ES-2/re Model Validation on FAA Requirements for Aircraft Side Impact with LS-DYNA®

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Abstract

For many years ES-2 and ES-2re dummy models are used in car side crash simulations. The use of the ES-2 and ES-2re dummy models in these simulations is precisely defined. Until recent work in the aerospace industry within Aerospace Recommended Practice (ARP) 5765 Revision B by SAE International (SAE) there were no instructions available for the exact use of the ES-2 and ES-2re dummy. SAE ARP 5765 Revision B aims for an easier seat certification process to fulfill Federal Aviation Administration (FAA) requirements giving best practice advice of how to work with ES-2re in side facing impact aircraft simulations. In connection with SAE ARP 5765 Revision B new side facing sled tests were performed by the FAA with special pulses. Based on these new side facing sled tests the DYNAmore ES-2 and ES-2re model was further validated to meet these new demands. With the end of the validation process the ES-2 and ES-2re V8 model, suited for car and aircraft side crash simulations, was released. Besides much better performance in the ARP side facing sled tests, also the overall performance of the already existing Partnership of Dummy Technology and Biomechanics (PDB) car side facing sled tests was increased.
To support the visualization of the increasing performance of the ES-2 and ES-2re dummy CORA ratings were created for the last three release versions of ES-2 and ES-2re. The ratings are available for the new FAA sled tests, the PDB sled tests and all the certification tests of the dummy.

Introduction

In the aerospace seat developing sector dynamic simulations in forward and vertical directions are common [1] [6]. However, side facing simulations are uncommon due to the lack of usage in aerospace environment. In SAE ARP 5765 Revision B the FAA, in corporation with many aerospace companies, plans to give best practice advice of how to fulfill FAA requirements within side facing simulations for an easier seat certification process. Within this project special aircraft sled tests with an ES-2re dummy were carried out. These tests are the basis of the development of an update of the ES-2 and ES-2re LS-DYNA simulation model suitable for the aerospace environment.

SAE ARP 5765 sled test setup

The sled test setup was developed by the FAA. Previous work [1] [2] [3] let to the final setup which was used within SAE ARP 5765 Revision B. It is visualized in Figure 1. The setup consists of three major parts: the bench, the belt and the dummy.
There are two different benches available. One bench with an armrest on the left side of the bench (Figure 1 left) and one bench without an armrest (Figure 1 mid). Besides the bench there is a plate available to represent the floor on which the feet of the dummy can be placed.
The belt is a three-point belt with fixed locations on the right hand side of the sled and on the left hand side behind the dummy pelvis. These two points are connected with belt and buckle around the dummy pelvis. The third part of the belt is attached to the buckle and leads across the chest of the dummy from the right abdomen to the left shoulder. Behind the left dummy shoulder the belt is guided through a shaft attached to the bench. The belt ends at the bottom of the backside of the bench. A scheme of the belt can be seen in Figure 1 on the right hand side.

