Virtual testing developments of the LS-DYNA® WorldSID 50th dummy model

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1 Abstract

In 2024 the European New Car Assessment Programme (Euro NCAP) Virtual Testing Crashworthiness (VTC) procedure for far-side impact is introduced. The LS-DYNA DYNAmore WorldSID 50th dummy model will be part of this procedure. Separate qualification criteria must be satisfied for the WorldSID model. They are specified in Technical Bulletin TB043-1 [1].
LS-DYNA DYNAmore WorldSID 50th version 8 will be the first model with the official certificate to satisfy all the defined criteria of TB043-1. TB043-1 includes three different stages of certification. Normative dummy requirements are checked in the first stage. Component level tests of head-neck and lumbar spine represent the second stage. The last stage includes a new full dummy sled test scenario representing the far-side load case. The dummy model must pass all three stages to be fully certificated.

2 Virtual testing in occupant safety

Virtual testing load cases in occupant safety side crash are discussed since many years. Goal of these tests is to increase the occupant protection with only little increase of required hardware tests. One of the first official virtual testing protocols will be implemented by Euro NCAP in 2024. The procedure is summarized in the Virtual Far Side Simulation & Assessment Protocol [2]. Figure 1 shows a flow chart of the assessment protocol.

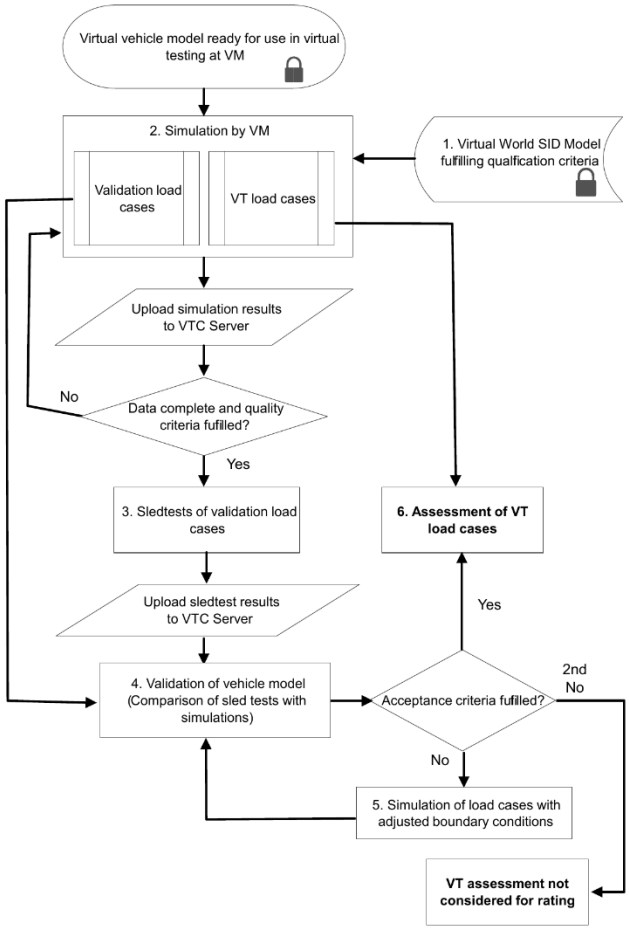


Figure 1: Flow chart of the Virtual Far Side Simulation & Assessment Protocol [2]

The inputs for the virtual testing assessment are a virtual vehicle model ready to use in virtual testing (VT) and a virtual WorldSID model fulfilling defined qualification criteria. There are eight virtual testing load cases available. Two of the load cases are validation load cases, which are used for the validation process. The vehicle manufacturer (VM) must provide simulation results of the validation load cases to Euro NCAP by uploading them on the VTC server. As soon as they fulfill the required quality criteria, hardware sled tests of the validation load cases must be performed. These hardware sled test results will then be used for the validation of the previously submitted virtual models, by comparing the results. If the virtual models fulfill defined acceptance criteria, the virtual models are assessed for virtual testing. If not, the vehicle manufacturer has a chance to rerun the virtual validation models with adjusted boundary conditions. When the acceptance criteria are still not fulfilled, the virtual testing assessment will not be considered for the rating. [2]

Besides the virtual vehicle model, provided by the vehicle manufacturer, the WorldSID model is the second input required for the assessment. The WorldSID model needs to be delivered by the dummy supplier with a certificate of fulfilling defined qualification criteria. The qualification criteria are defined in a separate document by Euro NCAP called Technical Bulletin 043-1 (TB 043-1) [1]. The DYNAmore LS-DYNA WorldSID version 8.0 model will be the first dummy version coming with the certificate of fulfilling all qualification criteria of TB 043-1.
The previous version 7.6.1 was already very close to receive the certificate, but there were some minor differences in assembly mass and range of motion, due to the ISO 15830 [5] being updated in 2022. Therefor the TB 043-1 certification was one major topic of the WorldSID version 8.0 development.

