Challenges in Steering Wheel Rim to Thorax Impacts Using Finite Element Hybrid III and Human Body Models for Heavy Vehicle Frontal Crash Applications

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ABSTRACT

A risk of severe injuries from steering wheel rim to thorax contacts has been identified in heavy vehicle frontal collisions. The objective of this study was to investigate the effects in changing the steering wheel rim tilt angle on the thorax of the Hybrid III and a human body model THUMS with respect to chest deflection and steering wheel rim contact interaction. It was found that the Hybrid III chest is more sensitive to changes in steering wheel tilt angle than the THUMS.

Keywords: Finite element method, Steering Wheels, Hybrid III, Thorax, Truck

THE SITUATION OF THE DRIVER IN HEAVY COMMERCIAL VEHICLES IS DIFFERENT to drivers of passenger cars in respect to the driver cabin geometry and the seated posture. In the event of a frontal crash in a heavy vehicle, such as a truck, these differences increase the risk of steering wheel rim to upper body contact (Gwehenberger et al., 2002) which means that the driver of a truck is at risk of sustaining severe thoracic injuries (Sukegawa et al., 2001). The Hybrid III dummy is used for frontal truck crash testing even though this crash test dummy was mainly developed for passenger car safety evaluation, due to high accumulated laboratory knowledge and availability. To be able to determine if the Hybrid III dummy can be appropriately used in frontal truck crash testing, it is necessary to determine how the dummy behaves under the given conditions. By establishing that the sampled sensory data from the dummy reflect the responses and general kinematical behavior of a human, the full potential of the Hybrid III dummy as a tool to improve safety, can be put to use.

The objective of this study is to investigate the use of the Hybrid III dummy in frontal crashes with chest to steering wheel contacts in heavy truck conditions. In addition an extended understanding of the Hybrid III's sensitivity to steering wheel tilt angle on the deflection response, and similarities or differences to a human driver will be studied using finite element simulations.

METHODOLOGY

A generic finite element (FE) truck steering wheel was used to simulate impacts on the thorax of the FE Hybrid III (LS-Dyna Ver. 7.1.2 by First Technology Safety Systems) and the ***T****otal* ***HU****man* ***M****odel for* ***S****afety* (LS-Dyna Ver. 3.0 Toyota Central R&D Lab., inc.) FE human body model (hereafter called THUMS) using the FE solver code LS-DYNA® (Hallquist, 2007). The basic shape of the steering wheel is a torus with a greater diameter of 430 mm and minor diameter of 25 mm. It was tilted at a number of angles (0 to 30 degree with a 10 degree increment) and constrained in the centre hub. The FE driver models were adjusted to impact the steering wheel perpendicularly to the coronal plane for the 0 degree steering wheel tilt angle (Figure 1A). The steering wheel tilt angle was changed by rotating the steering wheel in the midsagittal plane, keeping the location of impact identical at each angle. The point of impact on the thorax of the Hybrid III was midsagittally centered between the third and fourth rib. Similarly, for the THUMS the location was centered on the chest at of the fourth interspace of the ribs. Static and dynamic contact friction coefficient was set to 0.3.

The FE driver models were set to an initial velocity of 5.0 m/s to represent the relative velocity of a belted driver to the steering wheel in a 30 km/h delta-v crash. The model's femurs were constrained along their longitudinal axis using non elastic springs with stiffness characteristics given in Figure 1B, to stay below the femur fracture level (Nahum and Melvin, 1993). The springs were modeled to simulate a knee bolster contact, set to engage approximately 50 mm after first contact with the steering wheel. The purpose of the springs was to keep the models from sliding under the steering wheel in an unnatural manner.

Chest deflection of the THUMS was calculated from nodal data on the anterior and posterior thorax. The targets in Figure 1C indicate the location of measurement of the chest deflection calculation on a midsagittal sectioning of the THUMS and the Hybrid III chests. The deflection was calculated as the relative change in distance from front of the sternum to the anterior side of the corresponding vertebra at the initial point of impact for the THUMS. The deflection of the Hybrid III chest was calculated, in a similar manner, as the relative change in distance at the initial point of impact on the sternal plate to the thoracic spine. Resultant steering wheel rim to chest contact forces were sampled for both FE models. To be able to distinguish the main shape of the sampled contact forces from vibrations and noise, the force data was filtered using a SAE CFC180.

