Far side crash correlation and sensitivity study for virtual testing

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1 Motivation

In 2024 the monitoring phase of the virtual far side occupant assessment is going to start. The vehicle manufacturer will carry out the physical sleds and virtual tests. Variations of the impact angle and the seat position are going to be assessed with purely virtual tests. The car manufacturer has to show that the correlation level of his simulation model is sufficient. For that the ISO score rating according to ISO/TS18571 and the selected ATD ('dummy') injury criteria are used on the two validation tests.
To be prepared for this challenge, Stellantis put together a cross functional, international CAE team of methods development and safety department members. The task was to test if the existing model content and the level of detail in the subsystems fulfill all performance requirements and to identify the key enablers to reach the correlation targets.

For doing this a compact class production vehicle was chosen, which was not designed to meet the far side test requirements. In addition, the used Worldsid50 LS-Dyna FE model version 7.6.1 is not qualified for the virtual far side load case. Nevertheless, the ATD kinematics and its predictivity were investigated under far side load conditions.
The authors would like to take this opportunity to thank Carlos Gonzáles from Applus+ Idiada as part of our team for the extremely productive support in this project.

2 Boundary conditions

The far side test requirements include a comparison of the far side B-pillar velocity and displacement curves between the full vehicle and the sled. This is to prevent the sled pulse from being 'better' than the vehicle pulse. Consequently, it should be understood that the pulse response of the body-in-white on a sled can also be quite different between simulation and physical test. This is due to a more or less ideal transition of the test pulse in the FE-model. In our investigations it turned out that the body rigidification needed special attention for improving the correlation.

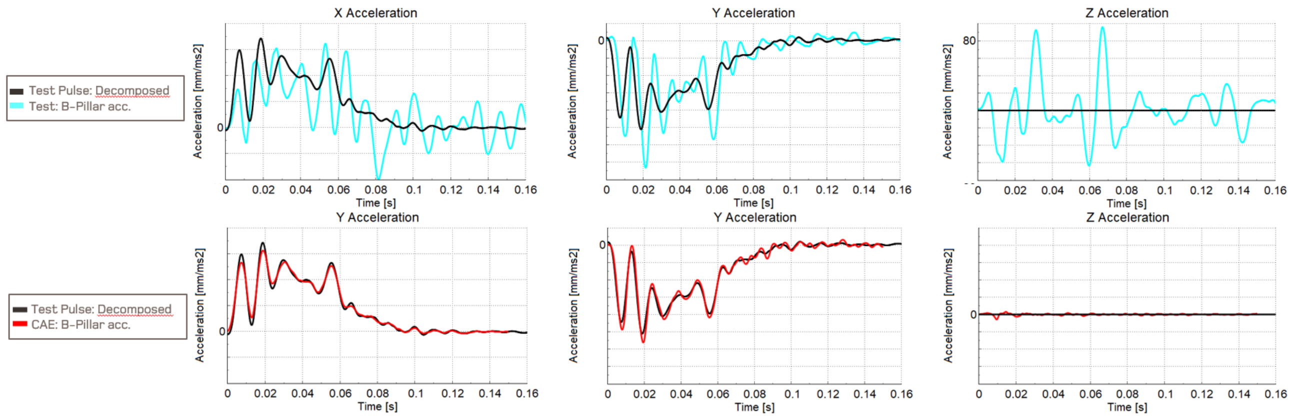

Fig.1: Transfer of the pulse to the B-pillar foot in physical sled test and simulation

We investigated the effect of using the sled B-pillar pulse as test pulse in simulation. To some extend it can influence the ISO score, for example this was the case for the thorax ribs displacements:

