Innovative Seat Belt System for Reduced Chest Deflection

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ABSTRACT

An innovative seat belt concept aimed at reducing chest injuries was evaluated by means of mechanical tests and mathematical modelling. The tools used were mechanical THOR dummy, mathematical THOR dummy model, THUMS human body model and (Post Mortem Human Surrogates) PMHS. The potenital chest injury reducing benfits with a innovative seat belt concept relative to a state of the art belt system was evaluated in sled tests. The reference belt system was a state of the art belt system with a pretensioning of 2kN at the retractor, a force limiter of 4.5kN and an outer lapbelt pretensioner with a pretensioning force of 3.5kN. The innovative seat belt concept was consisting of a retractor equipped with a 2kN pretensioner at the retractor, a force limiter of 6kN and two 3.5kN pretensioners at the buckle and outer lap belt anchorage. The belt was split at the buckle and the lower end of the diagonal belt was moved 50mm forward. With the altered belt geometry the load on the lower part of the chest was reduced and the peak chest deflection was reduced relative to a state of the art belt system. In mechanical sled tests with rigid seat and an impact velocity of 35 and 30kph with the THOR dummy peak chest deflection was reduced by 8.0mm compared to a state of the art belt system. In the corresponding sled model with the THOR dummy model peak chest deflection was reduced by 13mm. Head x-displacement was increased by 26mm for the mechanical THOR dummy and 24mm for the THOR dummy model. For the THUMS model pleak chest deflection was reduced by 10mm with the split buckle system.

Generally for the mechanical THOR dummy, the THOR dummy model and the Autoliv THUMS model peak chest deflection was reduced by approximately 8-13mm with the split buckle belt system while only a minor increase in head x-displacement was observed relative to a state of the art belt system.

INTRODUCTION

Occupant fatalities and injuries in car crashes remains a global health issue. World Health Organization (WHO) found road injuries to be the 9th leading cause of death in the world after diseases such as stroke and heart disease [1]. Restraint systems have been developed and improved and have contributed to reduce the number of seriously and fatally injured occupants in vehicle crashes. However people are still being injured and killed in traffic. In Europe, frontal crashes still account 40% of all fatalities in car accidents [2]. In these accidents, injuries to the thorax are common and account for 13% of all moderate injuries and 29% of all severe injuries [3]. Statistics also show that the most frequent severe thoracic injuries are rib fractures [4]. Furthermore, the number of rib fractures is a good indicator of injuries to the thoracic and abdominal organs [5].

In testing with post mortem human subjects (PMHS) it was found that the injury threshold for chest deflection is strongly dependent upon the age of the subject [6]. This is true regardless of whether injury onset or severe injury is considered. A 30-year-old has a 50% risk of sustaining one rib fracture at a chest deflection level of 35% (of the

total width of the chest). A 70- year-old has a 50% risk of more than 6 rib fractures at 33% deflection. The age-fragility correlation is particularly important while in 2012 about 17% of all Europeans were aged 65 and older, the share of those above age 65 will rise to 28% in 2020 [7]. Due to their greater frailty and fragility, there is a need to develop restraint systems that reduces the load on the chest of the elderly occupants.

The use of mathematical human body models for restraint evaluation is increasing. One advantage with the human body models is that injuries can be assessed based on physical parameters such as strain for fracture analysis. A strain-based probabilistic method to predict rib fractures with finite element human body models was developed based on data from cortical bone coupon tests [8]. The method combined the results with collision exposure information to predict injury risk and potential intervention effectiveness in the field. An age-adjusted ultimate strain distribution was used to estimate local rib fracture probabilities within an FE model. These local probabilities were combined to predict injury risk and severity within the whole ribcage.

