# The CASIMIR Model for Simulation in Seating Comfort Applications

# - A Status update for LS-DYNA -

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## 1 Introduction

For those who spend a lot of time driving, issues of comfort can become issues of health and safety. Therefore seating comfort is an important point in the seat development. Currently, the OEM and Tier-1 are mainly using experimental setups with test drivers for the evaluation of seating comfort. An enhanced seat development is possible by a virtual analysis using software tools like Wölfel Group's *CASIMIR/Automotive* [1]. The virtual analysis shows the advantages that non-measureable quantities can be evaluated, the results are reproducible, the assessment is objective and the application is feasible within the early development phase, leading to reduced time and cost expenditure.

The human body model CASIMIR is currently only available for ABAQUS. To open the model to a wider range of customers, the model is converted to LS-DYNA. This paper gives an overview about the procedure, model and the current status of translation.

## 2 Seat Development with *CASIMIR/Automotive*

### 2.1 Virtual Procedure for Seat Development

The seat is the most important link between occupant and vehicle, and there are a lot of conflicting requirements within the development. On the one side it should be comfortable and support the occupant while driving, but on the other side it should also be strong enough to sustain a crash and finally it needs to be cost-effective and packaging wise efficient.

Avoiding discomfort and negative influences on the driver's health, the static and dynamic comfort must be considered within the seating development. At the moment the OEM of the automobiles and construction vehicles carry out corresponding evaluations using measurements in the vehicle or on the test rig. As this is executed on the basis of hardware-prototypes, an optimization due to static and dynamic comfort criteria is very time consuming and costly.

The software tool *CASIMIR/Automotive* represents a virtual process chain for seat development considering all aspects from the design [2]. The goal is to evaluate new seat designs with respect to comfort issues in the early digital development phase to eventually reduce time and cost efforts.

The process chain for applying *CASIMIR/Automotive* consists of the following three model setups and reflects the stages of the current seat development using hardware prototypes:

- Seat structure
- Unoccupied seat
- Occupied seat

Thereby the investigations of seat structure and unoccupied seat are defined as preparatory steps (see **Fehler! Verweisquelle konnte nicht gefunden werden.**Fig. 1**Fehler! Verweisquelle konnte nicht gefunden werden.Fehler! Verweisquelle konnte nicht gefunden werden.**). The evaluation of the static and dynamic seating comfort can only be carried out by utilizing the occupied seat, which requires the application of human body models as e.g. CASIMIR.

## 2.2 Seat Modelling

The setup of the seat model always defines the starting point for the digital development. Considering the final goal of evaluating static and dynamic seating comfort all components with strong influence must be included, which are:

- Structural components
- Coupling elements there between (e.g. joints)
- Attached assemblies (e.g. airbag)
- Interfaces to upholstery (suspension, lordosis support)
- Upholstery consisting of foam, padding and trim materials

The modelling procedure of the seat structure consists of the – rather simple – setup of the structural parts (geometry), and the – rather complex – definition of the kinematical system, including adequate stiffness properties for the joints.

*Fig.1: Finite-Element-Model of Seat Structure and Unoccupied Seat (courtesy of Ford).*

Similarities are observed for the modelling of the upholstery. While the geometrical representation can easily be created by today's software tools, the implementation of the hyperelastic and frequency dependent material properties is more labour-intensive [3]. Therefore *CASIMIR/Automotive* enables the identification of material parameters based on experimental data of foam and trim specimens using the *Material Manager* tool.

## 2.3 Human Body Model CASIMIR

The human body model CASIMIR was invented in the 1990s at Darmstadt University of Technology [4], [5] in cooperation with BAUA (*Federal Institute of Occupational Health*, Germany) in Berlin. The initial goal for the modelling was to compute internal forces acting on the lumbar spine due to vibrations which occur in working environments. Within the last 15 years the model has been improved stepwise [6] and nowadays is implemented in the software *CASIMIR/Automotive* to investigate static and dynamic seating comfort in the automotive industry (see Fig. 2). The model is available for different percentiles of the European, North American and Asian population.

