Development of special new versions of the FAT/PDB Dummy models for quick analysis response. The Rapid Analysis Models (R.A.M.).

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1 Introduction

The finite element model of the FAT and PDB Dummy models have been developed in co-operation with the German Automotive Industry for the last few years. One of the major goals during the development of the models was to achieve a high degree of accuracy of the model as well as to have a robust model without numerical instabilities.

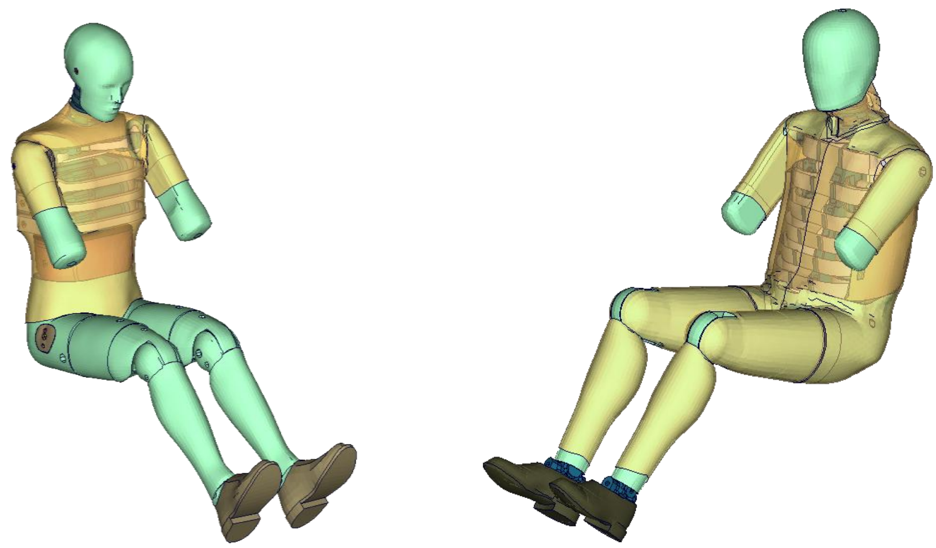

Fig. 1: Left: FAT ES-2version 5.0; Right: PDB WorldSID 50% version 2.0 models.

During the course of the model development, the geometry of various components has evolved considerably and finite element meshes for the various components have gotten finer. New material tests were also carried out for many components resulting in the use of advanced material models. This has naturally resulted in an increase in the computation times for the model. Increased computation times are definitely a hindrance when it comes to carrying out a study with a large sample set for example. The computational time of the last two official ES-2re versions for three different sled tests are shown in the following table.

Barrier configuration	ES-2re model version	Simulation time
Barrier D1	ES2_v4.5	4h 37m 06s
	ES2_v5.0	8h 05m 19s
Barrier D3	ES2_v4.5	4h 34m 09s
	ES2_v5.0	7h 31m 56s
Barrier D4	ES2_v4.5	4h 29m 17s
	ES2_v5.0	8h 04m 57s

Tab.1: Computational time increase from ES-2re v4.5 to ES-2re v5.0 in sled test.

Keeping this in mind, we at DYNAmore have developed a simplified version of the ES-2/ES-2re model meant for rapid prototyping. This simplified model requires considerably lesser computation time and delivers extremely good results in the component and barrier tests, considering the degree of simplicity of the model. The geometry of the model has remained unchanged. Simplified and "quicker" material models have been used wherever possible and all the certification and component tests were carried out for the model. Development of a R.A.M. model of the WorldSID 50% has also been started.

As a final step, the software CORA [1] (CORrelation and Analysis) was used to obtain an objective comparison of the simplified model to the original model.

2 Changes for the R.A.M. models

In a huge database of simulations of the ES-2/ES-2re and WorldSID 50% we recognized that the latest versions of the models need more computational time than the older versions. The Element number or types have not changed significantly in the models compared to the older versions. So where does the higher computational time come from?

In the latest FAT and PDB Dummy versions we were using the materials MAT_181 and MAT_183 excessively for rubbers, foams and plastics. The advantages of the materials are the strain rate dependency and the complete nonlinear elastic behaviour by also using separate unloading behaviour. So the material can be described much better than with the previously used material models like MAT_ELASTIC, _VISCOELASTIC and _VISCOUS_FOAM.

The following figure shows the Parts of the ES-2re which use MAT_181 or MAT_183.

