Ideas on Applying Very Fine Models in Dummy Model Development

Uli Franz[1], Alexander Gromer[1], Matthias Walz[2],
Jens Zschieschack[1], Yupeng Huang[3]
[1] *DYNAmore GmbH*
[2] *Mercedes Car Group, Daimler AG*
[3] *Sunrise Auto Safety Technology*

Abbreviations

FAT: German Association for Research on Automobile Technology
PDB: Partnership for Dummy Technology and Biomechanics

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Abstract

Very fine models allow investigating the behavior of dummies with high accuracy. Even if element numbers for a dummy model above 3 Million elements are currently not suitable for standard simulation in vehicle development, the usage of such models contribute to the development of coarser dummy models. Due to the detailed representation physical effects occurring can be captured very realistically with the very fine models. The paper present current methodology to develop models within the FAT or PDB frame work and outlines first experiences with very fine models to enhance coarse dummy models.

Introduction

During the last decade the authors developed several finite element dummy models [1]. The activities were initiated and guided by a working group of the German Association for Research on Automobile Technology (FAT). The latest activities for new models are hosted by the Partnership for Dummy Technology and Biomechanics (PDB) - an organization of German OEMs. The companies and representatives in the PDB working group contributed formerly to the dummy development projects in the FAT framework. The PDB adopts similar proceedings as the FAT.

The projects result in various finite element dummy models, which are used frequently world wide in the development of restraint systems. Side impact dummy models of EUROSID-1, ES-2, ES-2re, USSID, and SIDHIII and a model of the rear impact dummy BioRID II have been developed. Currently, a model of the World SID 50% is under development.

All projects have in common that finite element technology is used to define appropriate tests for validation. Initial models are generated with geometry and detailed material test data. Subsequently, the initial models are used to investigate the loads in a vehicle crash and compared with loads in possible test set ups. For the model development it is important that the validation tests apply loads comparable to real crash loads. Otherwise, a model might fail predicting the injury values in certain load cases. The results contributed to the specifications of the tests performed. For each project a huge test database with component and fully assembled tests for validation was generated.

With the currently used mesh densities the dummy models are still not capable to capture all effects occurring. As a consequence, a certain number of tests are needed for the validation of the model. The tests are especially needed for assembled parts, if the stiffness of the connection of an assembly is not clearly distinct, and for interacting parts. With very fine models the validation work is reduced since many physical effects can be included in the model. Unfortunately, the computation effort of very fine models is considerably high and does not fit to current vehicle modeling techniques.

In the following first experiences with very fine models during the development of reasonably fine models are outlined and discussed. The examples contributed to the enhancements for the upcoming release of the ES-2 and ES-2re model.

Experimental DatA for ES-2 Dummy Model Project

During the projects a lot of experiments are performed to obtain parameters determining the behavior of materials, components, and the assembled dummy. The definition of experiments is an ongoing process interacting with the results of the finite element simulations, user input, and observations during validation.

Material Tests

The specimens are taken from new parts or specifically produced material blocks delivered by the hardware manufacturers. Exceptions are some vinyl skins, which come from a repair kit for the dummy models, and the pink confor foam which is provided by the manufacturer.

The following are carried out: static tension tests, dynamic tension tests, static compression tests, dynamic compression tests, relaxation tests, hydrostatic triaxial compression tests, static shear tests and dynamic shear tests. In the later projects the goal of the tests was to obtain data which can be used directly as an input for the LS-DYNA materials like Mat_Fu-Chang_Foam and Mat_Simplified_Rubber. Hence, the focus is on static and dynamic tension and compression tests. The tests usually cover a wider range of loads than expected in a vehicle load case.

As an example the experiments for rate dependent foams are described in more detail:

- Static compression test on an cubic specimen (30x30x30 mm**3).
- Dynamic compression on a cubic specimen with almost constant compression speed. This results in information of the material behavior for the strain rates 20/s, 100/s and 400/s. Depending on the foam the considered maximum volumetric strain is 90% or 50%.
- Static tension tests.
- Dynamic tension tests with strain rates of: 20/s, 100/s, 400/s.

Component Tests

Often the material data gives a satisfactory basis to predict the behavior of a part. For the dummy components further tests are needed since several connected and joined parts determine the behavior significantly and the meshes are not sufficiently fine to model the connections. Furthermore, the behavior of preloaded parts is difficult to examine in a simple material test.

The experimental databases of the projects contain head drop tests, dynamic shear tests for the lumbar spine, pendulum tests for the lumbar spine, neck pendulum tests, drop tests for the damper, partial and complete thorax impact tests, pendulum tests for the abdomen, impact tests for the pelvis and impact tests for pelvis/upper leg. Many of the tests are specifically designed to be in a load range comparable to loads in a vehicle crash. The calibration tests of the dummies are also used for validation purposes, but some of the tests have the disadvantage that they are not in the load range of interest.

As an example the experiments for the ES-2 rib cage (depicted in Figure 2) are described in more detail:

- Velocity of pendulum is determined to reach 10,20,30,40 and 50 mm rib intrusion.
- 4 different impact locations.
- 2 different angles.
- Pendulum with 2 different masses.
- Tests with and without damper.
- In total 25 different tests with the single rib.

