# THE INFLUENCE OF THE SAFETY BELT ON THE DECISIVE INJURY ASSESSMENT VALUES IN THE NEW US-NCAP

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**ABSTRACT**

Contrary to the recent past when frontal crash restraint systems for the American market were specifically configured with the objective to minimize the occupant injury criteria HIC and chest acceleration, this subsequent study shows that, as a result of the New Car Assessment Program (NCAP) changes, the Neck Injury Criterion Nij and chest deflection have become the new focus of restraint system design. In addition, maximum chest acceleration must still not be exceeded, according to legal requirements. With regard to the neck criterion Nij, tests with the HIII 5% dummy have shown that Nij-values, relevant for the rating, can already arise during pretensioning or during the subsequent coupling phase, prior to the load limiting phase. From this it follows that the maximum pretensioning performance may be limited by this criterion for a few vehicle environments on the passenger side. With reference to the deflection it can be shown that lower thorax acceleration does not automatically lead to reduced chest deflection. Much rather, the belt geometry as well as the belt forces are to be optimized for improved chest deflection values.

**Keywords:** FRONTAL IMPACTS, SAFETY BELTS, HYBRID III, NECK, THORAX

**THE NEW US-NCAP SIGNIFICANTLY** changes the layout and configuration of restraint systems for the American market. Whereas previously the Head Injury Criterion (HIC) and the chest acceleration were assessed, the new NCAP evaluates the HIC, the Neck Injury Criterion (Nij), chest deflection instead of chest acceleration and the femur forces. The probability of injury is determined at hand of risk-curves for the respective injury criteria. Additionally, the Hybrid III 5% will also be tested on the passenger side for frontal crash tests (NHTSA 2007). In order to determine the Injury Assessment Values (IAVs) that are critical for the NCAP-rating, 11 frontal crash tests conducted by the NHTSA (National Highway Traffic Safety Administration) with vehicles from the model year 2010 were analyzed, these also being the validation tests of the NCAP for the NHTSA which can be gathered from the vehicle database of the NHTSA (NHTSA 2010). Refer to Table 1 in the Appendix for the evaluated vehicles.

It becomes apparent that particularly the Nij injury criterion as well as the chest deflection are the most important criteria in order to attain an overall positive rating, as shown in Figure 1. These results

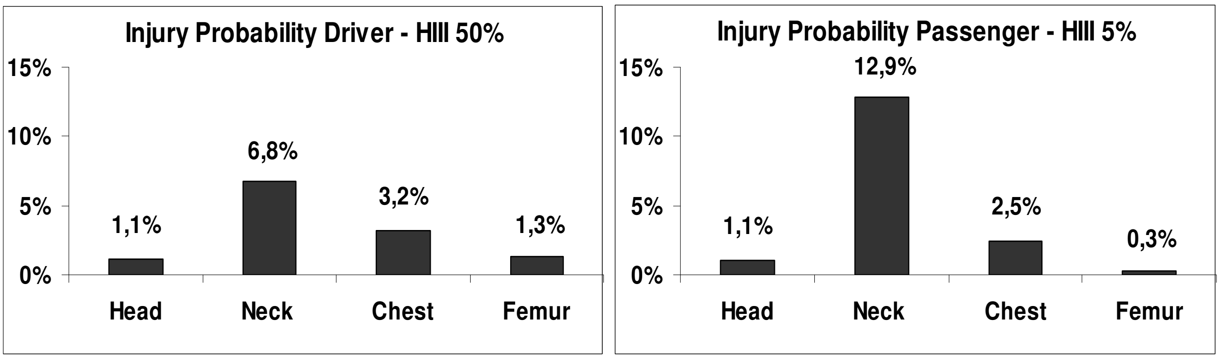



**Fig. 1: Average injury probability for the driver and passenger according to the US-NCAP rating. Data: 11 NHTSA crash tests (NHTSA, 2010)**

are in accordance with previous findings (Eickhoff et al. 2009). Furthermore, the minimization of the Nij for the passenger (HIII 5%) seems to be more challenging than previously assumed.