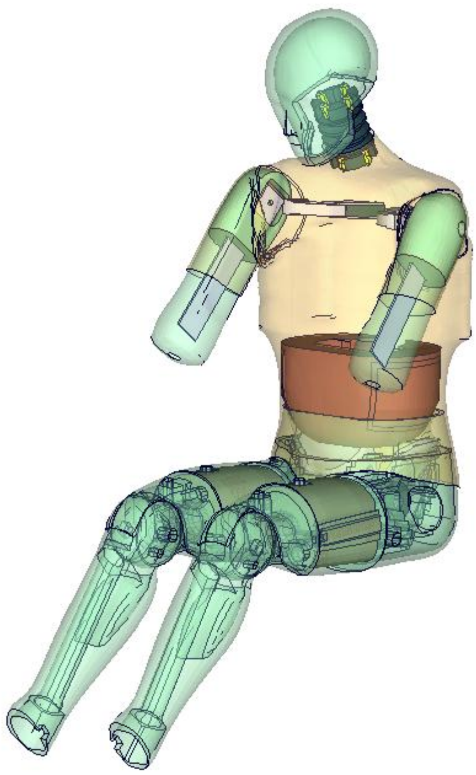

Fig. 2: ES-2re v5.0 and WorldSID 50% v2.0 MAT_181 and MAT_183 parts.

These parts are all important rubber, rubber foam (like upper arm foam), and plastic (clavicle and iliac wings) parts. Also the neoprene jacket is currently using the MAT_183.
These material types are replaced step by step by simple material models. Three different Material Models are used. MAT_ELASTIC, MAT_VISCOELASTIC and MAT_VISCOUS_FOAM. The assignment is shown in the following figure.

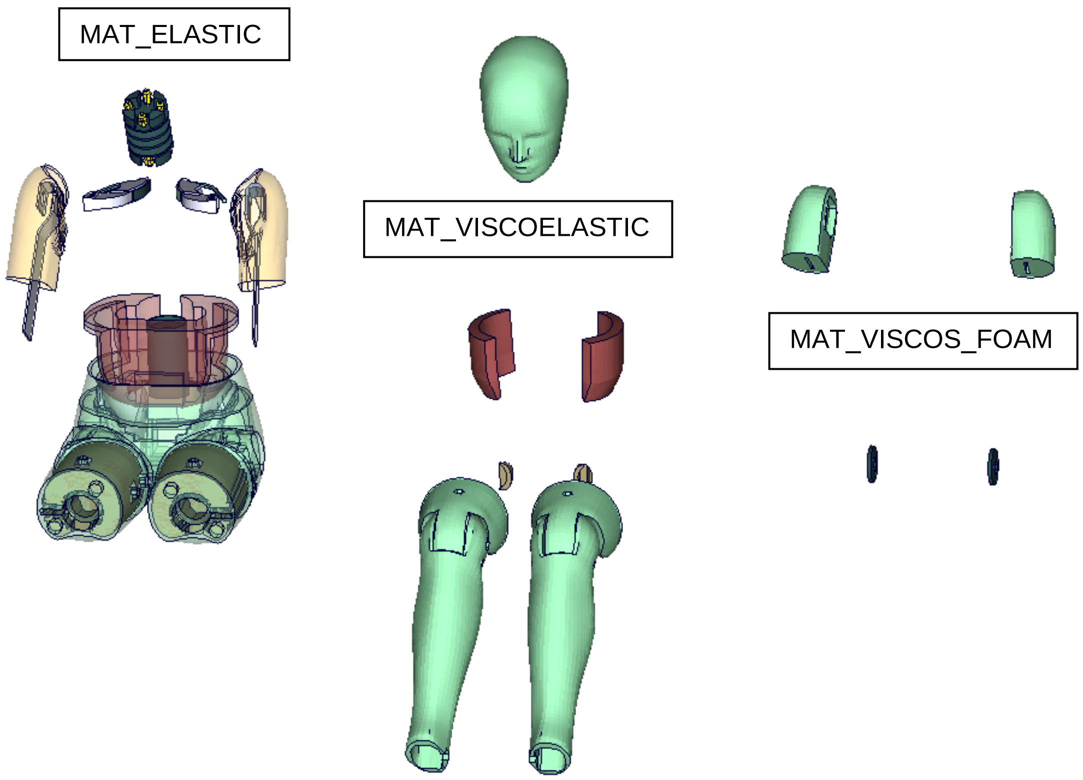

Fig. 3: ES-2re MAT_181 and MAT_183 parts.

The material changes are the only differences to the highly validated models. No other changes have been made. Only in some cases, the Hourglass control for some selected parts had to be changed.

Nodes and elements, joint definitions and all possibilities to extract results from the model are still the same. So it is very easy to swap the models in car environment.

3 Validation of the R.A.M. model in component tests

The validation o the R.A.M. models has been carried out by using the huge database of component and sled tests. In a first step the components were validated. In the following, some selected results of the component tests are shown.

3.1 Clavicle component test

One major test for validation is the clavicle test. The clavicle is impacted from different directions and the pendulum and clavicle accelerations are measured. The load cases are depicted in the following.