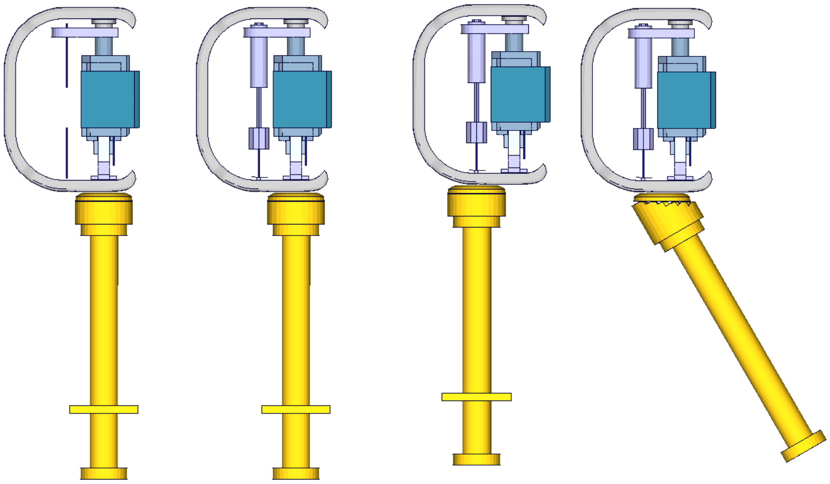

Figure 1: Simulation of different impact tests on single rib of ES-2.

Tests with Fully Assembled Dummy

The data of the material tests and the component tests still misses the information on the interaction of the different parts. Since the interaction has a significant influence on the injury values many tests are performed to study the assembled dummy.

Pendulum Tests

A pendulum test has the advantage that a certain body region can be loaded separately. For instance the abdominal forces of ES-2 or can be validated against pendulum tests effectively. Like for the component tests, the standard calibration tests were. Figure 3 depicts the pendulum impact locations tested for ES-2 development and a test to the ES-2re thorax.

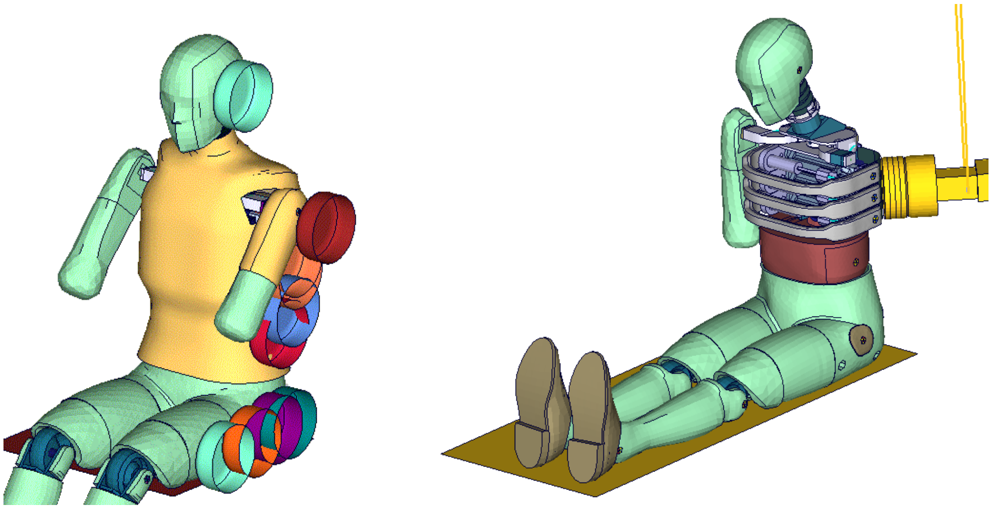

Figure 2: Tested impact locations of pendulum to validate ES-2 model (left); pendulum impact on thorax of ES-2re (right).

Sled Tests

The sled tests apply a load close to the load in a vehicle. Hence, this test type is the most important for the validation of the fully assembled dummy. The experiments for the side impact models are performed with rigid wooden barriers. The speed varies from 4 to 8 m/s with barrier masses above 1 t. The recorded experimental data are: Accelerations, forces, moments, and intrusions. Usually, the dummies are equipped with the maximum instrumentations available. Furthermore, contact foils are used to determine time of contact. In the early projects a plane barrier and barriers with a shaped contour to load specific body regions were used. Figure 4 depicts the latest barrier model used for development of the ES-2 model. A test with a new barrier shape representing an intruding door under FMVSS 214 conditions is in process.