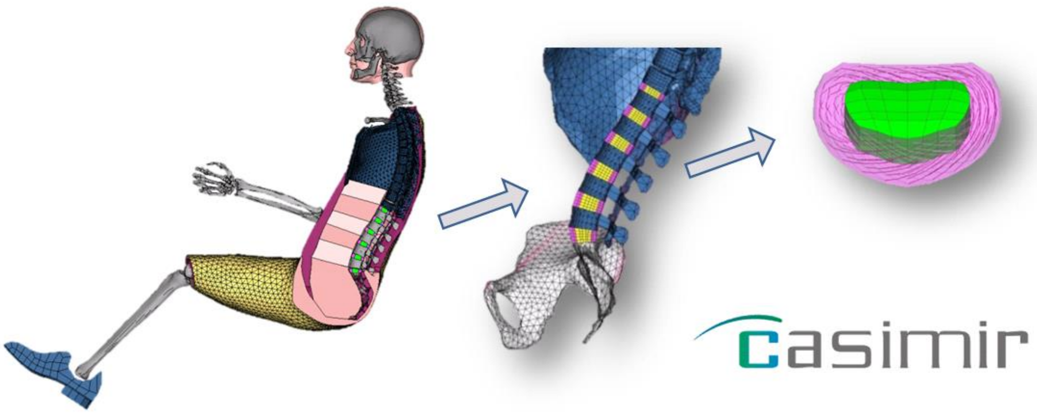


*Fig.2: Setup of Human Body Model CASIMIR: Cross section and details of lumbar spine model.*

The main parts of the model are the bones, modelled via rigid bodies, the tissues and the joints connecting the different skeletal parts with each other. Using the model in the seat development it is important to reflect real driving scenarios. Thereby one point is the representation of the right posture, which is included in the software by a *Posture Processor*, enabling a model change in its main degrees of freedom, as e.g. the outward rotation of the hip or the change of the lumbar spine curvature.

The nonlinear properties of the different types of tissue as muscle, fat and skin tissue are covered by hyperelastic material approaches, which are superposed by viscoelastic definitions covering the time dependent behavior. Representing the real behavior accurately, the material parameters have been identified and validated by in vivo and in vitro test data of animals and human tissue specimen.

Another important part is the state of muscle activation. In the latest research version of the model the muscles of almost the complete body are taken into account. For the seat development the focus is only on the muscle strings in the abdomen and the back, which are required for stabilization of the upright seating posture.

The level of muscle activation is computed separately for each new posture. Due to the included muscle strings the setup is redundant and therefore the level of activation is optimized with the goal to reduce the energy to a minimum and fulfilling the equilibrium for the translational and rotational degrees of freedom.

### 2.4 Simulation and Results

In the final step both model parts, human body and seat, are combined in the pre-processing (see Fig. 3). In a first step the manikin is moved on top of the seat surface using the *Positioning Manager* tool. Then the interaction is defined using general contact pairs. The friction coefficient can determined with respect to surface structure of the seat and is normally in the range of 0.2 up to 0.3.

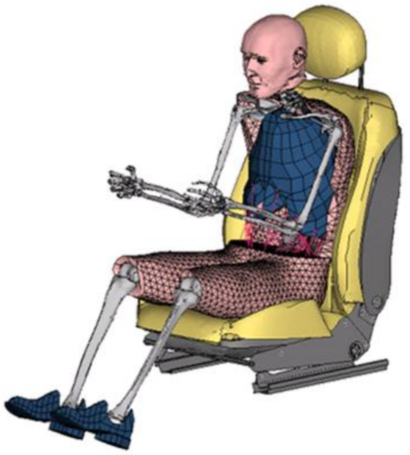


*Fig.3: Setup of occupied seat model.*

The numerical simulation consists of two parts: the static seating under gravity and the dynamic exposition. The static computation is carried out nonlinearly, regarding for nonlinear material properties, finite displacements and contact between different parts. The static comfort is evaluated by the following results:

- Displacement in z-direction on the cushion and in x-direction on the backrest
- Location of body segments especially hip joint
- Contact pressure on the seat cushion and on the backrest
- Meat-to-Metal (shortest distance between structural parts and the human tissue)

Comparing the results of the simulation with real test data a good correlation is achieved. As an example, Fig. 4 shows the pressure distribution computed with CASIMIR and a measurement with a real test person of percentile m50.

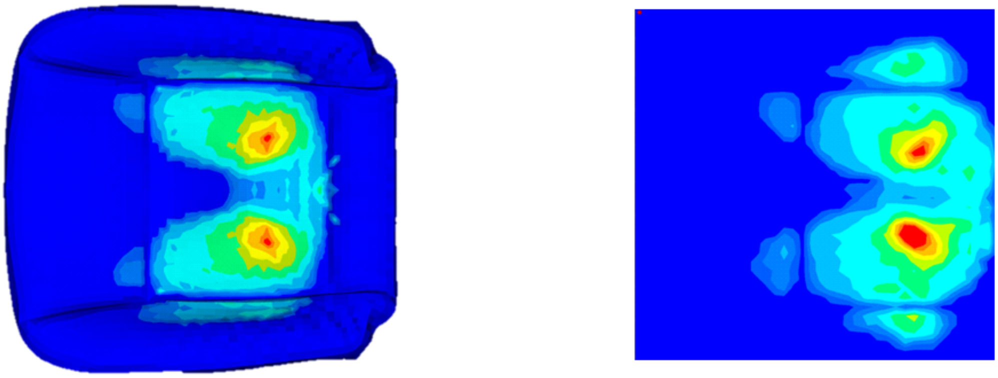


*Fig.4: Comparison of pressure map from simulation (left) and measurement (right).*

The dynamic simulation is based on the static seating process. Computing the dynamic response in the frequency range the simulation is carried out linearly, i.e. all system properties are linearized about the operation point from the static seating process. Normally the dynamic comfort is evaluated by the seat transfer function, which describes the seat behaviour in the occupied state. Using the human body mode, additional internal and external quantities can be evaluated.