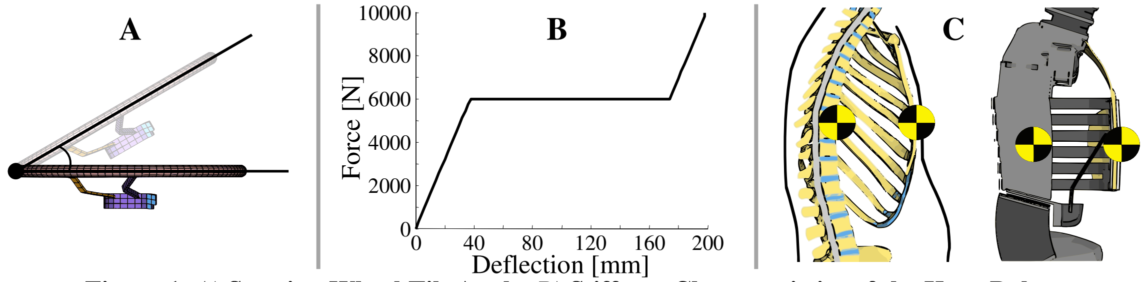

Figure 1. ***A)*** **Steering Wheel Tilt Angle.** ***B)*** **Stiffness Characteristics of the Knee Bolster.** ***C)*** **Location of Chest Deflection Measurement.**

RESULTS

The chest deflection responses for the THUMS and Hybrid III for all four steering wheel tilt angles are shown in Figure 2. The graphs show that the THUMS sustained internal chest deflection peak values ranging from 63 mm to 82 mm.

The lowest chest deflection was obtained at the 0 degree steering wheel tilt angle impact and the highest deflection at the 20 degree angle. The 10 and 30 degree angles produced very similar deflection responses with peak values around 77 mm. Similarly to the THUMS, the Hybrid III shows the lowest chest deflection at the 0 degree tilt angle, peaking at 56 mm. In contrast to the responses in the THUMS, the Hybrid III peak deflection sustained from the 30 degree angle, of 61 mm, was lower than the deflection from the impacts with the steering wheel at 10 and 20 degree tilt angles. These impacts showed peaking tendencies in deflection after 75 mm deflection.

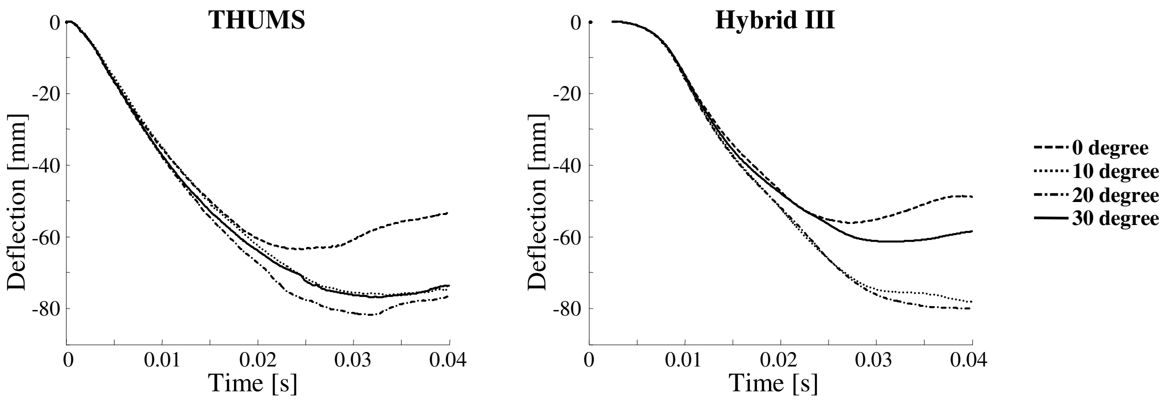

Figure 2. Chest Deflection of the THUMS (left) and the Hybrid III (right).

The resultant contact forces were plotted against deflections in Figure 3. The results of the two FE models appear to be consistent regardless of steering wheel tilt angle during the loading phase up to near maximum deflection. The force level for the THUMS steadily increases with the level of deflection up to peak deflection for the three lower angles but is showing a dip in force prior to peak deflection for the 30 degree steering wheel tilt angle. The Hybrid III also shows a steady increase in contact force for the two impact conditions producing the highest chest deflection, the 10 and 20 degree steering wheel tilt angles. For the 0 and 30 degree, steering wheel tilt angle impacts the forces are decreasing before maximum deflection is reached.

