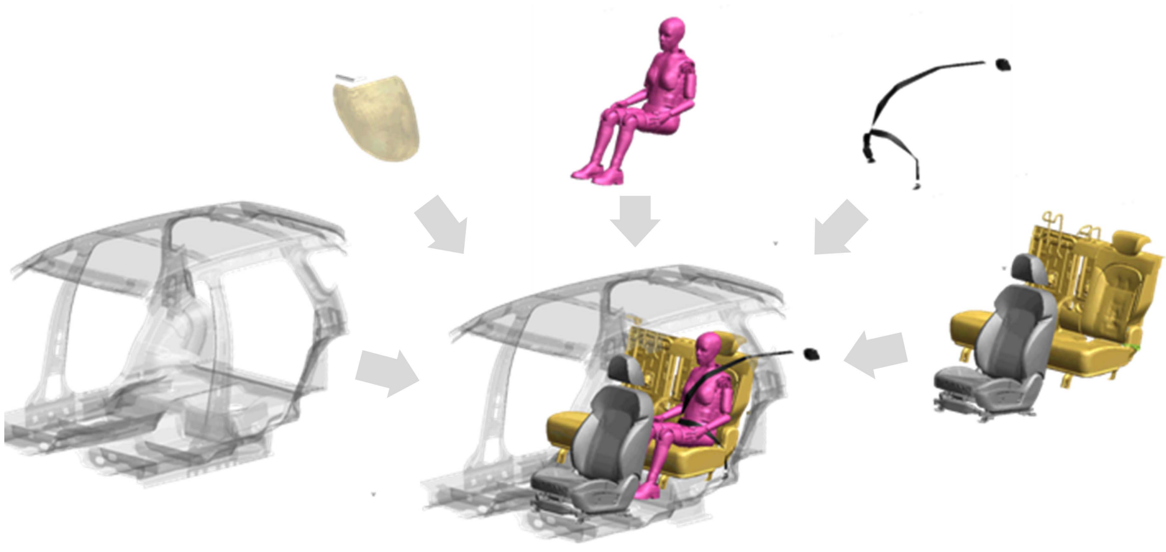


Figure 3 Rear seat occupant protection model for frontal impact

2.1 Full Vehicle Frontal Impact Tests with HIII 5% Female Dummy

According to the protocol of C-NCAP[9], full-wrap frontal barrier impact at 50km/h, called FFB, and 40% overlap frontal deformable barrier impact at 64km/h, called ODB, are carried out with one under development vehicle model. HIII 5% Female dummy is seated at rear seats in both tests, shown as Figure 4. The Seatbelt is normal emergency locking retractor with extra high level of belt load limiter, about 5kN.

a) Dummy at the seat b) Dummy in the vehicle

Figure 4 Full vehicle test with AF05 female dummy

The injury possibility of dummy in both tests is shown as figure 5. Here, the injury possibility of individual location is assessed by the method as the same as that of US-NCAP [10]. The joint injury possibility is about 41.5% in FFB at 50km/h and 31.2% in ODB at 64km/h respectively. It is reasonably that the injury possibility of lower limbs is neglect-able, 0.0%, resulted from merely no hazardous deformation to rear occupants in frontal impact.

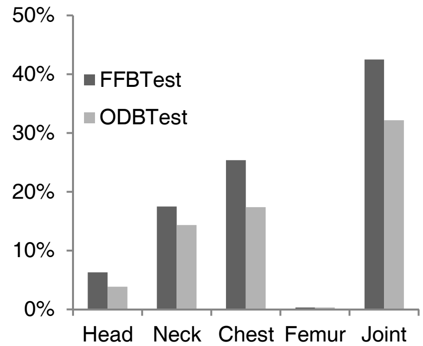
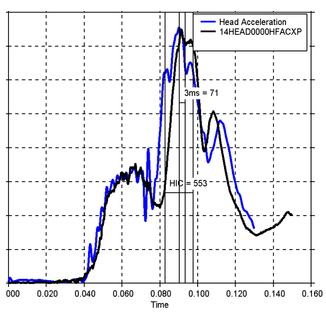


