



upscale

**Upscaling Product development Simulation Capabilities exploiting Artificial intelligence
for Electrified vehicles**

D5.5 Requirements for setting up a reduced order model of a full vehicle model with parametrized boundary conditions

Ch. Breitfuss (VIF), P. Kolm (VIF), K. Ismail (VIF), F. Daim (ESI), A. Dumon (ESI), Alain Trameçon (ESI), N. Hascoët (ENSAM), S. Menegazzi (CRF), M. Andres (VW), C. Jiménez (IDIADA), S. Shaik (IDIADA)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 824306.

PROJECT TITLE	Upscaling product development simulation capabilities exploiting artificial intelligence for electrified vehicles
PROJECT ACRONYM	Upscale
GRANT AGREEMENT NUMBER	824306
INSTRUMENT	RIA
CALL	LC-GV-2018
STARTING DATE OF THE PROJECT	November, 1 ST 2018
PROJECT DURATION	42 Months

The UpScale Project

UPSCALE is the first EU project with the specific goal of integrating Artificial Intelligence (AI) with traditional physics-based Computer Aided Engineering to reduce the development time and increase the performance of electric vehicles (EVs).

Nowadays High-Performance Computing (HPC) and Computer Aided Engineering (CAE) play a decisive role in vehicle development processes, thus the two most HPC and CAE intensive parts of the development, which are vehicle aero-thermal and vehicle crash performance, have been chosen as use cases for the endeavour.

Through the combined effort of universities, research laboratories, European automotive OEMs, software companies and an AI-SME specialized in Machine Learning (ML), the UPSCALE project will provide a unique and effective environment to produce novel AI-based CAE-software solutions to improve the competitiveness of the automotive industry.

The UpScale Consortium

PARTICIPANT N°	PARTICIPANT ORGANISATION NAME	COUNTRY
1 (Coordinator)	IDIADA AUTOMOTIVE TECHNOLOGY SA (IDIADA),	Spain
2	VOLVO PERSONVAGNAR AB (Volvo Cars)	Sweden
3	VOLKSWAGEN AG (VW)	Germany
4	CENTRO RICERCHÉ FIAT SCPA (CRF)	Italy
5	ESI GROUP (ESI GROUP)	France
6	ENGYS LTD (ENGYS LTD)	United Kingdom
7	VIRTUAL VEHICLE RESEARCH GmbH (VIF)	Austria
8	VRIJE UNIVERSITEIT BRUSSEL (VUB)	Belgium
9	ECOLE NATIONALE SUPERIEURE D'ARTS ET METIERS (ENSAM PARISTECH)	France
10	ALGORITHMICA TECHNOLOGIES GMBH (ALGORITHMICA)	Germany
11	F INICIATIVAS I MAS D MAS I SL (F-INICIATIVAS)	Spain

Document Details

DELIVERABLE TYPE	Report
DELIVERABLE N°	D5.5
DELIVERABLE TITLE	Requirements for setting up a reduced order model of a full vehicle model with parametrized boundary conditions
NAME OF LEAD PARTNERS FOR THIS DELIVERABLE	ENSAM
VERSION	01
CONTRACTUAL DELIVERY DATE	Month 24
ACTUAL DELIVERY DATE	Month 27
DISSEMINATION LEVEL	Public

ABSTRACT

This report gives a short description of the deliverable D5.5 which is the framework of how to set up a ROM of a battery cell within a full vehicle crash scenario with respect to parametrized load case parameters. The ROM is set up for the battery cell envelope using s-PGD. Three load case parameters were identified to be most sensitive to the cell deformation. The cells with the highest deformation are identified for the ROM creation.

Revision History

The following table describes the main changes done in the document since it was created

REVISION	DATE	DESCRIPTION	AUTHOR (ORGANIZATION)
r00	28.09.2020	Template	N. Hascoet (ENSAM)
r01	12.10.2020	Draft Version	N. Hascoet (ENSAM)
r02	27.10.2020	Revision	M. Andres (VW)
r03	29.10.2020	Revision	S. Menegazzi (CRF)
r04	30.10.2020	Revision	F. Chinesta (ENSAM)
r05	30.10.2020	Revision	F. Daïm (ESI)
r06	30.10.2020	Final review	M. Andres (VW)
r07	01.12.2020	Review	Albert.R de Liébana (IDIADA)

Disclaimer

THIS DOCUMENT IS PROVIDED "AS IS" WITH NO WARRANTIES WHATSOEVER, INCLUDING ANY WARRANTY OF MERCHANTABILITY, NONINFRINGEMENT, FITNESS FOR ANY PARTICULAR PURPOSE, OR ANY WARRANTY OTHERWISE ARISING OUT OF ANY PROPOSAL, SPECIFICATION OR SAMPLE. Any liability, including liability for

infringement of any proprietary rights, relating to use of information in this document is disclaimed. No license, express or implied, by estoppels or otherwise, to any intellectual property rights are granted herein. The members of the project Upscale do not accept any liability for actions or omissions of Upscale members or third parties and disclaims any obligation to enforce the use of this document. This document is subject to change without notice.

Abbreviations

ROM	Reduced Order Model
DoE	Design of Experiment
SC	Short Circuit
VPS	Virtual Performance Solution
sPGD	Sparse Proper Generalized Decomposition
BEV	Battery Electric Vehicle
BiW	Body-in-White
KPI	Key Performance Index
ERFH5	ESI Result File Hdf5
FE(M)	Finite Element (Method)
CPU	Central Processing Unit
PID	Part ID

Table of Contents

1	Executive Summary	6
2	Introduction to the sPGD technology	7
2.1	Methodology	7
2.2	Model Reduction Techniques - Overview	7
3	Design of Experiment.....	9
3.1	Full Vehicle Load Cases	9
3.1.1	Modelling strategy.....	9
3.1.2	Full vehicle analysis DoE	10
3.1.3	Battery pack results and intrusions	12
3.1.4	Cell results generated from full vehicle analysis	23
4	Model Order Reduction	24
4.1	Model Parametrization	24
4.2	Applied Model Reduction Technique	27
4.3	Use of kinematic ROM	28
4.3.1	Generation of submodelling file	28
5	Possible risks and elaboration on the risks	32
6	Conclusion	32
7	References.....	32
8	Figures	32
9	Tables	33
10	Acknowledgement.....	34

1 Executive Summary

The present deliverable describes the framework of how to set up a ROM of battery components depending on load case parameters of full vehicle crash simulations. The motivation for this deliverable comes from the fact that when dealing with BEV additionally to the safety of the human beings, occupants and pedestrians, the safety of the battery itself is of high importance. Due to this fact the required legal tests have been adjusted and new tests have been defined, e.g. GB/T19751-2005, GB/T18384.1-2015, FMVSS305 80 km/h rear impact, for the BEV approval, see (CATARC 2012), (D.H. Doughty 2012). As a consequence the car manufacturers are extending the ranges of the load case parameters for some load cases. E.g. in the pole side crash the hitting position and hitting angle are varied in a wider range for robustness studies in order to assess the safety of the battery. Larger parameter ranges and higher amounts of varied parameters lead to a very large amount of simulations that need to be performed and post-processed. This results in higher costs concerning the CPU time consumption and the time the engineer is spending for the post-processing of the simulation results. Here, the sPGD technology is able to reduce the necessary amount of simulation runs and furthermore facilitate the post-processing of the results. The sPGD needs only a DoE in the range of the number of parameters to create a ROM and the final ROM is just a single result file including the simulation results for all chosen parameters in their corresponding parameter ranges.

The sPGD was developed by the ENSAM team and implemented to a software suite by ESI during the last year. After defining the parameters of interest and their corresponding ranges the tool creates a DoE list with the parameter combinations that need to be simulated by the engineer. After uploading this DoE the engineer may define the parts of interest for which the tool computes the ROM. The ROM is included in a single result file, that may be post-processed by the engineer. The chosen parameters can be changed by sliders and the corresponding result is shown in real-time.

The report is divided into three main chapters. In chapter 2 the technology of the sPGD method is explained in more detail. Chapter 3 describes the full vehicle analysis done by CRF; two load cases are presented and the chosen load case parameters for each load case are defined. The simulation results are shown, i.e. the deformation fields of the battery cells for every DoE run. Finally, the cells exhibiting the highest deformations are identified. Chapter 4 is dedicated to the training and post-processing of the ROM. In chapter 5 a risk analysis is done and finally conclusions are stated in chapter 6.

The deliverable objectives according to the proposal could be fulfilled. Some delay on the delivery date happened as partners involved had to internally check potential confidentiality issues due to the “Public” condition of the deliverable.

2 Introduction to the sPGD technology

The following subchapters describe the applied methodology and give an overview on general model reduction techniques.

2.1 Methodology

For robustness studies and also for the assessment of the battery safety usually parametrized crash simulations are performed. In this case the parameters of the full vehicle crash simulations are all related to the load case, e.g. the speed of the vehicle/barrier, the mass of the barrier, hitting angles and positions. This leads to a variety of possible parameter combinations each leading to a crash simulation with more or less different deformation and fracture behavior of the structural parts and finally to different KPIs that are usually post-processed in order to assess the safety level of the vehicle. KPIs are e.g. intrusions, velocities, accelerations of distinct points, but also more complex functions such as occurrence of failure, kinks, etc. In the examples presented here, the focus lies on the deformation behavior of the battery cells within the BEV. In order to handle the number of simulations that are necessary, a model order reduction technique is used, explained in section 2.2. At the end, the engineer gets a parametric solution including the possibility to post-process the simulation result of an arbitrary parameter combination in real-time. Before, a DoE needs to be performed that includes crash simulation results for a certain amount of parameter combinations. These results are used in the training phase of the ROM. First, the desired parts of interest, e.g. components, FE-PIDs, within the FE-model of the vehicle are defined leading to a reduction of complexity and file size. Second, the output variables of interest, e.g. nodal displacements, forces, stresses, strains, are defined for the chosen FE-parts. Finally, the ROM is trained based on the DoE results leading to a single solution file that can be post-processed by the engineer without losing the overview.