### 2.5 Post-Processing

A very important issue using the digital development procedure is the post-processing of the results. In experimental setups the comfort is subjectively evaluated by the test drivers using questionnaires. As emotions are not part of the simulation, comfort models must be used, relating the physical quantities to subjective ratings. Therefore *CASIMIR/Automotive* includes several stand-alone post-processing tools, which can be used for measurements and simulations to enable a combined development process improving the overall accuracy and the capabilities.

A typical post-processing tool is available for the seat pressure distribution using the Bodymap procedure developed at the TU Munich [7]. Thereby the pressure map is divided in 17 sections, where for each section, discrete values, e.g. the peak pressure or the distributed load, are computed. Typical screenshots of the post-processing tool are depicted in Fig. 5.

Using this tool different seat designs can easily be compared to each other enabling a straightforward decision process. Further subjective ratings can be included by defining target values or reference measurements.

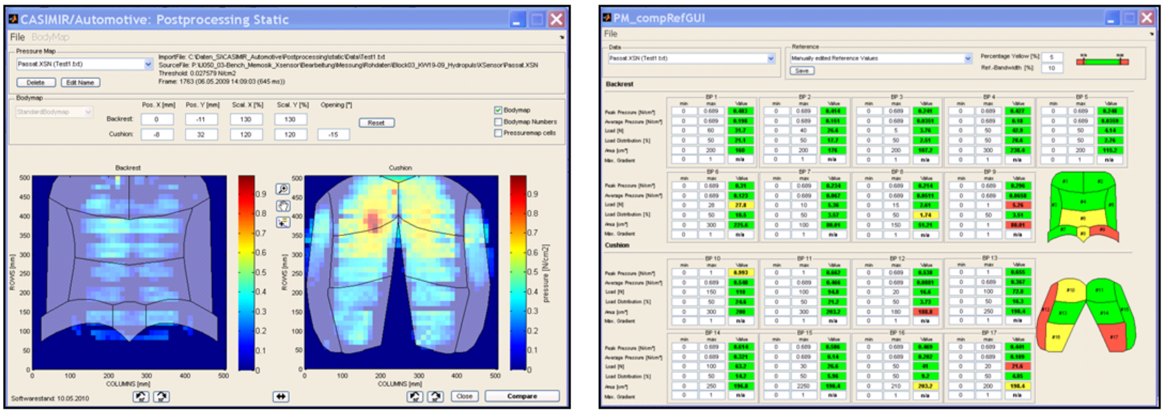


*Fig.5: Post-Processing tool for pressure mapping using the Bodymap procedure.*

## 3 LS-DYNA Integration Process

Since the *CASIMIR/Automotive* is currently only available for ABAQUS and due to an increasing demand for a LS-DYNA version, the tool is at present converted. As mentioned before, implicit solution schemes are applied for simulating the seating process, like non-linear static simulations, eigenvalue calculations and – for advanced users – quasi-dynamic simulations in the frequency domain (steady-state dynamics). Both solvers have different model requirements and modeling techniques and therefore, the translation is not a simple one-to-one mapping of the keywords but rather a complex process of transferring model functionalities from one code into the other. First steps toward success have been made in terms of a static seating simulation of the CASIMIR model, where already decent results have been achieved.

As a first step the converted human body model was tested on a simplified seat model (Fig. 6) regarding seat pressure distribution and eigenmode respectively eigenvalue extraction to compare model properties between both codes. The seat model consists of a spatially fixed rigid frame and deformable cushion, backrest and headrest structures.

For validation purposes, three different cases have been investigated

1. the first case considers elastic materials of both human body tissue and seat foam – this simplified model reduces the influence of non-linear material behavior and translation differences between both codes,
2. the second case includes non-linear material behavior of the tissue but linear material for the foam, mainly to validate the non-linear tissue material of the CASIMIR model,
3. the third case finally also includes a more realistic, non-linear material formulation for the seat foam. This material is based on a strain energy function, which cannot exactly be translated to LS-DYNA and therefore, differences are expected for this case.

The model performance is shown by means of a static seating procedure, where the seating pressure and stresses are evaluated and compared with the results obtained by the original ABAQUS model.