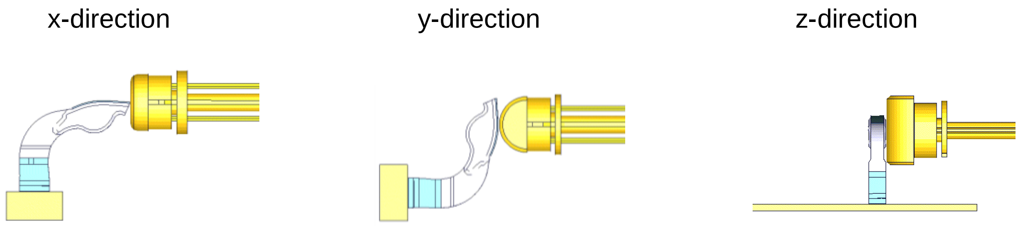

Fig. 4: ES-2 clavicle component test load cases.

The following time history curves show the results of the clavicle test in y-direction for two different velocities.

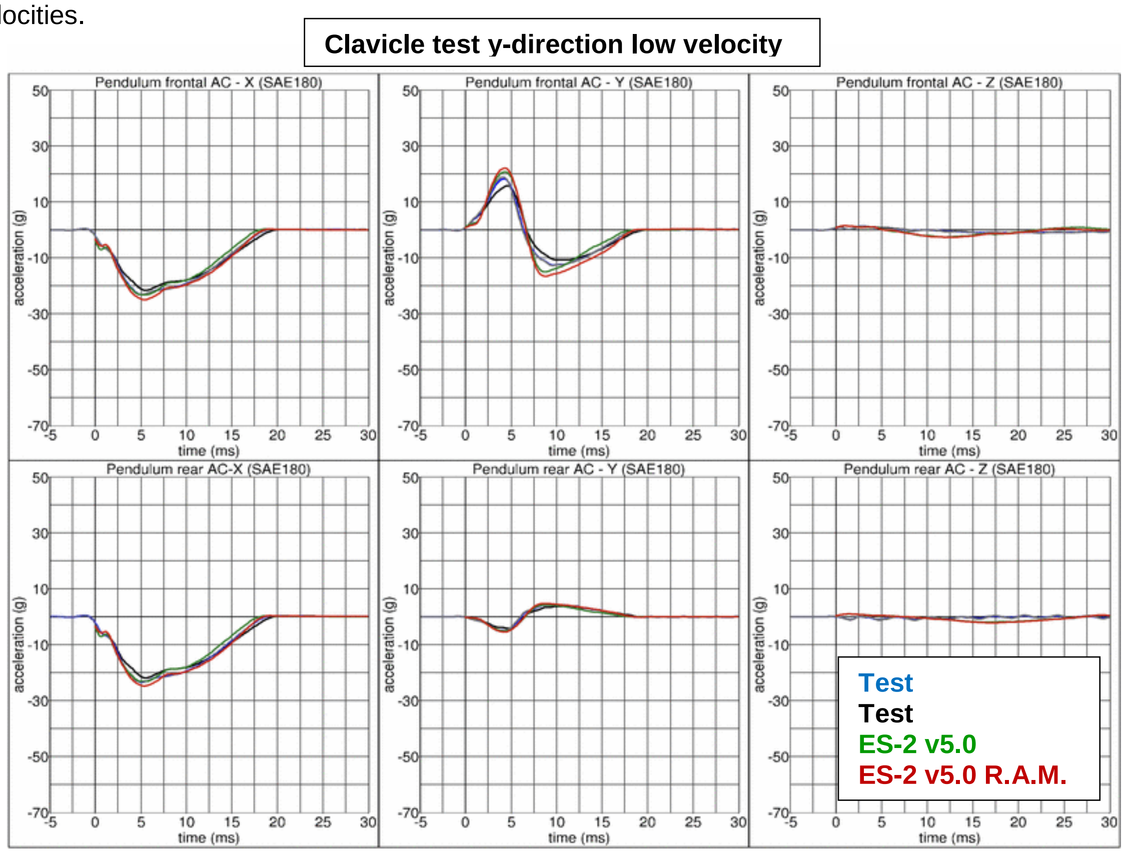

Fig. 5: ES-2 clavicle component y-direction results low velocity.