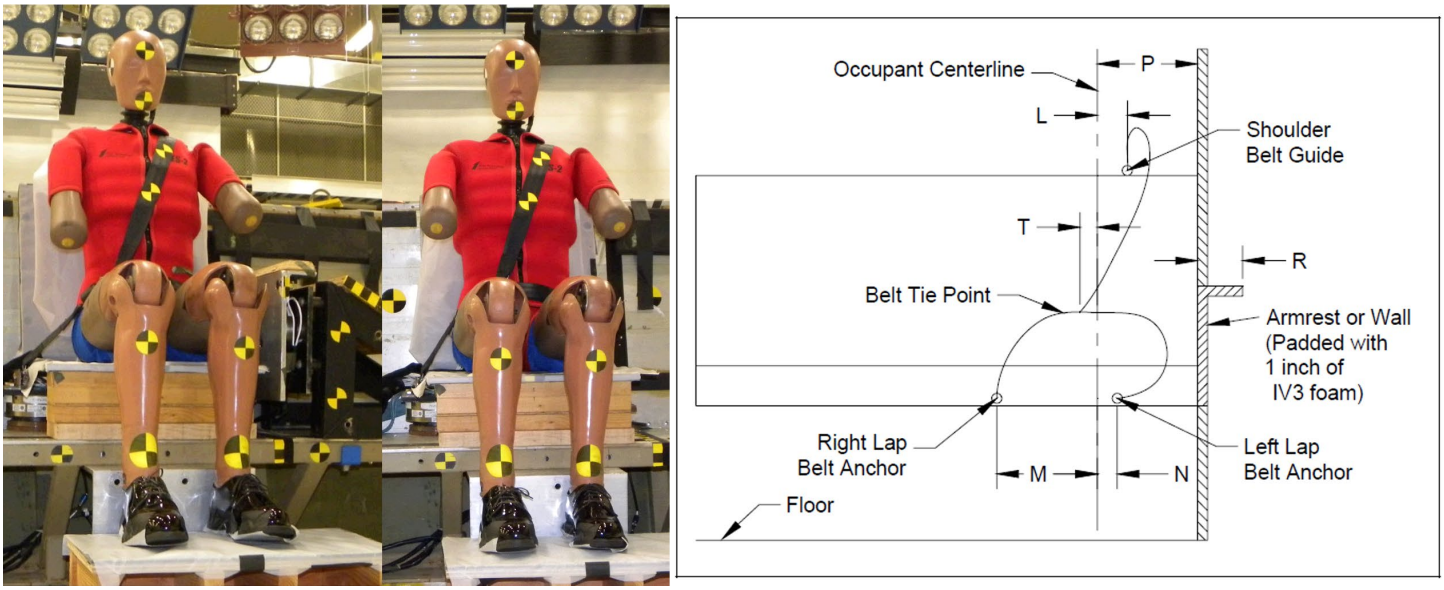

Figure 1: ARP 5765 sled test setup with armrest (left), without armrest (mid) and belt scheme (right) [1]

The ES-2re model is used as the dummy of the setup. It is seated to match the geometry of the bench. The feet are placed flat on the bottom plate. The angle between upper and lower leg is about 96 degrees. The belt is fitted to have no slack.

The simulation setups are based on the real test setups. It consists of the same three main parts: the bench, the belt and the dummy. On the right hand side of Figure 2 and Figure 3 the simulation setups with and without armrest are shown. In the same figures on the left hand side some of the performance curves of the ES-2re V7 model are compared with real test curves.

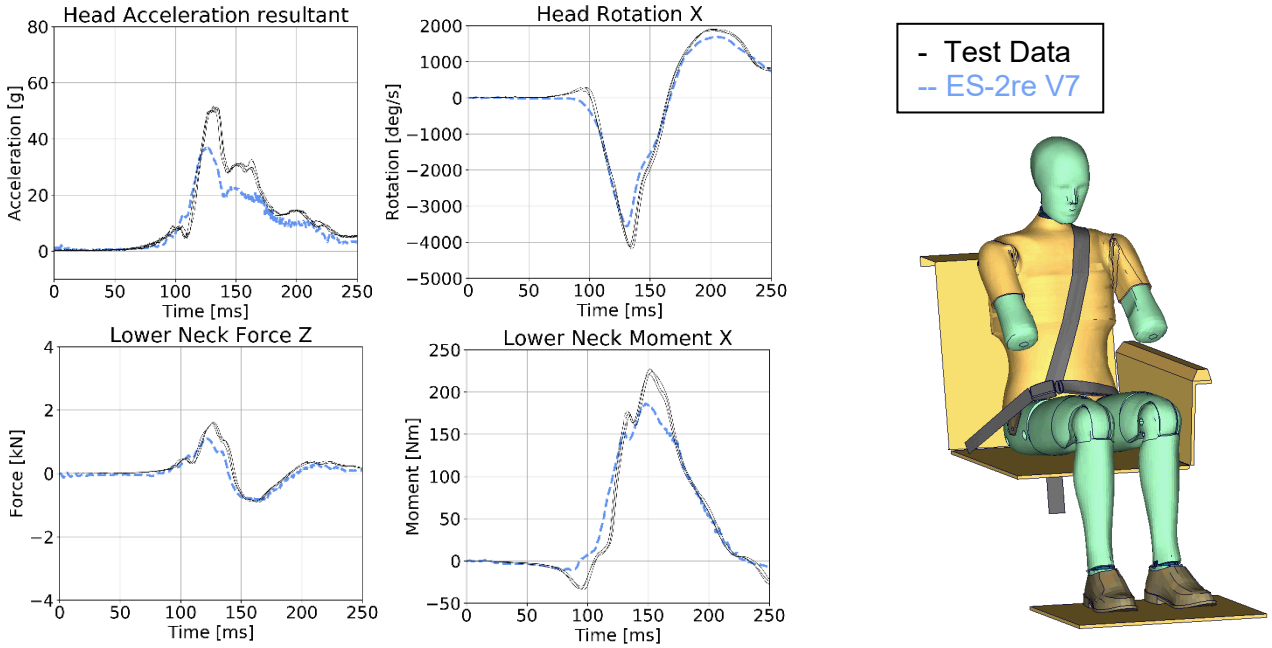

Figure 2: Results with armrest ES-2re V7

On the one hand the shape of the model curves is similar to the test curves. On the other hand, the peaks are much smaller in the model curves for both, the simulation with and without armrest. Due to these differences the ES-2re V7 model is not well suited for the new side facing aircraft simulations and has to be improved.