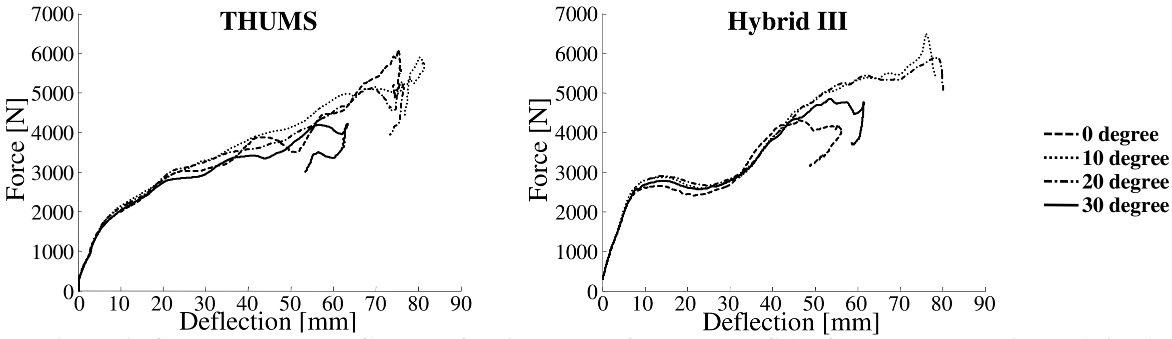

Figure 3. Contact Force vs. Chest Deflection Data of the THUMS (Left) and the Hybrid III (Right)

Figure 4 shows the general upper body kinematics and steering wheel interaction of the FE models at the four different tilt angles of the steering wheel at the time of initial contact (0 ms), 20 ms and 40 ms. The shaded pictures designate the earlier phases of the impact. The general interaction between the THUMS and the Hybrid III model, and the steering wheel was similar for all angles, except for the 0 degree angle. Here, the steering wheel rim surface slid upwards on the Hybrid III chest, showing a larger deformation for the Hybrid III model than the THUMS. The largest steering wheel deformation was seen for both models in the 30 degree tilt angle impact.

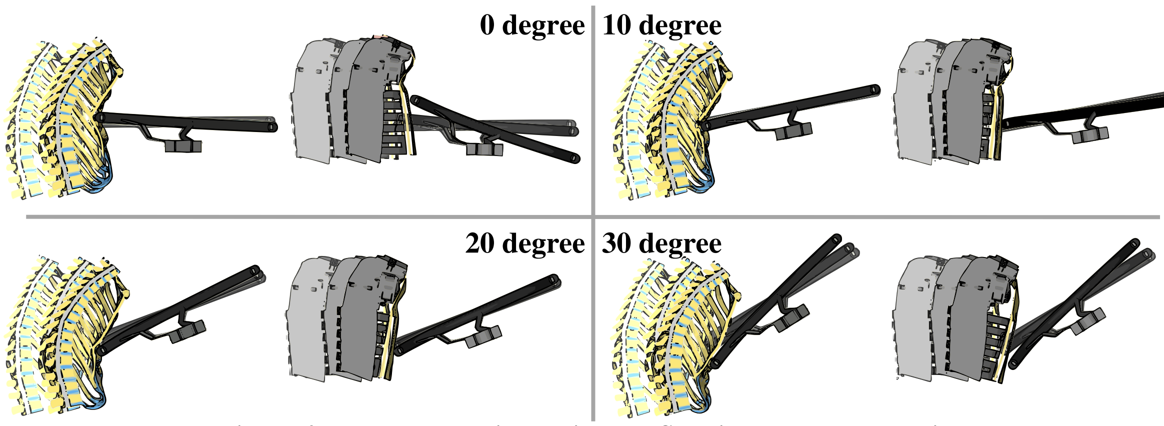

Figure 4. Upper Body Kinematics and Steering Wheel Interaction

DISCUSSION

The use of the Hybrid III dummy in frontal crash tests with chest to steering wheel contact has been investigated. This study increases the understanding of the Hybrid III sensitivity to steering wheel tilt angle on the deflection response. Comparisons with the THUMS were made to find similarities or differences.