The Autoliv THUMS model was derived from the THUMS model (Total Human Body Model for Safety, version 1.4). The THUMS model was updated with a number of in-house modifications to improve its biofidelity in frontal impacts using table top and sled PMHS tests [9, 10]. The rhomboids major and rhomboids minor muscles that connect the medial border of the scapula to the spine were missing in the original THUMS and were added to the Autoliv THUMS. The aim of the study is to evaluate the potential injury reducing benefits of an innovative belt system, which alters the load distribution of the seat belt on the chest, relative to a state of the art 3-point belt system.

METHOD

The evaluation of the innovative seat belt system was carried out by combining mathematical modelling with mechanical testing [11]. The sled test fixture (Gold Standard) consisted of a rigid metallic frame allowing complete visual access to the occupant while preserving the basic geometry of a standard seating position of a passenger car. This test fixture was used elsewhere as a reasonable approximation to the passenger posture in the study of ATD biofidelity and in the development of thoracic injury criteria [12, 13]. The 50%-ile THOR model (THOR-M version 0.6) was used to validate the test environment (seat and seatbelt) by matching predictions from the model to experimentally measured THOR test responses (Figure 1). The impact velocity was 35 km/h and peak acceleration 20g and a duration of approximately 80ms. The reference belt system was a state of the art belt system with a pretensioning of 2kN at the retractor, a force limiter of 4.5kN of the diagonal belt and a 3.5kN outboard lap belt pretensioner.

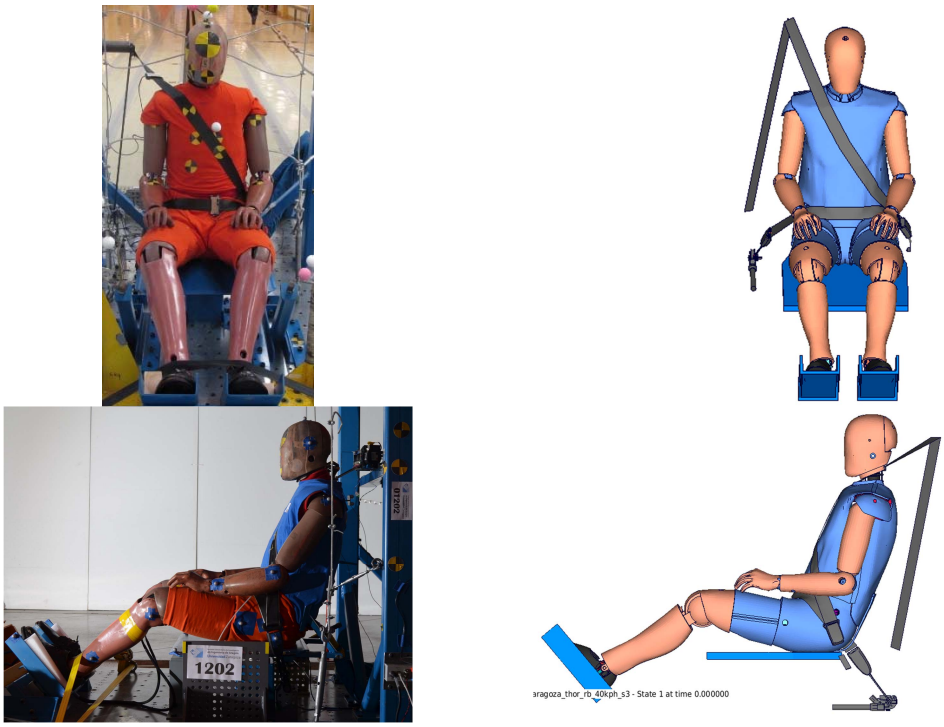

Figure 1. THOR in Gold Standard

When satisfactorily agreement between mechanical test results and mathematical model predictions was obtained for the reference belt system, the model of the restraint system was considered to be validated. The reference belt system was replaced with an innovative belt system (split buckle). The split buckle system consisted of a retractor equipped with a 3kN pretensioner at the retractor, a force limiter of 6kN at the diagonal belt and two 3.5kN pretensioners, one at the buckle and one at the outer lap belt anchorage. The belt was split at the buckle and the lower end of the diagonal belt was moved 50mm forward (Figure 2). THOR simulations were carried out with the advanced belt system, and thereafter corresponding mechanical tests with the THOR dummy were run to confirm the model predictions.