2.2 Model Reduction Techniques - Overview

The selected strategy for addressing real-time exploration of the parametric space consists in considering a separated representation of the unknown field, at the heart of the so-called Proper Generalized Decomposition.

In such a separated representation framework, transient problems in which the unknown field implies space and time, are written a finite sum of functional products, each involving a function depending on the space coordinate and the other on time. Thus, the 3D transient solution reduces to a sequence of 3D space problems and 1D time problems, allowing in some case for impressive computing time-savings.

When making optimization, inverse identification and uncertainty propagation, direct problems must be solved many times. In the case of optimization, different calculations are performed for different values of the parameters that the model involves. After each calculation the cost function is evaluated, and the new choice of parameters is chosen to reduce as much as possible the cost function. Then the problem is solved again, and the procedure continues until reaching the minimum of the cost function. The main drawback of the standard optimization techniques

just described lies in the fact that the problem at hand must be solved many times online, fact that has an important impact on the solution efficiency. Furthermore, in some optimization problems the cost function cannot be defined analytically or is depending on several factors that are each weighted and thus leading to a limitation of the solution space.

Within the Proper Generalized Decomposition framework, model parameters are assumed problem extra-coordinates (playing the same role as space and time), and then the multi-dimensional problems that integrate as coordinates, space, time and all the parameters involved in the optimization process is solved by using the separated representation that allows circumventing the so-called curse of dimensionality. Thus, a generic parametric 3D transient solution is found by solving sequentially some problems involving the space coordinates, some one-dimensional problems involving the time and a series of one-dimensional algebraic equations concerning functions depending on the parameters.

This parametric solution, computed offline, can be viewed as a sort of vademecum, that as soon as it is available, allows real-time particularizations, making optimization even without cost function, inverse analysis and uncertainty propagation possible almost in real-time.

That version of the separated representation constructor is too intrusive, making necessary re-programming the computer algorithms involved in the solution procedure for any physics. In this circumstances, non-intrusive strategies for coupling the separated representation constructor with any commercial simulation program, and in particular to those used for addressing the different physics involved in the considered case studies, were proposed.

The so-called SSL consists of using a collocation approximation in the parametric space, combined with a greedy procedure combined with a hierarchical basis. At the resulting hierarchical collocation points, the high-fidelity problem is solved by invoking any available commercial simulation code. The hierarchical nature of the approximation offers an error estimator, that drives the sampling in the parametric space and allows ensuring the solution accuracy.

Then the solution associated to each one of these points is collected, and the PGD (in its standard formulation) is considered for expressing all the collected solution as a finite sum of functional products, i.e. the parametric problems separated representation, as described in (D. Borzacchiello 2019).

However, SSL needs too many data when either, the approximation degree or the number of parameters increase. To circumvent such a difficulty, the collocation framework was applied on the data resulting from a sparse sampling of the parametric space. Then, a separated representation of the searched solution is enforced to approach the collected data (R. Ibanez 2018). Thus, even in the low-data limit, nonlinear regressions can be constructed.

Richer solutions need increasing the approximation degree, however, that enrichment can result in an overfitting. In those circumstances different regularizations can be used for either improving the approximation accuracy (limiting overfitting) or to enforce the approximation sparsity.

3 Design of Experiment

This chapter describes the full vehicle load cases that were used in order to investigate the feasibility and performance of the sPGD model of the battery cell. Two load cases applied to the city car by CRF are presented where three load case parameters in each of the load cases are changed. The DoE consists of 10 simulation runs for each load case.

3.1 Full Vehicle Load Cases

Following sub chapters describe the carried-out vehicle load case simulations and the modelling strategy.

3.1.1 Modelling strategy

The starting base of the activity on full vehicle DOE ROM training result generation is the full vehicle model translated to ESI VPS solver.

In the battery modules, all the dummy cell models were removed and substituted with the macro scale cell model developed in WP1. Each battery module holds 12 cells.

The module casing, part of the battery pack include, has been modified in order to host the macro-scale cell models and to guarantee the stable hold of the cells in the module.

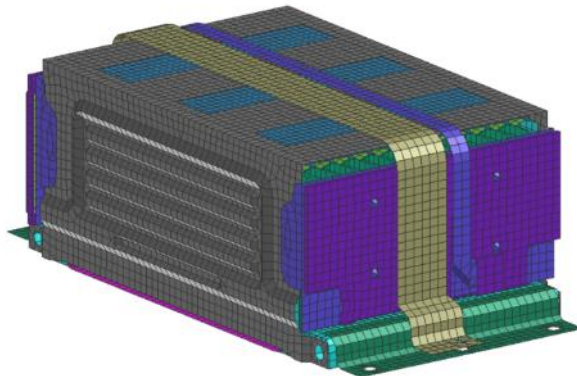


Figure 1: External module protection

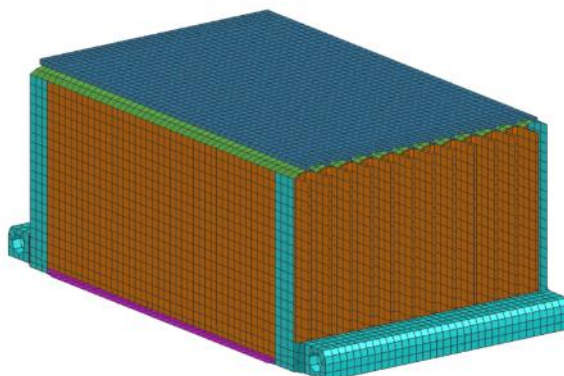


Figure 2: Internal cell holding structure

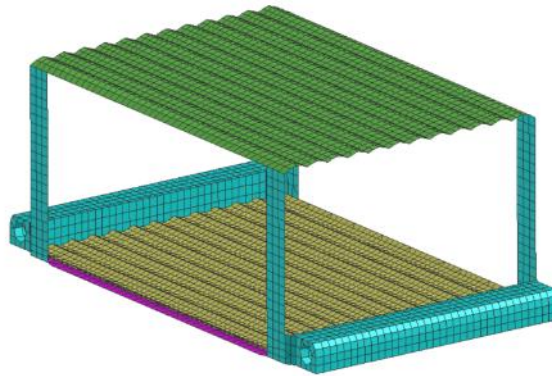


Figure 3: Cell shaped holding and distancing structure copying the cell shape

In order to reach the objective of guarantee a stable hold on the cells it has been necessary to model several components that guarantee the cell positioning with a geometrical interface. To simulate the anode and cathode connector hold in place by an electrical clamping system, the modelling strategy was to introduce a tied contact interface.

This interface connects rigidly the nodes of the anode or cathode connector with the cell holder structure.

The cells are therefore hold in place with a tied connection on the positive and negative connectors, by a shaped casing and by direct contact interaction with the neighbor cells.

In the following table it is represented the information relative to the full vehicle model solved in the DOE.

The cell positioning has been managed with CATEXP card from VPS as reported in chapter **¡Error! No se encuentra el origen de la referencia.** of the UPSCALE deliverable D3.2. The position grid and cell modular input was generated with a script from ESI that enabled a fast and efficient model assembly process exploiting repeated import of a single submodel.

Table 1: Full vehicle model information

Total number of nodes	7'961'373	Total number of elements	6'559'326
Total number of solid parts	268	Of which SHELL3	16'780
Total number of shell parts	1175	Of which SHELL4	5'148'627
Total number of materials	1475	Of which SOLID6	66
Total number of cells	204	Of which SOLID8	1'358'278

3.1.2 Full vehicle analysis DoE

The DOE parameter ranges have been defined based on LS-DYNA simulation results on the vehicle model with simplified battery pack.

This set of simulation permitted to assess which level of severity increase lead to sensitive deformation of the battery pack and of the battery modules.

The parameters choice for side pole impact are:

1. impact speed increment
2. pole height
3. pole X offset

For the rear impact instead the parameters are:

1. wall width
2. extra mass on barrier
3. barrier speed increment

The DOE has been generated by means of a random distribution covering the design space based on the considerations in Table 2.

Table 2: Overview of parameters and corresponding ranges

Parameter	Continuous/Discrete	Range
Δ SPEED	Discrete with 1m/s step	2 to 7 m/s
POLE HEIGHT	Discrete 2 steps	60% or 100%
POLE Δ X POS	Discrete with 50 mm step	0 to 500 mm
WALL WIDTH	Discrete 2 steps	1.1 m or 3 m
EXTRA MASS	Discrete 2 steps	0 kg or 400 kg
EXTRA SPEED	Discrete with 1m/s step	5 m/s to 10 m/s

For each load case between side pole impact and rear impact with rigid barrier, 10 designs were generated and are reported in Table 3 and Table 4.

Considering the large amount of cells present in a battery pack it has been defined a small amount of designs per crash scenario that revealed more than sufficient with the increased severity of the impact.

Table 3: Pole impact DOE parametrization

ID	Δ SPEED	POLE HEIGHT	POLE Δ X POS
DOE ID 0	6 m/s	100 %	-150 mm
DOE ID 1	2 m/s	100 %	-50 mm
DOE ID 2	5 m/s	100 %	-350 mm
DOE ID 3	2 m/s	100 %	-250 mm
DOE ID 4	4 m/s	60 %	-300 mm
DOE ID 5	7 m/s	60 %	-50 mm
DOE ID 6	3 m/s	60 %	-200 mm
DOE ID 7	6 m/s	60 %	-150 mm
DOE ID 8	7 m/s	100 %	-450 mm
DOE ID 9	3 m/s	60 %	-450 mm

Table 4: Rear impact DOE parametrization

ID	WALL WIDTH	EXTRA MASS	EXTRA SPEED
DOE ID 0	3 m	400 kg	8 m/s
DOE ID 1	1.1 m	400 kg	10 m/s
DOE ID 2	3 m	400 kg	6 m/s
DOE ID 3	1.1 m	400 kg	7 m/s
DOE ID 4	1.1 m	0 kg	7 m/s
DOE ID 5	3 m	0 kg	10 m/s
DOE ID 6	1.1 m	0 kg	8 m/s
DOE ID 7	3 m	0 kg	9 m/s
DOE ID 8	3 m	400 kg	5 m/s
DOE ID 9	1.1 m	0 kg	5 m/s

3.1.3 Battery pack results and intrusions

The following tables represent the results of the simulation and the effect on the battery pack in the VPS model of the full vehicle. The displacement plot representing the barrier intrusion on the battery pack is relative to a BiW connection spot opposite to the impacted area of the vehicle as defined in Figure 4.