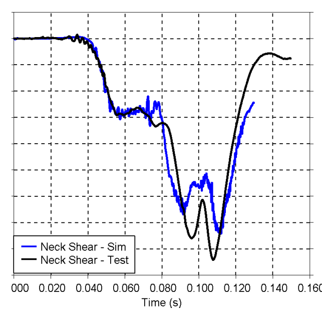
Figure 5 ASI 3+ possibility of HIII 5% Female dummy in frontal impact tests

2.2 Correlation of Sled model with HIII 5% Female Dummy

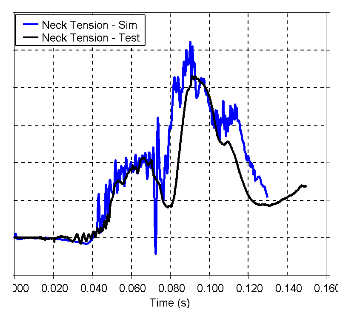
Based on the data of accelerometers from the tests, the motion of the vehicle is assigned to the virtual model, shown as figure 3. Correspondingly, the seatbelt and position of dummy is adjusted as that of tests. The results of simulation are compared with tests are shown as Figure 6, which shown good correlation level between simulation and tests in FFB.



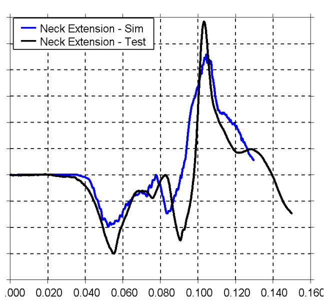
a) Head Acceleration



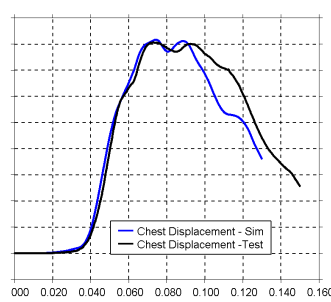
b) Neck Shear



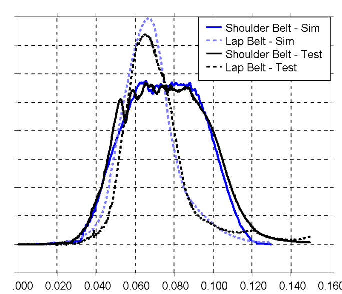
c) Neck Tesion



d) Neck Moment



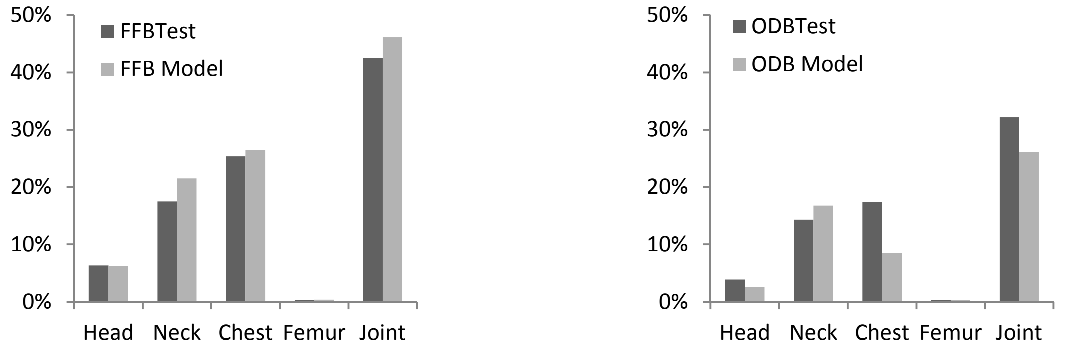
e) Chest Displacement



f) Belt Force

Figure 6 Injury and kinemics of AF05 predicted by sled model compared with that of test in FFB

The comparison of injury possibility between sled model and test are shown in figure 7. In FFB, the error of body locations predicted by sled model is less than 4%, which resulted in good joint injury possibility, 46.1%, error about 3.6%. In ODB, the injury possibility predicted by sled model is about 26.1%, 6.1% less than that of test. The injury possibility of chest predicted by sled model is 8% lower than that of test. Except for the chest, the injury possibility of other locations has good accuracy, error less than 2.4%. The error of injury possibility predicted by sled models is shown in table 1. The accuracy of sled models is acceptable to study parameters of restraint system.