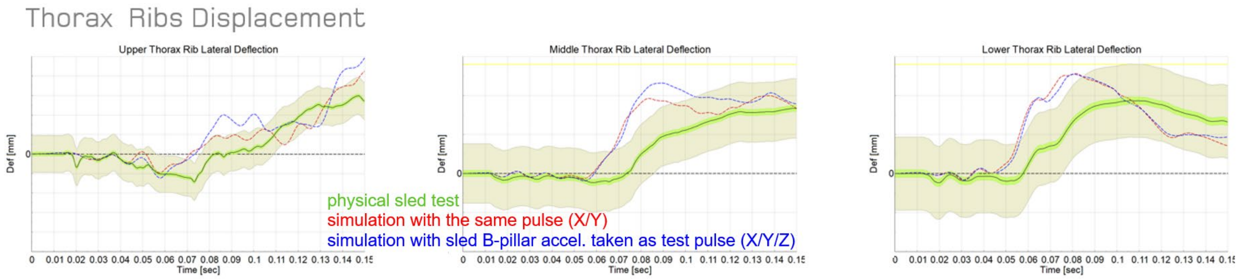

Fig.2: Influence of X/Y/Z B-pillar excitation on the upper thorax rib deflection

This investigation was purely a side study, apart from that the simulation pulses of all other studies have been performed with same impact pulse as used for the physical sled, as it should be carried out for virtual testing. It would require additional investigations of the test buck stiffness and its implementation into the FE-model to achieve a better correlation of the response of the cabin on a sled, in particular the far side B-pillar acceleration. However, this was out of scope of this project. Body fixations are set rigid in our simulations, and the true stiffness of the test buck struts has not been considered. What has been done yet to avoid a non-realistic stiffening of the body-in-white was to position the rigid boundary conditions more accurately.

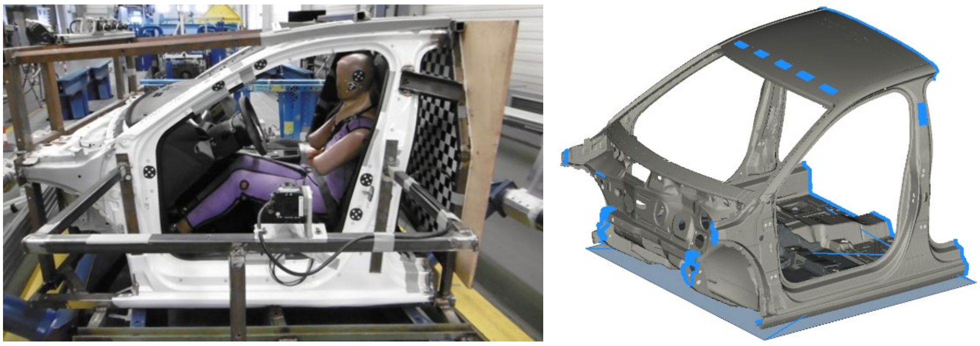

Fig.3: Body fixations on sled / boundary conditions in simulation

3 Simulation model setup

3.1 Model content

The FE-model is based on a front occupant simulation model. From that the ATD and seats have been exchanged as per the far side requirements. The body has been rigidified as shown in Fig.3:. The same FE-seat belt as in front occupant simulations has been used but was only re-belted. The WorldSID50%ile FE-model version 7.6.1 was used, which is not qualified for virtual testing.

The hardware tests took place in February 2022, the execution was done according to the standards valid at that time. The seat foams have not been cut-out for the installation of EPP spacers. Hence, the EPP spacers in our investigation fill the empty space between the body-in-white and the seat cover. In the meantime, the regulation for the design of the EPP spacers has been changed in the latest protocol.