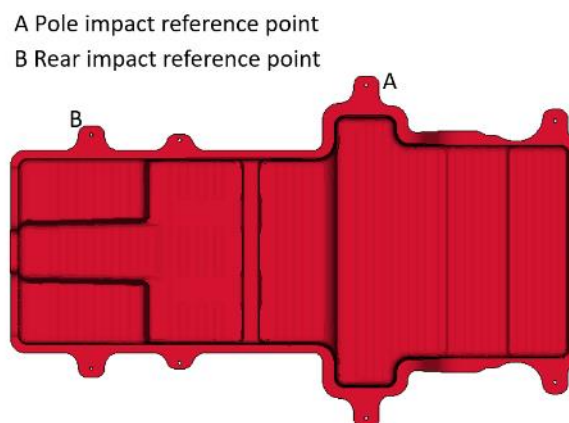


Figure 4: Deformation reference points for the Pole impact and Rear impact load cases

Table 5: Pole impact DOE results - design 0

POLE – DOE ID 0	Deformation [mm]
-----------------	------------------

D5.5 Requirements for setting up a ROM of a full vehicle model with parametrized boundary conditions

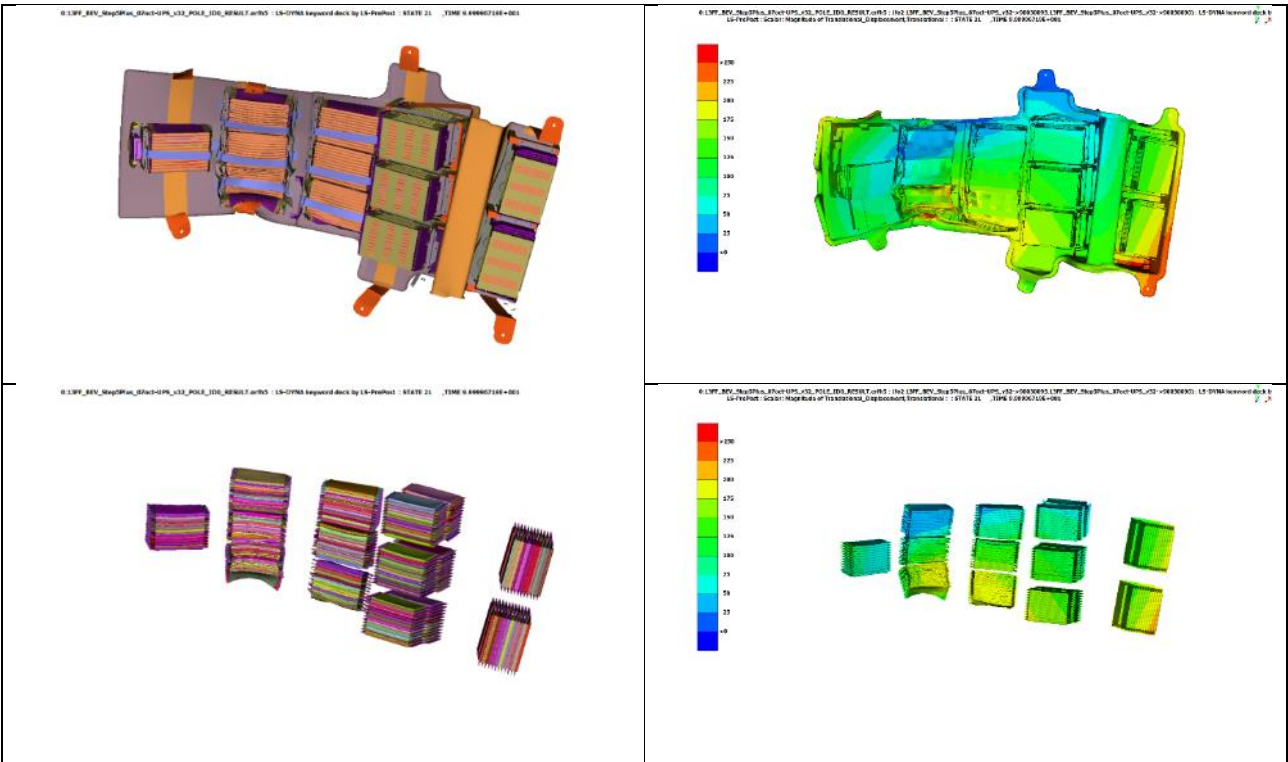


Table 6: Pole impact DOE results - design 1

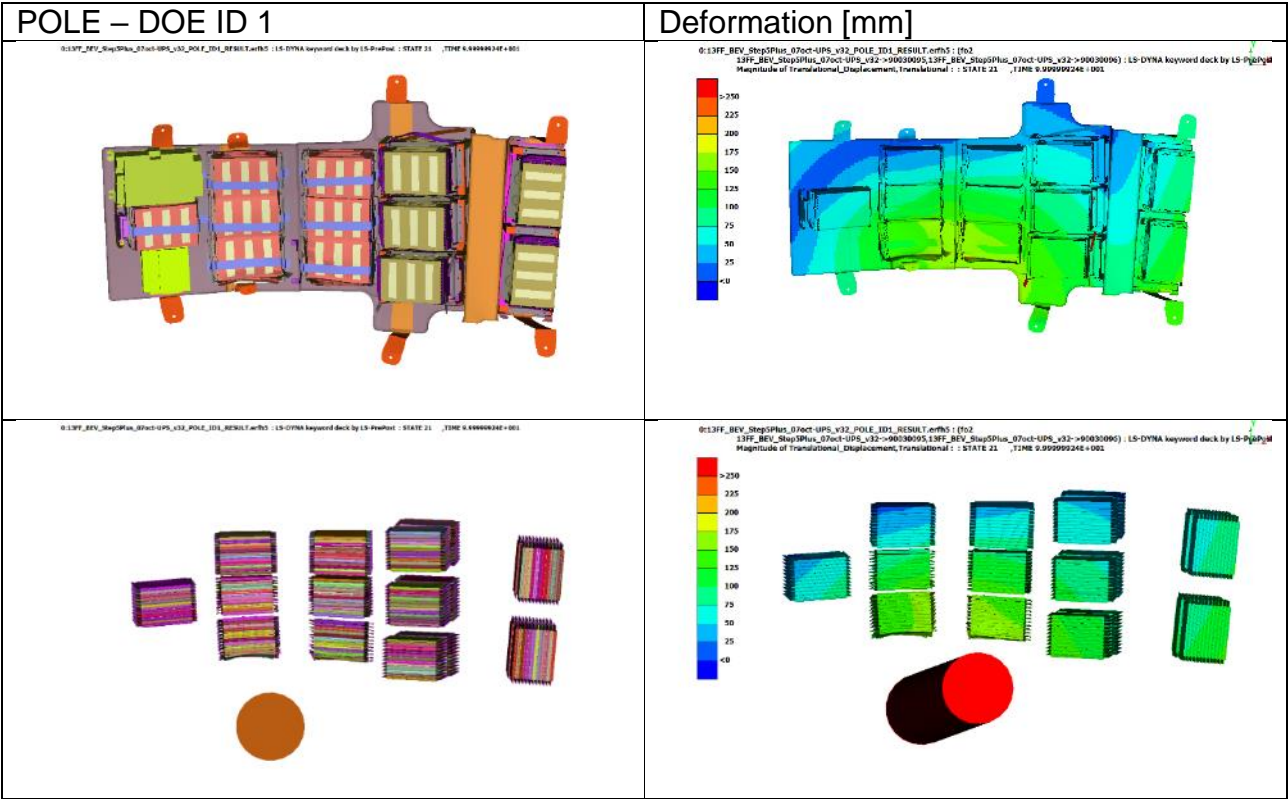


Table 7: Pole impact DOE results - design 2

POLE – DOE ID 2	Deformation [mm]
-----------------	------------------



Table 9: Pole impact DOE results - design 4

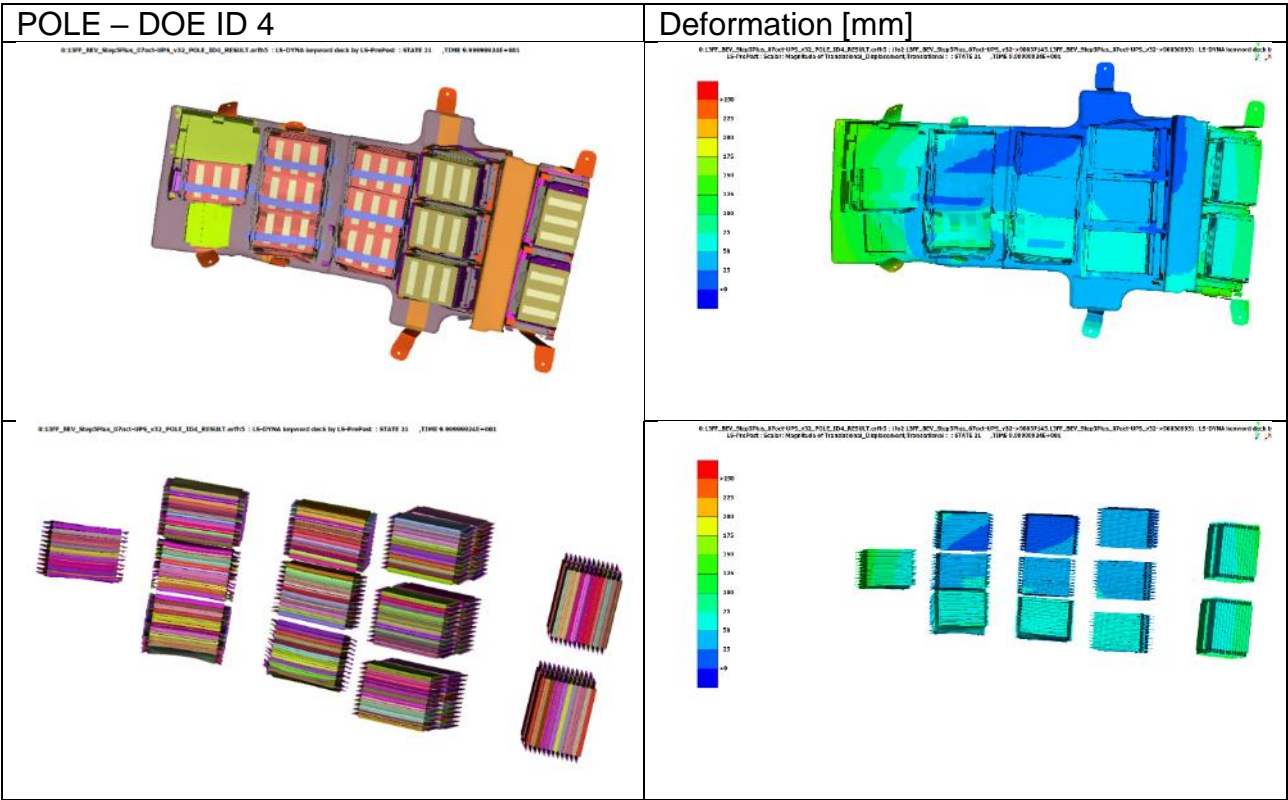


Table 10: Pole impact DOE results - design 5