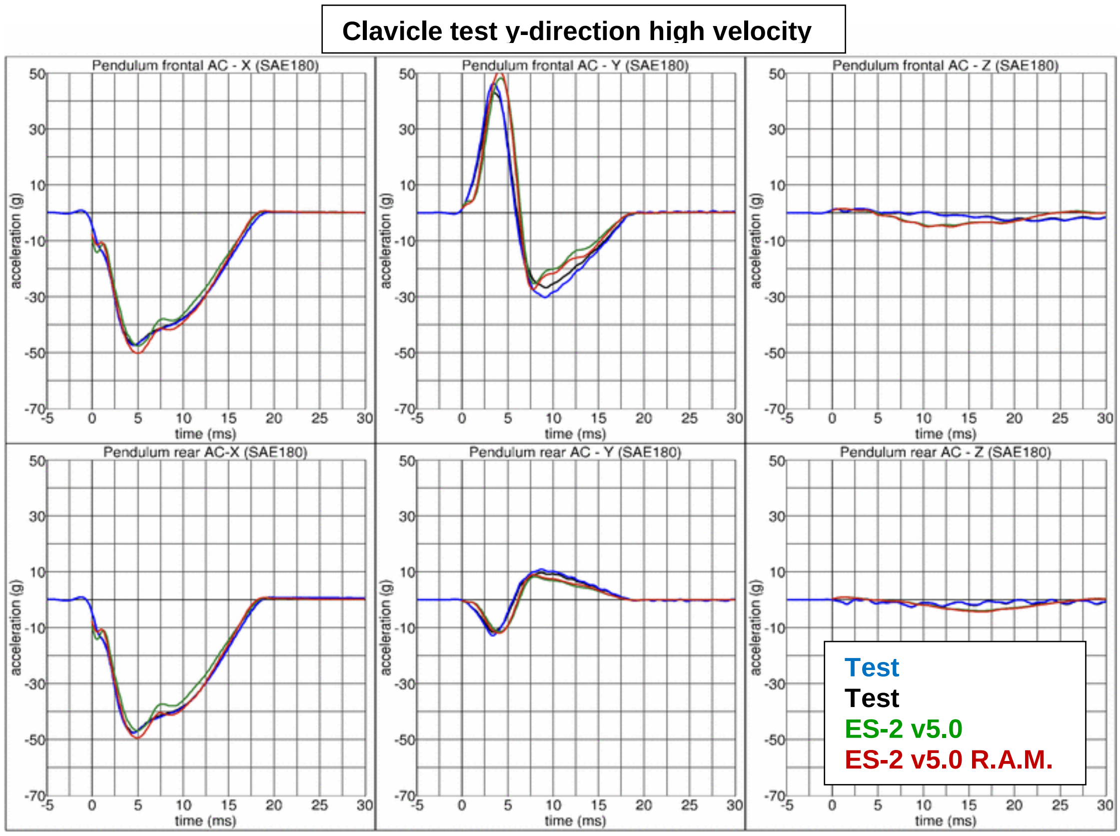

Fig. 6: ES-2 clavicle component y-direction results high velocity.

The results are very close together and there is not much difference visible between the ES-2 v5.0 and the ES-2 v5.0 R.A.M. models. In this case the performance of the ES-2 R.A.M. model is very good. This is also seen if the results are compared by using the curve evaluation tool CORA [1]. In CORA, value for a variant lies between 0 and 1. The greater the value for a particular variant, better is the correlation of that variant with the test results.

	ES2_v5.0 R.A.M.	**ES2_v5.0**
Clavicle	0.705	0.750

Tab.2: Comparison of Cora results for clavicle test of ES2_v5.0 and ES2_v5.0 R.A.M.

The Cora results show the same as the time history plots. The results of both models are very close together and correlate very well to the test. The ES-2 v5.0 is slightly better.

3.2 Lumbar spine component test

Second test under consideration is the lumbar spine component test. Also for this component the MAT_181 and MAT_183 are replaced by MAT_ELASTIC. After that the main validation is done by using the following component test.

There are used three different kinds of test for the lumbar spine. For the first test the main deformation mode is bending. The second one is for shear deformations and the last one is defined for torsion deformation modes.

The test setup is depicted in the following picture.

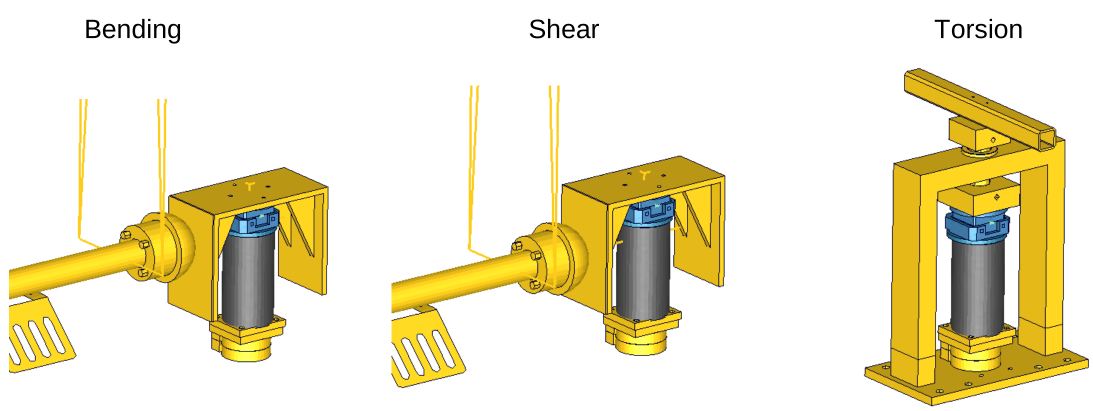

Fig. 7: ES-2 lumbar spine component test.