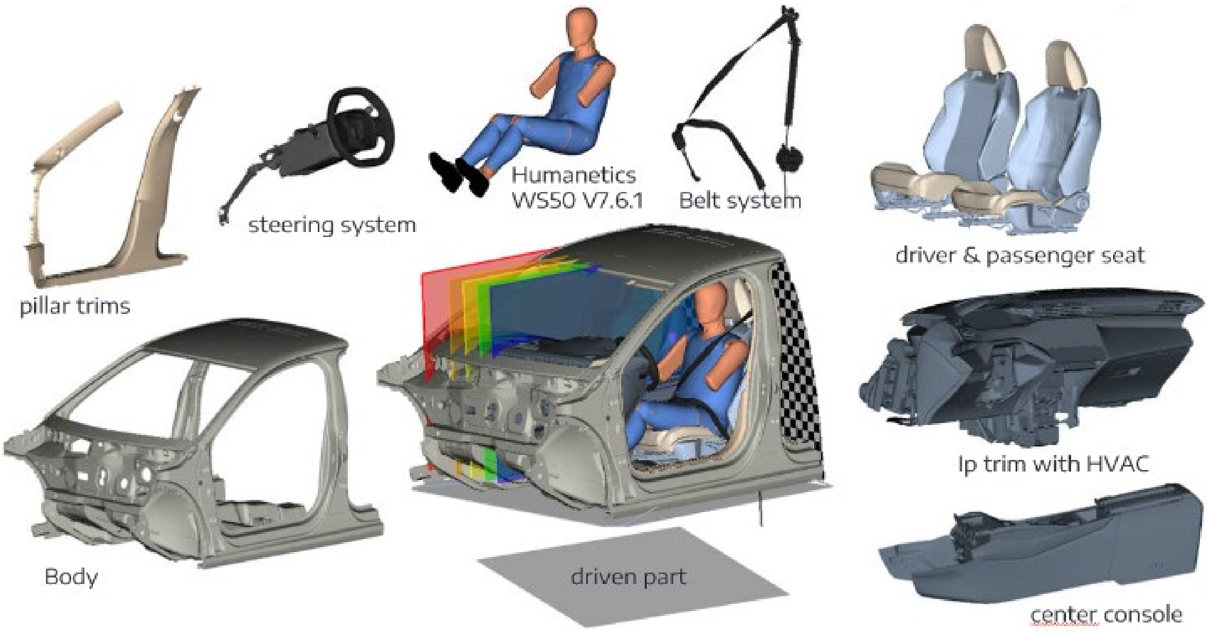

Fig.4: Subsystem overview

3.2 Seat configuration for virtual testing

The virtual testing protocol defines two positions of the seat:

- x-ref. / z-ref / seatback in design position
- x-ref@z-high / z-high / seatback angle shall be adjusted in case of implausible angles

For this study the seatback angle was modified at high seat position to avoid an implausible thorax angle.

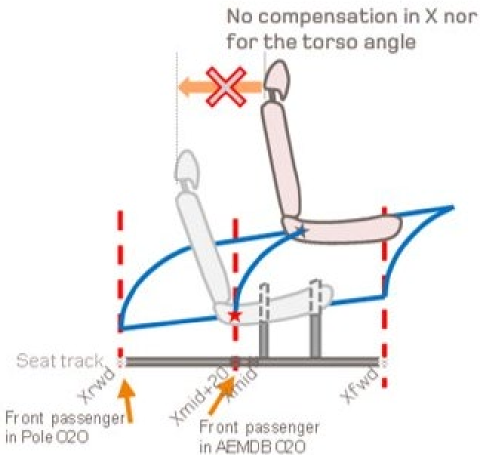

Fig.5: Seat positions

4 Main influencers for the correlation

4.1 Belt routing

In the test setup with a single pretensioner seat belt the buckle position had a big influence on the head excursion and the ATD kinematics in general. A tight routing of the belt, positioned true to the test, had to be ensured for a realistic ATD behavior.