3 ISO 18571 rating calculation

ISO 18571 provides rating procedures to be used to calculate the level of correlation between two signals. [3] The rating is used in TB043-1 to evaluate the performance of the dummy model, by comparing given test curves with generated curves of the simulation model. In this chapter a small overview of the used ISO 18571 rating calculation is given.
The calculation of the ISO 18571 rating consists of four different ratings: the corridor rating, the phase rating, the magnitude rating and the slope rating. A rating > 0.94 is considered as excellent, a rating > 0.80 and ≤ 0.94 as good, a rating > 0.58 and ≤ 0.80 as fair and ratings ≤ 0.58 as poor. [4]
For the corridor rating an inner and outer corridor are internally created around the test reference curve. At each time step of the simulation, it is checked if the point of the simulation curve is within the inner corridor (rating 1.0), between the inner and the outer corridor (rating 1.0 – 0.0) or outside of the outer corridor (rating 0.0). To get the total corridor rating the average of all time step ratings is calculated. [4]
The phase rating considers the x-offset of the simulation curve to the test curve, the magnitude rating considers the difference in the magnitude of test and simulation curve, after the offset modification. The slope rating evaluates the slope of the simulation curve compared to the reference test curve. A more detailed explanation of all the sub ratings can be found in der CORA-manual of the used CORA-software provided by the Partnership for Dummy Technology and Biomechanics (PDB). [4]

4 Technical Bulletin 043-1: LS-DYNA WorldSID 50th Version 8.0

TB 043-1 is divided into three stages. All three stages will be shown in this paper with the example of the new LS-DYNA WorldSID 50th version 8.0. The three stages are:

1. Normative dummy requirements
2. Component level tests
3. Full scale tests

All three stages must be passed to be fully certified. In the following chapters an overview for all three stages will be given with the example of the LS-DYNA WorldSID 50th version 8.0. A detailed description of all three stages can be found in TB043-1. [1]

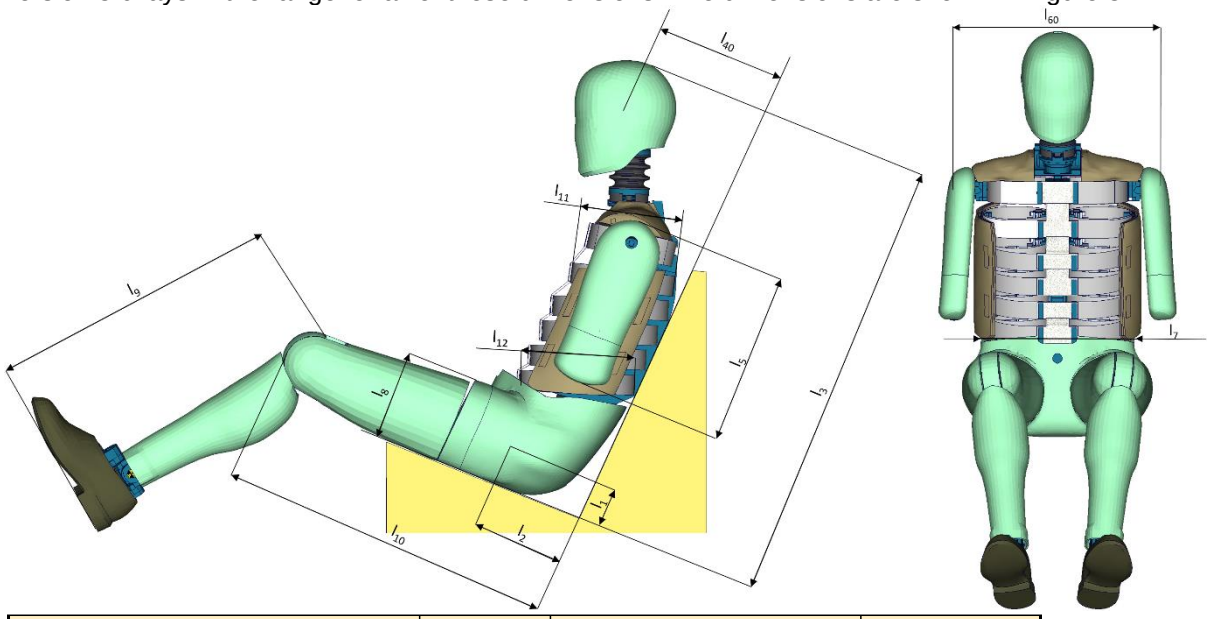
4.1 Normative dummy requirements (ISO 15830)

The first stage is checking some general requirements of the WorldSID model. This includes mass properties, external dimensions, range of motion, sensors and dummy dynamic qualification procedures. In Figure 2 the mass properties of the dummy model are compared to the hardware mass properties defined in ISO 15830-2:2022. [5] The dummy model has exactly the same assembly masses as defined for the hardware.

Item	Hardware Mass [kg]	ISO 15830-2 Range [kg]		Model Mass [kg]
Head	4.29 ± 0.05	4.24	4.34	4.29
Neck	2.86 ± 0.02	2.84	2.88	2.86
Thorax/abdomen/shoulder	20.56 ± 0.35	20.21	20.91	20.56
Lower Torso	19.30 ± 0.20	19.10	19.50	19.30
Two half Arms	3.52 ± 0.08	3.44	3.60	3.52
Two Upper Legs	11.72 ± 0.08	11.64	11.80	11.72
Two Lower Legs	10.12 ± 0.14	9.98	10.26	10.12
Clothing	1.62 ± 0.16	1.46	1.78	1.62
Total	73.99 ± 1.08	72.91	75.07	73.99

Figure 2: Mass properties (ISO 15830-2:2022)

The allowed external dimensions of the dummy are defined in ISO 15830-5:2022. [5] The WorldSID version 8.0 lays in the range for all of these dimensions. The dimensions are shown in Figure 3.