Figure 2. Split buckle

For both belt systems, standard and split buckle, chest loading in terms of mutlipoint deflection and strain were evaluated. The deflection measurement in the THOR consists of four 3D IR-Traccs (3D Infra-Red Telescoping Rod for the Assessment of Chest Compression) and their location was replicated in the THUMS model by deflection measurement at the level of the 4th rib for upper thorax, and between rib 6 and 7 for the lower thorax (Figure 3). In addition for THUMS rib strain was assessed. Head displacement (x-direction) and belt forces were also evaluated for the two systems.

Figure 3.Upper Left, Lower Left, Upper Right, Lower Right Chest Deflection Transducers THOR and THUMS

The THOR dummy model was replaced with the human body model Autoliv THUMS. Both the reference belt system and the split buckle system were analyzed with the Autoliv THUMS model. Post Mortem Human Subject (PMHS) tests were previously carried out in the same test set-up using both the reference belt system and the split buckle system, and the results were to some extent compared to the Autoliv THUMS model results in this study [11]. The PMHS were of approximately the same age (reference: 42 YO, 60 kg, 159 cm; advanced: 39 YO, 62 kg; 175 cm). The predicted head x-displacement and belt forces were compared to the corresponding measurements in the PMHS tests, and the predicted risk to sustain rib fractures were compared to the number of fractured ribs in the post mortem human subject (PMHS) tests.

A parameter study, to evaluate the influence on chest deflection on diagonal belt lower attachment point, was carried out. The lower attachment point of the diagonal belt was moved in steps of 50mm horizontally (Figure 4). The buckle was moved 50mm rearwards, 50mm forward and 100mm forward relative to the test position.

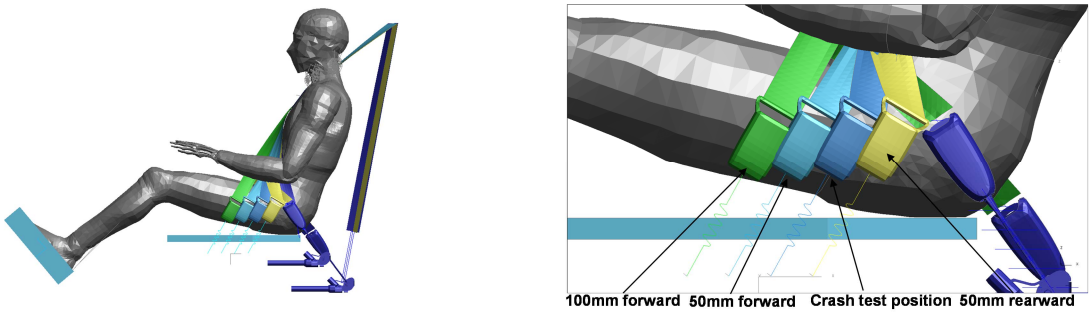

Figure 4. Lower attachment point in parameter study

RESULTS

Model Benchmark

The average peak chest x-deflection in the mechanical reference test with a state of the art belt system was for the mechanical THOR dummy 32mm in upper left IR-Tracc (Figure 5). The predicted peak chest deflection with THOR dummy model was 33mm in the upper left IR-Tracc. For the split buckle system the chest deflection in the mechanical THOR test was 25mm. For the model the predicted peak chest deflection was 20mm.

For the mechanical reference test with the THOR dummy head x-displacement was 397mm. The predicted head x-displacement was 343mm (Figure 5). For the split buckle system the x-displacement in the mechanical reference test was 405mm while for the model the head x-displacement was 367mm.

