Study of Influence of Seatbelt and Airbag on Chest Deflection of THOR-50M in Simulated MPDB Impact

Bo Shang, Haidong Shen, Ruiqiang Dong, Yi Sun, Fuhao Mo, Yaowu Tan, Hailiang Wang, Xin Chen

I. INTRODUCTION

During vehicle frontal impacts, thorax is the most likely part to suffer injuries in the whole-body region for drivers after the introduction of seatbelts and airbags [1-3]. Moreover, rib fractures were commonly observed in accidents with belted occupants [4], the vast majority of chest injuries were caused by the restraint systems.

The test device for Human Occupant Restraint (THOR), an advanced dummy with better biofidelity and measurement capability, especially in chest injury prediction, was developed and planned to be used in the upcoming frontal mobile progressive deformable barrier (MPDB) impact test assessment of [5-7]. The thoracic responses of THOR dummy had been studied in sled tests and vehicle tests [8-10], and the maximum chest deflections of THOR was found in the upper right Infrared - Telescoping Rod for Assessment of Chest Compression (IR-TRACC) position. [8] investigated the effect of belt positions, double pretensioners and load limiter (LL) type on chest deflection. However, the influence of driver side airbag (DAB) was not included. [9] analyzed frontal rigid barrier impact tests using the THOR dummy conducted by NHTSA, and concluded that THOR showed a great sensitivity to combined loading by the seatbelt and the airbag, but did not describe the relationships between chest deflection and belt load level and DAB parameters.

The main goal of this study was to analyze the influence of the belt system and airbag parameters on chest deflection of the THOR dummy, using computational simulations with finite element (FE) THOR dummy models. Furthermore, to provide an optimal restraint design for the vehicle development.

II. METHODS

Front Seat Model Development and Validation

In this study, a FE model that represented the front row of a compact sedan was built. In the vehicle model, the instrument panel, the crushable steering column(2.0kN), the steering wheel with DAB, a standard 3-point belt with constant load limiter (4.0kN) and double pretensioners, the driver seat, the accelerate pedal and the front floor carpet were built. The driver seat was positioned in the frontal impact test condition of the China NCAP. The FE models of seat belt, DAB, seat and steering column had been validated by suppliers of Pan Asia Technical Automotive Center (PATAC). The full vehicle model with 50th Hybrid-III FE dummy (Version 7.18, from Humanetics, Figure 1) was well correlated with a front offset deformable barrier (ODB) test, at an impact velocity of 64.5km/h, as shown in Figure 1.

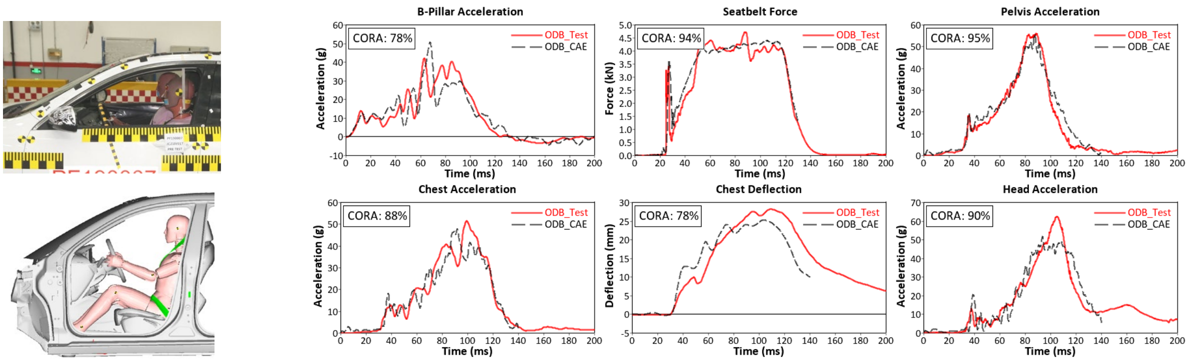

Fig 1. Front seat model, and correlation between ODB test and simulation

With the aim of studying THOR dummy thorax responses in MPDB load case, the driver model was changed from the Hybrid-III dummy to the THOR dummy (Version 1.61, from Humanetics, Figure 2). In addition, the vehicle pulse was updated from MPDB crash simulation based on the validated vehicle model above, as shown in Figure 2.