The general behavior of the THUMS and the Hybrid III dummy model appears similar with respect to chest deflection and steering wheel rim contact forces. The gross kinematics of the models in the simulations also look similar with the exception of the 0 degree tilt angle where the steering wheel bended more for the Hybrid III model. The steering wheel strikes perpendicularly to the flat surface of the sternal plate of the Hybrid III chest at the 0 degree impact, which could be sensitive to small changes in the steering wheel tilt angle since the sliding of the rim could occur in either an upward or downward direction. The sliding of the steering wheel on the Hybrid III's chest at the 0 degree impact condition can largely be attributed to the exterior vest, representing the flesh, which slides on the anterior surface of the ribcage. It is tempting to find out if this is an artifact in the FE model or if this can be seen in the physical dummy. It is important to be able to distinguish whether chest deflection is indicative of a more severe injury or not. Comparing the severity of the anticipated injuries by means of the C_{max} criterion, the Hybrid III sustained C_{max} ranging from 25% to 35%, and the THUMS received values of 31% to 40%. According to Kroell et al. (1974), these values correspond to minor injury (AIS 1, C_{max}=24%) to severe life threatening (AIS 4, C_{max}=40%). Therefore, there is a risk that the Hybrid III is underestimating the injury severity.

Indications of the differences between the two FE models can be found when comparing the force/deflection curves. It can be seen that the THUMS more consistently shows an increasing force up to peak deflection. On the other hand, the Hybrid III shows either a slight force peak prior to deflection maximum, as seen in the 10 degree tilt angle, or that the contact force decreased before peak chest deflection, as seen for the 0 and 30 degree steering wheel tilt angle. This decrease in force near peak deflection was seen for the THUMS at 30 degree angle.

The force/deflection data from the two models could indicate that the Hybrid III chest has, or is close to, bottoming out at the 10 degree angle, which is also confirmed by the animations. The force component was found to decrease prior to peak deflection indicating that the steering wheel rim was sliding during the contact, which also changes the point of loading.

The THUMS simulations showed a large proportion of hourglass energy to internal energy, between 10% and 25%. Therefore, the effect of the element formulation and different hourglass damping was investigated. Unfortunately, the fully integrated element was not an option since severe element distortion caused the simulation to crash approximately half time. It was found that the contact force and chest deflections with fully integrated elements were almost identical to the presented simulations. Furthermore, no apparent zero energy modes were visible and hence the performed simulations were considered acceptable. However, improvements of the THUMS model's robustness and mesh are suggested.

CONCLUSIONS

- The FE Hybrid III model response was found to change with the steering wheel tilt angle.
- The Hybrid III shows consistent responses with the THUMS at 10 and 20 degree steering wheel tilt angles.
- The Hybrid III interaction with the steering wheel at 0 degree is greatly affected by vest's slip on the anterior ribcage.
- Both the THUMS and the Hybrid III are affected by steering wheel sliding on the chest for the 30 degree tilt angle, from the change in loading path and loading location.
- The robustness of the THUMS model needs to be investigated and measured to ensure a physical response need to be taken.

ACKNOWLEDGEMENTS

This study has been conducted at Chalmers University of Technology and has been funded by the Swedish Vehicle Research Program (PFF) through VINNOVA.

REFERENCES

Gwehenberger, J., Langwieder, K., Bromann, G., Zipfel, D. (2002) *Injury risk for truck occupants due to serious commercial vehicles accidents~Results of real-world-crash analysis*. 2002 International IRCOBI Conference on the Biomechanics of Impact, Munich, Germany. Resource Nr: 2002-13-0007. International Research Council on Biokinetics of Impacts, Bron, France.

Hallquist, J., O. (2007) *LS-DYNA Keyword User's Manual*. Livermore Software Technology Corporation. Livermore, California.

Kroell, C., K., Schneider, D., C., Nahum A., M. (1974) *Impact tolerance and response of the human thorax II*. 18th Stapp Car Crash Conference, Ann Arbor, Michigan, USA. Resource Nr: 741187. Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, USA.

Nahum, A., M., Melvin, J., W. (1993) *Accidental Injury - Biomechanics and Prevention*, 0-387-97881-X: 0-387-97881-X, Springer-Verlag New York.

Sukegawa, Y., Matsukawa, F., Masuda, N. (2001) *Experimental research on truckdriver's safety in frontal collision*. International Technical Conference on the Enhanced Safety of Vehicles, Amsterdam, The Netherlands. Resource Nr: 2001-06-0099. National Highway Traffic Safety Administration, Washington, D.C., USA.