Linear parameter	Symbol	ISO 15830-5:2022 [mm]	Model data [mm]
Hip pivot height	l_1	85 ± 10	88
Hip pivot to back line	l_2	175 ± 10	167
Seated height	l_3	865 ± 20	871
Head reference mark to seat	l_{40}	250 ± 20	258
Arm length	l_5	330 ± 10	337
Width across shoulder	l_{60}	435 ± 10	441
Waist width	l_7	340 ± 10	337
Thigh clearance	l_8	170 ± 10	174
Knee to shoe height	l_9	580 (l) / 588 (r) ± 35	580
Knee to back line	l_{10}	665 ± 15	654
Thorax rib 1 front to back	l_{11}	205 ± 10	204
Abdomen rib 2 front to back	l_{12}	225 ± 10	225

Figure 3: External dimensions (ISO 15830-5:2022)

The allowed ranges of motion are defined in ISO 15830-1:2022. [5] The ranges of the WorldSID dummy model are within the allowed ranges of motion.
All the required sensors defined in ISO 15830-3:2022 [5] are present in the dummy model. They will not be shown in this paper, since there are too many of them.
The dummy qualification procedures according to ISO 15830-2:2022 are also not shown in this paper but are fully satisfied. A detailed overview for all procedures can be found in the official WorldSID version 8 TB043-1 certification document [7].

4.2 Component level tests

The component test simulations consist of two different test setups. They are precisely defined in TB043-1. [1] The first test is a head-neck test in 90° and 75° position accelerated with a pulse of 35 g. It includes the head-neck assembly of the WorldSID dummy model mounted on a mounting plate. The mounting plate is accelerated.
The second test is the lumbar spine test, where the WorldSID lumbar spine assembly is mounted on a mounting plate in 90° and 60° positon. Again the mounting plate is accelerated with a pulse of 35 g. Additionally a bulk mass with sensors is mounted on top of the lumbar spine assembly.
Both component test setups are shown in Figure 4. The pulse and geometry of the non-dummy parts are provided within TB043-1.

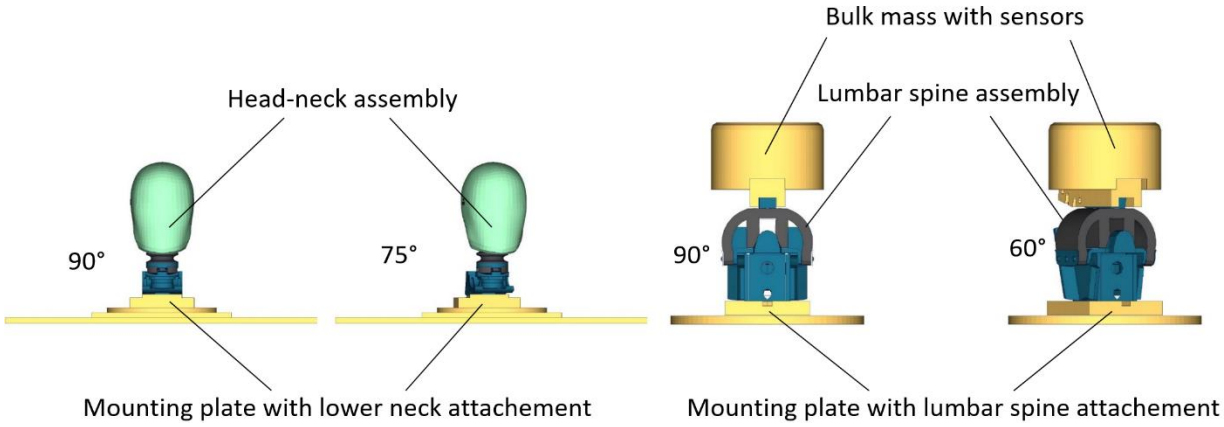


Figure 4: Head-neck (left) and lumbar spine (right) component test

The results of these simulations are used to calculate an ISO 18571 rating. To pass the second stage, the total ISO 18571 rating of the component test needs to be ≥ 0.70.
To calculate the ISO 18571 rating, mean reference test curves need to be provided. They can be downloaded from a website mentioned in TB043-1. The simulation results are compared to these reference test curves to calculate the rating. Before the simulation curves can be used for ISO 18571 rating calculation, they need to be filtered (CFC60) and bias removed (see TB043-1).
For the rating calculation an example for the lumbar spine 90° configuration is given. The required output signals for the lumbar spine configuration are the angular rotation of the bulk mass, the lumbar spine force and the lumbar spine moment. For each signal x-, y- and z-direction are considered. The curves of simulation and test are shown in Figure 5. The interval of evaluation is defined by TB043-1 from 15 to 115 ms.