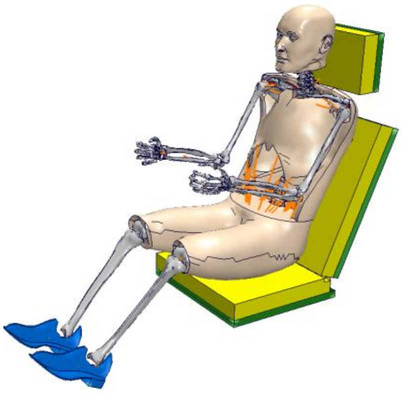


*Fig.6: LS-DYNA CASIMIR model in a simplified seat model used for validation and performance evaluation.*

### 3.1 Load Case Setup

The seating simulation was performed using an implicit static approach. The CASIMIR model was subjected to gravity loading to achieve static equilibrium. A segment-based mortar contact definition considering friction was defined between the human model and the seat cushion and backrest. In order to improve convergence, the body model was initially guided into the seat using adequate boundary conditions and released after the onset of contact between the model and the seat. The general setup and the final state are depicted in Fig. 7.

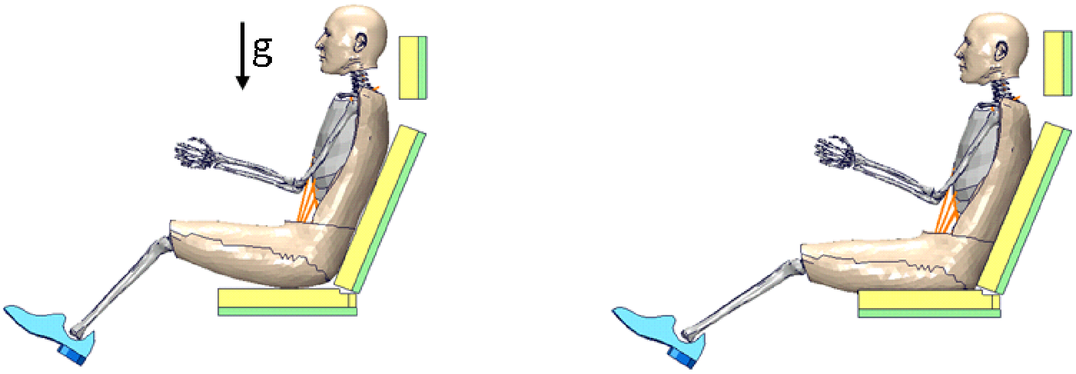


*Fig.7: Seating procedure: initial position of CASIMIR (left) and seated human body (right).*

## 3.2 Static Seating Simulations

The results for the static seating procedure are given for the three cases, defined earlier.

### *3.2.1 Case 1 – All elastic*

The results for the first – all-elastic – case are depicted in Fig. 8 and Fig. 9. The LS-DYNA simulations with the simple seat model (Fig. 8, left) show a good correlation to results obtained from ABAQUS regarding the seat stress distribution in terms of the von-Mises stresses in the seat cushion (Fig. 8, right). Both the stress distribution and the peak values are very similar and show a good correlation.

Fig. 9 shows a comparison for the seat contact pressure, which represents another important quantity. Both solvers provide similar trends considering the total pressure distribution. Nevertheless the peak values differ slightly. This difference can mainly be explained by the unequal contact algorithms and projection approaches when evaluating the contact pressures.

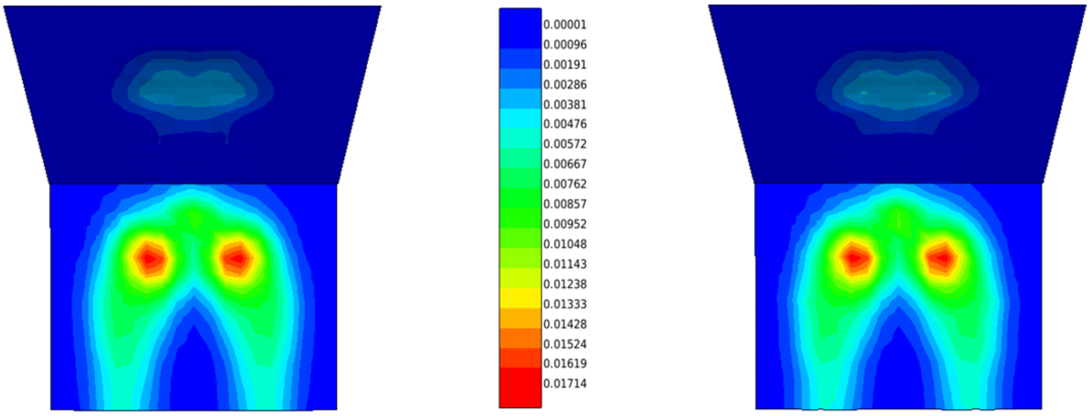


*Fig.8: Von Mises stress distribution on the seat of the model with elastic materials in MPa: LS-DYNA results (left) and ABAQUS results (right).*