Peak belt force in the mechanical reference test was 5582N (Figure 5). While the predicted force was 4770N. In the mechanical split buckle belt system test the average diagonal belt force was 6085N. The predicted force for the split buckle system was 5606N.

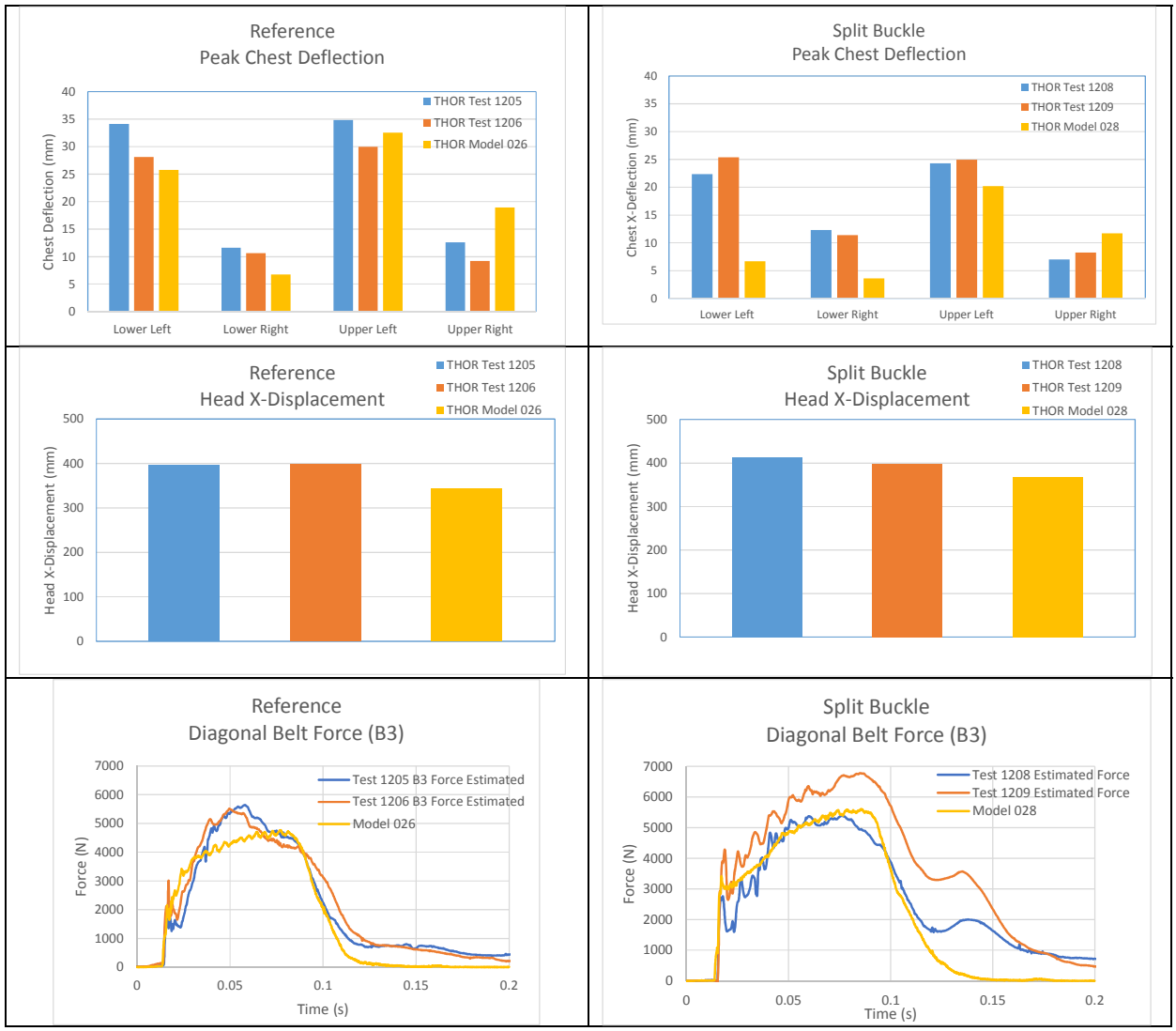

Figure 5. THOR Test Results and Model Predictions, Chest Deflection, Head X-Displacement, Diagonal Belt Force

For the THUMS model the predicted chest deflection for the reference belt system was 30mm in the upper left transducer and for the split buckle system the predicted chest deflection was 20mm (Figure 6).