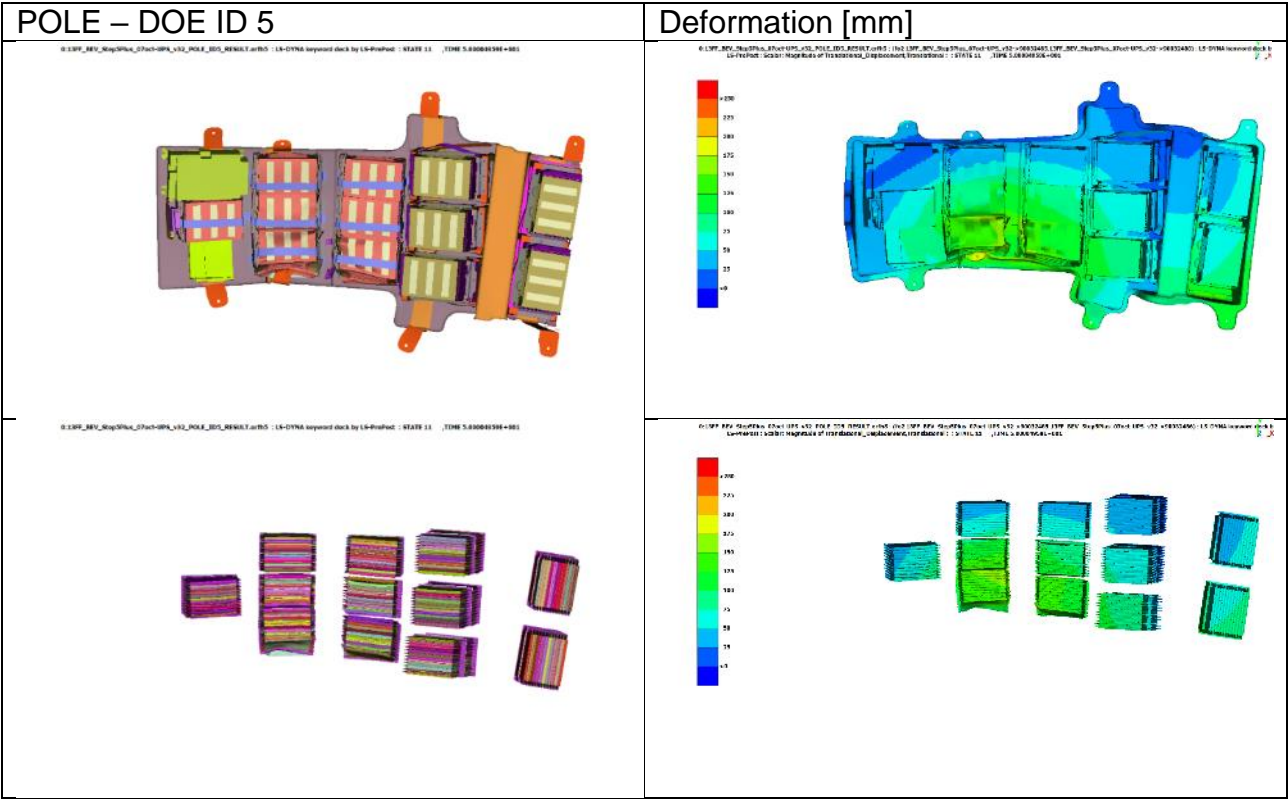


Table 11: Pole impact DOE results - design 6

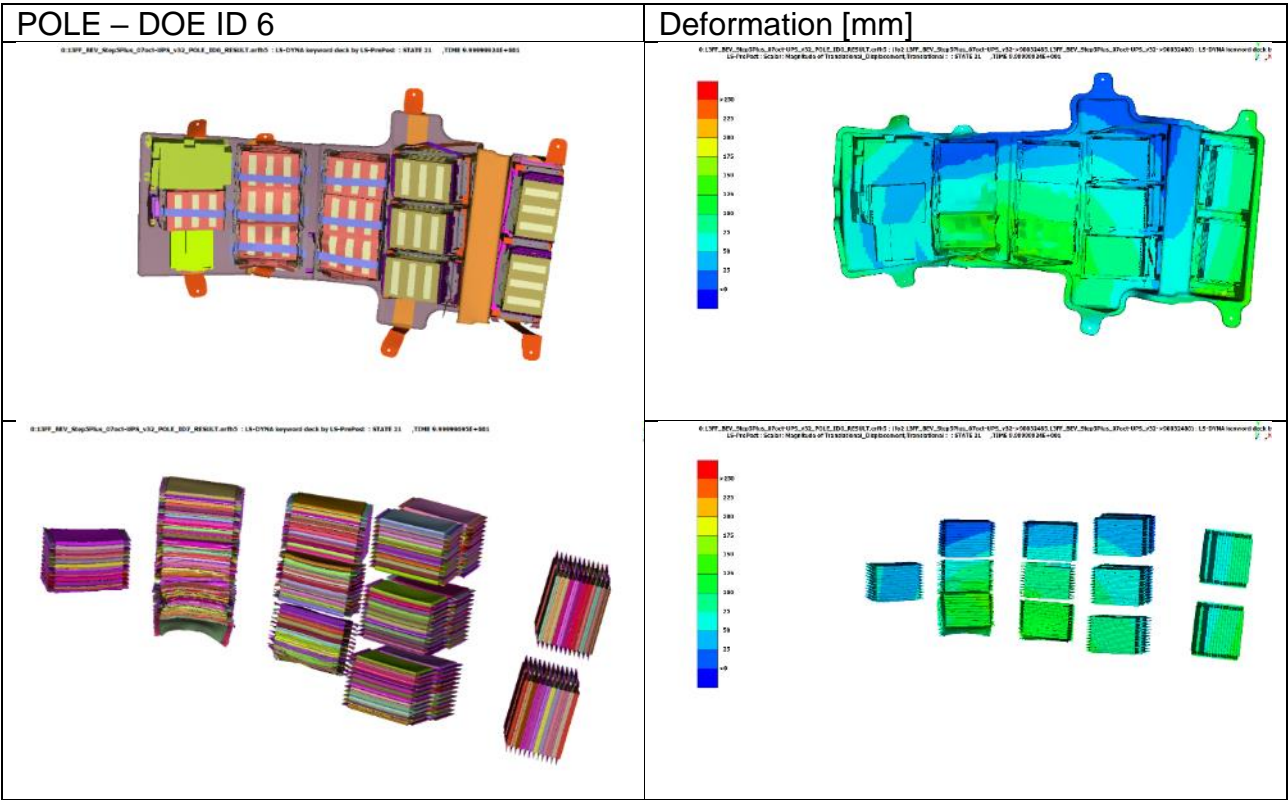


Table 12: Pole impact DOE results - design 7

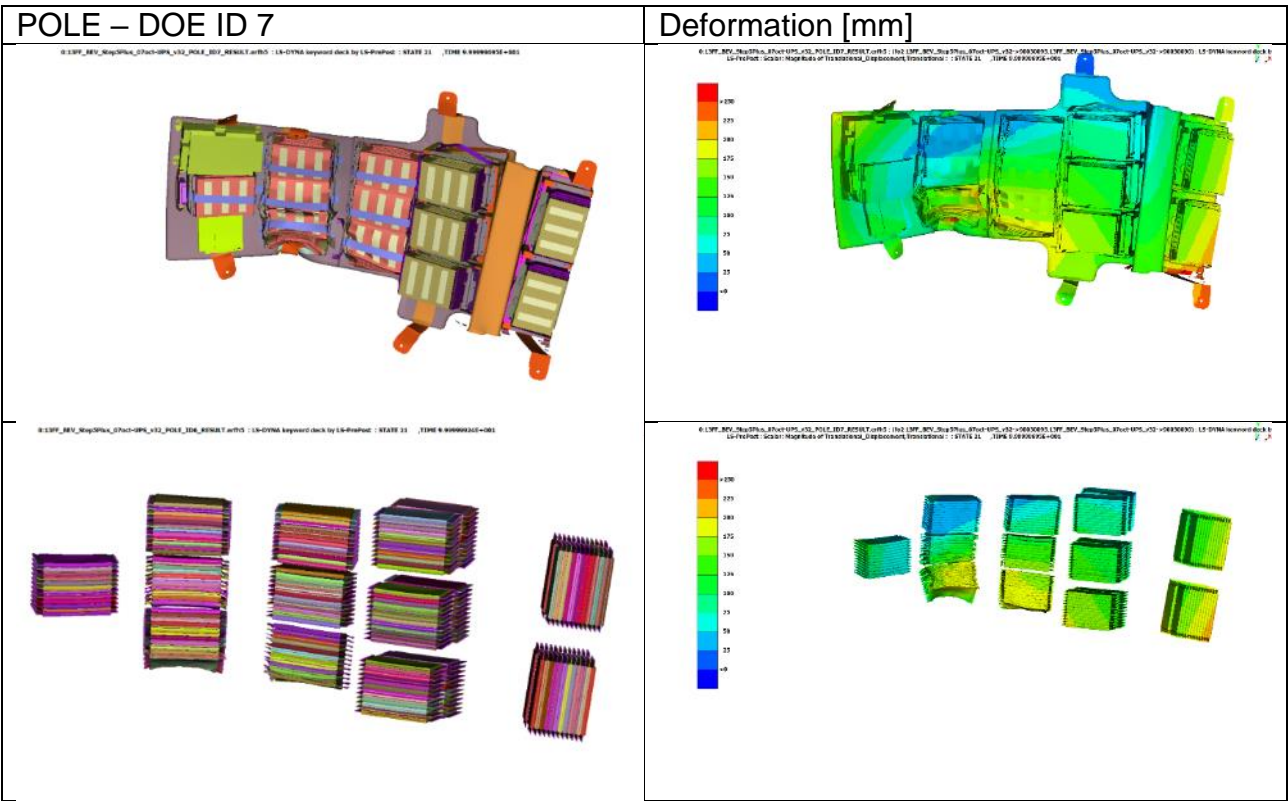


Table 13: Pole impact DOE results - design 8

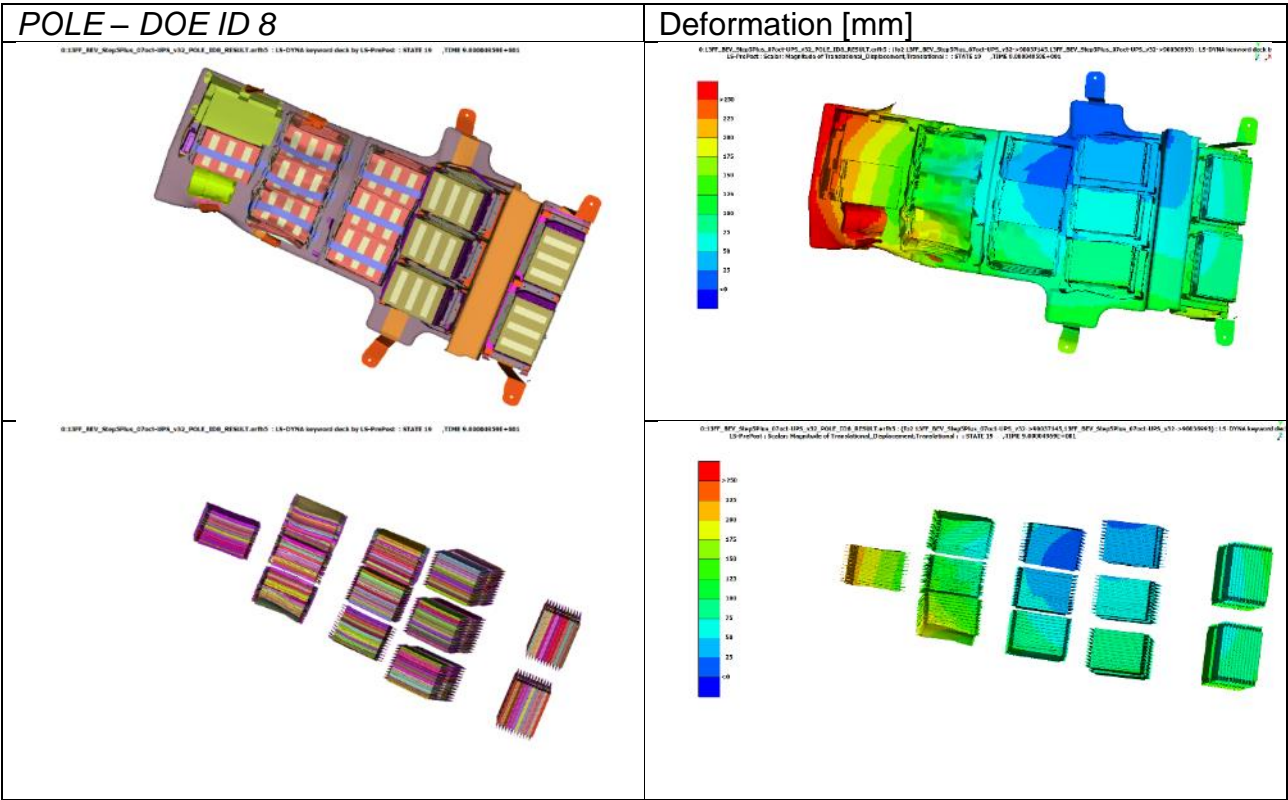


Table 14: Pole impact DOE results - design 9