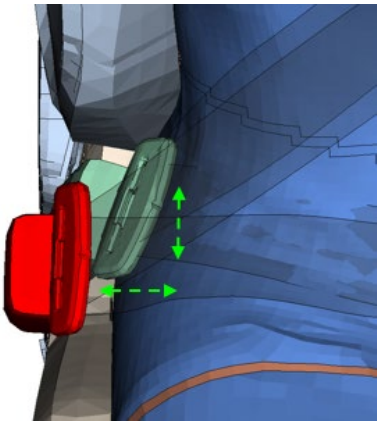

Fig.6: The position of the buckle in front occupant model was moved to a narrow position for far side

4.2 ATD jacket to belt interaction and friction

The used dummy version is equipped with a sleeveless jacket. In tests it was observed that the belt slides into the gap between shoulder and arm, while the small sleeve in the FE-model prevents this behaviour. Secondly, an increase of the belt friction on the jacket has been investigated and resulted in improved correlation. However, it was required to also increase the internal friction of the jacket so that this measure could take effect. Another point is that the dummy jacket is reinforced with rubber patches in relevant places, which are missing in the simulation model.
All these points have been discussed with DYNAmore and they confirmed to make further investigations.

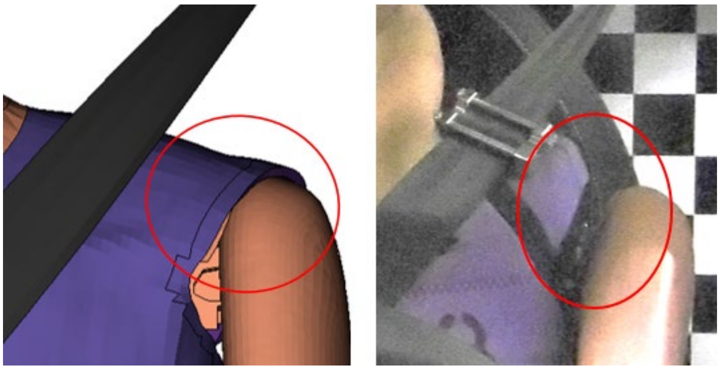

Fig.7: Jacket sleeves are different in FE-model V7.6.1 and in physical ATD

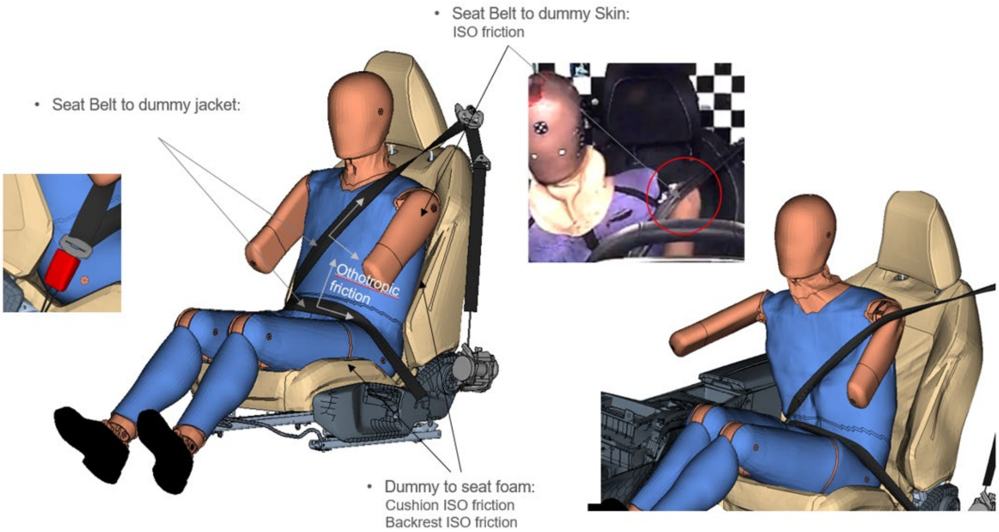

Fig.8: Best results with internal friction between jacket and ribs much higher than 0.2 and orthotropic friction between belt and jacket

Fig.9: Rubber patches in physical jacket are not present in the FE-model

4.3 Center console

It can be stated that the behaviour of the console was relevant for the ATD kinematics and had to be considered correctly for a good correlation of the injury criteria. The screw connections to the body of the FE center console subsystem already took failure into account. This turned out to be of particular importance in our investigations. In our case the spacers did not support the seat and console as much in lateral direction as it could be the case with extended length of the spacers when seat foams are cut-out as described in the latest far side protocol. Such a modification can also avoid failure in the center console fixations.