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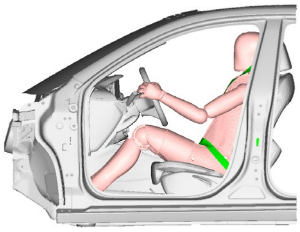
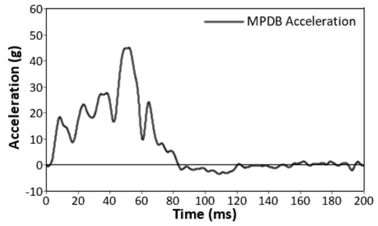


(a) front MPDB model



(b) MPDB crash pulse

Fig 2. Front MPDB model and 50km/h MPDB crash pulse

Parametric Study

To examine the influence of the seatbelt load limiter (upper shoulder belt force level) and parameters of DAB on the THOR dummy chest deflection, an analysis matrix was built based on the Taguchi method. Totally nine simulations (Table 1) were performed using the correlated front row FE ODB model and the THOR FE model. Three levels of DAB vent size, time to fire of DAB (TTF), and seatbelt load limiter were chosen.

The deflection measurements of four IR-TRACCs were chosen as the outputs. Additionally, the contact force between DAB and the thorax of THOR (DAB Contact Force), the relative displacement of chest and vehicle were examined. The simulation results were further analysed to provide an optimal combination of the belts and DAB to reduce the chest deflection.

Table 1. FE Simulation matrix of THOR dummy for changing seatbelt LL, vent and TTF of DAB

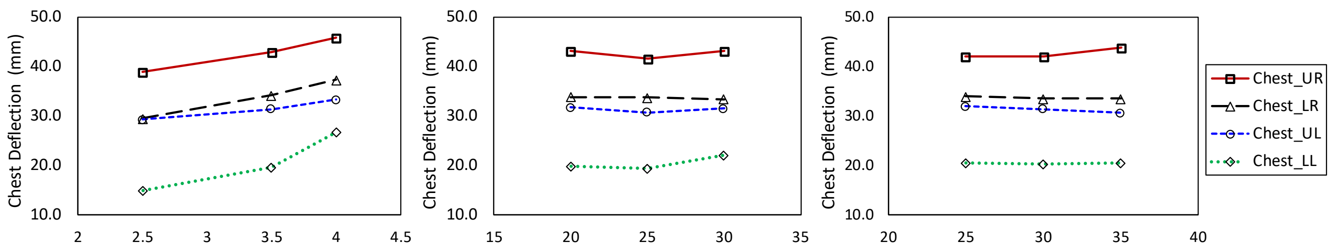
No.	Seatbelt			DAB	
	Load limiter (kN)	Reactor TTF (ms)	Anchor TTF (ms)	Vent (mm)	TTF (ms)
S01	4.0	25	30	30	25
S02	4.0	25	30	25	30
S03	4.0	25	30	20	35
S04	3.5	25	30	30	30
S05	3.5	25	30	25	35
S06	3.5	25	30	20	25
S07	2.5	25	30	30	35
S08	2.5	25	30	25	25
S09	2.5	25	30	20	30

III. INITIAL FINDINGS

The linear correlation coefficient between the seatbelt load limiter and the chest deflection was larger than 0.88, while it was 0.17 and -0.30 between DAB Vent and chest deflection, DAB TTF and chest deflection, respectively. The relative displacement of chest and vehicle, the contact force between DAB and thorax were found strongly related to shoulder belt load limiter force levels (Figure 3).

	Load Limiter	DAB Vent	DAB TTF	Chest_UR	Chest_UL	Chest_LR	Chest_LL	Chest Relative Displacement	DAB Contact Force
Load Limiter	1.00								
DAB Vent	0.00	1.00							
DAB TTF	0.00	0.00	1.00						
Chest_UR	0.88	0.02	0.23	1.00					
Chest_UL	0.90	-0.07	-0.30	0.78	1.00				
Chest_LR	0.99	-0.05	-0.06	0.87	0.92	1.00			
Chest_LL	0.88	0.17	0.00	0.76	0.81	0.88	1.00		
Chest Relative Dispacement	-0.99	0.04	0.06	-0.86	-0.92	-0.99	-0.88	1.00	
DAB Contact Force	-0.80	-0.25	0.53	-0.58	-0.88	-0.81	-0.79	0.82	1.00