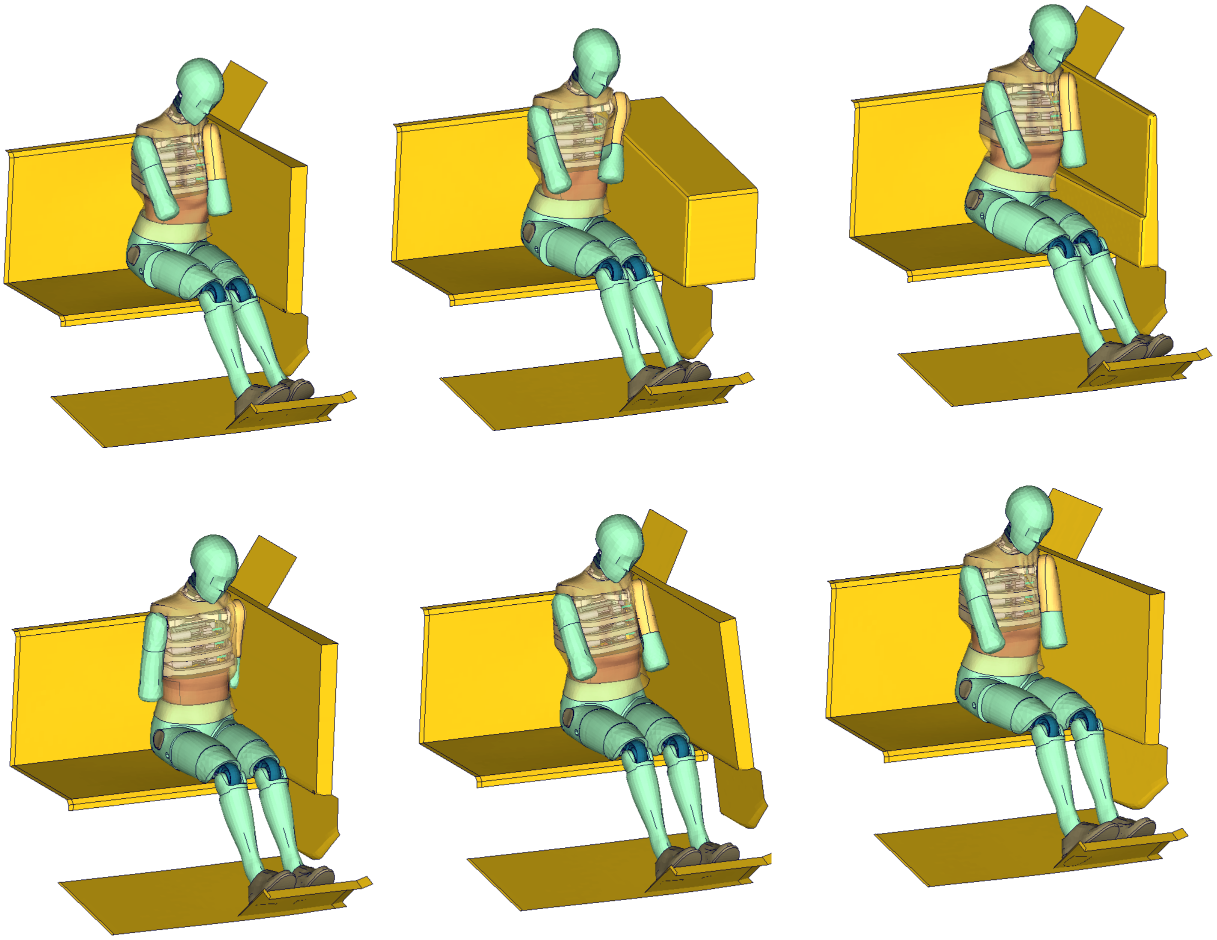

Figure 3: ES-2 model in sled tests with varying barrier shapes, oblique barriers, and initial arm positions.

Very Fine Model Compared to the Regular One

A very fine model is generated that includes all details and occurring effects. Therefore, the CAD data has been meshed with an edge length of roughly 2 mm. The time step is 0.2 micro seconds. To keep the number of elements limited the parts are meshed with hexahedrons instead of tetrahedrons. Since tetrahedron elements tend to lock under shear deformation for rubber like materials, the new meshing is more appropriate for some parts. But it has the disadvantage of possible zero energy modes occurring in hexahedron elements. The geometry is modified to capture deformation due to assembly, gravity or positioning. Since almost no geometric simplifications are made, each part has the exact mass and inertia by using the material density. The model allows combining very fine and coarse meshes for the different parts, depending on the purpose of the simulation. The very fine model has the ability to include pre-stress in all parts, event the bolts can be pre-stressed if required. Joint definitions, extra nodes for rigid bodies, or rigid body merge cards can be eliminated totally. If desired each part can be considered as deformable. The model contains a few contact entities and an over all contact definition. Currently, the fine model is used as tool to enhance the commercial model. The validation is completed for parts of interest for the commercial models. Figures 4 to 10 compare several details of the standard mesh with the mesh of the very fine model. The numbers of elements is by a factor of 8-12 higher, e.g. the finely meshed thorax (Figure 9) has approximately 300,000 hexahedrons and 50,000 shell elements. In comparison, the regular one (Figure 8) has 40,000 tetrahedron and 17,000 shell elements.

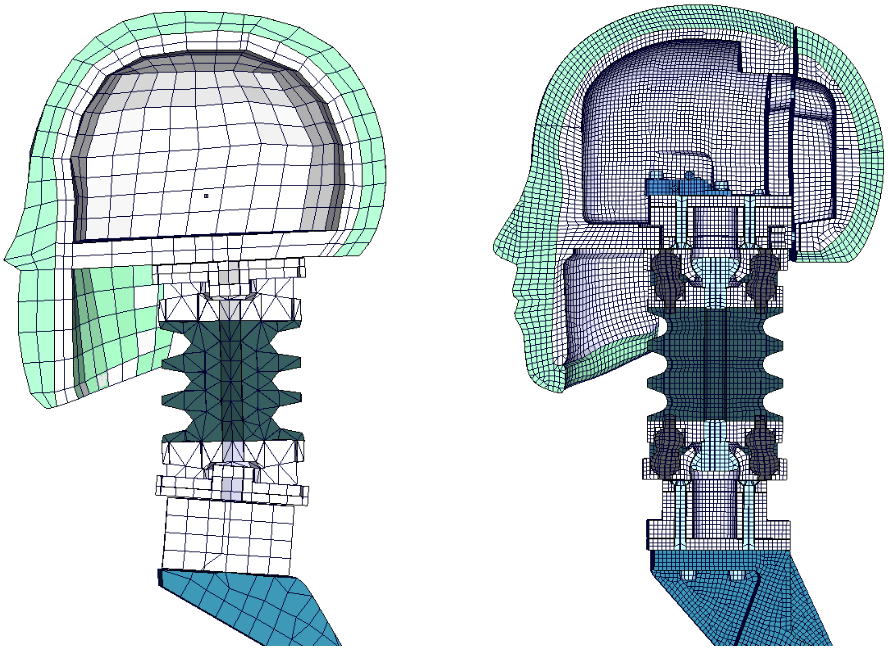

Figure 4: Mesh of the ES-2 head and neck model; regular model (left), very fine model (right).