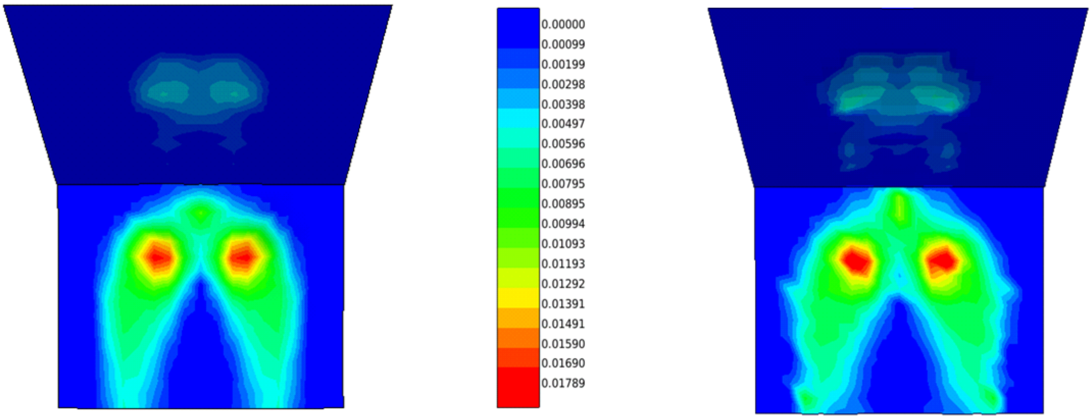


*Fig.9: Seat contact pressure distribution of the model with elastic materials in N/mm$^2$: LS-DYNA results (left) and ABAQUS results (right).*

### *3.2.2 Case 2 – Nonlinear pelvis flesh, linear seat foam material*

The second case contains a nonlinear human tissue, based on a Mooney-Rivlin material and a linear seat foam material. Similar results can be obtained for the von-Mises stresses in the seat (Fig. 10) and the contact pressure distribution (Fig. 11).

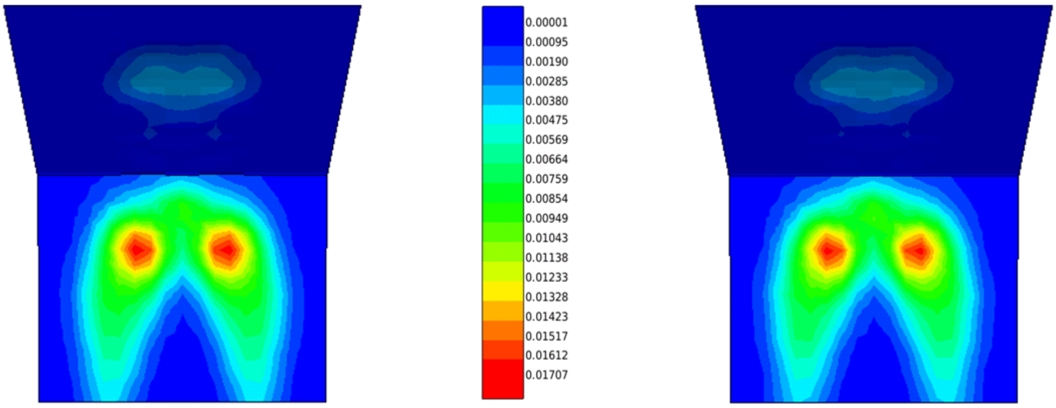


*Fig.10: Von Mises stress distribution on the seat of the model with elastic material for the foam and non-linear material for the flesh in MPa: LS-DYNA results (left) and ABAQUS results (right).*

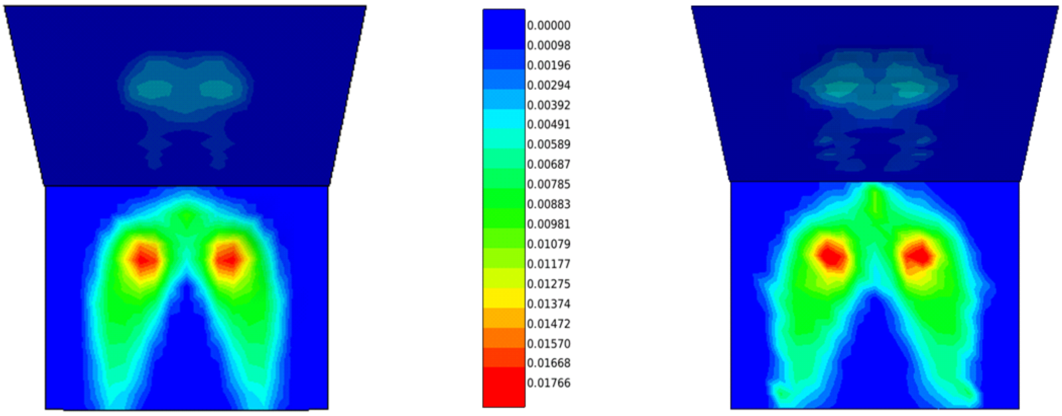


*Fig.11: Seat contact pressure distribution of the model with elastic material for the foam and non-linear material for the flesh in N/mm$^2$: LS-DYNA results (left) and ABAQUS results (right).*

### *3.2.3 Case 3 – All non-linear materials*

Fig. 12 shows the distribution of the von-Mises stresses in the seat for case 3. The results again show identical distributions, whereas the contact pressure looks slightly different (Fig. 13).