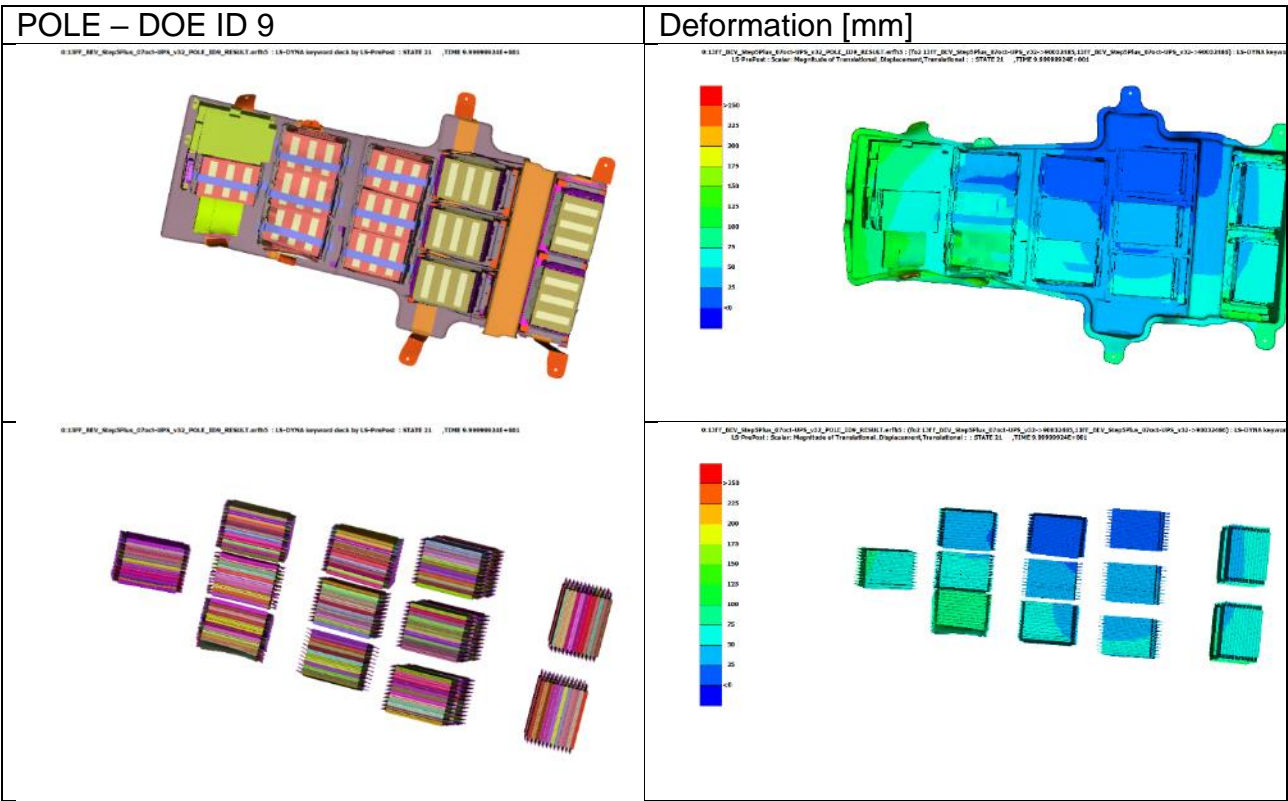


Table 15: Rear impact DOE results - design 0

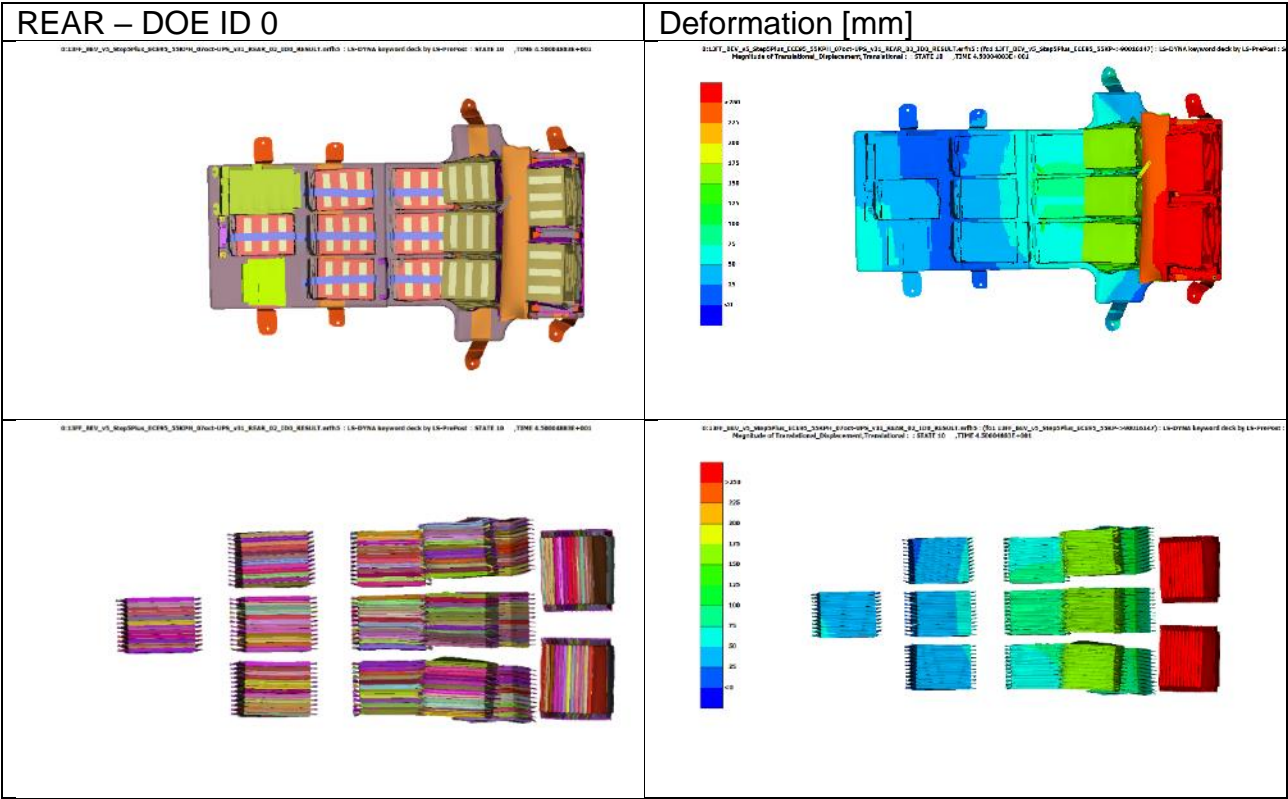


Table 16: Rear impact DOE results - design 1

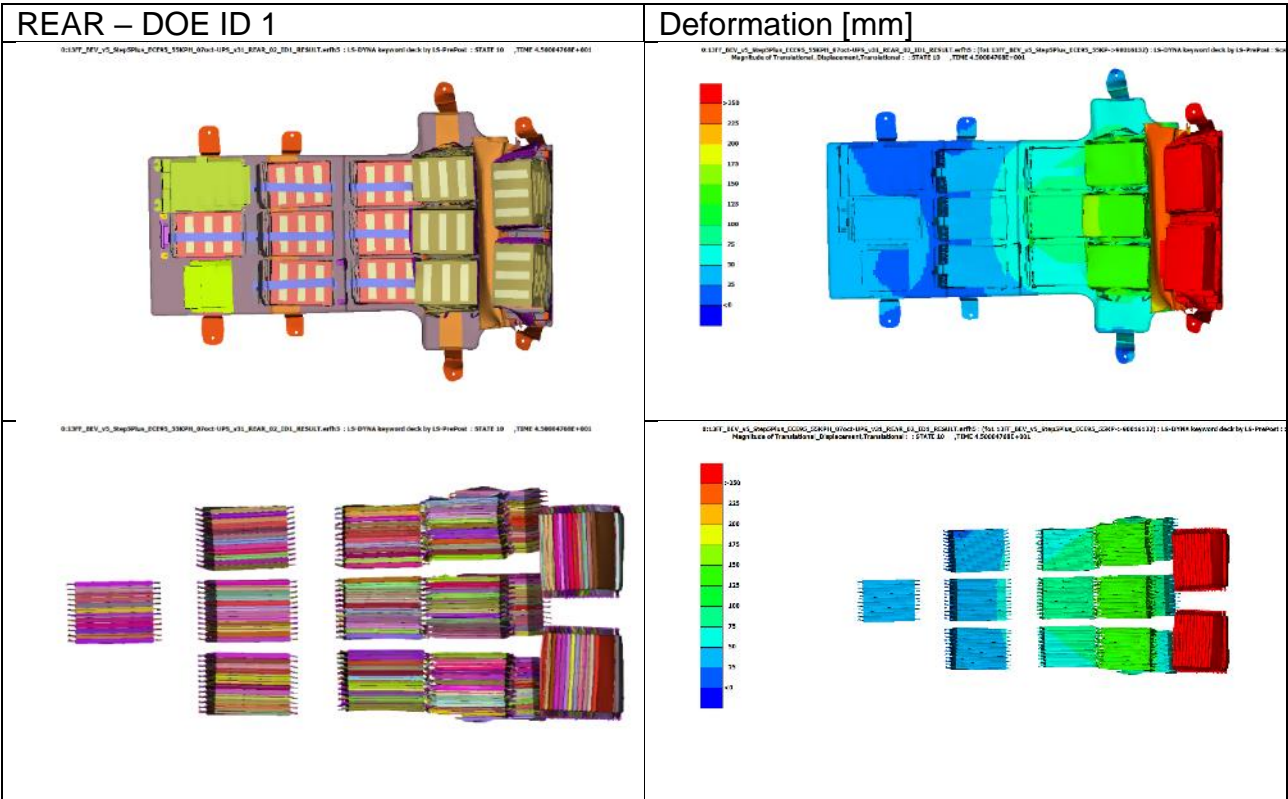


Table 17: Rear impact DOE results - design 2

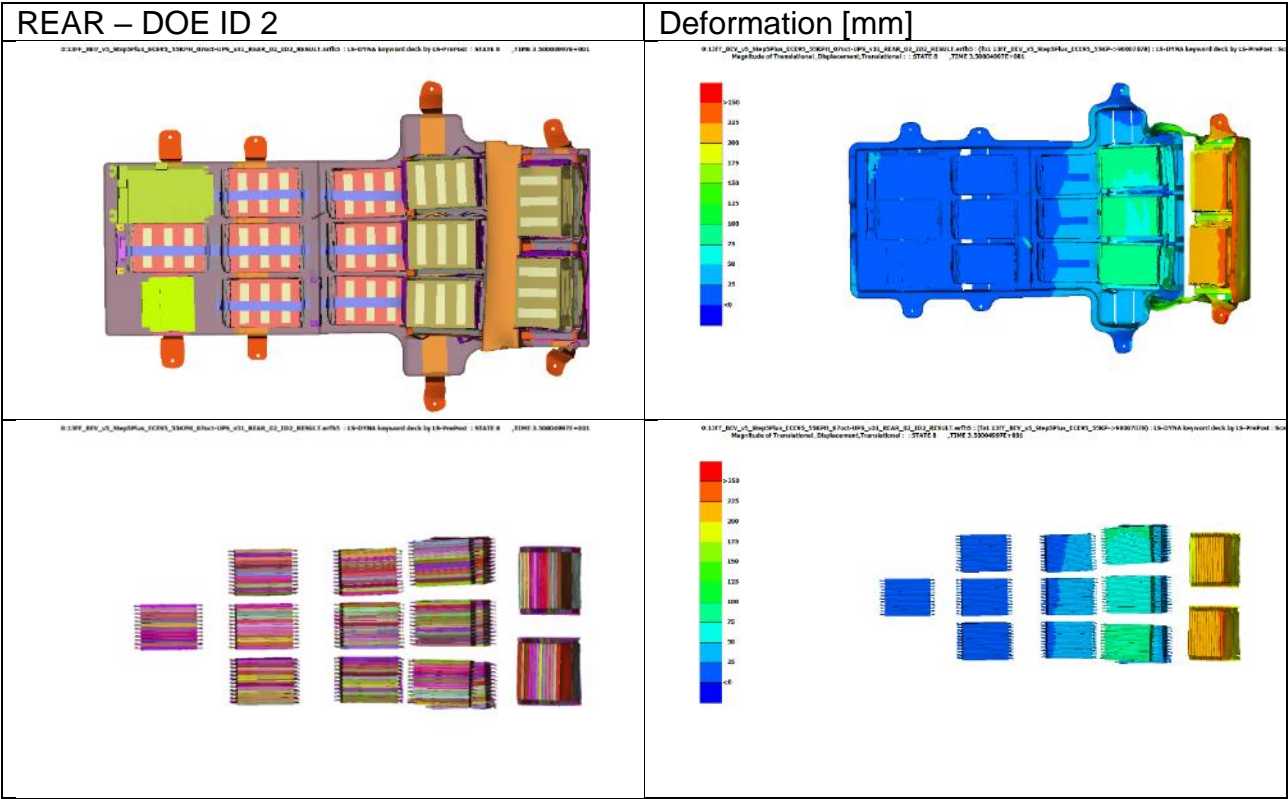
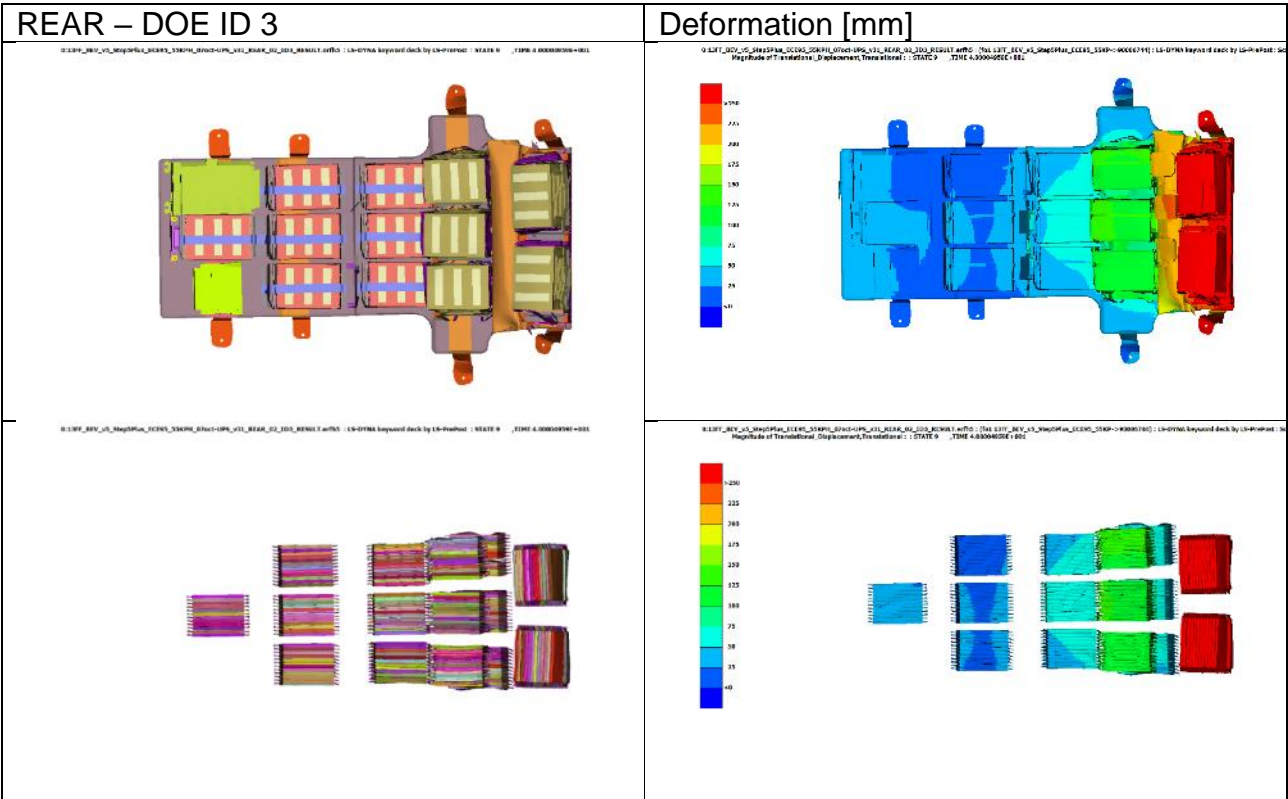