The max head x-displacement in the reference test for the PMHS was 189mm while for THUMS the predicted head x-displacement was 378mm (Figure 6). For the split buckle system the max head x-displacement for the PMHS was 306mm while for THUMS the predicted x-displacement was 409mm.

The diagonal belt force in the reference PMHS test was 4000N. The predicted force with THUMS was 3900N. For the split buckle system the diagonal belt force in the PMHS test was 6000N while the predicted force was 5500kN.

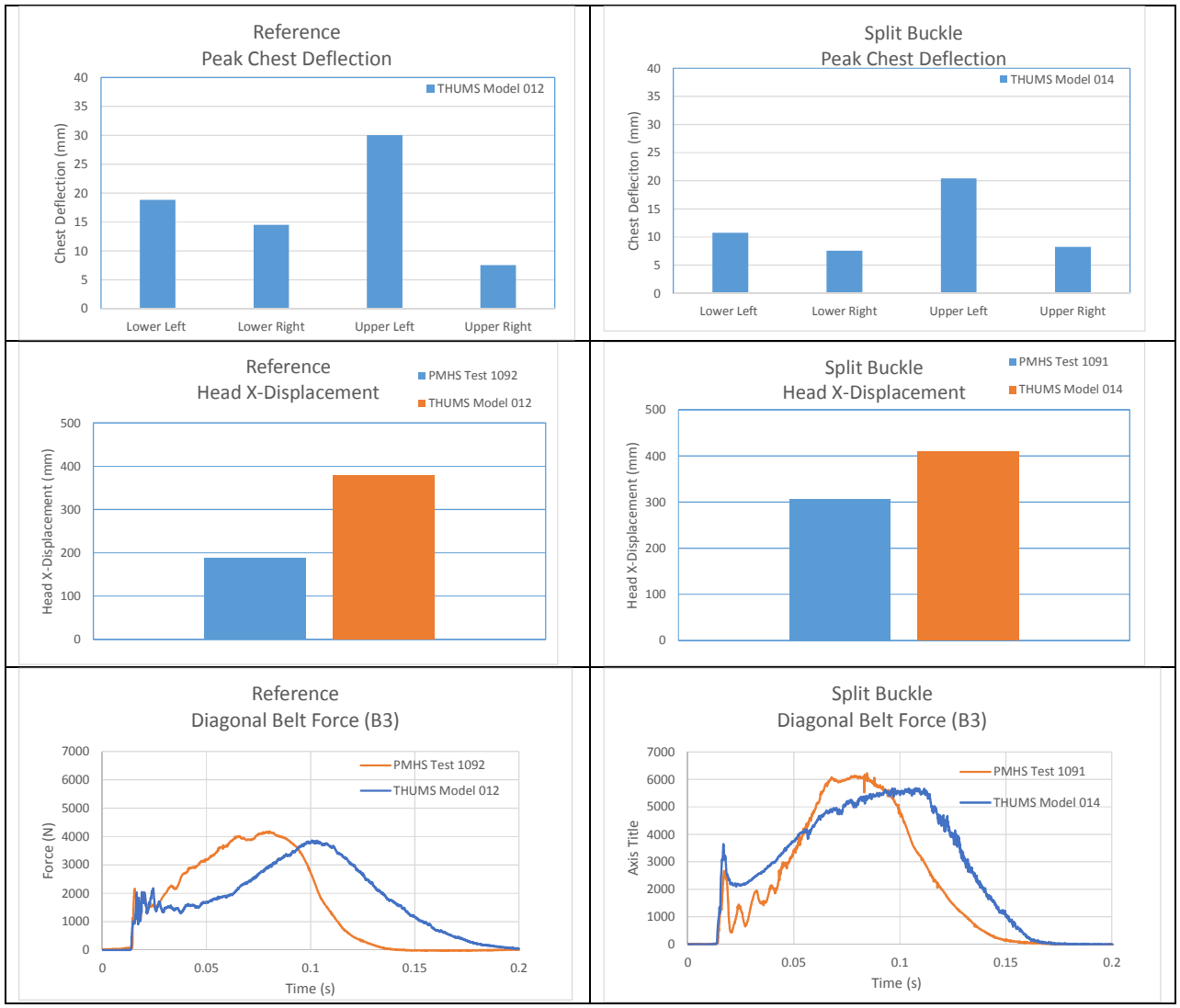

Figure 6. PMHS Test Results and THUMS Model Predictions Chest Deflection, Head X-Displacement, Diagonal Belt Force

Split Buckle Parameter Study

In the parameter study carried out for the split buckle system the lower attachment point for the diagonal point was moved in steps of 50mm. The predicted peak chest deflection for THOR was obtained at the upper left IR-Tracc for all locations of the lower attachment point (Figure 7). By moving the attachment point 150mm forward in the vehicle the chest deflection was reduced from 22mm to 15mm while ead x-displacement was increased by 41mm, from 357mm to 398mm.

For THUMS the peak chest deflection was for the upper left IR-Tracc (Figure 7). By moving the lower attachment point 150mm forward peak chest deflection was reduced from 24mm to 15mm while the head x-displacement was increased by 95mm, from 376mm to 471mm.

Peak belt forces for both the THOR dummy model and THUMS were 5500N. The belt forces were not altered when the attachment point was moved forward in the vehicle.