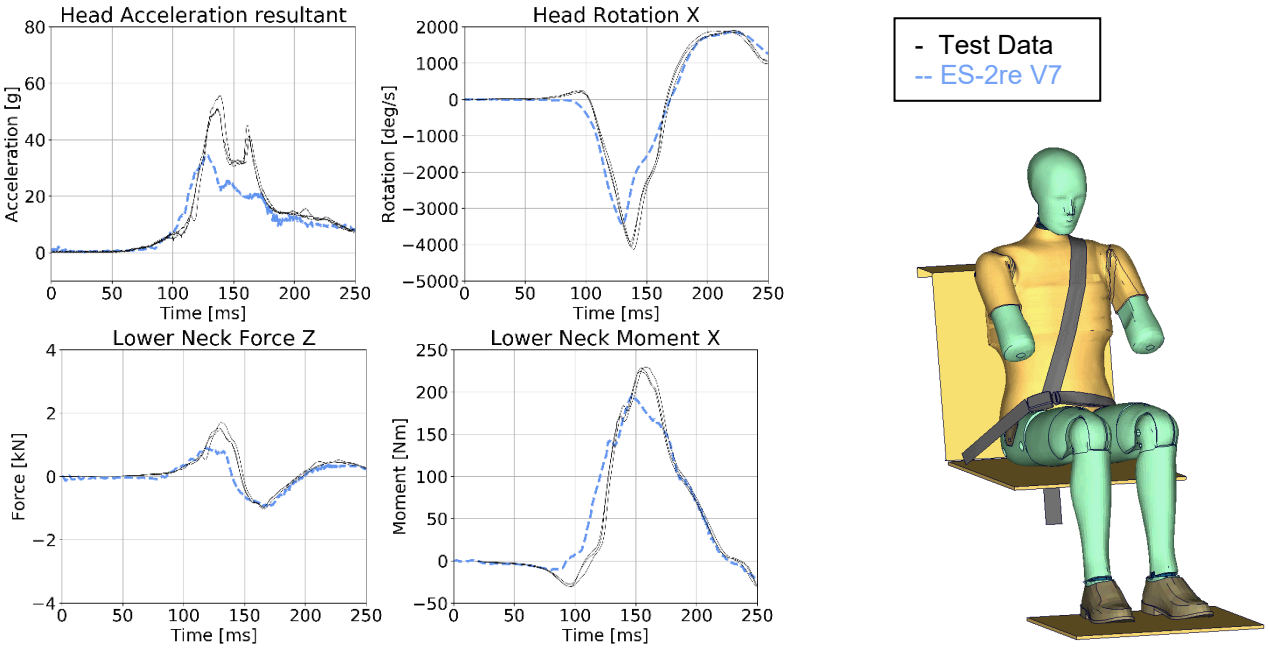

Figure 3: Results without armrest ES-2re V7

ES-2 and ES-2re version 8 model updating process

The dummy model updating process consists of three main steps: the sled tests, the certification and component tests and the enhancement of the model. The methodology is visualized in Figure 4.