Table 18: Rear impact DOE results - design 3



D5.5 Requirements for setting up a ROM of a full vehicle model with parametrized boundary conditions

Table 19: Rear impact DOE results - design 4

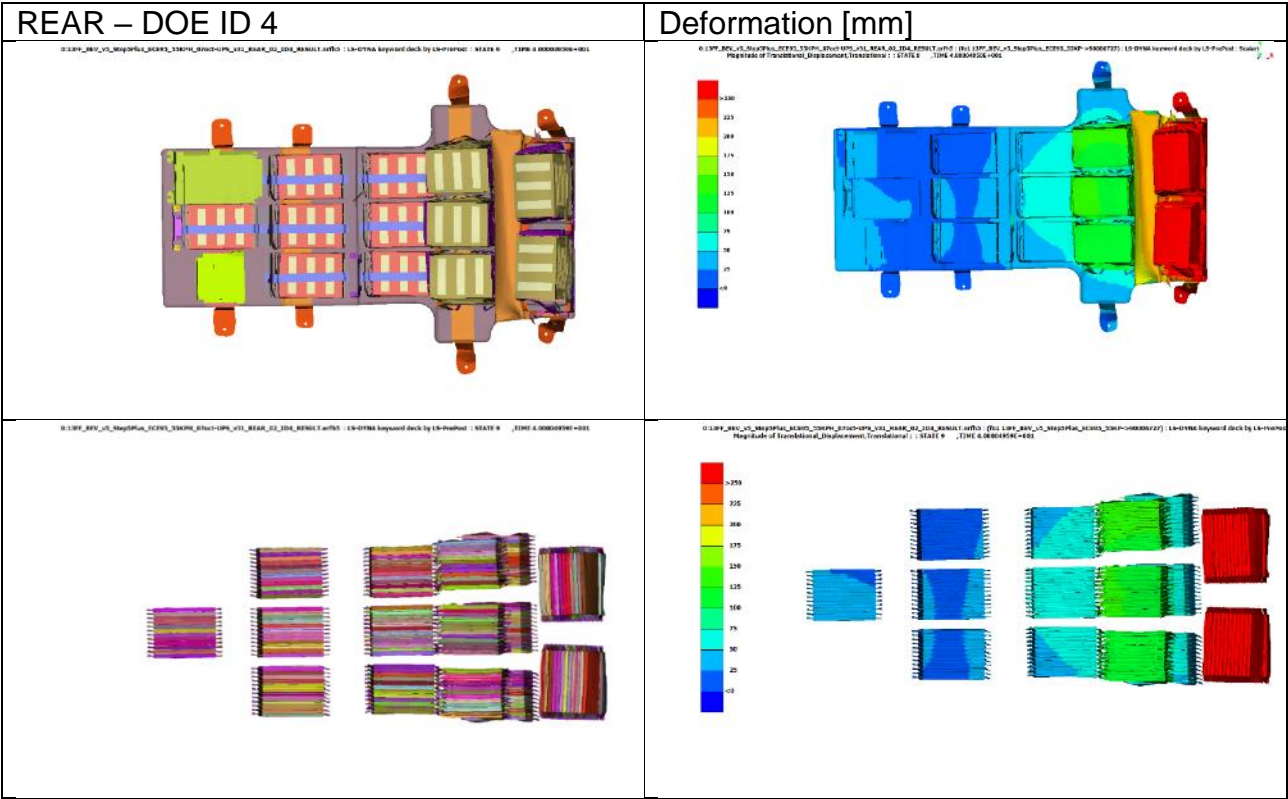


Table: Rear impact DOE results - design 5

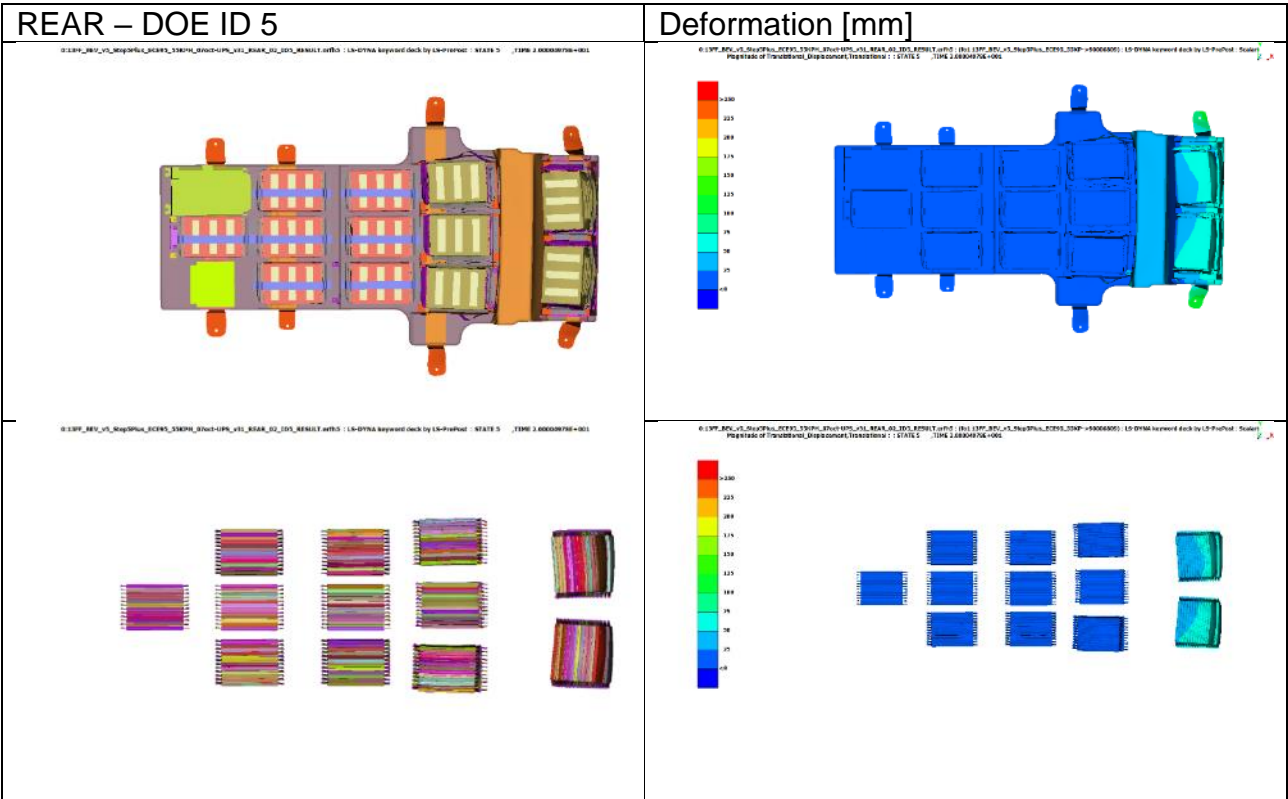


Table 20: Rear impact DOE results - design 6

[illegible]

Table 21: Rear impact DOE results - design 7

[illegible]