Fig. 3. Linear correlation coefficient (where UR is upper right, UL is upper left, LR is lower right, LL is lower left)



(a) Shoulder blet load limiter force (kN) (b) DAB vent size(mm) (c) DAB TTF(ms)

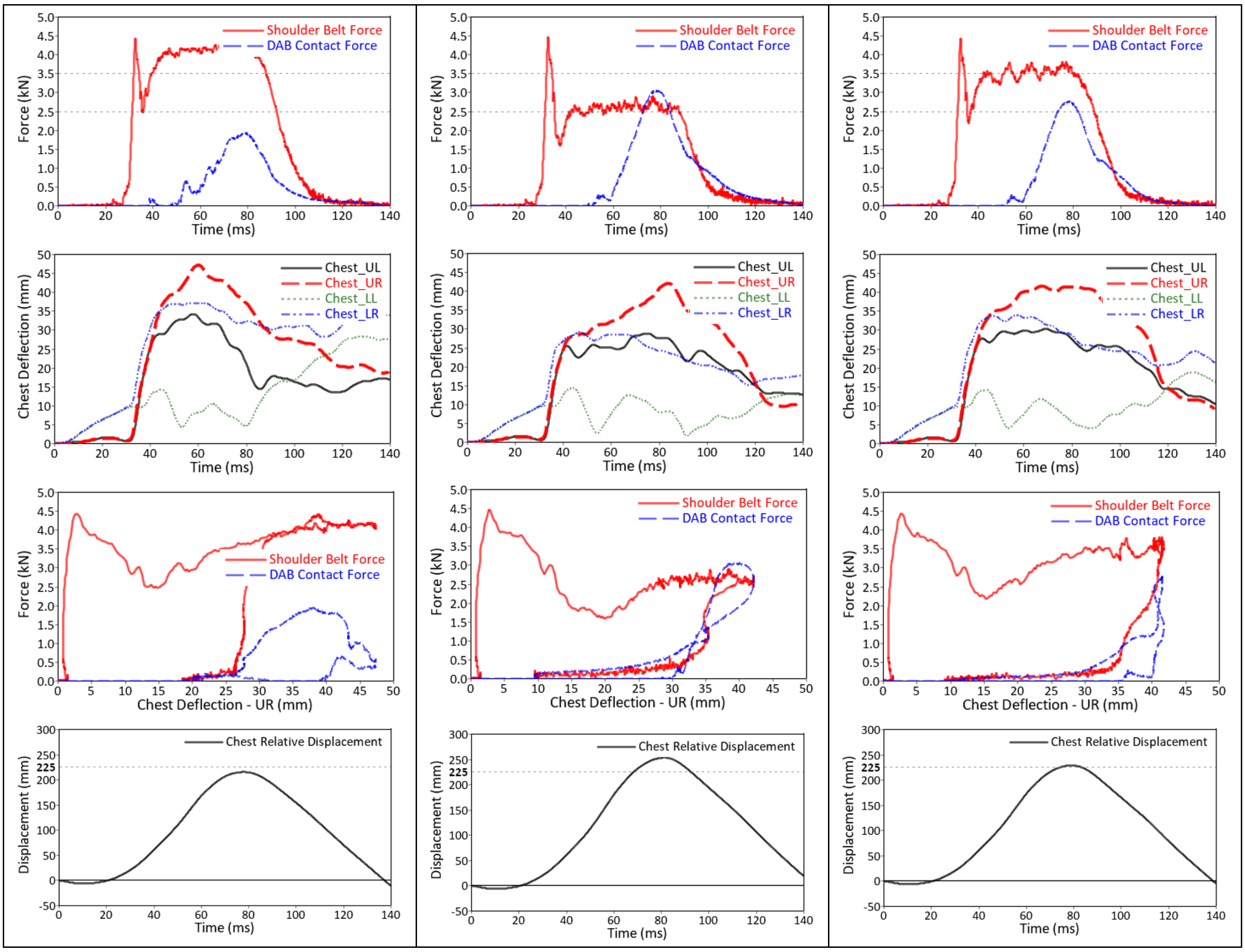
Fig. 4. Trends of chest deflection of the THOR dummy

Figure 4 showed the changes of four IR-TRACCs in the measurements of chest deflection. The highest deflections were occurring at the upper right IR-TRACC position. In general, the chest deflection of the THOR dummy from four IR-TRACC increased when the belt load limiter became higher. While the DAB TTF and vent size didn't show a clear relationship with the chest deflections.