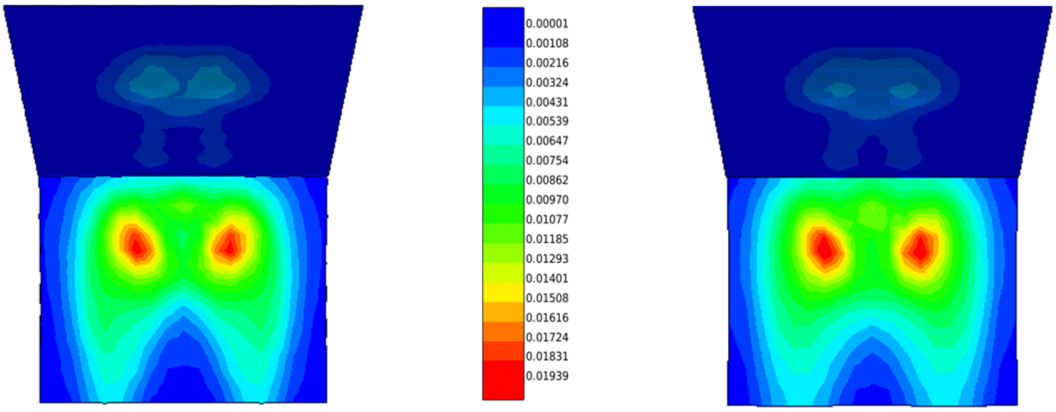


*Fig.12: Von Mises stress distribution on the seat of the model with non-linear materials for the foam and for the flesh in MPa: LS-DYNA results (left) and ABAQUS results (right).*

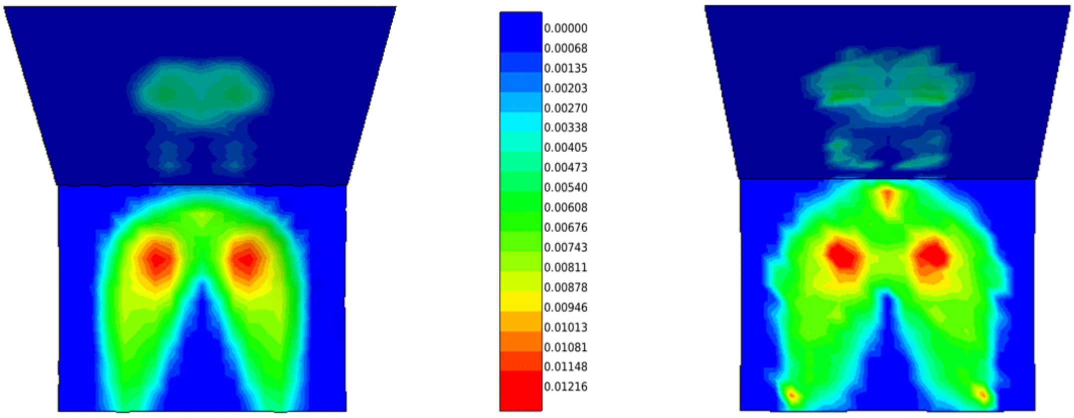


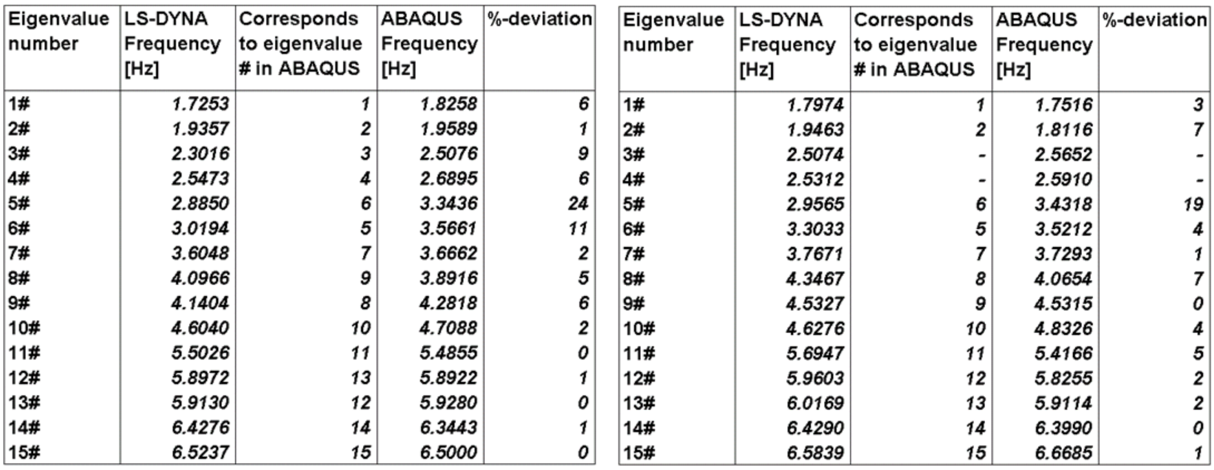
*Fig.13: Seat contact pressure distribution of the model with non-linear materials for the foam and for the flesh in N/mm$^2$: LS-DYNA results (left) and ABAQUS results (right).*