For each single test two different velocities are used. For validation the lumbar spine load cell, the lower lumbar load cell and the pendulum acceleration output was used. The test setup for bending and shear loading are the same. Only the target point of the pendulum is different. For bending load, the pendulum hits the U-Profile at the upper side. For shear loading, the pendulum is moved downwards so that the first deformation of the lumbar spine looks like an S shape. After that the lumbar spine also has bending deformation.

The comparison of the results between ES2- v5.0 and ES-2 v5.0 R.A.M. are shown in the following. Only the results of the bending mode have been shown.

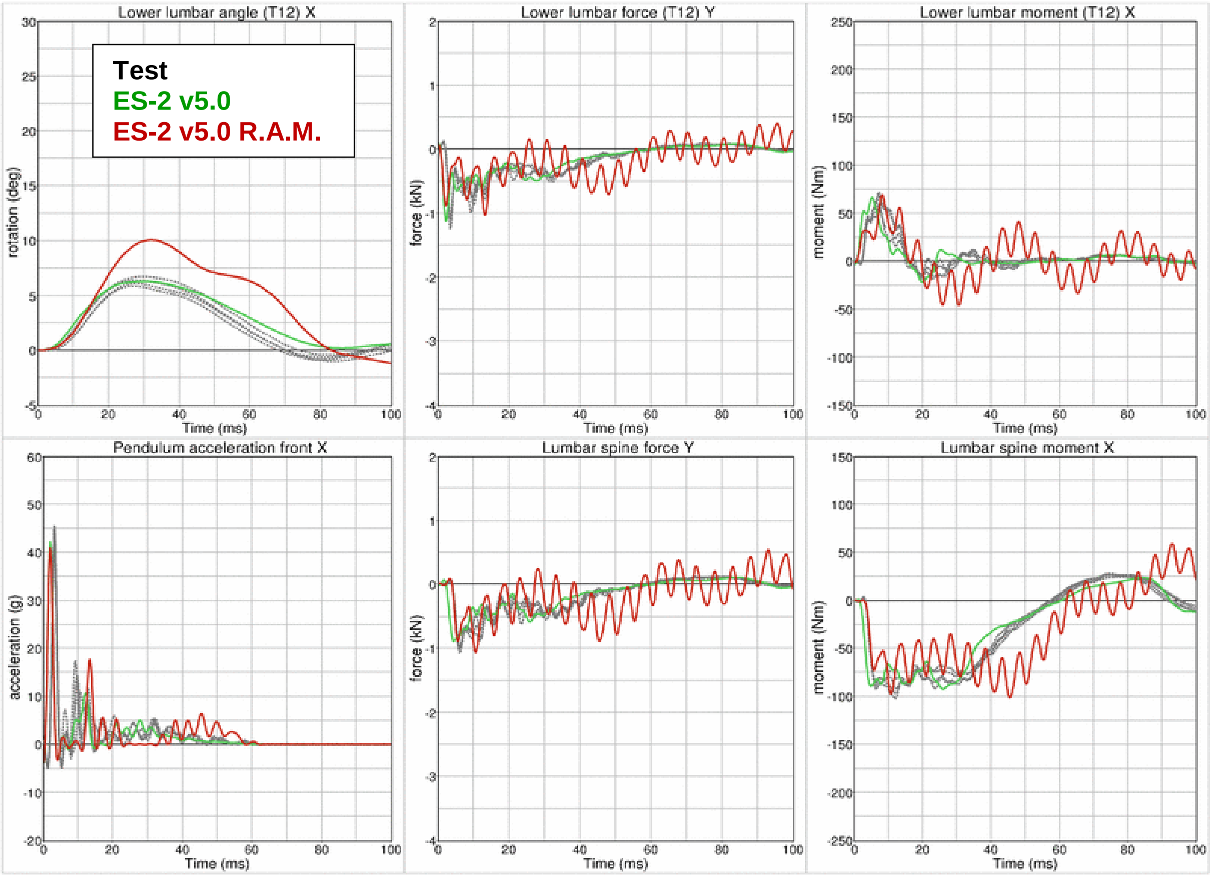

Fig. 8: ES-2 lumbar spine component test results ES-2 v5.0 vs. ES-2 v5.0 R.A.M low velocity