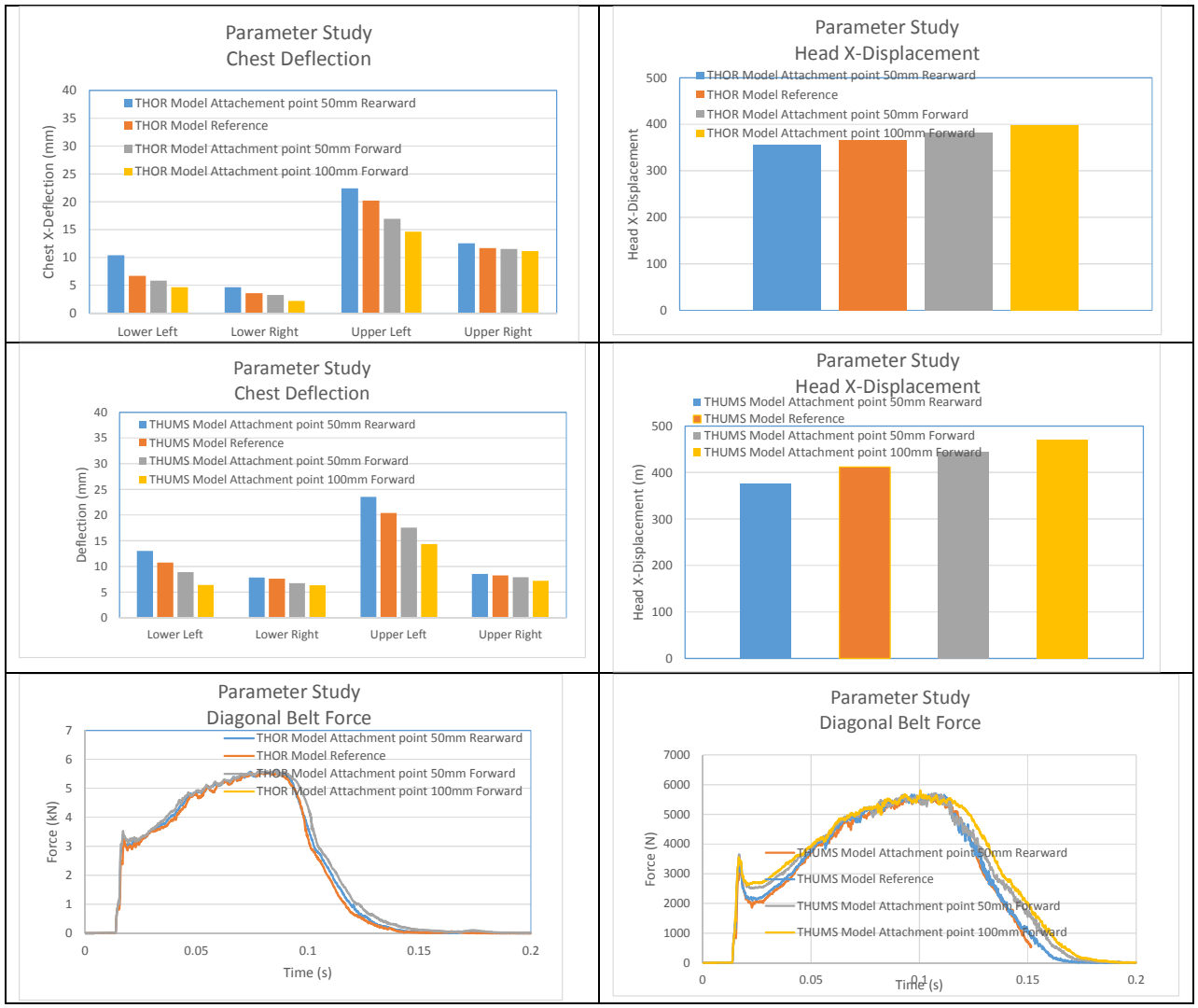

Figure 7. THOR model & THUMS Chest Deflection, Head-Displacement and Belt Forces for Altered Lower Attachment Point

For the Autoliv THUMS 0 fractured ribs were predicted for 39 and 60 year old occupants for both the reference belt system and the split buckle system.

DISCUSSION

By splitting the belt system and moving the lower attachment point of the diagonal belt forward in the vehicle, increasing the pretensioning force and adding a lap belt pretensioner peak chest deflection was reduced. By moving the lower attachment point forward the load from the belt is reduced in the lower part of the chest. By increasing the level of the load limiter the excursion of the body was kept at the same level as for the reference belt system while the chest deflection was reduced. There is a potentially increased risk of clavicle injuries due to the increased force at the shoulder level. However, in the PMHS tests no clavicle injuries were observed [11]. In addition, the influence on pelvis kinematics of the split buckle system will be evaluated in future analysis.

A split buckle in vehicle system can consists of one buckle that splits in a crash (Figure 8). The occupant buckles up in the same way as a state-of-the-art belt system today. Both the diagonal belt and the lap belt are pretensioned by moving the buckle downwards. In a crash the lower point of the diagonal belt is moved forward while the lap portion of the belt remains at the initial location.