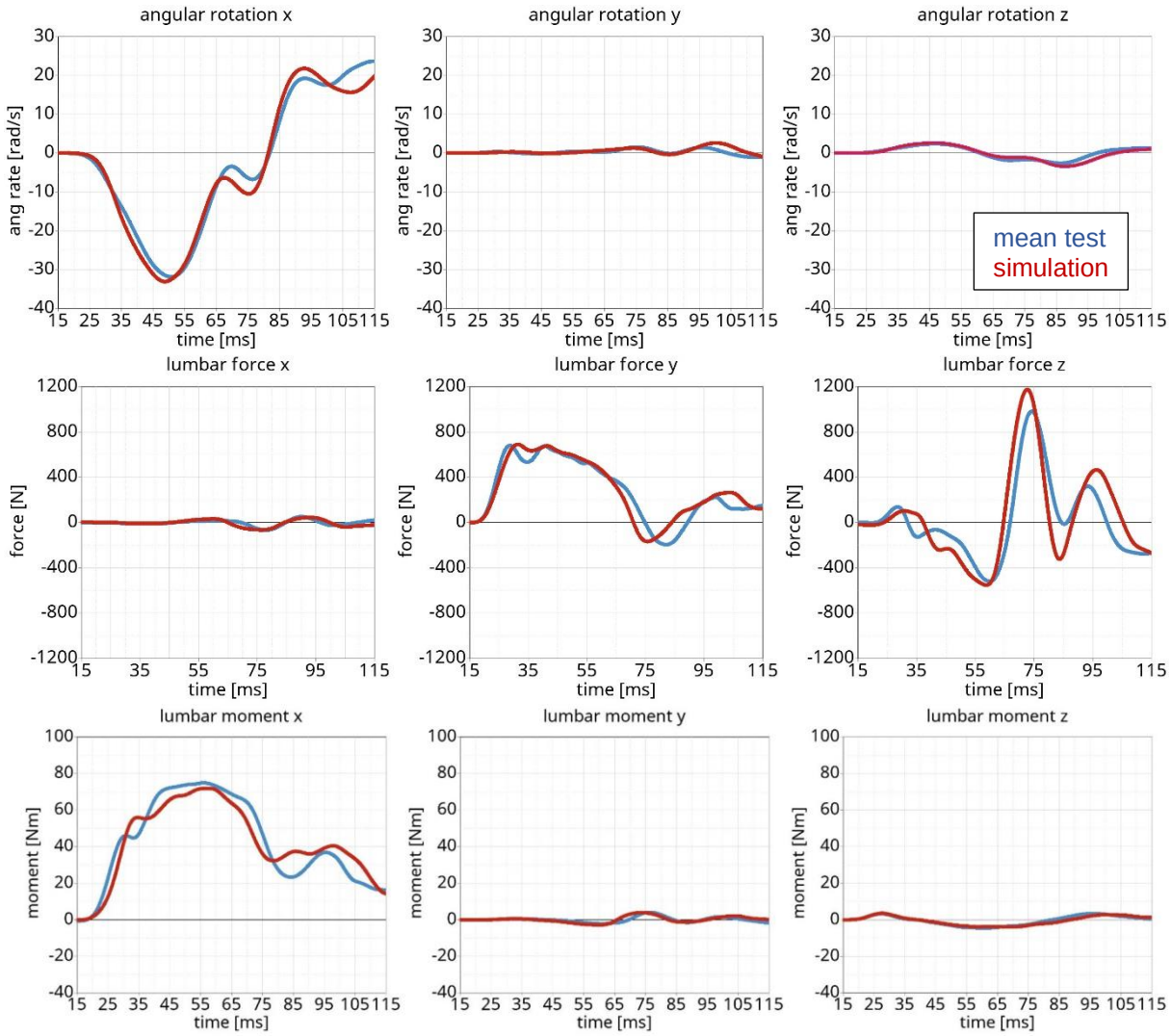


Figure 5: Lumbar spine 90° ISO 18571 curves for test and simulation

To calculate a signal rating S_{signal} the x-, y- and z-direction ratings are weighted and summarized. If the sum of all weighting factors of a signal is not equal to 1.0, the lowest weighting factor is modified accordingly. [1]

$$S_{signal} = \sum_i w_i * S_{Ch,i} \quad with\ i = x, y, z \tag{1}$$

The weighting of all cannels is provided in TB043-1. For the weighting calculation w_i, the maximum absolute value $\max(|Ch_{test,i}|)$ of each test channel is divided by the sum of the maximum absolute value of all test channels of the signal. [1]

$$w_i = \frac{max\ (|Ch_{test,i}|)}{max(|Ch_{test,x}|) + max(|Ch_{test,y}|) + max\ (|Ch_{test,z}|)} \quad with\ i = x, y, z \tag{2}$$

The total load case rating is calculated as the average of all signal ratings. An overview of the ratings for the 90° lumber spine component test is shown in Figure 6.

Channel	$S_{Ch,i}$	w_i	S_{signal}	$S_{loadcase}$
ABDO0001AVX	0.892	0.8838	0.885	0.832
ABDO0001AVY	0.792	0.0500		
ABDO0001AVZ	0.857	0.0721		
LUSP0000FOX	0.784	0.0386	0.778	
LUSP0000FOY	0.828	0.3936		
LUSP0000FOZ	0.743	0.5678		
LUSP0000MOX	0.831	0.8960	0.835	
LUSP0000MOY	0.857	0.0486		
LUSP0000MOZ	0.877	0.0554		

Figure 6: Lumbar spine 90° ISO 18571 rating

For the other load cases the ratings can be found in the overview of Figure 7. The total component rating is calculated as the arithmetic mean of all the component load cases. With a total component rating of 0.837 the value is clearly above the requested rating of 0.70.