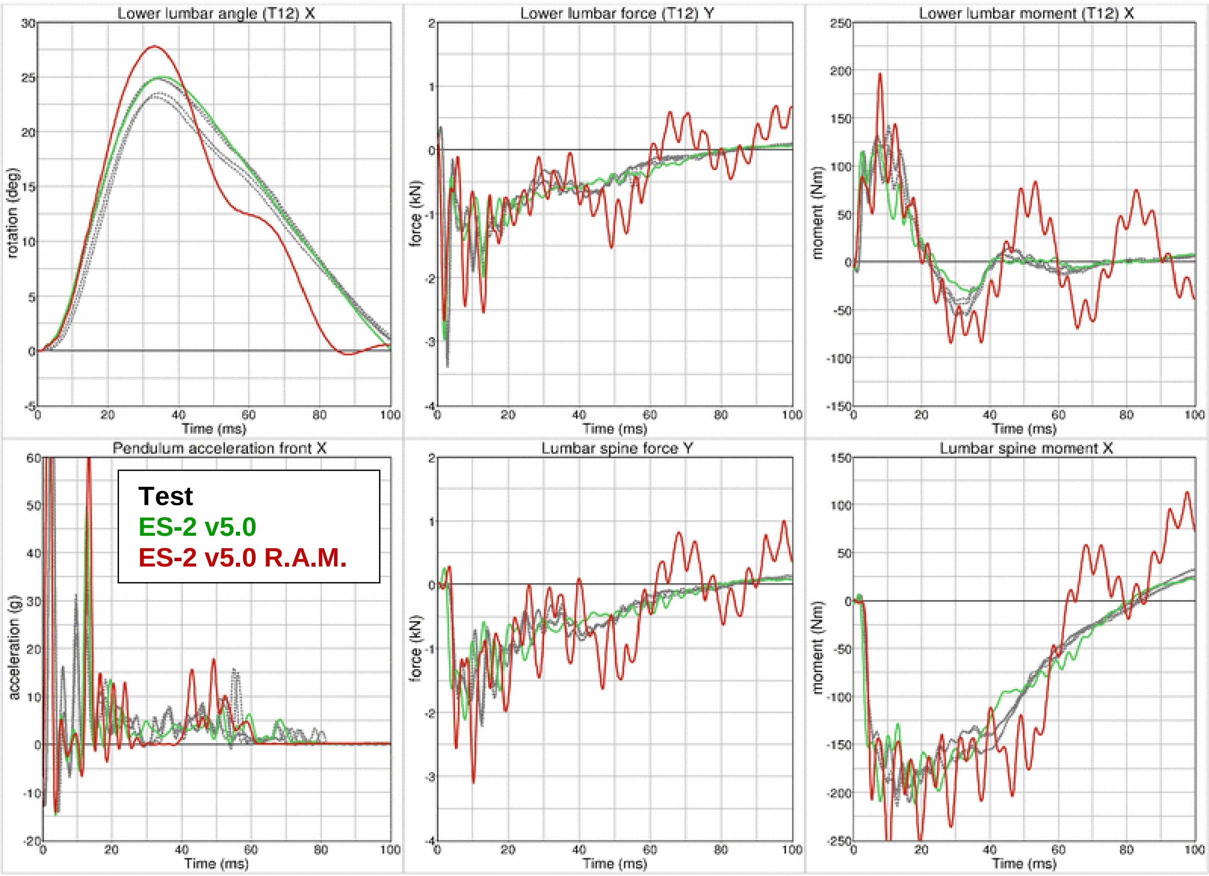

Fig. 9: ES-2 lumbar spine component test results ES-2 v5.0 vs. ES-2 v5.0 R.A.M high velocity

In case of the lumbar spine component test the results don''t correlate like in the clavicle component test. It was not possible to get better results by using MAT_ELASTIC for the lumbar spine. Also the CORA evaluation of all load cases shows a similar behaviour.

	ES2_v5.0 R.A.M.	**ES2_v5.0**
Lumbar spine	0.542	0.731

Tab.3: Comparison of Cora results for lumbar spine component test of ES2_v5.0 and ES2_v5.0 R.A.M.

3.3 CORA Results for all component test

The following table shows the CORA results for all component tests. You can find a detailed description of the component tests in [2]. For the rib component there was no material change. So the results for the ES-2 v5.0 R.A.M. are the same.

	ES2_v5.0 'RAM'	**ES2_v5.0**
Clavicle	0.705	0.750
Clavicle Box	0.577	0.634
Rib	--------	0.855
Abdomen	0.797	0.776
Abdomen Slab	0.612	0.619
Lumbar spine	0.542	0.731
Arm	0.558	0.728
Femur	0.701	0.774
Iliac Wings	0.388	0.563

Tab.4: Comparison of Cora results for all component test of ES-2 v5.0 and ES-2 v5.0 R.A.M.

In some tests the correlation between model and test are the same for both models. For example the clavicle, Femur and abdomen slab tests are very close together for ES-2 v5.0 and ES-2 v5.0 R.A.M. models. In some other tests it was not possible to reach a similar accuracy for the R.A.M. model like we have for the original version of ES-2 v5.0.