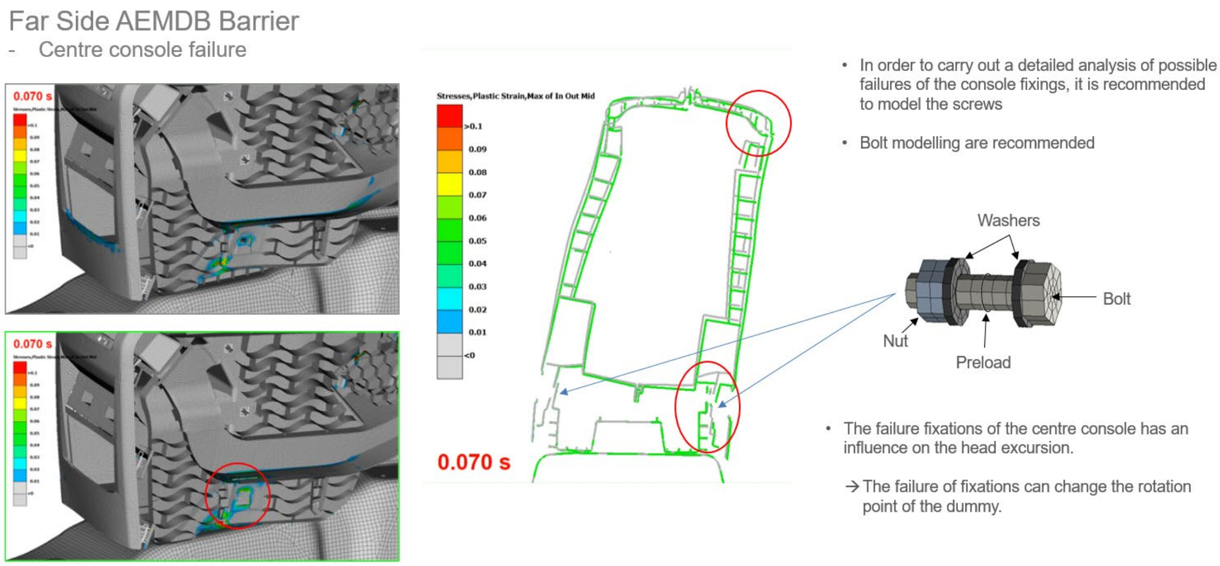

Fig.10: Fixation with / without failure

5 Validation criteria

5.1 Criterion 1 – ISO Scores

The resulting ISO TS 18571 score showed the most critical results for those channels which will become relevant after the monitoring phase.

Channels of particular interest for the two tests

Sensor	Iso Score
Head CoG Angular velocities	0.743
Head CoG Accelerations	0.709
Upper neck Forces	0.659
Upper neck Moments	0.657
Lower neck Forces	0.731
Lower neck Moments	0.829
Spine – T4 Accelerations	0.654
Spine – T12 Accelerations	0.664
Pelvis accelerations	0.622
Lumbar spine loadcell Forces	0.657
Lumbar spine loadcell Moments	0.542
Shoulder joint Forces	0.593
Shoulder – rib Displacement	0.604
Thorax - Upper rib Displacement	0.506
Thorax - Mid rib Displacement (corrected)	0.501
Thorax - Lower rib Displacement	0.484
Abdomen – Upper rib Displacement	0.352
Abdomen – Lower rib Displacement	0.125
Pubic Symphysis Loadcell Forces	0.767
B-Pillar Accelerations	0.664
Lap Belt (B6) Force	
Shoulder Belt (B3) Force	0.833