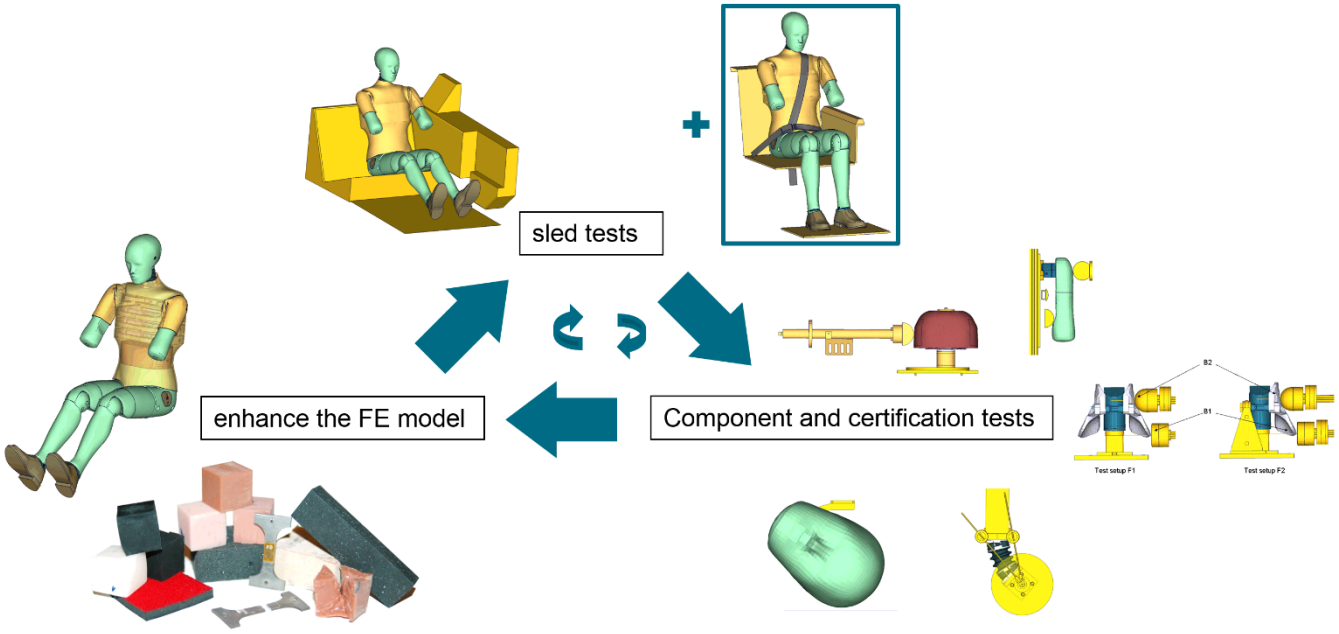

Figure 4: Methodology of dummy model updating

These steps are repeated until all the tests show satisfying results. Altogether there are more than one hundred tests in total. The most important tests are the certification and sled tests.

The main visual enhancements of the ES-2 and ES-2re V8 dummy model are shown in Figure 5 and Figure 6. The neck was remeshed due to insufficient behavior in very large bending situations. The iliac wings were remeshed to receive better behavior of the pelvis.

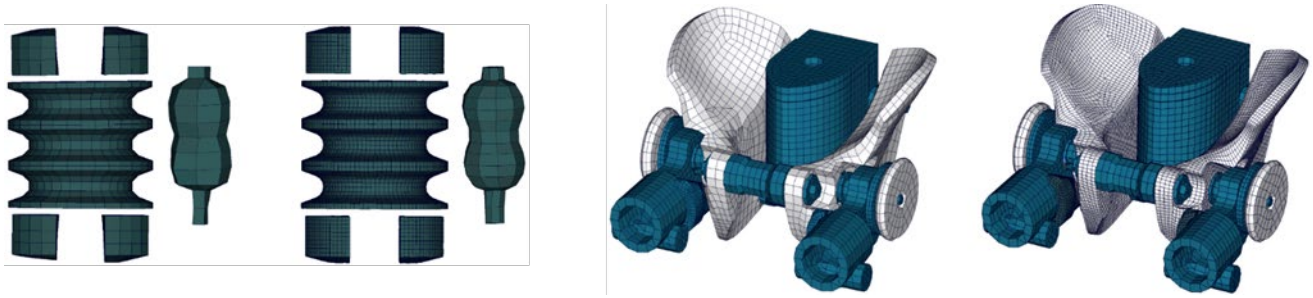

Figure 5: Comparison of old (left) and new mesh (right) of neck/neck buffers and iliac wings

The head accelerometer was split up into three accelerometers for each direction. The old and new accelerometer locations and its nodes can be seen in Figure 6. In hardware the acceleration is also measured at three slightly different positions.