a) ASI 3+ possibility of AF05 in FFB b) ASI 3+ possibility of AF05 in ODB

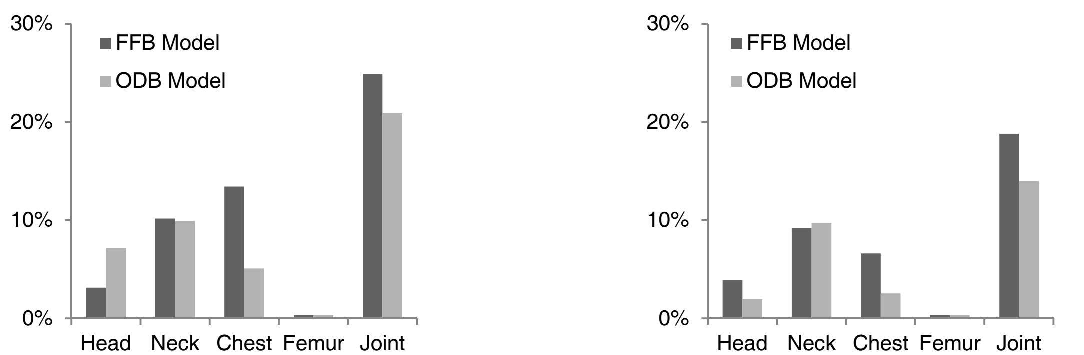
Figure 7 Comparison injury possibility of rear-seat AF05 in frontal impact between sled models and tests

Table1. Error of ASI 3+ possibility predicted by sled models compared with tests

Cases	Head	Neck	Chest	Femur	Joint
FFB	-0.1%	4.0%	1.1%	0.1%	3.6%
ODB	-1.3%	2.4%	-8.9%	0.0%	-6.1%

2.3 Adapted Sled models with HIII 50% and 95% Dummies

For the rear occupants, not only female dummy seated, normal gentle man and bigger size of occupants seat there in real life. Respectively, AF50 and AF95 dummy are adapted to the correlated sled model. The injury possibility of AF50 predicted by sled models is about 24.5% in FFB and 20.9% in ODB respectively. That of AF95 is about 18.8% in FFB and 14.0 in ODB respectively. Here, the injury limits of AF50 are used for assessment of AF95. The injury possibility of AF50 and AF95 is shown as Figure 8.



a) ASI 3+ possibility of AF 50 b) ASI 3+ possibility of AF 95

Figure 8 Injury possibility of AF 50 and AF95 in frontal impact at rear seat predicted by adapted sled models.

As the dummy size increased, the trend of injury possibility shows reduction, which is appropriate to common sense, shown as figure 9. How to provide good protection to smaller female occupants will be challenge for current restraint system. FFB load cased and AF05 will be focused in following paragraphs to improve performance of protection to rear-seat occupants.

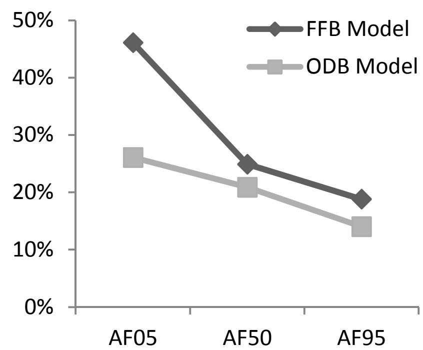


Figure 9 The trend of ASI 3+ possibility respects to dummy size in frontal impact.

3.0 RESTRAINT SYSTEM STUDY

In 2013, Jeongkeun Khim[11] and etc. studied protection performanceof different kind of seatbelt to rear occupant, AF 05 Female, via correlated sled model within LS-DYNA,which prepared for EuroNCAP FFB implemented in 2015[12]. It is reported that the pretensioner with constant load limiter will improve the dummy injuries in reduction of HIC15, Neck tension and Chest compression. As the load limiter level reduce, the chest displacement will be reduced as well, which are coincident between simulation and tests.

3.1 Affect of Load Limiter Levels

Based on correlated sled model with AF05, different levels of load limiter are studied. The injury possibility is shown as figure 8. The trend of injury possibility shows reduction overly, including head, neck and chest, as the level of load limiter decreased. The joint injury possibility ranges from 32.5% to 50.2%.