Figure 5a showed the chest deflections, upper shoulder belt force and DAB contact force time histories of Case S01. Shoulder belt force-chest UR deflection and DAB contact force-chest UR deflection, the relative displacement between chest and vehicle were also plotted in Figure 5a. The maximum of chest deflection at the upper right IR-TRACC position occurred around 60ms, and at the stage of DAB contact force began increasing. While the results of S02, S03, S04 and S06 showed a similar changing trend, and in these cases, the shoulder belt reactor force limiter was exceeding 3.5kN, the magnitude of the contact force between DAB and the thorax was less than 2.5kN, the relative forward displacement of chest was smaller than 225mm.

Figure 5b showed that of plots of Case S07. The maximum of chest deflection at the upper right IR-TRACC position occurred after the DAB contact force had reached maximum. In this case, the shoulder belt reactor force limiter was no more than 2.5kN, while the DAB contact force was greater than 3.0kN, and the relative forward displacement of chest was larger than 225mm.

Figure 5c showed that of plots of Case S05. The chest deflection at the upper right IR-TRACC position plot showed an obvious steady stage, which started from the time of the DAB contact force began to increase and lasted to the stage of this contact force decreasing after it reached the maximum. The results of S08 and S09 showed a similar changing trend, and in these cases, the shoulder belt force was between 2.5kN and 3.5kN, while the DAB contact force was around 3.0kN, the relative forward displacement of chest was just greater than 225mm.



(a) Case S01 (b) Case S07 (c) Case S05

Figure 5. Upper should belt force, DAB contact force vs chest deflections

IV. DISCUSSION

In this study, the influences of load limiter of the shoulder belt, the vent size and TTF time of DAB on chest deflection of the THOR dummy were investigated. Although these results suggested that load limiter force level of the shoulder belt was playing an essential role in the chest deflection, the response of chest deflection might sensitive to the combination of seatbelt and airbag loading.

Based on the data analyses with simulation results, it was found that the chest deflection at the upper right IR-TRACC position was appeared to be primarily dependent on the belt load limiter when it larger than 3.5kN. When the load limiter force of the seatbelt was higher, forward displacements of the thorax became smaller, the contact force between DAB and the thorax also got smaller. The chest deflection became larger as load limiter force increasing. This was in agreement with previous study [11]. However, a higher chest deflection led to a much lower chest score in the NCAP test assessment.

When the force level of the upper shoulder belt was lower than 2.5kN, the belt was not able to better constraint dummy forward movement, forward displacements of the thorax became larger. The dummy would bottom out and contact with the steering wheel as the DAB was soft. A hard DAB could prevent this phenomenon but would cause a higher contact force and make the thorax compression larger.

While in another case, the belt load limiter force was between 2.5kN and 3.5kN, forward displacement of the thorax was constrained by the belt first and then transferred to the DAB. Under this condition, with a better tuned DAB, the thorax displacement relative to vehicle was larger than Case S01 but lower than Case S07. Moreover, there would be a good energy transition from the seatbelt loading to the DAB loading, chest deflections would not increase rapidly and helped to produce a steady behavior in the thorax deformation, which could reduce the chest deflection. A type of degressive load limiter (DLL) was effective in reducing chest deflection [8-9]. Because reactor with DLL had a higher belt force in the early stage and step-down force in the late stage, which had a potential to manage dummy movement and adjust the belt loading transition to airbag loading.

This study was conducted based on analysis of one compact sedan model with double pretensioners. The restraint system configurations may vary among fleets, and the relative distances between the THOR dummy and the interior compartment may also changes. Hence, further studies can be carried out to investigate the influences of different sizes of vehicle models and other restraint systems parameters on the thorax injuries of the THOR dummy.

V. REFERENCES

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