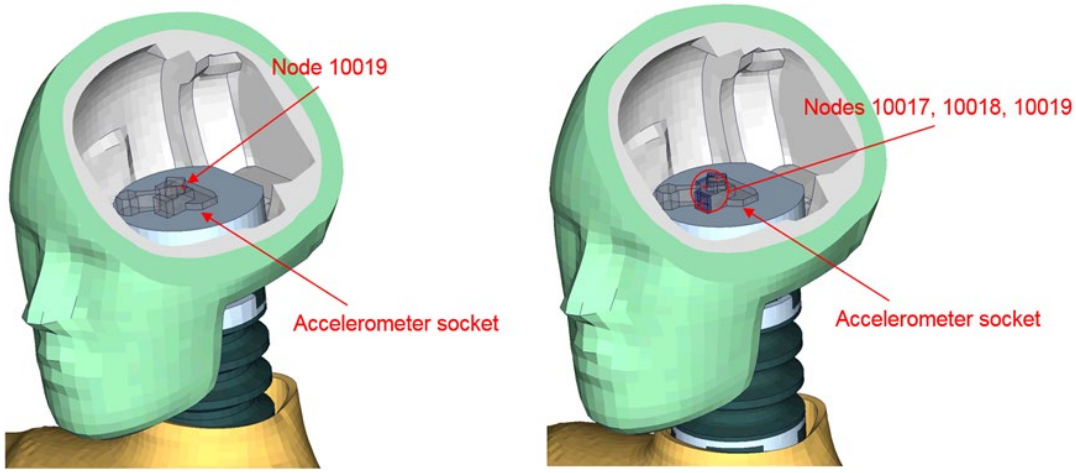

Figure 6: Comparison of old (left) and new (right) head accelerometer positions

There were several additional enhancements like material, joint and contact optimization. All changes are listed in the official manual of ES-2 and ES-2re V8. [4]

Results

The new ES-2re V8 model shows strongly improved results in the new ARP 5765 sled tests. Figure 7 shows some of the results of the simulation setup with armrest of ES-2re V7 and V8 compared to the test results. The peaks of the ES-2re V8 model simulation are much higher than with V7. They are now very similar to the real test peaks.