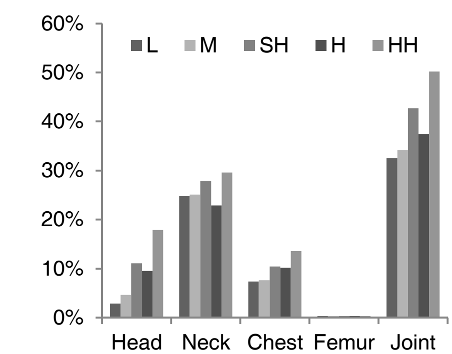


Figure 10 ASI 3+ possibility of rear-seat AF05 in FFB predicted by sled models regarding different level of load limiter:

L: Low M: Mid SH: Sub-High H: High HH: Hyper-High

However, the joint injury possibility is still very high, more than 30%, even for vehicles fitted with low level of belt load limiter of emergency retractor.

3.2 Affects of Retractor with or w/o Pretensioner

Pretenioner is common for front seats, which can constrained the occupants earlier during impact compared with emergency seat belt. Different levels of load limiter with pretensioner are studied in the sled models. As load limiter level reduced, the trend of injury possibility shows reduction overly, which is similar to the trend of emergency seatbelt, shown as Figure 11. The injury possibility can be reduced to about 20% for rear seat AF05 using low level of load limiter seatbelt with pretentioner. In addition, adding pretensioner can reduced the injury possibility of AF05 by 10% to 20% at least comparing with corresponding load-limiter level of emergency seatbelt, shown as Figure 12.

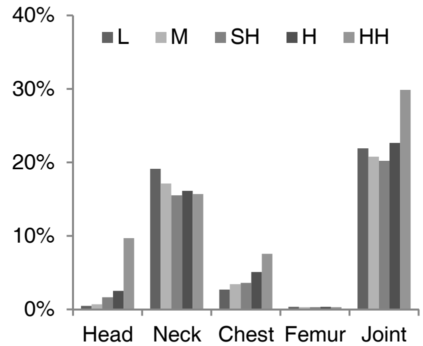


Figure 11 ASI 3+ possibility of rear-seat AF05 due to belt pretensioner respects to different levels of belt load limiter:

L: Low M: Mid SH: Sub-High H: High HH: Hyper-High

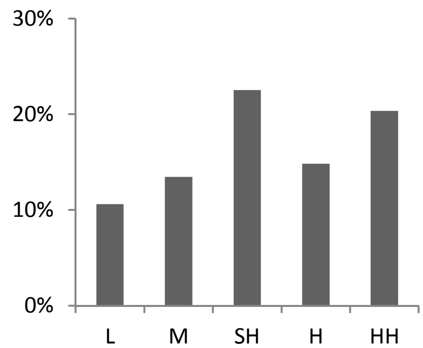
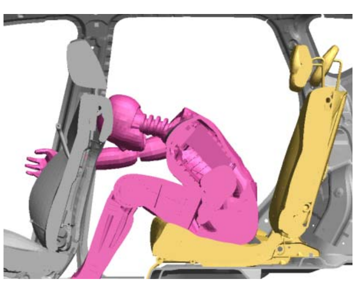


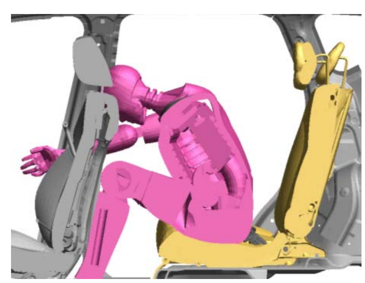
Figure 12 Improvement of ASI 3+ possibility due to belt pretensioner respects to different level of load limiter:

L: Low M: Mid SH: Sub-High H: High HH: Hyper-High

However, the lower level of load-limiter, the dummies will move more displacement. The bigger size of occupant, the dummies will moves more displacement as well. For AF05, the low level of load limiter seatbelt can be fine, there is no secondary contact. According to the results of simulation, the secondary contact can be observed for AF 50 and AF95 with low level of load limiter seatbelt, shown as Figure 13. The joint injury possibility is increased by 4.6% from 14.3% to 18.9% for AF50 and by 11.2% from 12.9% to 24.0% for AF95 respectively due to secondary impact, shown as figure 14. The fatal injury comes from head and neck. For AF50, the injury possibility is increased by 3.7% for head and by 2.6% for neck respectively. For AF95, bigger size body, the injury possibility of head is increased much more than that of AF50, mediate body, 11.1% increased. For bigger size of occupants, the injury may severer using seatbelt of low-level load limiter and pretentioner in risks of secondary contact.