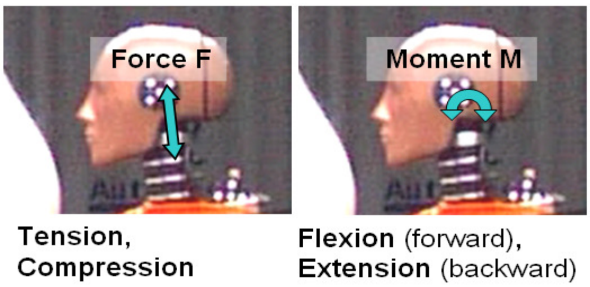
Beyond a good rating, the fulfillment of the FMVSS 208 (Federal Motor Vehicles Safety Standard) for the load case with belted occupants must also be considered for both dummies. Here, the fulfillment of the maximum allowable chest acceleration of 60g is known to be a notably critical issue. As a result of these considerations the question that must be addressed relates to which belt parameters, such as pretensioning, load limiting and geometry, must be focused on for belt layout considerations for the American market, since these have a significant influence on the relevant IAVs Nij, chest deflection and chest acceleration. This paper is focused on the neck loading criterion Nij.

## METHODS

Static deployment tests as well as sled tests were conducted in order to investigate the influence of the belt on the Nij. No simulations were carried out since the dummy models available for this study have not shown adequate correlation between test and simulation. Two mid-sized vehicles with real seat assemblies, 3-point belt systems with pretensioning and load limiter were selected as test environments. The HIII 5% dummies were used, since these tend to show particularly high Nij-values. Within this paper, the comments relating to chest acceleration and chest deflection are primarily based on theoretical considerations.

## RESULTS

Nij: With regard to the Nij calculation: This value is computed from the axial tensile and compressive neck forces as well as neck bending moments, each being normalized with respect to a critical force and moment, respectively, as shown in Figure 2. Four values are determined in this manner for the load cases Ncf (Neck Compression Flexion), Nce (Neck Compression Extension), Ntf (Neck Tension Flexion) and Nte (Neck Tension Extension). The highest value is then relevant for the rating.




$$Nij = \frac{F}{F\ critical} + \frac{M}{M\ critical}$$

**Fig. 2: Computation of the Nij, for details refer to FMVSS 208**

The analysis of the 11 dynamic tests (cf. Fig. 1) shows that the Nte value already reaches relevant magnitudes prior to contact between head and airbag, i.e. already during the coupling phase between belt and dummy. In order to further investigate the effect of the belt during this phase of the crash, pretensioner deployment tests in a static vehicle environment (static deployment tests) with varying pretensioning performance were carried out, the results of which are shown in Figure 3. The magnitude of the pretensioning performance is evaluated by using chest acceleration, since this acceleration of the thorax leads to the forces and moments at the upper neck and there are no external forces acting on the head. Note that the chest acceleration is induced by the pretensioner only. It is shown that it is already possible during static testing to reach Nte values in the range of 0.2 and more when high performance pretensioners are used.

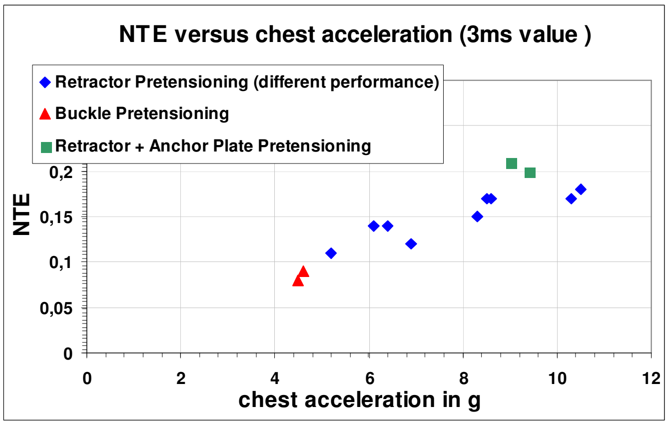



**Fig. 3: Nte during static testing with pretensioning performance as the variable parameter**

In order to put the results from static tests into perspective with respect to those of dynamic tests, both static as well as dynamic tests were conducted during a sled-test-series, using a further vehicle environment. Again, pretensioning performance was the varied parameter. The resulting chest acceleration during the coupling phase with the belt is shown in Figure 4 and the corresponding Nte