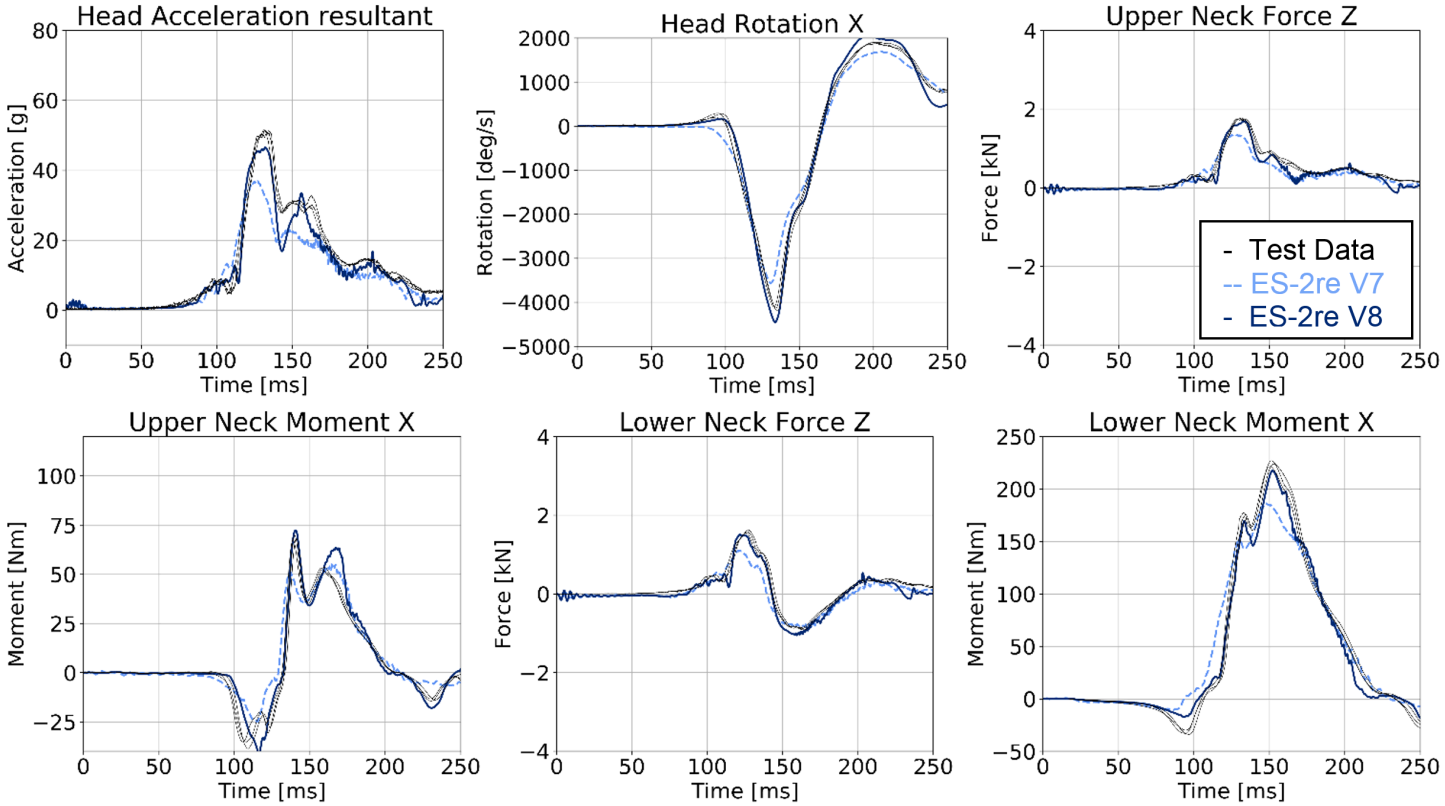

Figure 7: Selected results for setup with armrest

In Figure 8 the results of the simulation setup without armrest are pictured. For this setup the simulation results, especially the peaks, also show a much better match to the test curves.