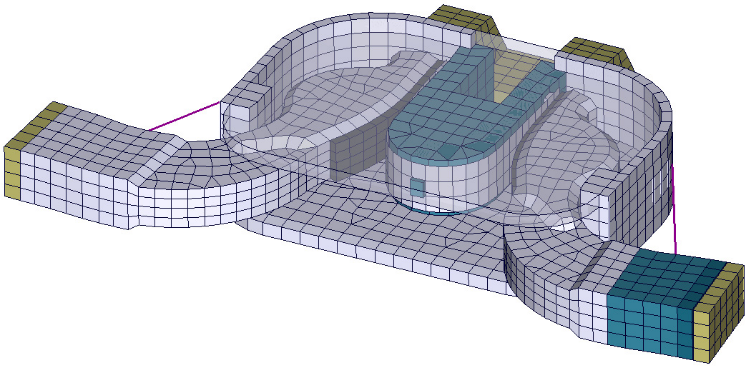

Figure 5: Mesh of the clavicle box and connected parts of regular ES-2 model.

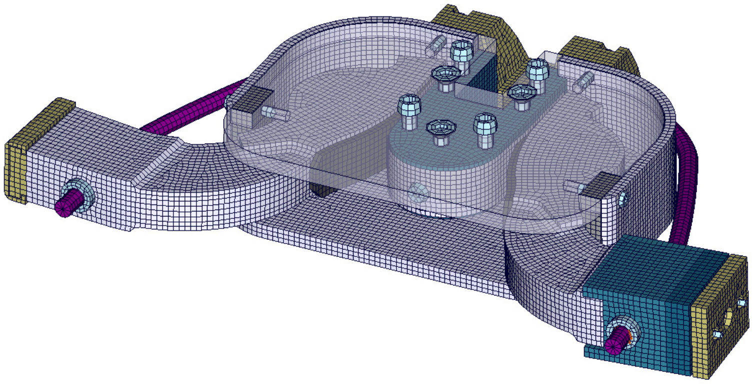

Figure 6: Mesh of the clavicle box and connected parts of very fine ES-2 model.

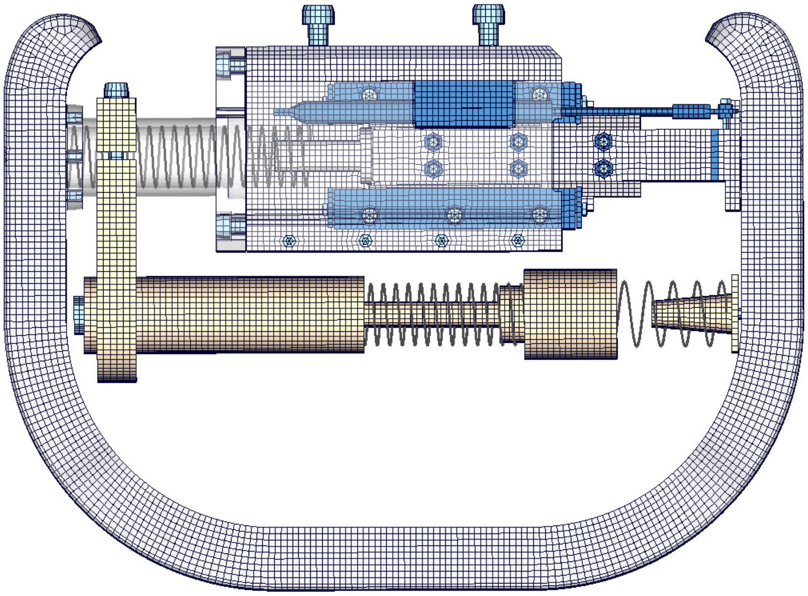

Figure 7: Mesh of the rib assembly of very fine ES-2 model.

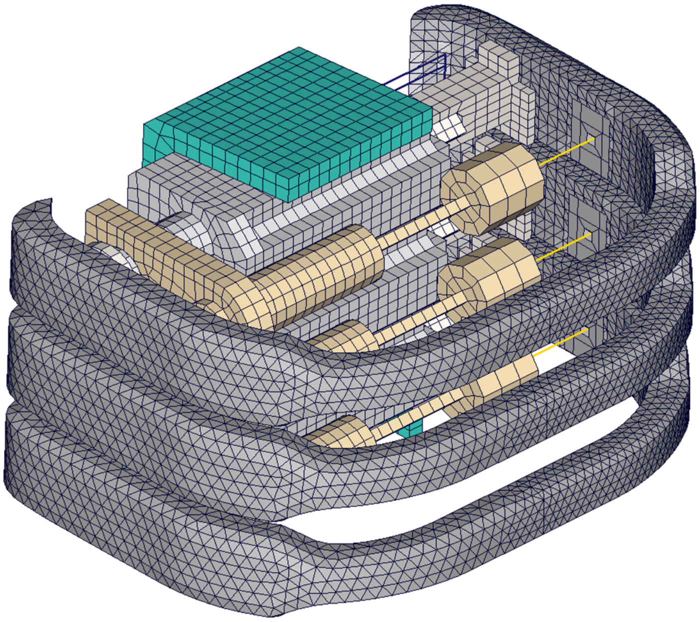

Figure 8: Mesh of the thorax of regular ES-2 model.