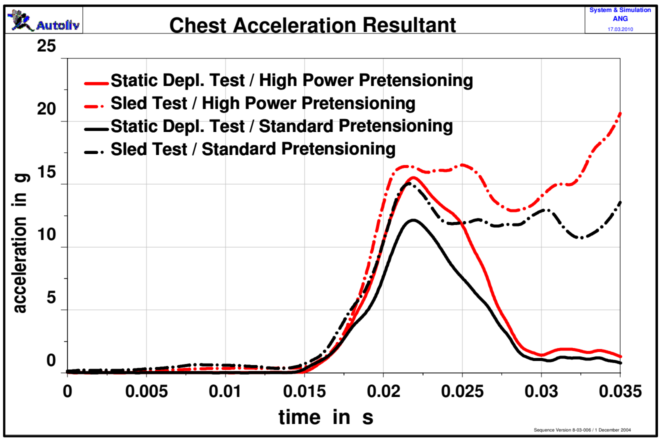



**Fig. 4: Comparison of chest acceleration between static and dynamic sled tests during coupling with the belt**

values are shown in Figure 5. It is shown that the Nte values are of a greater magnitude immediately after pretensioning during the dynamic load case in comparison with the static load case. Furthermore, for the dynamic tests, the Nte value continues to increase during the coupling phase with the belt before the contact between head and airbag occurs (remark: the airbag contact at about 50ms is not illustrated in Figure 4 and 5).

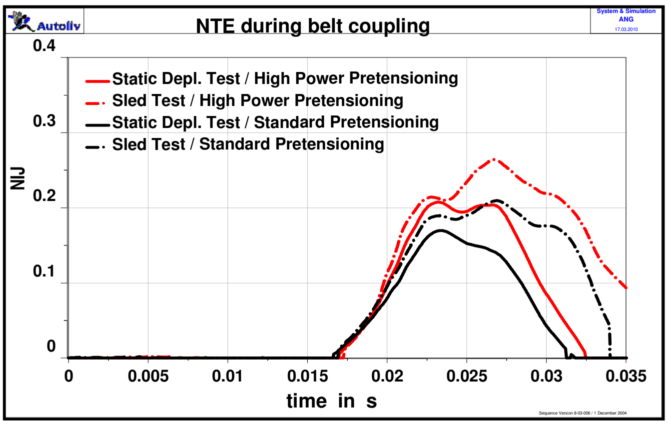



**Fig. 5: Comparison of the Nte in static and dynamic sled tests during coupling with the belt**

Belt induced chest acceleration and chest deflection: Whilst the chest acceleration is a consequence of the forces acting on the thorax, the chest deflection evaluates how these forces are transmitted into the thorax. Thus, increased chest acceleration does not necessarily imply increased chest deflection, as shown in Figure 6, which plots the chest deflection versus the chest acceleration from the evaluation of the previously mentioned crash tests of the NHTSA.

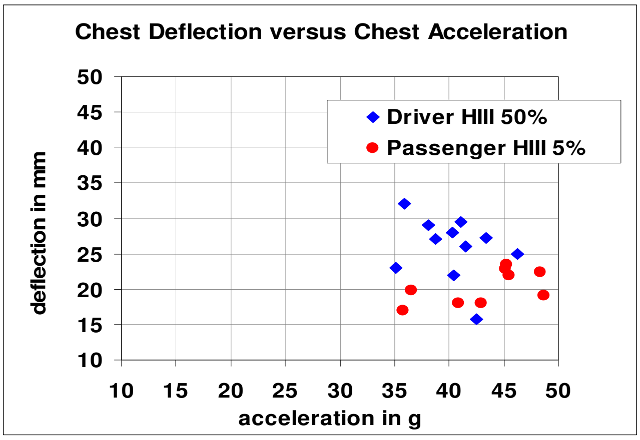
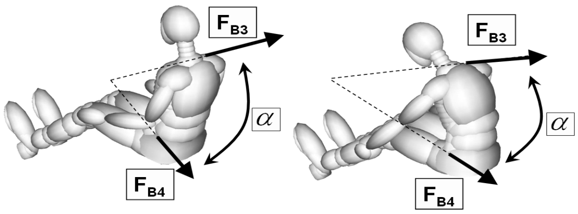