Head-Neck 90°	Head-Neck 75°	Lumbar Spine 90°	Lumbar Spine 60°
0.868	0.865	0.832	0.781
Component rating			
0.837			

Figure 7: Component ISO 18571 rating overview

The curves of the other component tests can be found in the dummy certification report. [7]

4.3 Full scale tests

The full scale far side sled test simulations include the whole dummy model. It is shown in Figure 8. The dummy is seated on a sled consisting of a seat pan and a simple backrest. To the right-hand side of the dummy a pelvis and legs centre console is located. The dummy feet are positioned on a footrest. A three-point belt is used to restraint the dummy. There are two different pulses for the sled test available (8 m/s and 11 m/s), both are applied in 75° oblique direction. [1]

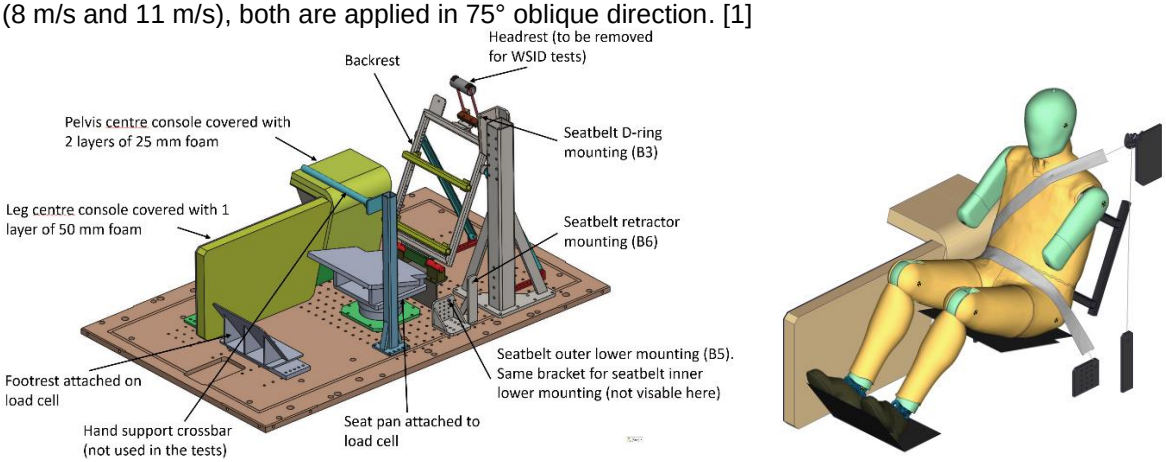


Figure 8: Structure of hardware sled test (left) [6] and associated simulation model (right)

For the simulation model build up a reference geometry model is provided by TB043-1. Only the dummy and the seatbelt path are given as a geometry input by the dummy supplier. The friction of the contacts can be modified in a certain range (0.1 – 0.6).
The procedure to get the ISO 18571 is the same as for the component tests described in chapter 4.2. The rating for the stage 3 tests needs to be ≥ 0.61. Within this paper, only the curves of the 8 m/s pulse are shown in Figure 9, Figure 10 and Figure 11. The curves for 11 m/s can be found in the dummy certification report. [7]