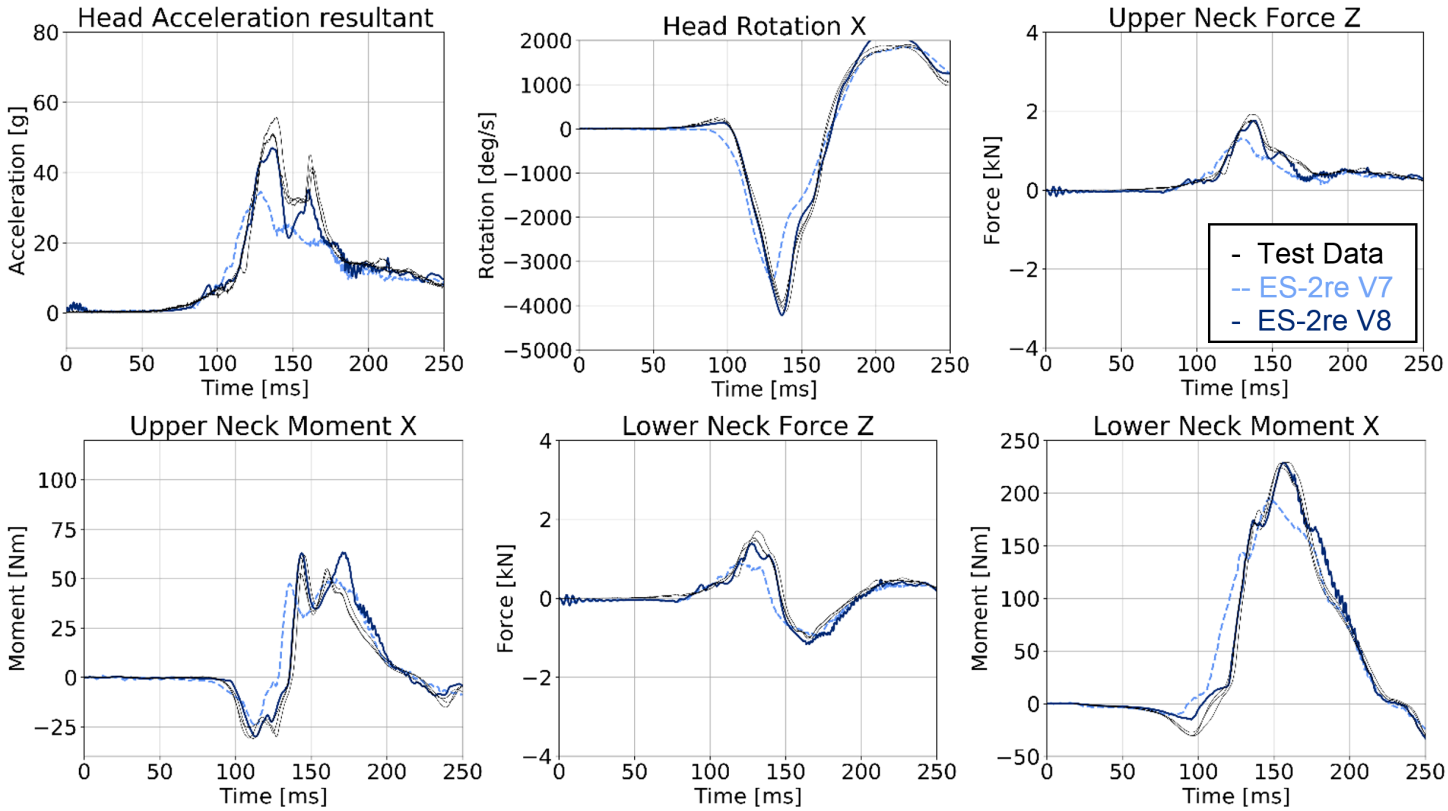

Figure 8: Selected results for setup without armrest

There are more results for the ARP 5765 sled test with and without armrest available in the ES-2 and ES-2re V8 model manual [4]. Within this manual the results from all the other sled tests, certification tests and component tests are also included.

CORA

To track the ongoing development of the ES-2 and ES-2re dummy model CORA (CORelation & Analysis) is used. CORA was developed by the PDB. It can be used to evaluate time history signals from test and simulation. The methodology of CORA is visualized in Figure 9. It consists of two different ratings, the cross correlation rating and the corridor rating. With the two different approaches CORA tries to compensate the disadvantage of each approach for his own. The rating ranges from 0, which means very bad fit, to 1, which means very good fit [5].
For the corridor rating two different corridors are created surrounding the mean curve of the test curves. For this rating the values of each time step are compared. If the simulation curve value is within the inner corridor of the mean curve the rating for this time step is 1. If it lays between the first and the second corridor it is interpolated between 1 and 0. If it lays outside of the second corridor the rating is 0. For the total corridor rating the mean of all time step ratings is calculated.
The cross correlation rating itself is divided into three separate ratings. The phase rating considers the time shift between the simulation and test curve. The size rating calculates the area under the curves and so compares the size. The shape rating checks the general shape of the two curves. The exact way of the ratings is documented within the CORA manual [5].

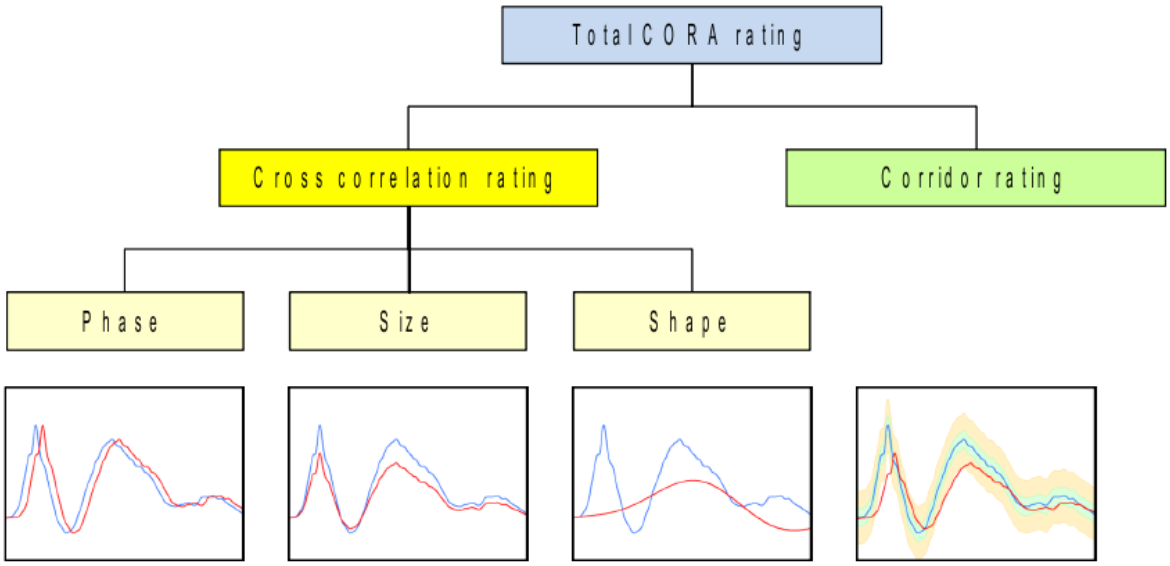

Figure 9: Methodology of the CORA rating [5]

For the CORA ratings different parameters have to be set. On the one hand the base parameters are the same for the different test scenarios. On the other hand, the evaluated dummy output curves and the weighting of this curves is different between ARP sled test ratings, PDB sled test ratings and certification test ratings. The considered output curves correspond to the defined outputs in the tests. The weighting of the curves was defined by consideration of some critical values and experience. It is important to use the defined settings for all the old dummy model versions and the new ones to keep the comparability.