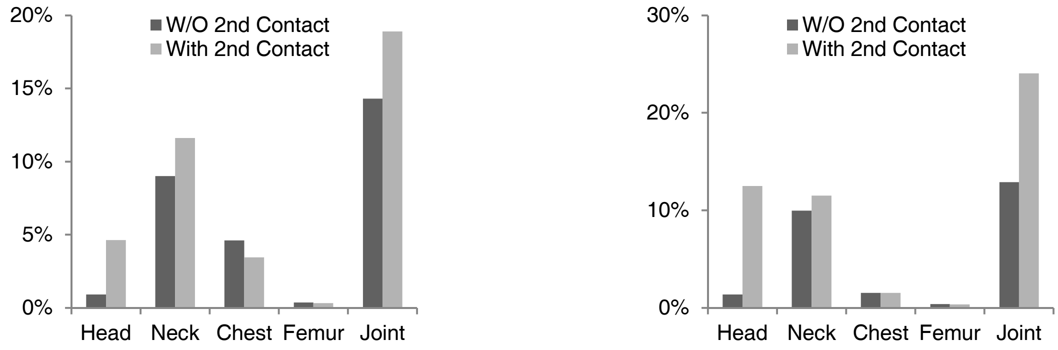


a) Secondary Contact of AF50 @100ms



b) Secondary Contact of AF 95 @100ms

Figure 13 Observed secondary contact between head and front seats for AF50 and AF95 using low level of belt load limiter



a) ASI 3+ Possibility of AF50 b) ASI 3+ Possibility of AF95

Figure 14 Comparison of injury possibility of AF50 and AF95 between with and w/o secondary contact predicted by sled models

3.3 Affects of Roof Airbag

As discussed above, the belt with low level of load limiter and pretensioner could provide better protection to rear seat occupants if there was no secondary contact, which is not suitable for most of current commercial vehicle due to constraint of the space. The roof airbag can protect the head from secondary contact even working with low level of belt load limiter. Interaction between roof airbag and different size of dummy is illustrated in Figure 15. There is no secondary contact observed. The ASI 3+ possibility of rear-seat occupants is reduced to 14.5% for AF05, 12.5% for AF50 and 10.1% for AF95 respectively, shown as Figure 16.

a) AF05@125ms b) AF 50@125ms c) AF95@125ms

Figure 15 Interaction between roof airbag and different size of rear-seat occupants in frontal impacts

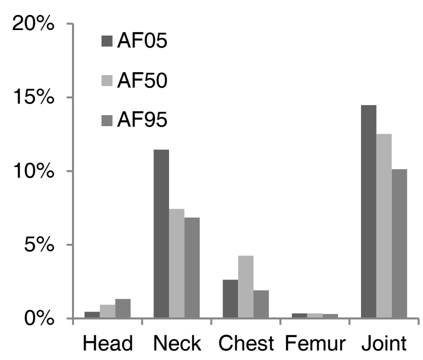


Figure 16 ASI 3+ possibility of rear-seat AF05, AF50 and AF95 with Roof Airbag in frontal impact predicted by sled models

Regarding risks of secondary contact, compared with that of w/o roof airbag, the joint injury possibility of occupants protected with Roof Airbag is reduced by 6.3% for AF05, 6.4% for AF50 and up to 13.9% for AF95 respectively, shown as figure 17. Restraint system having low-level belt load limiter, belt pretensioner and roof airbag can provide better protection to rear-seat occupants in frontal impact.