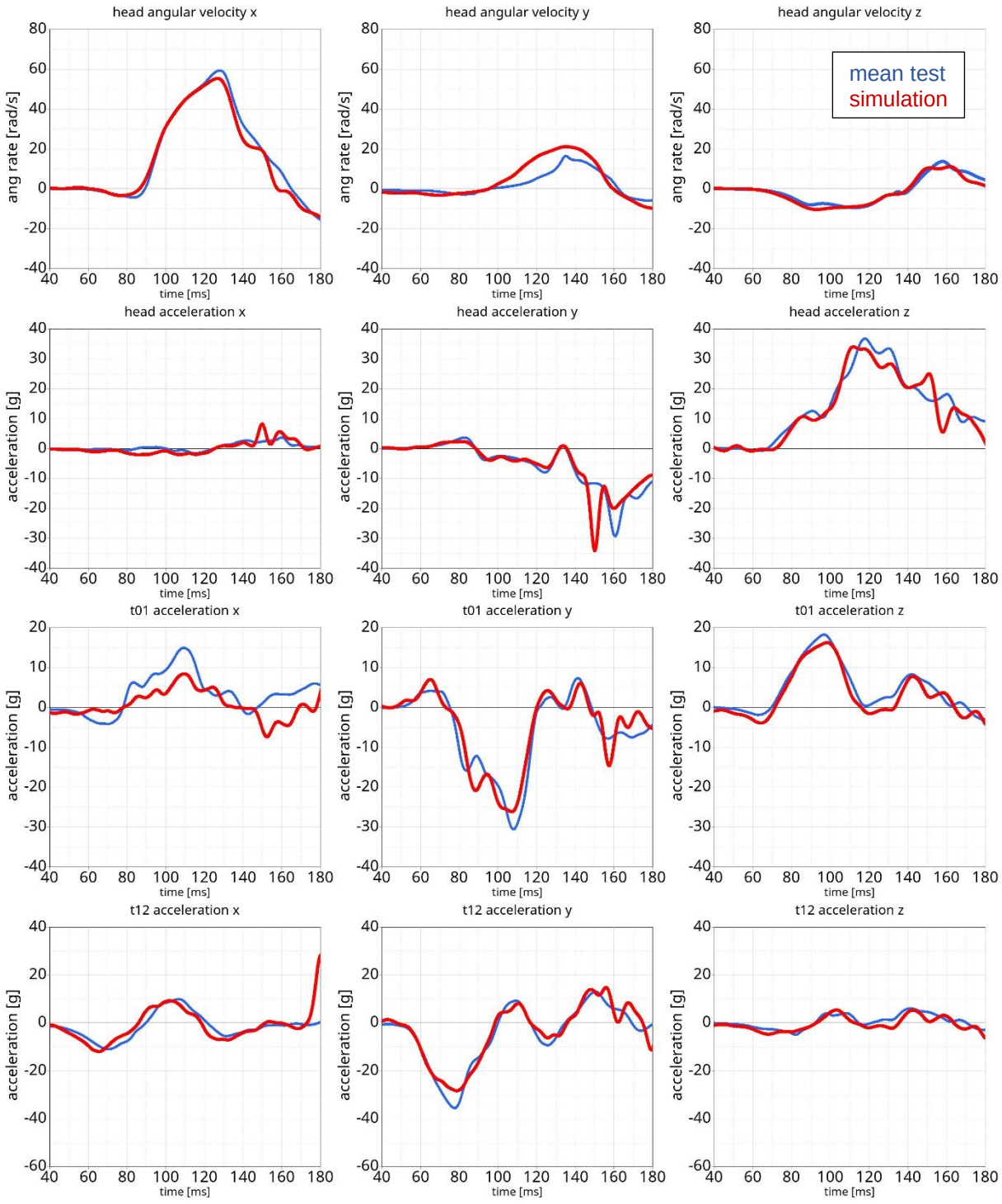


Figure 9: Far side sled test 8 m/s results part 1

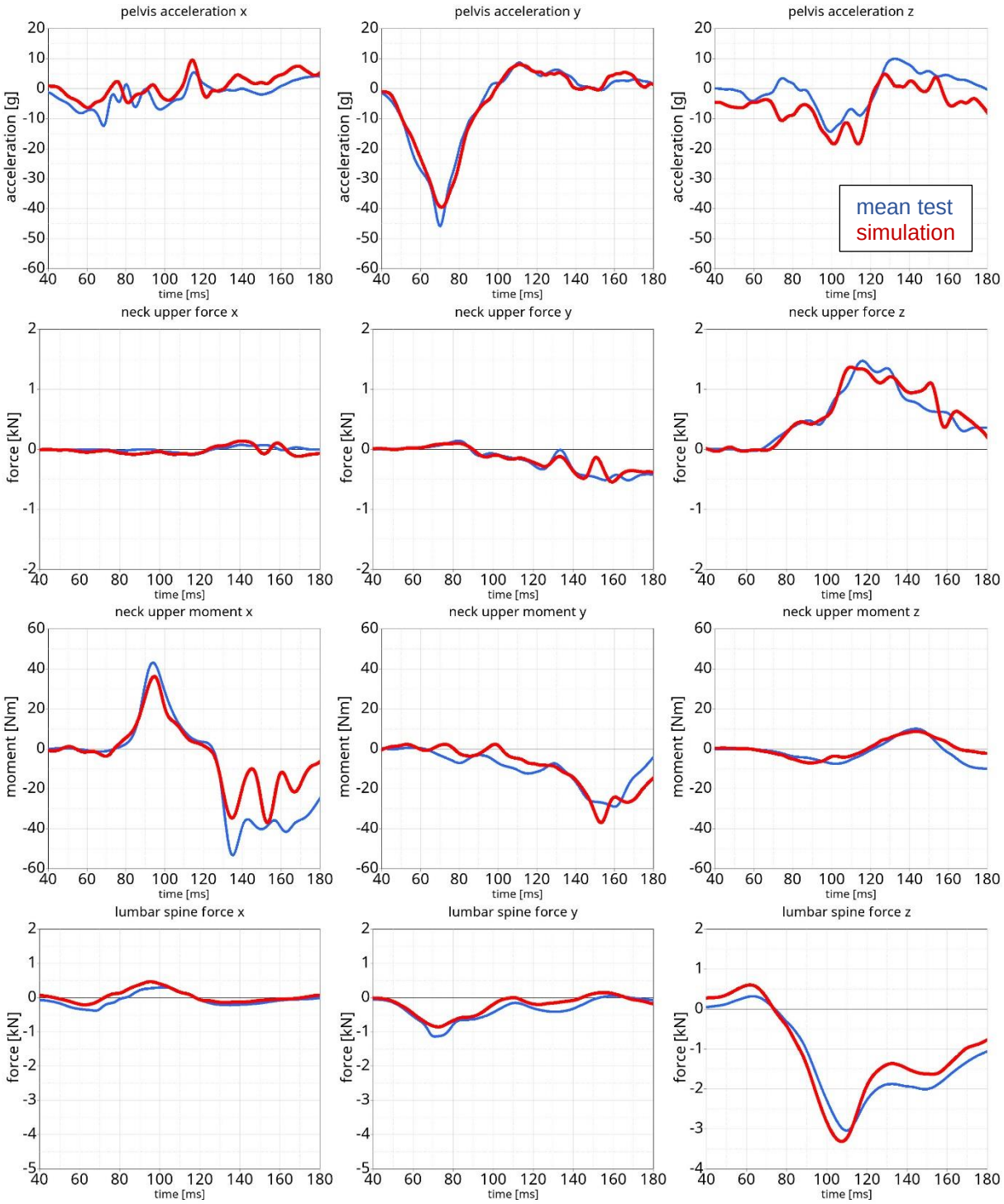


Figure 10: Far side sled test 8 m/s results part 2

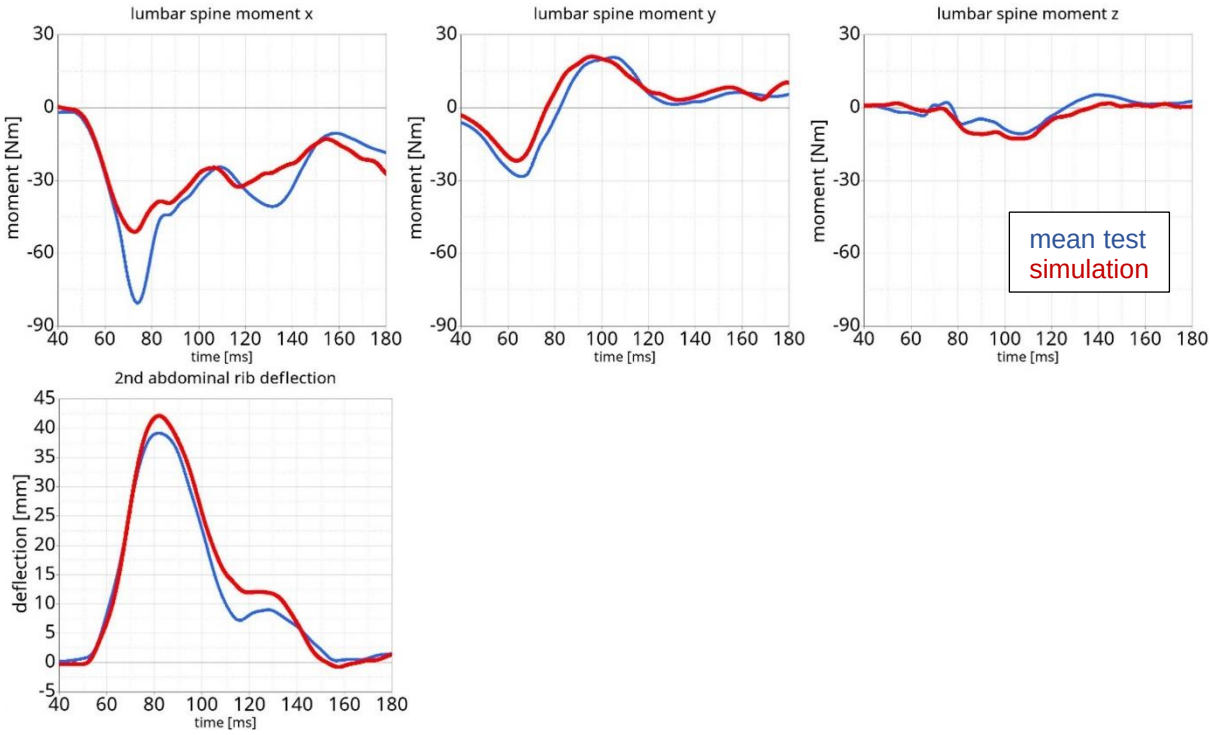


Figure 11: Far side sled test 8 m/s results part 3

For the far side sled test ten signals, from head to pelvis, are evaluated. The interval of evaluation is set by TB043-1 from 40 to 180 ms. The signal of the second abdominal rib deflection has only one channel output. All the other signals are calculated out of the weighted x-, y- and z-channel outputs as shown in chapter 4.2. The ISO 18571 rating for the 8 m/s simulation is shown in Figure 12 on the left hand side. On the right hand side the ISO 18571 rating of the 11 m/s simulation is also shown. The total sled test rating is 0.768, thus clearly above the requested value of 0.61 required from TB043-1.

	Channel	S_{signal}	$S_{loadcase}$
Far side 8 m/s	HEAD0000AV	0.849	0.790
	HEAD0000AC	0.757	
	THSP0100AC	0.728	