Sensor	Iso Score
Head CoG Angular velocities	0.784
Head CoG Accelerations	0.663
Upper neck Forces	0.666
Upper neck Moments	0.586
Lower neck Forces	0.636
Lower neck Moments	0.798
Spine – T4 Accelerations	0.621
Spine – T12 Accelerations	0.672
Pelvis accelerations	0.628
Lumbar spine loadcell Forces	0.576
Lumbar spine loadcell Moments	0.440
Shoulder joint Forces	0.679
Shoulder – rib Displacement	0.661
Thorax - Upper rib Displacement	0.578
Thorax - Mid rib Displacement (corrected)	0.595
Thorax - Lower rib Displacement	0.565
Abdomen – Upper rib Displacement	0.297
Abdomen – Lower rib Displacement	0.229
Pubic Symphysis Loadcell Forces	0.793
B-Pillar Accelerations	0.693
Lap Belt (B6) Force	
Shoulder Belt (B3) Force	0.785

Fig.11: Validation criterion 1 – ISO scores for AEMDB (left) and Pole (right)

5.2 Criterion 2 – Performance limits

The performance limits criteria have been fulfilled for the VT monitoring phase, but some AEMDB figures would be insufficient after the application.

AEMDB

#	Assessment Criterion (AC) Monitoring Phase	AC Limit	Ratio	Deviation
1	HIC15	700	44%	
2	a3ms	80g	83%	28%
3	Upper Neck Fz	3.74kN	58%	10%
4	Upper Neck MxOC	248Nm	29%	
5	Upper Neck MyOC	50Nm	42%	
6	Lower Neck Fz	3.74kN	60%	10%
7	Lower Neck Mx (base of neck)	248Nm	83%	1%
8	Lower Neck My (base of neck)	monitoring		
9	Chest compression	50mm	51%	14%
10	Abdomen compression	65mm	35%	
11	Pubic Symphysis Force	3kN	27%	
12	Lumbar Fy	2kN	46%	
13	Lumbar Fz	4kN	69%	6%
14	Lumbar Mx	120Nm	61%	22%
15	Head excursion	80mm	87%	13%
	If *Ratio* > 0.5 then the *Deviation* shall be < 0.3		OK	

POLE

#	Assessment Criterion (AC) Monitoring Phase	AC Limit	Ratio	Deviation
1	HIC15	700	25%	
2	a3ms	80g	54%	4%
3	Upper Neck Fz	3.74kN	19%	
4	Upper Neck MxOC	248Nm	25%	
5	Upper Neck MyOC	50Nm	57%	9%
6	Lower Neck Fz	3.74kN	44%	
7	Lower Neck Mx (base of neck)	248Nm	75%	1%
8	Lower Neck My (base of neck)	monitoring		
9	Chest compression	50mm	42%	
10	Abdomen compression	65mm	28%	
11	Pubic Symphysis Force	3kN	24%	
12	Lumbar Fy	2kN	39%	
13	Lumbar Fz	4kN	70%	14%
14	Lumbar Mx	120Nm	49%	
15	Head excursion	80mm	79%	17%
	If *Ratio* > 0.5 then the *Deviation* shall be < 0.3		OK	

Fig.12: Correlation criterion 2 – Performance limits

6 Summary

- It has turned out to be a good approach to derive the far side FE-model from the front occupant sled model.
- We received a good level of predictivity with respect to the ISO score rating. That will help us in our strong ambition of physical test reduction.
- The enablers which have been identified to achieve a good correlation involve the ATD itself and its near environment:
  - Friction between belt and jacket
  - Friction between jacket and shoulder rib
  - Exact position of the buckle
  - Shape and length of the EPP foam spacers
  - Body rigidification
  - Tight belt routing
- An update of the WS50 FE-model is announced by DYNAmore, which will be qualified for far side testing. The potential impact on the results shall be cross-checked in further investigations.
- The rigid representation of the sled that we have in simulation does not represent the physical device. This results in different responses of the body and may influence the correlation.

7 Literature

Euro NCAP: "VIRTUAL FAR SIDE SIMULATION & ASSESSMENT PROTOCOL", Vers. 1.0, 2023
Euro NCAP: "FAR SIDE OCCUPANT TEST & ASSESSMENT PROCEDURE", Vers. 2.3, 2022