Surprisingly the abdomen component test is slightly better for the R.A.M. model but the CORA numbers are very close together. So we can define this as same validation quality.

4 Validation of the R.A.M. model in certification tests

Second step of R.A.M. model validation are the certification tests. Available are:

- Shoulder pendulum (full dummy without Jacket)
- Thorax pendulum (full dummy without Jacket)

- Rib pendulum (component certification)
- Abdomen pendulum (full dummy without Jacket)
- Lumbar spine pendulum (component certification)
- Pelvis pendulum (full dummy without Jacket)
- Head drop (component certification)
- Neck pendulum component certification)

In the following the four full dummy tests are depicted.

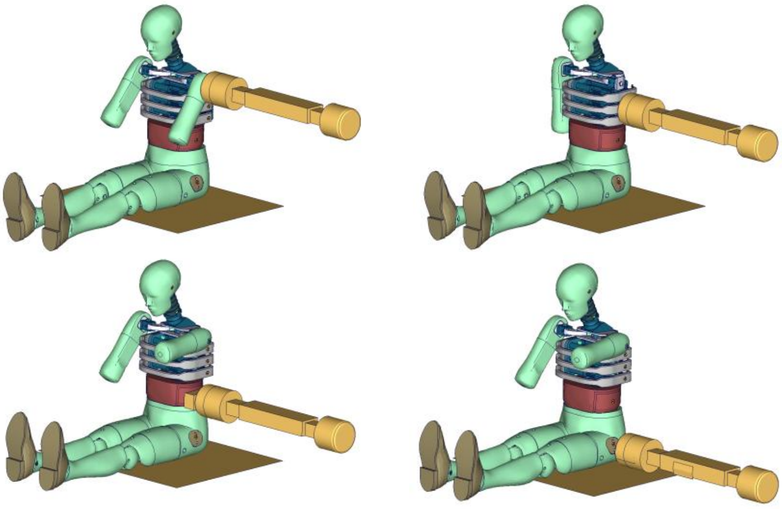

Fig. 10: ES-2 certification tests on full dummy

The test results of the ES-2 v5.0 and a small description of each test are shown in [2]. In this paper only the results of CORA for the tests are shown in the following table.

	ES2_v5.0 'RAM'	ES2_v5.0
Shoulder	0.693	0.852
Thorax	0.906	0.911
Rib	--------	0.806
Abdomen	0.729	0.774
Lumbar spine	0.380	0.568
Pelvis	0.709	0.785
Head drop	0.815	0.899
Neck	0.581	0.638

Tab.5: Comparison of Cora results for all certification test of ES-2 v5.0 and ES-2 v5.0 R.A.M.

The results of the R.A.M. model in the certification test seem to be on a good level. In most of the tests the correlation is only slightly lower. It seem that the lumbar spine is the part where some more work has to be put in to increase the correlation level in the same range like the other tests.

5 Validation of the R.A.M. model in sled tests

Final validation and stability checks are then done by using the complete database of the FAT and PDB sled tests. The FAT tests are done by using six different Barriers (D1 to D6) with different speeds. They are shown in Figure 12. Only the ES-2 was tested on these sleds.

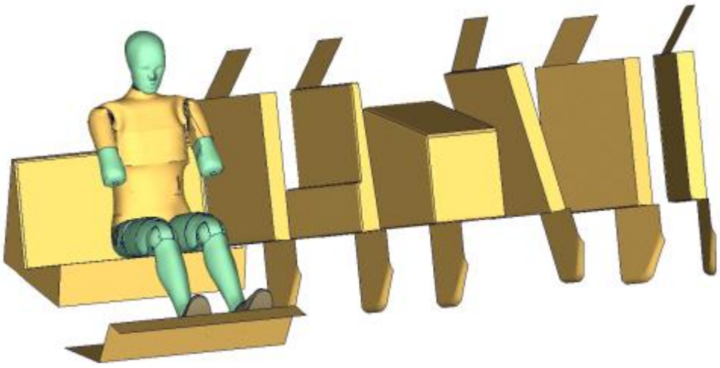

Fig. 11: FAT ES-2 sled tests on full dummy.

The second data set are the PDB sled tests which are done by using the ES-2re. There are three different barrier shapes with different speeds.

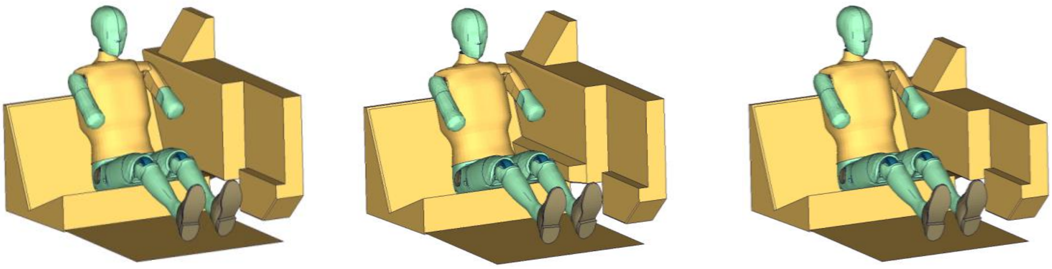

Fig. 12: PDB ES-2re sled tests on full dummy.