	THSP1200AC	0.792	
	PELV0000AC	0.770	
	NECKUP00FO	0.778	
	NECKUP00MO	0.699	
	LUSP0000FO	0.786	
	LUSP0000MO	0.816	
	ABRIRI02DS	0.922	

	Channel	S_{signal}	$S_{loadcase}$
Far side 11 m/s	HEAD0000AV	0.842	0.747
	HEAD0000AC	0.671	
	THSP0100AC	0.747	
	THSP1200AC	0.711	
	PELV0000AC	0.718	
	NECKUP00FO	0.805	
	NECKUP00MO	0.623	
	LUSP0000FO	0.785	
	LUSP0000MO	0.695	
	ABRIRI02DS	0.874	

Figure 12: Far side sled test ISO 18571 rating 8 m/s (left) and 11 m/s (right)

5 LS-DYNA WorldSID version 8.0 release notes

In this chapter some of the updates of the new LS-DYNA WorldSID version 8.0 are listed. The list does not include all the updates since there are too many. All modifications can be found in the release notes chapter of the dummy manual. [8]

- Jacket update: the jacket was modified in the shoulder region and does not include an optional sleeve anymore (see Figure 13)

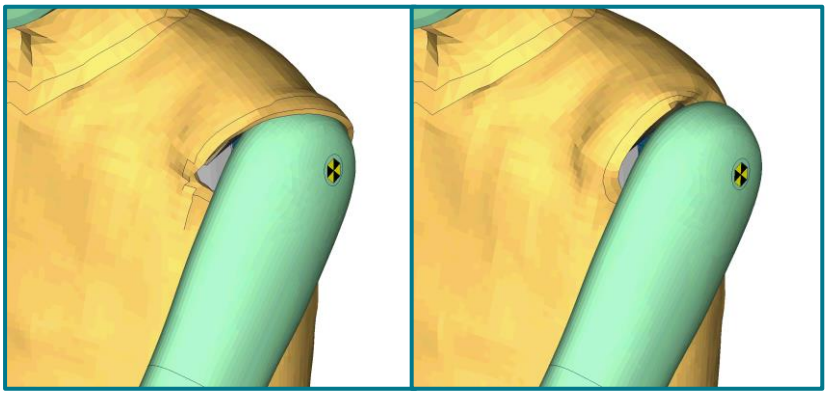


Figure 13: Comparison of dummy jacket of version 7.6.1 (left) and version 8.0 (right)