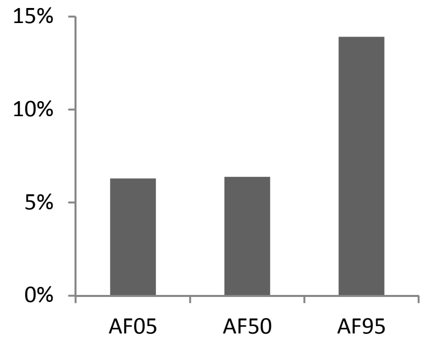


Figure 17 Benefit to ASI 3+ possibility of rear-seat AF05, AF50 and AF95 due to Roof Airbag in frontal impact predicted by sled models.

3.4 Engineering Approach of Roof Airbag

3.4.1 <u>Interaction Stability</u> In ODB impact, the benefit of protection to rear-seat occupants maybe not as good as that in FFB impact. Due to the rotation of vehicle, the head may rotate and pass by the side of the Roof airbag, shown as figure 18. The rotation of head may result in severer neck injury. It could be solved by modifying the shape of the airbag.

a) Head of AF05 passes by roof airbag   b) Head of AF05 is restrained by roof airbag

Figure 18 Head of AF05 interacts with roof airbag in ODB impact.

3.4.2 <u>Customer Survey</u> The idea has been shown on The 3rd Technology Day of Great Wall Motors at first time, which was held in October of 2014, shown as figure 19.

Figure 19 Sample of Roof Airbag shown on the 3rd Tech. Day of Great Wall Motors

Meanwhile, customer survey has been conducted on the show. The questionnaire includes seven closed questions, covering users' safety consciousness, recognization of design purpose, protection effects, demanding, numbers, impact by sunroof and price acceptance, and one open question for suggestions. 300 pieces of sheet were finished during the events. According to the investigation data, the typical number of Roof Airbag is about 2.5, which depends on the vehicle seats. As concerned, the demand of sunroof and roof airbag is about 40% and 60% respectively, shown in figure 20. More surprising, a reasonable price is appropriately accepted by customers to fit Roof Airbag, which reduces the pressure of cost due to low volume at early stage.

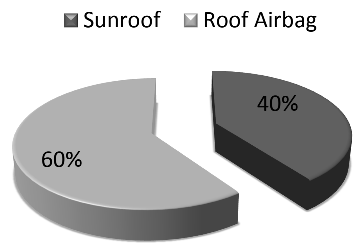
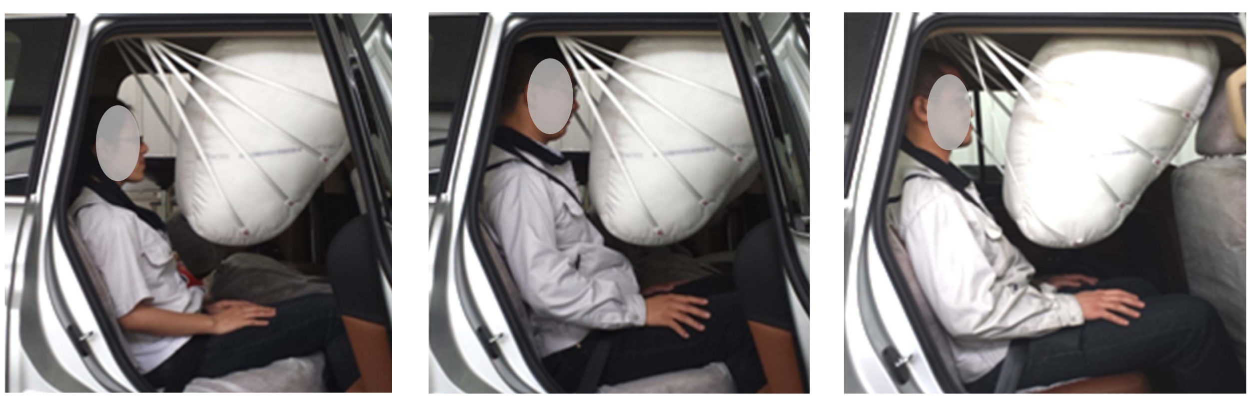


Figure 20 Demand of Roof Airbag vs. Sunroof

3.4.3 <u>Package, Transportation and Hazardous deployment</u> The airbag should cover most sizes of occupants. The shown sample can covers typical short female adult, nominal 50% and 95% male adults, shown as Figure 21.