The Cora results of the FAT and PDB sled tests are printed in the following table. Furthermore in the comparison we added an older version of ES-2 / ES-2re. The v4.5 is the direct forerunner of the v5.0.

	ES2_v4.5	ES2_v5.0 'RAM'	ES2_v5.0
$D1_F$ barrier, v1	0.607	0.620	0.775
$D1_F$ barrier, v2	0.511	0.507	0.587
$D3_F$ barrier, v1	0.573	0.548	0.695
$D3_F$ barrier, v2	0.647	0.580	0.697
$D4_F$ barrier	0.529	0.646	0.667
$D5_F$ barrier	0.535	0.524	0.657

D6$_F$ barrier, v1	0.594	0.610	0.640
D6$_F$ barrier, v2	0.775	0.704	0.794
D7$_F$ barrier	0.419	0.434	0.497

Tab.6: Comparison of Cora results for ES-2 v5.0 and ES-2 v5.0 R.A.M. in FAT sled tests

	ES2_v4.5	ES2_v5.0 'RAM'	ES2_v5.0
D1$_P$ barrier	0.522	0.504	0.617
D3$_P$ barrier	0.609	0.492	0.724
D4$_P$ barrier	0.564	0.527	0.657

Tab.7: Comparison of Cora results for ES-2re v5.0 and ES-2re v5.0 R.A.M. in PDB sled tests

	ES2_v4.5	ES2_v5.0 'RAM'	ES2_v5.0
PDB tests	0.565	0.508	0.666
FAT tests	0.556	0.565	0.668

Tab.8: Comparison of Cora results for ES-2/ES-2re v5.0 and ES-2/ES-2re v5.0 R.A.M. of all sled tests

The CORA results show that the ES-2 / ES-2re v5.0 has the highest correlation level of the three models. The older version of the model and the R.A.M. version seem to be on a similar level for correlation. Advantage is that the R.A.M. model is using exactly the same geometry and construction like the high validated model.

6 Computational time comparison of the R.A.M. model

The main effort of the R.A.M. model should be a much faster computation time in simulations. In the following the Table 1 the timings of the R.A.M. model are added.

Barrier configuration	ES-2re model version	Simulation time
Barrier D1	ES2_v4.5	4h 37m 06s
	ES2_v5.0	8h 05m 19s
	ES2_v5.0 R.A.M.	3h 22m 21s
Barrier D3	ES2_v4.5	4h 34m 09s
	ES2_v5.0	7h 31m 56s
	ES2_v5.0 R.A.M.	3h 07m 56s
Barrier D4	ES2_v4.5	4h 29m 17s
	ES2_v5.0	8h 04m 57s
	ES2_v5.0 R.A.M.	3h 20m 15s

Tab.9: computational timings for ES-2re v4.5, ES-2re v5.0 and ES-2re v5.0 R.A.M. in sled test.

The speed up for the R.A.M. model is about 60% in sled test. This is a huge reduction of computational time. The R.A.M. model is also about 20% faster than the version v4.5.

But this speedup is only visible in small models like the sled test or maybe segment simulations, where only partial cars are computed. In full car simulations which use about 2.5 Mio. Elements the speed up is nearly not visible.

7 Summary

The R.A.M. models are built based on the high validated FAT/PDB models. The models are nearly identical, only the expensive materials are removed from the R.A.M. models and replaced by simple and numerically cheap material models.
The validation of the R.A.M. models is done by using nearly the whole database of component, certification and sled tests. The validation level is lower then for the high validated models, but is on a acceptable level for usage.
The computational time is reduced about 60% compared to the fine validated model in sled tests. In full car simulations this speedup may be much smaller.

So the R.A.M. models are not designed for usage in full car simulations. They only make sense in reduced models like segment runs when a high number of simulations have to be done. So the main areas of application are DOE studies, optimizations and robustness studies with high number of simulations. In this area the computational time can be reduced a lot.

8 Literature

[1] Gehre, C. et al; "Objective rating of signals using test and simulation responses"; 21st International Technical Conference on the Enhanced Safety of Vehicles Conference (ESV); Stuttgart; Germany; 2009; Paper 09-0407.

[2] Stahlschmidt S., Gromer A., Reuben D'Souza: "PDB ES-2 / ES-2re User's Manual for Model 5.0", Stuttgart, 2013.