### 3.3 Eigenmode Evaluation

The second step consists of an eigenvalue extraction of the occupied seat, i.e. the seated geometry including the CASIMIR and the seat models. This can also be used to validate the model by comparing the eigenvalues and –vectors, which can reveal missing part connections or wrong stiffness distributions. Therefore, the first 15 eigenmodes are extracted for the ABAQUS and LS-DYNA models with eigenvalues ranging from 0-6.5 Hz. These values are depicted in Fig. 14 for the all-elastic case (1) and the fully nonlinear case (3). The results of case 2 are omitted due to similarity to case 1.

The eigenvalues are very similar between both models. Deviations range from 0 to 10%, where only mode 5 and 6 show larger differences in both cases. Mode 5 represents a (global) forward-backward motion of the whole CASIMIR model while mode 6 is a (global) rotational mode of the torso.

For the fully-nonlinear case, eigenvalues 3 and 4 generally match but have slightly different eigenvectors. These two eigenmodes in LS-DYNA represent a combination of the same modes in ABAQUS and are identical with these from the cases 1 and 2. Generally, the vectors reflect an upward-downward motion of the model and a rotation of the torso, including an upward-downward motion of the thighs. The differences can mostly be explained by the unequal seat material definitions, based on a strain-energy function which is very similar in ABAQUS and LS-DYNA but still shows some differences.



| Eigenvalue number | LS-DYNA Frequency [Hz] | Corresponds to eigenvalue # in ABAQUS | ABAQUS Frequency [Hz] | %-deviation |
|---|---|---|---|---|
| 1# | 1.7253 | 1 | 1.8258 | 6 |
| 2# | 1.9357 | 2 | 1.9589 | 1 |
| 3# | 2.3016 | 3 | 2.5076 | 9 |
| 4# | 2.5473 | 4 | 2.6895 | 6 |
| 5# | 2.8850 | 6 | 3.3436 | 24 |
| 6# | 3.0194 | 5 | 3.5661 | 11 |
| 7# | 3.6048 | 7 | 3.6662 | 2 |
| 8# | 4.0966 | 9 | 3.8916 | 5 |
| 9# | 4.1404 | 8 | 4.2818 | 6 |
| 10# | 4.6040 | 10 | 4.7088 | 2 |
| 11# | 5.5026 | 11 | 5.4855 | 0 |
| 12# | 5.8972 | 13 | 5.8922 | 1 |
| 13# | 5.9130 | 12 | 5.9280 | 0 |
| 14# | 6.4276 | 14 | 6.3443 | 1 |
| 15# | 6.5237 | 15 | 6.5000 | 0 |

| Eigenvalue number | LS-DYNA Frequency [Hz] | Corresponds to eigenvalue # in ABAQUS | ABAQUS Frequency [Hz] | %-deviation |
|---|---|---|---|---|
| 1# | 1.7974 | 1 | 1.7516 | 3 |
| 2# | 1.9463 | 2 | 1.8116 | 7 |
| 3# | 2.5074 | - | 2.5652 | - |
| 4# | 2.5312 | - | 2.5910 | - |
| 5# | 2.9565 | 6 | 3.4318 | 19 |
| 6# | 3.3033 | 5 | 3.5212 | 4 |
| 7# | 3.7671 | 7 | 3.7293 | 1 |
| 8# | 4.3467 | 8 | 4.0654 | 7 |
| 9# | 4.5327 | 9 | 4.5315 | 0 |
| 10# | 4.6276 | 10 | 4.8326 | 4 |
| 11# | 5.6947 | 11 | 5.4166 | 5 |
| 12# | 5.9603 | 12 | 5.8255 | 2 |
| 13# | 6.0169 | 13 | 5.9114 | 2 |
| 14# | 6.4290 | 14 | 6.3990 | 0 |
| 15# | 6.5839 | 15 | 6.6685 | 1 |

*Fig.14: Comparison of the first 15 eigenvalues between LS-DYNA and ABAQUS models for the all-elastic case 1 (left) and the fully nonlinear case 3 (right).*

Samples for the eigenvectors are shown in Fig. 15 and Fig. 16, where first the eigenvector of mode 8 in LS-DYNA is depicted in yellow showing the maximum and minimum scaling of the mode (see Fig. 15). The grey models represent the initial seated (reference) model geometry. Fig. 16 shows the same mode for the ABAQUS model (eigenmode 9) in orange.