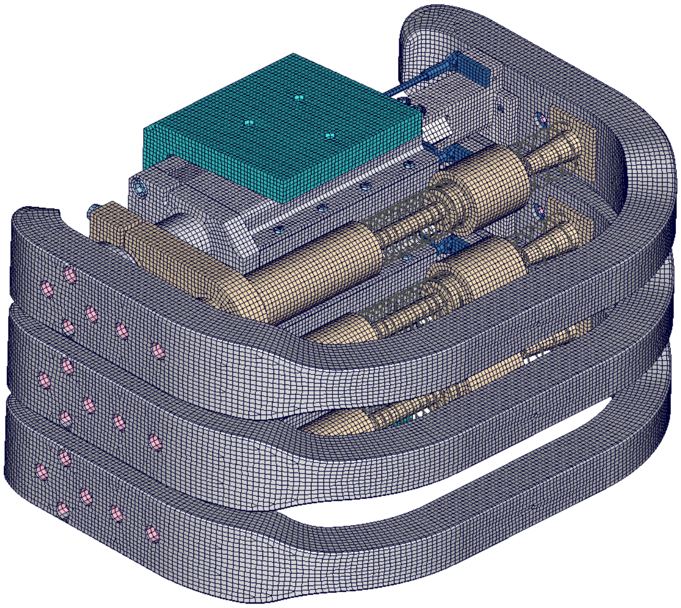

Figure 9: Mesh of the thorax of very fine ES-2 model.

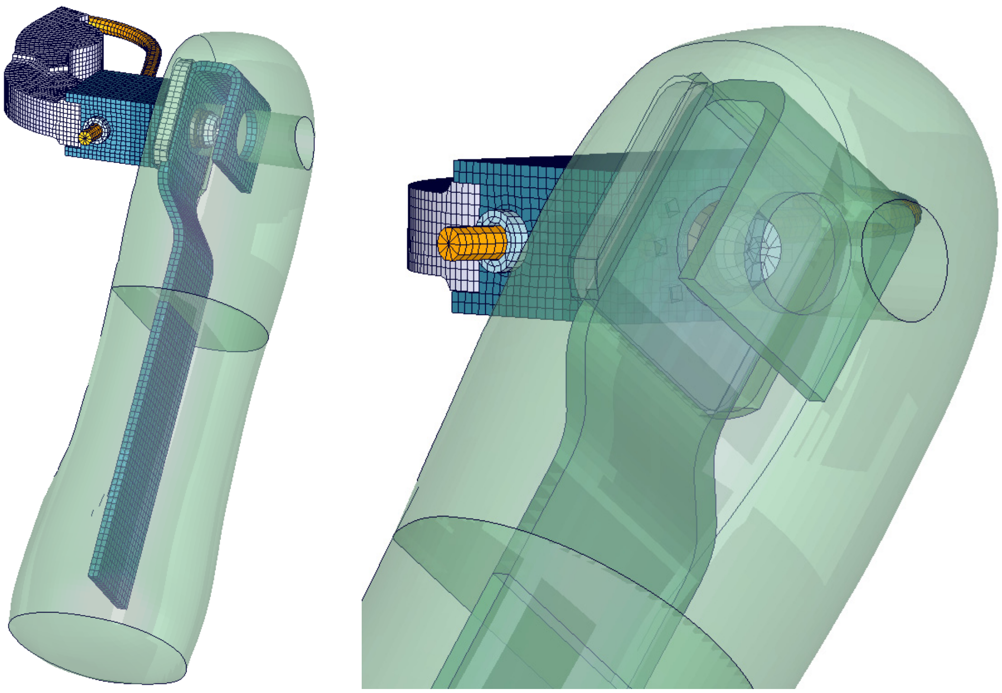

Figure 10: Mesh of the arm and adjacent parts of very fine ES-2 model;
Complete arm and clavicle (left), magnification of arm joint (right).

Usage of Very Fine Model

In the following 3 examples showcase the current usage of the very finely meshed model. The examples are from projects to enhance the commercial ES-2 and ES-2 re models. The first example discusses the possibility of generating validation data with the fine model, which is particularly of interest for tests having complex boundary conditions. In the second example the influences of a simplified jacket modeling are estimated by performing sensitivity studies with the different models. The third example shows how the fine model is used to evaluate the stiffness of the connection of parts bolted to the rib.

Validation data generated by simulation

Currently, a huge amount of tests is needed to ensure that the validation domain contains the application domain. Unfortunately, for many parts it is difficult to find appropriate tests. The tests would require a complex test set-up and moving boundary conditions. These tests show often an influence of the inertias of the actuators and a sensitivity regarding elasticity in the test set-up. Additionally, tests with prescribed motions have the disadvantage that the initial geometry has often a strong influence on the energy put into the system.

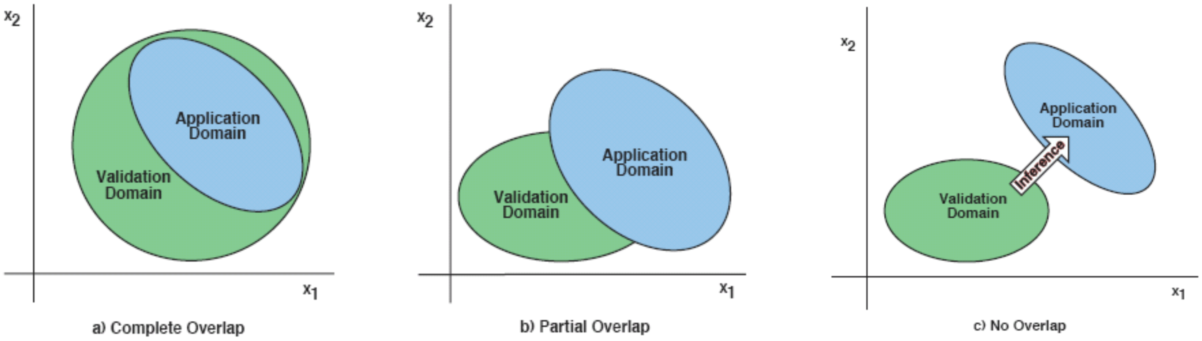

Figure 11: Application and Validation Domain, by Oberkampf et al. [2].