**Fig. 6: Chest deflection vs. chest acceleration.**
**Test data: Evaluation of the NHTSA-Database [NHTSA 2010]**

The evaluation of the resulting belt retention force acting on the thorax can be carried out by means of a simplified calculation. For this purpose the belt force $F_{B3}$ (upper diagonal belt force) and $F_{B4}$ (lower diagonal belt force) are evaluated as vectors. To be able to compare different vehicle environments in a simple manner, the load vectors are not decomposed in vehicle coordinates, but much rather evaluated in terms of an included angle α, as shown in Figure 7. Moreover, it can be seen that this angle becomes smaller with an increasing forward displacement of the dummy, whereby the overall retention force on the dummy also increases.




$$F_{Res} = \sqrt{F_{B3}^2 + F_{B4}^2 - 2F_{B3}F_{B4}\cos(\pi - \alpha)}$$

**Fig. 7: Simplified computation of the resulting belt force on the occupant.**
**Right: The forward displacement leads to higher forces acting on the dummy.**

For the belt induced chest deflection and apart from the resultant belt force on the thorax (Eickhoff et al. 2007) it is also essential how and where these are introduced (Shaw et al. 2005). It is well known that higher belt routes and an increased resting of the belt on the clavicle leads to lower deflections (Matsuoka et al. 1986). This means that apart from the belt forces, the belt geometry also offers possibilities for optimization. The goal is to reduce the deflection whilst maintaining the same belt retention forces on the thorax. Further publications are in preparation with regard to this topic.

**DISCUSSION**

As shown in Figure 1, the Nij as well as the chest deflection are IAVs of particular importance for the rating in the US-NCAP. Nij values relevant for the rating can already be reached with high performance pretensioning with the HIII 5% dummy without an airbag contact, and this even during the pretensioning phase, as shown in Figure 5. The question arises whether the dummy is sufficiently biofidelic enough for this kind of loading.

A Nij value of 0.25 already implies a AIS3+ injury-probability of 6.1%, for a quick reference see Table 2 in the Appendix. In order to achieve a 5-star rating in the NCAP, i.e. less than 10% risk of injuries in total, the Nij should be well below 0.25. This can imply that the pretensioner force must be reduced. On the other hand, a strong pretensioning is favourable to reduce chest deflection (Zellmer et al. 2005). In contrast to the test results shown in Fig. 1, the evaluation of real front crash accidents does not indicate a specifically high risk of severe neck injuries (O'Brien-Mitchell et al. 2009). A direct relation between the chest acceleration and the chest deflection was not found, as shown in Figure 6. This is justified by the cognition that the belt induced deflection is not only dependent on the resultant belt force, but also on where and how this force is acting on the thorax. This means that the belt routing and geometry also offers potential for optimization, apart from the actual belt force acting on the thorax. As a result of the forward displacement of the dummy, the belt retention force on the thorax of a standard, load limited belt system has a progressive behavior (Figure 7). The fulfillment of the FMVSS 208 (focus on the chest acceleration limit) will still require a decreasing belt force characteristic when considering challenging boundary conditions (pulse, geometry ...). At the same time very high shoulder belt forces are to be avoided as a result of the negative impact thereof on the chest deflection.