Note that the eigenvector obtained by LS-DYNA is shown using the deformed geometry, after the seating process, while the ABAQUS vector is shown with respect to the initial geometry, but taking into account pre-stresses and the new geometry of the seat.

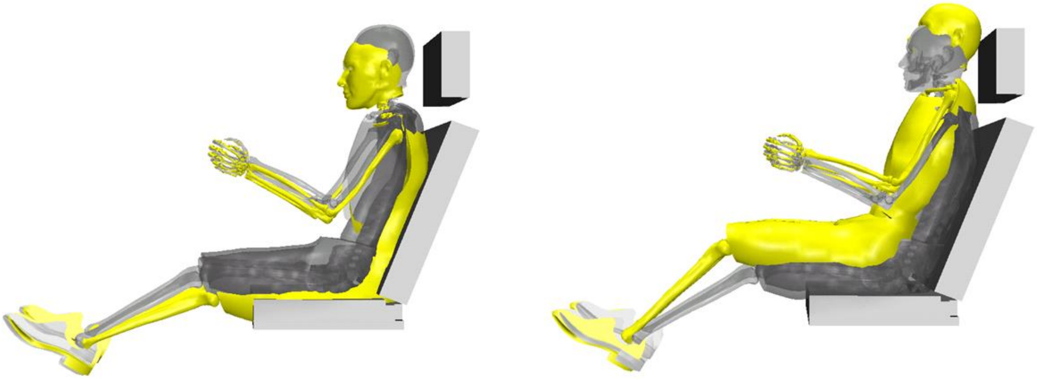


*Fig.15: Relevant deflections showing the eigenmode from eigenvalue number 8 in the LS-DYNA model – initial seated position (grey) and deflected position (yellow).*

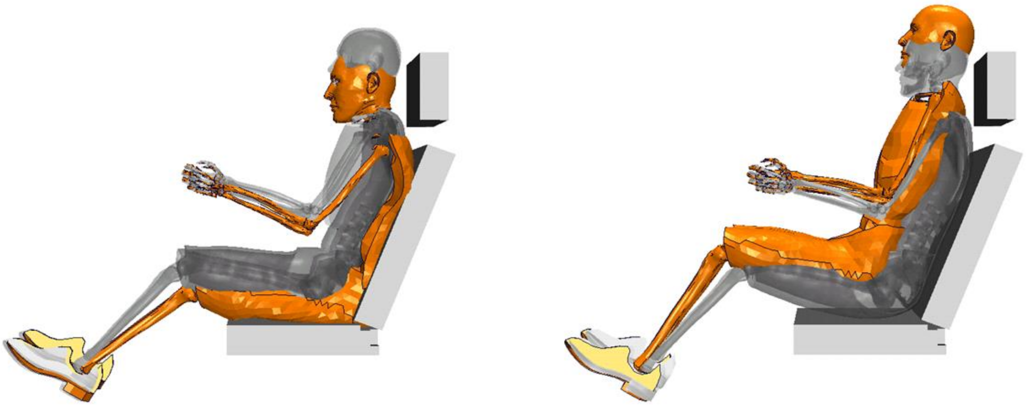


*Fig.16: Relevant deflections showing the eigenmode from eigenvalue number 9 (corresponding to eigenmode 8 in LS-DYNA) in the ABAQUS model – initial position (grey) and deflected position (orange).*

## 4 Summary and Outlook

In the exposed status update, the CASIMIR model for seating comfort simulations was presented. The human body model was initially developed for ABAQUS. Due to an increasing customer demand it is currently being converted to LS-DYNA. However the translation is still in progress. First LS-DYNA simulations using a simple seat model showed a good correlation to results obtained with ABAQUS regarding seat stress and pressure distribution and eigenmodes in seated position. In the comparison, both elastic and inelastic behaviors of the seat foam respectively human body tissue were taken into account.

Further developments in the model conversion will be the consideration of more complex seat models, frequency dependent materials and the extension to pre- and post-processing tools for LS-DYNA. A further perspective to work on is the steady state dynamic analysis where the seat is undergoing dynamic incitation and the frequency response function on the seat cushion surface is taken into account in order to predict comfort and health issues.

## 5 Literature

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