- Mass and range of motion adjustments to meet ISO 15830
- Material optimizations (for example of lumbar spine and pelvis)
- Pubic load cell geometry update (see Figure 14)

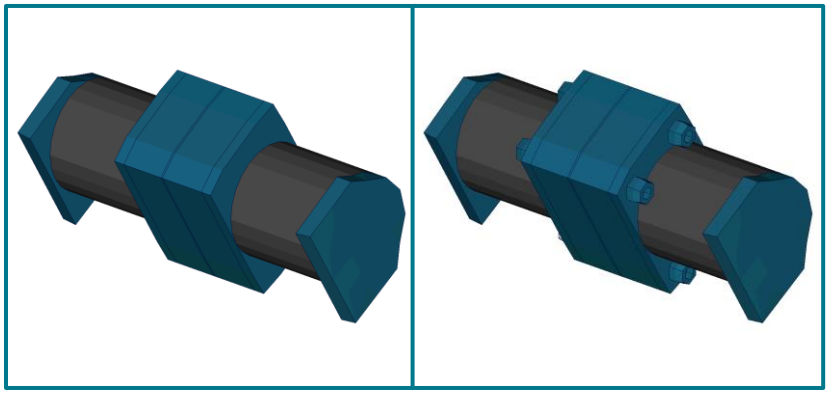


Figure 14: Comparison pubic load cell of version 7.6.1 (left) and version 8.0 (right)

- Pelvis tilt sensor position update
- Shoulder load cell geometry update (see Figure 15)

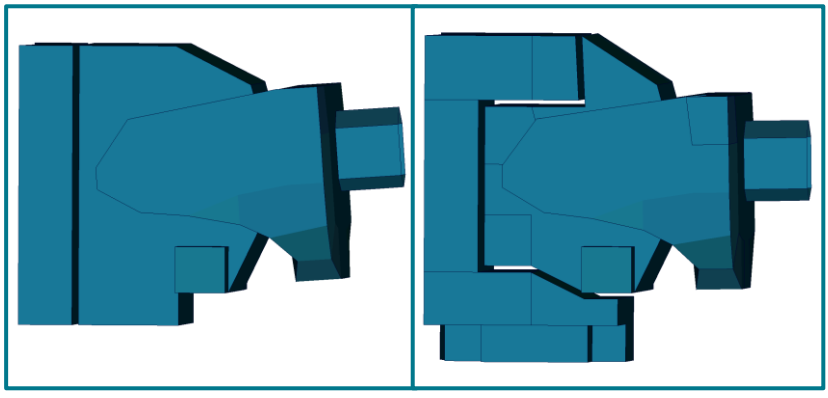


Figure 15: Comparison shoulder load cell of version 7.6.1 (left) and version 8.0 (right)

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6 Summary

With the DYNAmore LS-DYNA WorldSID version 8.0 there is now an officially certificated model for the Euro NCAP Virtual Far Side Simulation & Assessment Protocol available. The model is fulfilling all of the three required stages defined within TB043-1.
In chapter 4 an overview of the required stages of TB043-1 was given with the example of the DYNAmore LS-DYNA WorldSID version 8.0. In chapter 4.1 the normative dummy requirements of the dummy model were shown to pass the first stage. The second stage, consisting of two component tests, was presented in chapter 4.2. The WorldSID model shows an ISO 18571 rating of 0.837, which is clearly above the required rating of ≥ 0.70. For the third stage, discussed in chapter 4.3, a full scale far side sled test was simulated with two different velocities. The ISO 18571 rating for these far side sled tests is 0.768, again clearly above the required rating for the third stage of ≥ 0.61.

7 Literature

[1] Euro NCAP VTC Group: "Qualification Procedure for Virtual Dummy Models, Part 1: WorldSID AM50, Technical Bulletin 043-1", Version 1.0, 2023
[2] Euro NCAP VTC Group: "VIRTUAL FAR SIDE SIMULATION & ASSESSMENT PROTOCOL", Version 1.0, 2023
[3] ISO/TS 18571:2014: "Road vehicles – Objective rating metric for non-ambiguous signals", Edition 1, 2014
[4] Partnership for Dummy Technology and Biomechanics: "CORAplus Release 4.0.4, User's Manual", 2017, 33-37
[5] ISO 15830: "Road vehicles – Design and performance specifications for the WorldSID 50th percentile male side impact dummy – Part 1 - 5", third edition, 2022
[6] Petit et al: "Far Side Impact Injury Threshold Recommendations based on 6 Paired WorldSID / Post Mortem Human Subjects tests", Stapp Car Crash Journal, Vol. 63, 2019, page 3
[7] DYNAmore GmbH, an Ansys Company: "VTC Validation Report, PDB LS-DYNA WorldSID 50th – Version 8.0, Edition 1.0, 2023
[8] DYNAmore GmbH, an Ansys Company: "User's Manual, PDB LS-DYNA WorldSID 50th – Version 8.0, Edition 1.0, 2023