The external straps need to be hidden inside of roof interior to minus impact on styling. Additional effort is needed to package the module during transportation.

In real life, people may sit forward, which is out of position. In this case the airbag deployment will be hazardous to occupants. Seatbelt reminder will remind people to be belted, when vehicle drive forward. Intellectual system is needed to suppress the roof airbag in case the deployment being hazardous to occupants.



a) Anologous 5% female adult b) Anologous 50% male adult c) Anologous 95% male adult

Figure 21 Deployment of roof airbag covers most of general rest-seat occupants

4.0 DISCUSSION

Through out the world, the regulations and mandatory standards require vehicle providing protection to front-seat occupants in high speed frontal impacts. Lots of attentions has been paid to frontal-row occupants protection in frontal impact. However, the requirements of protection to rear-seat occupants are required mostly by cosumer protocols. In 2004, EuroNCAP started to assess vehicle performance of child protection in frontal ODB impact. In 2012, C-NCAP started to have AF05 in rear seat in frontal impact and the head, neck and chest injury is assessed. In 2015, FFB is integrated to EuroNCAP protocol, which focus on protection to AF05. The head, neck, chest and femur will be assessed and the limits is more serious than that of AF50. According to the data released by Euro-

NCAP from 2009 to mid of March 2015, about 7%, 17 out of 242, vehicle models are fitted with belt load limiter and pretensioner for rear seats. The trend of fitment ratio of belt load limiter and pretensioner for rear seats is shown as Figure 22. So far, 3 vehicle ratings is released and 1 of them is fitted with rear-seat belt load limiter and pretentioner. The fitment ratio soaring to about 33%. The new FFB of EuroNCAP has pushed the evolution of fitments for rear-seat occupants protection forward.

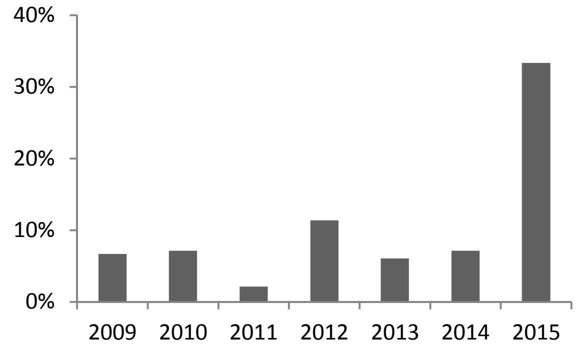


Figure 22 Fitment ratio of rear-seat belt load limiter and pretensioner by years, up to March 2015.

It can be estimated that if new protocol assessing more size of occupants will encourage the implement of roof airbag, which provide better protection to rear-seat occupants with belt load limiter and pretensioner.

5.0 CONCLUSIONS

Well correlated sled model is developed to study rear-seat occupants protection due to belt load limiter, pretensioner and roof airbag. The followings could be summarized:

1. The smaller size of occupants, the severer of injury possibility for specific restraint system.
2. For emergency belt, the lower level of load limiter, the better of protection to rear-seat AF05. The joint injury possibility of AF05 ranges from 32.5% to 50.2%.
3. Adding belt pretensioner, the joint ASI 3+ possibility of AF05 will be reduced by 10% to 20% compared with corresponding level of load limiter of emergency seatbelt. However, the ASI 3+ possibility of bigger rear-seat occupants may be increased by 6.4% for AF50 and by 13.9 for AF95 respectively in risk of secondary contact.
4. Roof airbag with low level of load limiter and pretensioner can protect all size of rear-seat occupants from secondary contact and provide better protection in frontal impact. The ASI 3+ possibility of rear-seat occupants can be reduced to 14.5% for AF05, 12.5% for AF50 and 10.1% for AF95, respectively.
5. Consumer protocols persuming better occupant protection has benefitted to rear-seat protection in frontal impact.

Protection to rear-seat occupants in frontal impact has come to vision of safety engineers. More efforts will be made to improve the performance. It will and must be stimulated by new protocol or standards requiring assessing more sizes of rear-seat occupants in frontal impact. The roof airbag or similar equipement will come true.

ACKNOWLEDGEMENTS

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