The CORA ratings for the ARP 5765 sled tests from ES-2re V6 to V8 are shown in Table 1. The ratings are continuously increasing from V6 to V8. In V6 and V7 there was a significant difference between the setup with and without armrest. Neither V6 nor V7 was optimized for the ARP 5765 sled tests. In the new ES-2re V8 the difference between with and without armrest is very little.

Table 1: CORA ratings SAE ARP 5765 sled tests

SAE ARP5765 sled test	with armrest	without armrest	total
ES-2re V8	0.831	0.826	0.828
ES-2re V7	0.810	0.765	0.787
ES-2re V6	0.765	0.721	0.743

In Table 2 the CORA ratings for the PDB sled tests are listed. The PDB sled tests are done with different barrier geometries and different impact velocities. The lower CORA values do not mean, that the model performance for the PDB tests is worse than the ARP sled tests. In the PDB sled tests the weighting is different to the ARP 5765 sled test ratings. Additionally, there are more output curves considered.
For the PDB sled tests we can also see an increasing performance with every new dummy version. Furthermore, the ratings between the different barriers are more homogeneous for ES-2re V8.

Table 2: CORA ratings PDB sled tests

PDB sled test	D1-barrier	D3-barrier	D4-barrier	total
ES-2re V8	0.747	0.748	0.752	0.749
ES-2re V7	0.723	0.733	0.759	0.739
ES-2re V6	0.734	0.714	0.746	0.731

The Cora ratings of the certification tests are shown in Table 3. There are four certification tests in component level environment and four certification tests with the whole dummy. The marked entries in the table signal that there was no change in the component to the previous version, therefore the rating is the same.

Table 3: CORA ratings certification tests

Certification	Head	Neck	Ribs	Lumbar	Shoulder	Thorax	Abdomen	Pelvis	total
ES-2/re V8	0.931	0.865	*0.941	*0.879	0.626	0.814	0.871	0.861	0.848
ES-2/re V7	*0.938	*0.776	*0.941	*0.879	0.650	0.843	0.923	0.849	0.850
ES-2/re V6	0.938	0.776	0.941	0.879	0.679	0.852	0.921	0.690	0.834

On the one hand the table shows increasing performance of the neck and the pelvis for ES-2 and ES-2re V8. On the other hand, it shows little decreasing performance for the head, shoulder, thorax and abdomen. The total rating of V8 is very similar to V7. Due to the much better ratings of the SAE ARP 5765 and PDB sled tests a slightly lower total value for the certification tests was accepted. Important for the certification test rating is that CORA does not consider the defined criteria of the hardware certification tests but the whole curve. For all the certification tests this criteria was ensured outside of CORA for all the dummy model versions.

Conclusion

With the recent update of the DYNAmore LS-DYNA ES-2 and ES-2re V8 dummy there is now a side facing crash test dummy model available optimized for the aerospace industry. The model shows a better match with the SAE ARP 5765 sled tests which are provided by the FAA for validation. The new version 8 also increases its performance in the PDB sled tests. It can now be used in both aerospace and car environment.
With the CORA ratings the increasing performance of the ES-2 and ES-2re dummy from V6 to V8 could be visualized. One has to keep in mind that the amount of the rating value itself is not comparable between different test setups.

References

[1] DeWeese, R. et al: Assessment of Injury Potential in Aircraft Side-Facing Seats Using the ES-2 Anthropomorphic Test Dummy, Federal Aviation Administration, May 2007, Washington DC
[2] Pellettiere, J.: Aircraft Seat Certification by Analysis from Regulatory Perspective, Federal Aviation Administration, January 2014
[3] Moorcroft, D.: Analytical Methods for Aircraft Seat Design and Evaluation, Federal Aviation Administration, October 2010
[4] DYNAmore GmbH: ES-2 50th - Version 8.0.2 User's Manual, February 2020, Stuttgart
[5] Partnership for Dummy Technology and Biomechanics (PDB): CORAplus 4.0.4 manual, May 2017
[6] Olschinka, C. et al: Dynamic Simulation of Flight Passenger Seats, Hamburg University of Applied Sciences, 2006, Ulm