## CONCLUSIONS

The changes in the US-NCAP will change the belt configurations for the US market. Whereas the HIC and chest acceleration were previously the criteria to be optimized, the Nij and the chest deflection have become the new relevant IAVs. Within this paper it is shown that Nte values that are relevant for the rating can already be attained for the HIII 5% in conjunction with high performance pretensioning. For the belt system layout, this means that the maximum capacity of the pretensioning performance may be limited by the Nij for a few vehicle environments. Vehicles with stiff pulses will still require decreasing belt force characteristics, partially also adaptive, in order to not exceed the maximum allowable chest acceleration. However, potentially high shoulder belt forces at the initial stages of load limiting must be avoided for such cases due to the negative impact thereof on the chest deflection. Besides the forces, the belt geometry also offers potential for optimization with regard to the chest deflection.

## REFERENCES

Eickhoff, B.; Zellmer, H.; Forster, E. (2007): The mechanism of belt induced chest deflection: Analysis and possibilities for reduction. Proceedings of 20th ESV Conference, Lyon, 2007

Eickhoff, B.; Gulde, A.; Gerisch, P. (2009): Safety of small vehicles in frontal crashes – An analysis concerning different market requirements, weight and cost aspects. 7. VDI Conference Vehicle Safety, Berlin, 2009

Federal Motor Vehicle Safety Standard (49 CFR PART 571) FMVSS 208 Occupant Crash Protection http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crashworthiness/Air%20Bags/FMVSS_208_II.pdf Date: 25/06/2010

Matsuoka, F.; Kumagai, K.; Takahashi, H. (1986): Problem and Improvement of HIII Dummy Rib Cage Feature, Proceedings of 9th ESV Conference, Kyoto, Japan 1986.

NHTSA (2007): National Highway Traffic Safety Administration [Docket No. NHTSA-2006-26555] Consumer Information; New Car Assessment Program http://www.nhtsa.gov/DOT/NHTSA/Vehicle%20Safety/Articles/Associated%20Files/NHTSA-2006-26555-0114.pdf Date: 20/03/2010

NHTSA (2010): Vehicle Database http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.f7761ac9dcb3a375141d01105631eecc/ Date: 20/03/2010

O'Brien-Mitchell, B.; Bailey, K.; Faust, D.; Jensen, J.; Kleinert, J.; Wodzinski, C.; Kohoyda-Inglis, C.; Wang, S. (2009): Analysis of injury trends in frontal University of Michigan CIREN cases in the context of crash tests. Proceedings of 21st ESV Conference, Stuttgart, Germany, 2009.

Shaw, G.; Lessley, D.; Kent, R.; Crandall, J. (2005): Dummy torso response to anterior quasi-static loading. Proceedings of 19th ESV Conference, Washington, D.C., USA, June 2005.

Zellmer, H.; Kahler, C.; Eickhoff, B. (2005): Optimised Pretensioning of the Belt System: A Rating Criterion and the Benefit in Consumer Tests. Proceedings of 19th ESV Conference, Washington, D.C., USA, June 2005.

## APPENDIX

**Table 1: Evaluated vehicles. Source: (NHTSA, 2010)**

| | Vehicle | Model Year | Test No |
|---|---|---|---|
| 1 | Toyota Lexus RX 350 5-DR SUV | 2010 | 6642 |
| 2 | KIA Soul Plus 5-DR MPV | 2010 | 6655 |
| 3 | MAZDA 3 I Sport 4-DR Sedan | 2010 | 6658 |
| 4 | Ford Mustang 2-DR Coupe | 2010 | 6723 |
| 5 | Honda Insight 5-DR LX | 2010 | 6724 |
| 6 | Ford Mustang Convertible | 2010 | 6727 |
| 7 | KIA Forte 4-DR Sedan | 2010 | 6763 |
| 8 | Toyota Camry LE 4-DR Sedan | 2010 | 6750 |
| 9 | Toyota Corolla 4-DR Sedan | 2010 | 6754 |
| 10 | Ford Fusion S 4-DR Sedan | 2010 | 6755 |
| 11 | Hyundai Genesis 2-DR Coupe | 2010 | 6764 |

**Table 2: Risk of AIS3+ injuries in relation to Nij, calculated according to (NHTSA 2007)**