Using the results of very fine models for validation of commonly fine meshed models eliminates the technical disadvantages described above. Furthermore, the simulation with the very fine model allows considering a huge variety of different loads in a very fast and cost efficient way. Of course, a very predictive fine model is required for the methodology.

A good example for the methodology is the neck of the ES-2. Three different models of the neck are depicted in Figure 12.

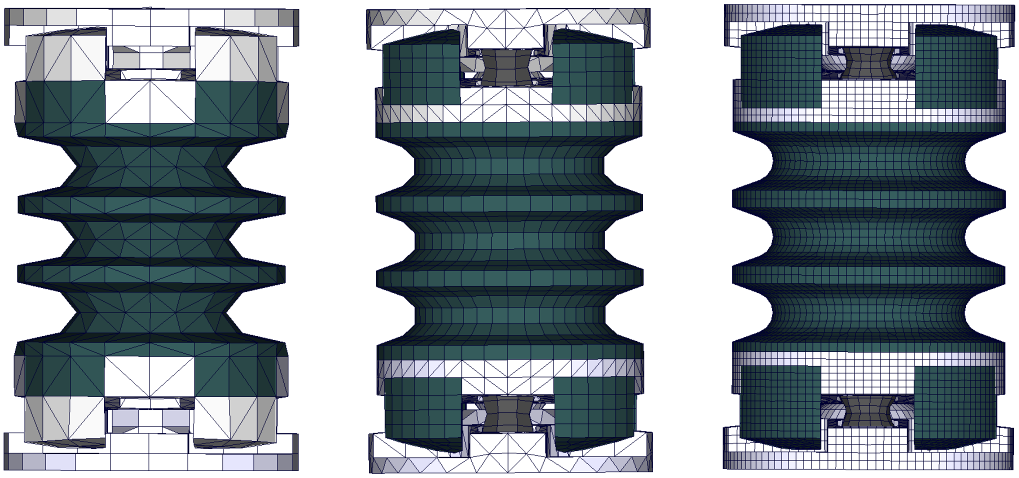

Figure 12: Different ES-2 neck models. Release 3.7 (left); upcoming release 4.1 (middle); very fine model (right).

All three models have a good correlation in simple pendulum tests. For this test the top adaptor plate of the neck is mounted to an approximately 1.8 m long pendulum. The lower adaptor plate is mounted to a block representing the inertia of the head. In the tests the swinging pendulum is decelerated by an aluminium honeycomb cube. During the deceleration the neck is bended due to the inertia of the mass mounted at the bottom of the neck. The test and occurring maximum deformations are depicted in Figure 13. If we compare the validation domain with the application domain we will observe several differences. The first difference is in the initial condition: In the application domain the neck is compressed and in the test a tensional force is applied. During the vehicle crash we observe a combination of bending, torsion and shear load. Furthermore, the displacements are influenced by an airbag in the application domain. In the pendulum test only a strong bending load occurs; shear and torsion is entirely missing.

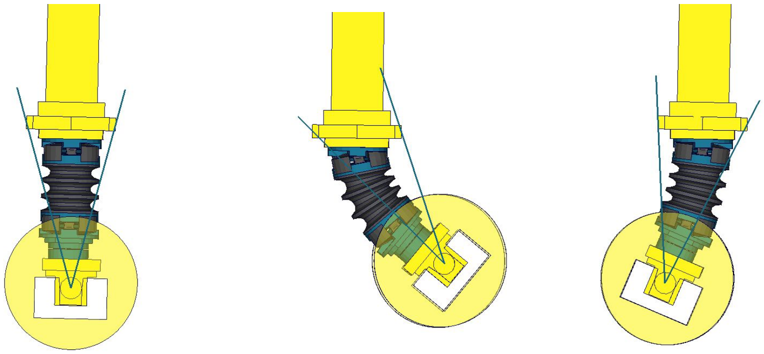

Figure 13: Bending during pendulum tests of neck at 0 , 65 and 150 ms in pendulum test.

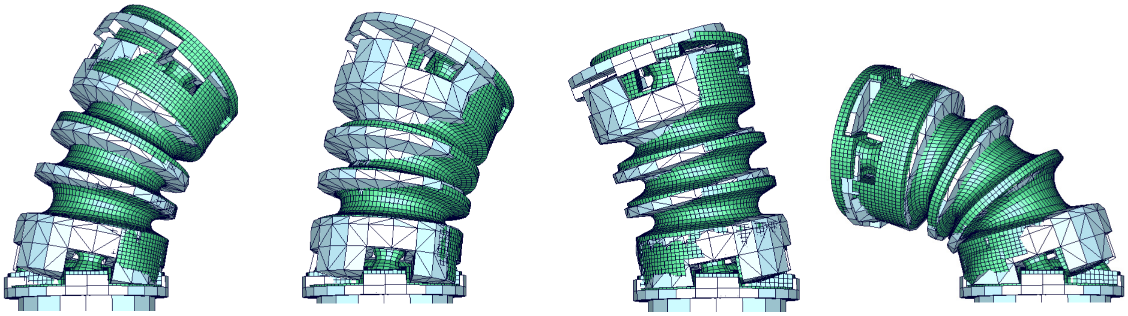

Figure 14: Deformation modes of 2 different neck models during pole impact of FMVSS 214 at 20, 40, 60 and 80 ms.