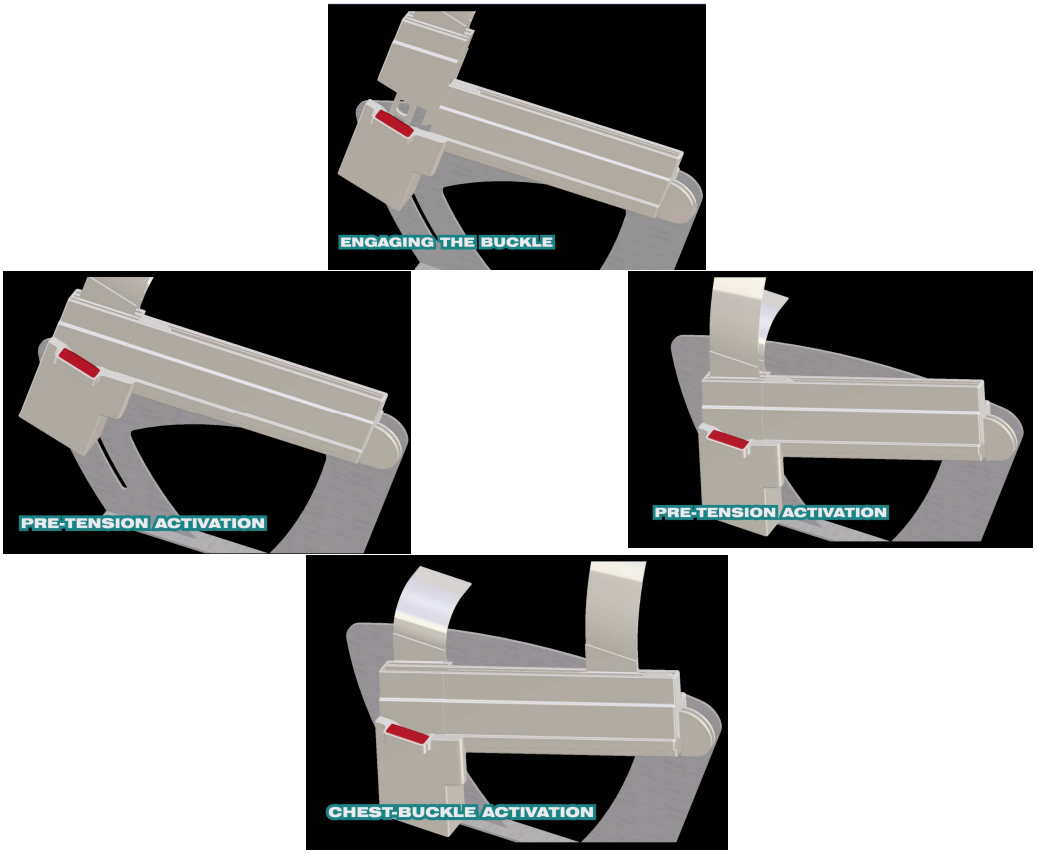

Figure 8. Split buckle activation

Generally there was agreement between the predictions from the model and the results from the mechanical sled tests. However, there were some discrepancies between predicted and measured chest deflections. However, for the reference test there was agreement for the two IR-Traccs with the greatest deflections (Figure 5). For the split buckle test there was agreement between the predicted and measured upper left and upper right deflections. The reason for the poor agreement for some of the chest deflection predictions can be that the model of the THOR dummy used was a beta version of the model and not fully validated. Due to the fact that the THOR model predicted the same reduction in chest deflection as was observed in the mechanical tests the model was considered sufficiently valid for the intentions of this study.

For the PMHS there was a significant (over 100mm) increase in head x-displacement with the split buckle system relative to the excursion with the reference belt system. Such increase was not observed for neither the mechanical THOR dummy, the mathematical THOR dummy model or for THUMS. For the mechanical THOR dummy there was an increase of 37mm in head x-displacement for the THOR dummy model and THUMS there were an increase in head x-displacement of 71mm and 31mm respectively. The reason for the significant increase in head x-displacement for the PMHS in the split buckle system compared to the reference system was an increased forward motion of the pelvis that resulted in reduced torso pitch. This finding is discussed in [11] in detail. However, it is important to point out that just one PMHS test is not enough to assess the performance of both systems. In future analyses, the reason for the increase for the PMHS will be investigated in more detail.

CONCLUSION

The split buckle system:

can reduce chest deflection for a belted occupant

can have a minor increase in head x-displacement

can reduce the number of fractured ribs for an elderly occupant

can be made with one buckle for identical buckle up proceedure as today

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