Figure 14 depicts the neck deformations of the ES-2re in a full side impact simulation by a pole, as defined in the new FMVSS 214. The head movement is influenced by a curtain airbag. The figures overlay the deformation of the coarse neck model with the fine model. For visualization purposes the neck bracket is fixed in space. At 40 and 60 ms the positions of the upper adaptor plates differ significantly. After 80 ms the models show again a similar behavior; at this time the neck is mainly bended like in the pendulum load case. The example shows the strong need for validation tests involving shear and torsion. Defining a simple test with comparable deformation modes of the neck is challenging. Hydraulic or pneumatic actuators may be able to move the neck bracket in space realistically, if we neglect the rotation of the neck bracket. Beside the head inertia the neck is loaded by an airbag. Including an airbag in a test is possible, but the modeling of the airbag in the accuracy needed is usually not possible. For validation it is required to model the boundary and initial conditions of the test with a much higher accuracy than the model itself. Alternatively, the airbag may be substituted by a foam pad mounted to the test set-up, but it is not easy to find a foam block with a comparable contact characteristic. The fine model allows a much more elegant way to penetrate the problem. The fine model is built with exact material data and is modeled with pre-stress. For the fine model no parameter fitting was needed to correlate the model with the pendulum tests. Hence, the fine model can be used with some confidence to simulate a test instead of performing it. Therefore, the movement of the neck bracket in a vehicle simulation is measured and used to define boundary prescribed motion cards. Subsequently, many virtual tests with the very fine model can be performed to generate data for the validation of the regular model. The proceeding allows investigating a huge variety of loads easily. A model of the airbag can be included in the simulations. If both models work with the same airbag model the drawbacks of a test will be eliminated.

Comparison of sensitivities

During validation parameters are adapted to correlate a model. Frequently, the relevant parameters are determined by sensitivity studies. Since the numerically obtained sensitivities are only valid for the current model, discrepancies might occur if another model release is used or if the sensitivity is compared to reality. Parameters considered as non-sensitive may show an influence if a model is refined or vice versa. For example coarse models show a much higher sensitivity to parameters related to the joint modeling than fine models. The opposite can be observed with pre-stress; the more predictive and finer a model gets the more sensitivities regarding the initial conditions can be observed. Thus, using the fine and the standard model to check sensitivities leads to a more reliable modeling.

As an example the modeling of the ES-2 jacket is outlined. The jacket is built of a 5 mm thick neoprene. In the standard model shell elements and a visco-elastic material is used to describe the behavior. Furthermore, several geometric simplifications are made to facilitate the positioning of the arm and to avoid instabilities in the axle area where the jacket is turned over during arm movement. To estimate the influence of the simplifications a jacket is modeled with a detailed mesh. For the foam hexahedron elements and for the fabric shell elements are used. In the considered load cases the thickness change of the jacket during impact is considerably small.

Often, the jacket has a big fold at the back of the arm joint and the shoulder. Its size depends on how the jacket is pulled over. The influence of the fold size and shape on the arm movement was analyzed with the standard and a very fine mesh. Both models showed a considerably small influence of the fold to the arm movement or the rib intrusions. Hence, the current simplifications in modeling are considered to be adequate. Figure 15 shows the fine jacket and some details of the shoulder area of the ES-2 model.

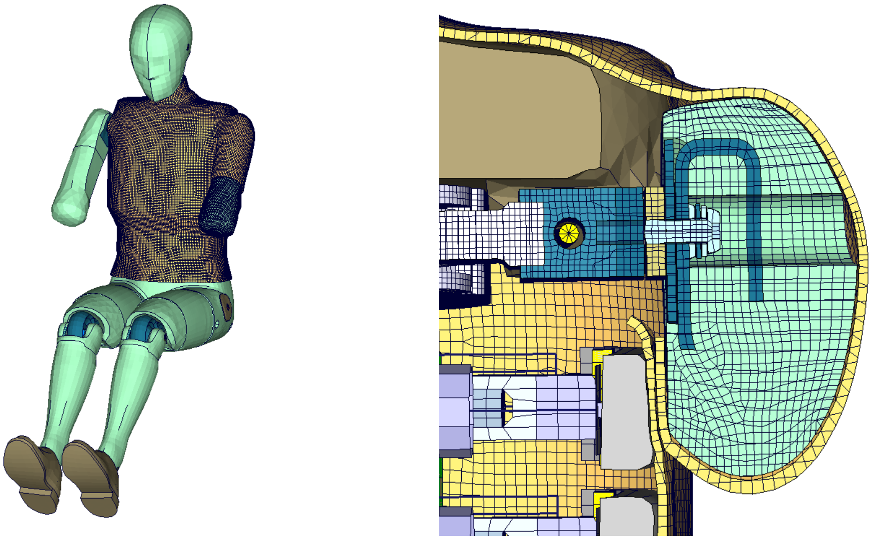

Figure 15: ES-2 with fine model for jacket; ES-2 model (left), cross section of right arm, jacket, clavicle,…. (right).

Stiffness of bolted parts

The following example uses the fine model to investigate the stiffness of the connection of the steel rib with the bearing system. For the ES-2 the bearing system is equipped with a flange at the end of its piston. The steel part of the rib is screwed by 4 bolts to the flange. Between the two parts the skin of the rib is squeezed. The skin consists of a thin fabric covered with rubber. The connection is not entirely stiff; some flexibility is maintained by the rubber. In most validation load cases the connection can be modeled by merged rigid bodies. Unfortunately, this is not true for every loading scenario. The papers [3] and [4] present load cases where the modeling of the connections has significant influence on the results of the FAT ES-2 and the PDB World-SID 50% model, respectively. The fine model allows investigating the connection in detail and to adapt the regular model accordingly. Like for the neck in the first example the fine model is used to generate data for validation of the rather coarse model. The value in this application is the time saving achieved with the very fine model. Finding the relevant load cases is only possible in late development stage of the model. Performing tests at a late development stage implies a painful waiting period. By using the simulation each question can by addressed instantly. Figure 16 and 17 show details of runs with the fine model to estimate the stiffness of the connection rib/bearing system. The model can be used for dynamic and static investigations.

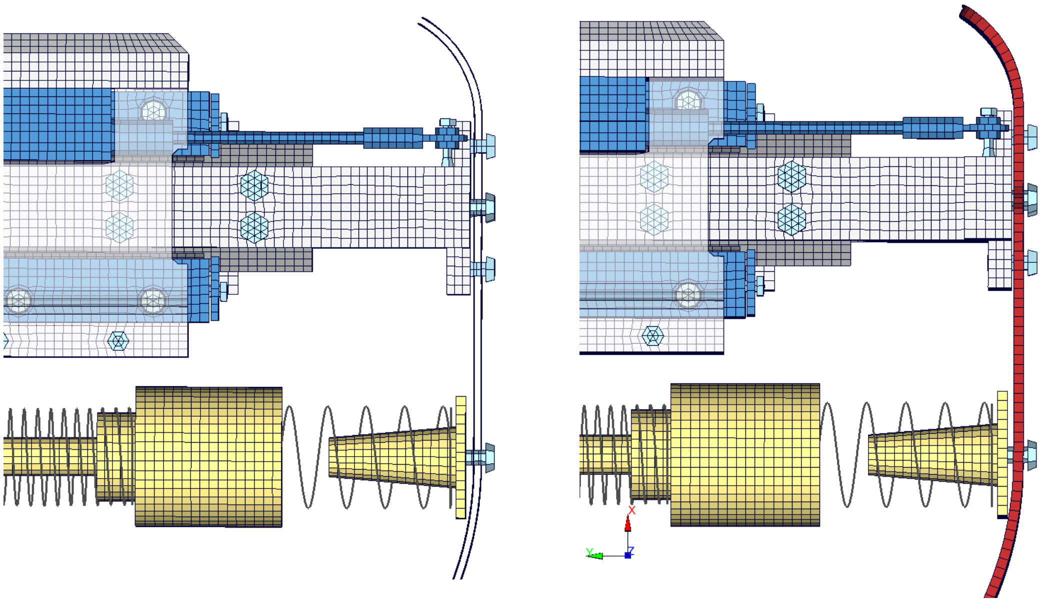

Figure 16: Steel and aluminum parts of rib and bearing system; different modeling of skin between rib and flange; shell elements (left), volume elements (right).

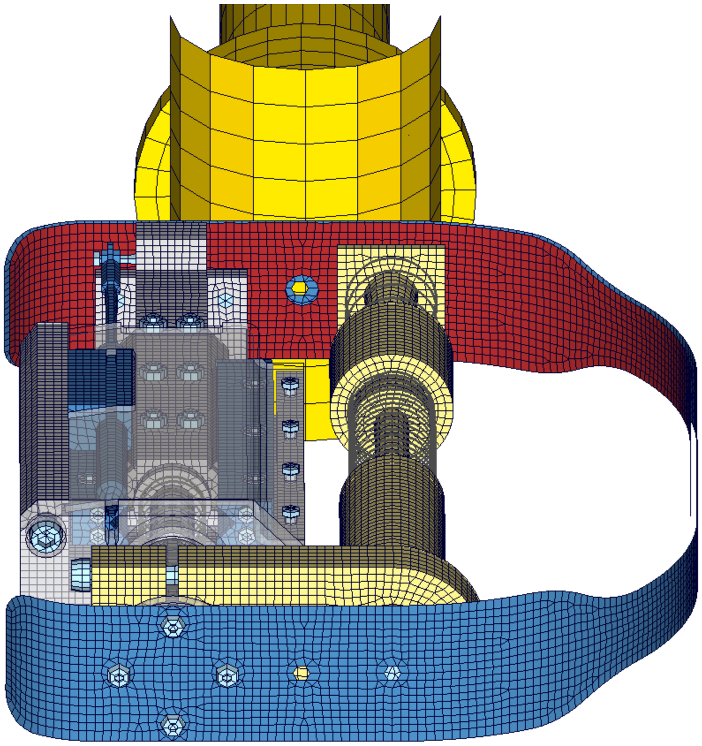

Figure 17: Virtual impact test without rib foam.

Conclusion

The authors have developed several LS-DYNA dummy models in the FAT and PDB consortium. The models are commercially available and many companies use the models to enhance occupant injury risks in vehicle accidents. All development projects have in common that coarse models are used to estimate the load levels of the dummy, its components, and materials in a vehicle accident. Subsequently, simulation was used to estimate the loads in tests and to define appropriate tests for the validation tests database. Based on this test database reasonably fine models were developed. Recently, a very fine model of the ES-2 is generated as tool to enhance the commercial models. The very fine model includes almost all details and all initial conditions. The computational effort of the very fine model can be reduced by combining fine and coarser meshed components or by neglecting certain effects. The fine model is too fine to be used in standard crash simulations but first experiences show the value in dummy model development. Three examples present the current usage of the fine model. The first example explains how the fine model is used to generate data for the validation of the coarse model. The fine model allows performing virtual tests for the neck of the ES-2 with very realistic boundary conditions. In the second example the influences of a simplified jacket modeling are estimated by performing sensitivity studies with the different models. The third example addresses questions related to the stiffness of the connection of parts bolted to the rib. The fine model helps to find a simple and appropriate modeling of the bolted connection. All three examples show the benefit and potential of very fine models. Even if generation, validation, and run time of the very fine models is are quite time consuming, the effort allows increasing the predictability of the reasonably fine meshed models.

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