Table: Rear impact DOE results - design 8

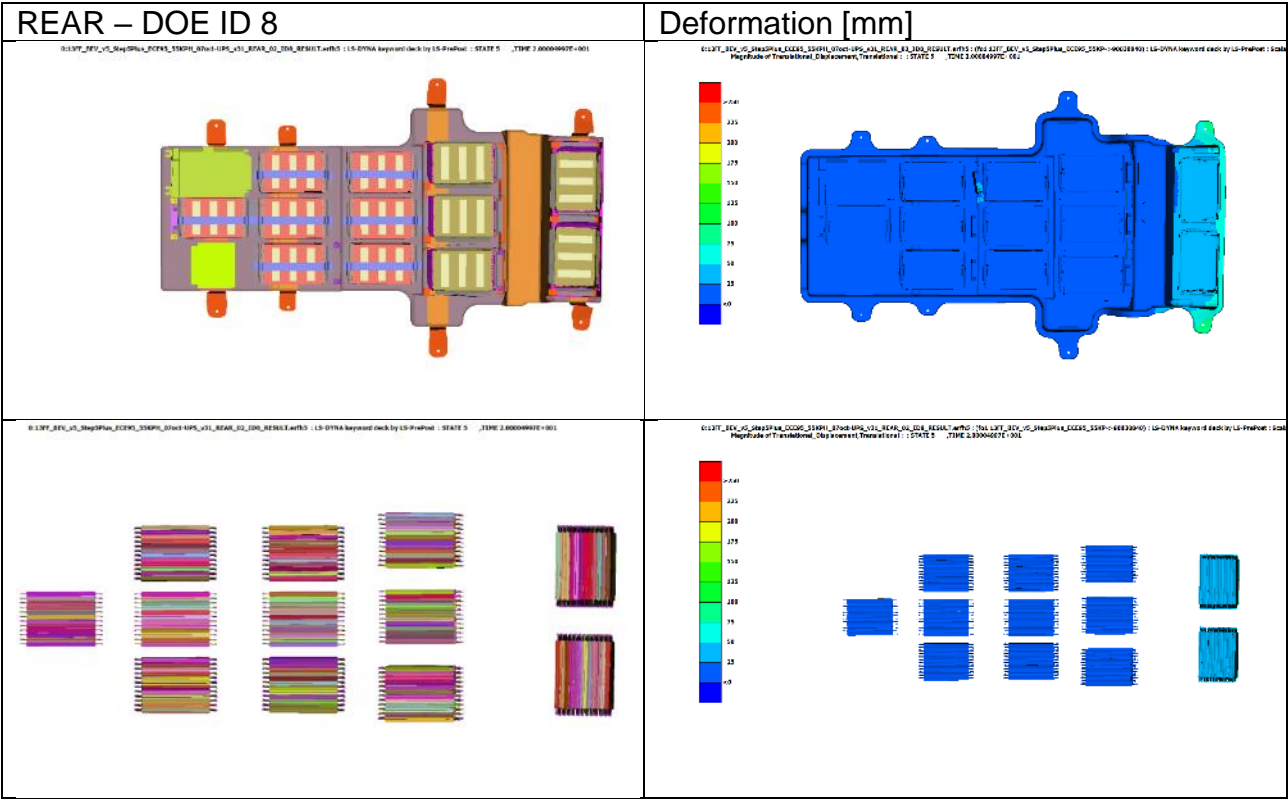
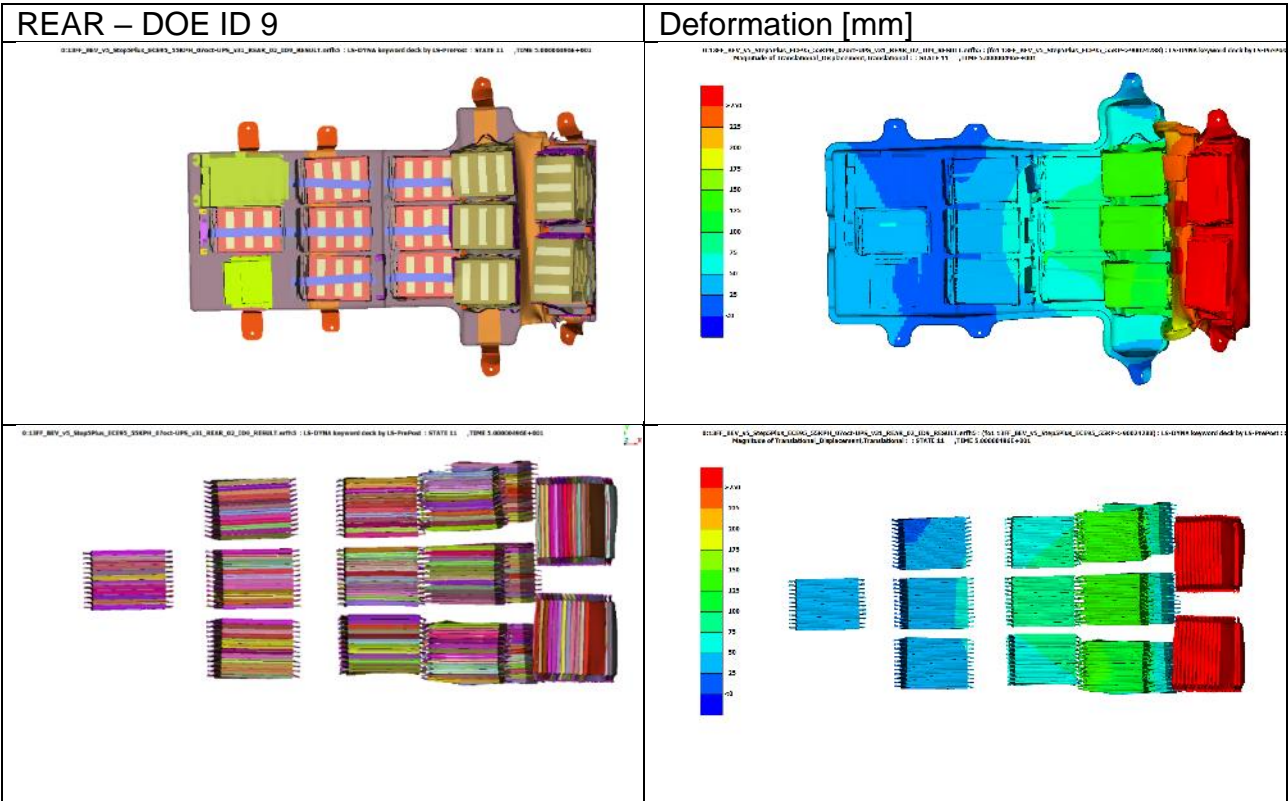


Table 22: Rear impact DOE results - design 9



3.1.4 Cell results generated from full vehicle analysis

The simulation results of the DOE computations on the full vehicle model with the macro-scale model of the cell were calculated. From the CATXP command in the solver a set of 204 cell result files were generated per DOE element.

By visual identification, the module deformation was analyzed and represented in Table 23 and Table 24. The orange cells in the table represent a failed module, numbered as reported in Figure 5, exhibiting a visible deformation of at least one of the twelve cells in the module.

Table 23: Pole impact DOE results deformed modules with ID 0 to 17

						MODULE ID																	
	ID	RUN END TIME 100	dSPEED	POLE HEIGHT	POLE dX POS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
POLE	DOE ID 0	100	6	100	-150																		
	DOE ID 1	100	2	100	-50																		
	DOE ID 2	100	5	100	-350																		
	DOE ID 3	100	2	100	-250																		
	DOE ID 4	100	4	60	-300																		
	DOE ID 5	51.1	7	60	-50																		
	DOE ID 6	100	3	60	-200																		
	DOE ID 7	100	6	60	-150																		
	DOE ID 8	94.9	7	100	-450																		
	DOE ID 9	100	3	60	-450																		

Table 24: Rear impact DOE results deformed modules with ID 0 to 17

						MODULE ID																	
	ID	RUN END TIME 80	WALL WIDTH	EXTRA MASS	EXTRA SPEED	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
REAR	DOE ID 0	47.7	3000	400	8																		
	DOE ID 1	46.4	1100	400	10																		
	DOE ID 2	39.6	3000	400	6																		
	DOE ID 3	41.8	1100	400	7																		
	DOE ID 4	44.5	1100	0	7																		
	DOE ID 5	22	3000	0	10																		
	DOE ID 6	48.4	1100	0	8																		
	DOE ID 7	33.63	3000	0	9																		
	DOE ID 8	23.7	3000	400	5																		
	DOE ID 9	51.4	1100	0	5																		

The complete DOE shows ~1400 deformed cell result files for the rear impact DOE and ~650 deformed cell result files for the pole impact DOE. To obtain such a large amount of cell deformation, it was necessary to increase in a sensitive way the amount of energy exchanged during the impact. The level of intrusion detected is not comparable to a side impact or a rear

impact scenario and the vehicle response is not realistic for those load scenarios that are usually reproduced virtually or in experimental crash tests.

On the other hand, this extreme loading condition permits to have some cell crash deformation results that are themselves extreme in the impact area. Nevertheless, at the same time, a large part of the cells behaviour in the surrounding modules is more limited, covering in this way different levels of deformation on the battery modules. The cell result files were shared and uploaded to the ESI data server in order to create the corresponding ROM.

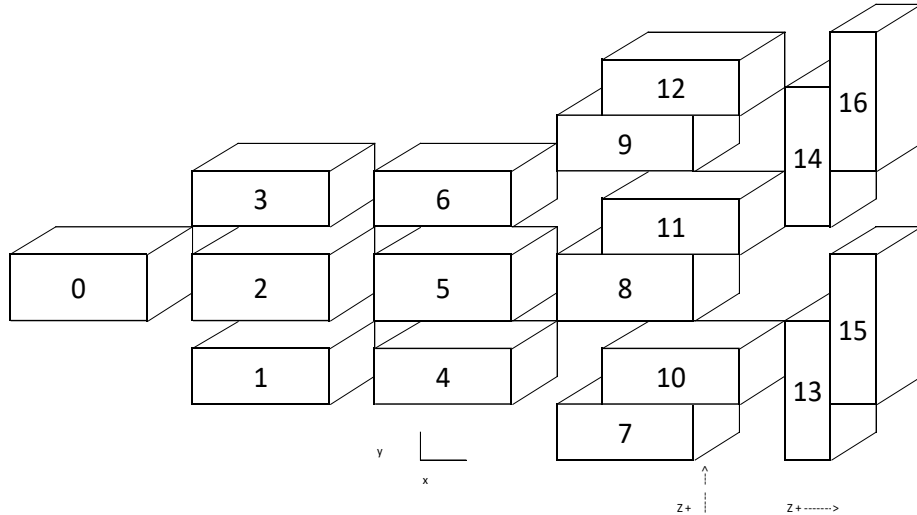


Figure 5: Module layout coding for battery pack positioning.

4 Model Order Reduction

In this chapter, the methodology for finding a ROM of the parametric full vehicle simulations is explained in detail.

4.1 Model Parametrization

In this study, we build a parametric solution of cell one of module one (see, Figure 5) for the pole impact scenario. Due to the location of this cell, in particular with respect to the parameter values in this full-vehicle crash study, this cell is one of the most deformed during the crash. In order to apply the sPGD technique to construct this parametric solution in respect of the three parameters: impact speed increment, pole height and pole X offset, we use the 9 ERFH5 files obtained via the CATGEN files generated by the high-fidelity models (Finite Element simulation results). In Figure 6, we can see the norm of the final displacement for this cell for each of the simulations from Table 25.

Table 25: The configurations used for the sPGD parametric solution

Module 1, Cell 1	ID	dSPEED	POLE HEIGHT	POLE dX POSITION
POLE	DOE ID 0	6	100	-150
	DOE ID 1	2	100	-50
	DOE ID 2	5	100	-350
	DOE ID 3	2	100	-250
	DOE ID 4	4	60	-300
	DOE ID 6	3	60	-200
	DOE ID 7	6	60	-150
	DOE ID 8	7	100	-450
	DOE ID 9	3	60	-450

D5.5 Requirements for setting up a ROM of a full vehicle model with parametrized boundary conditions

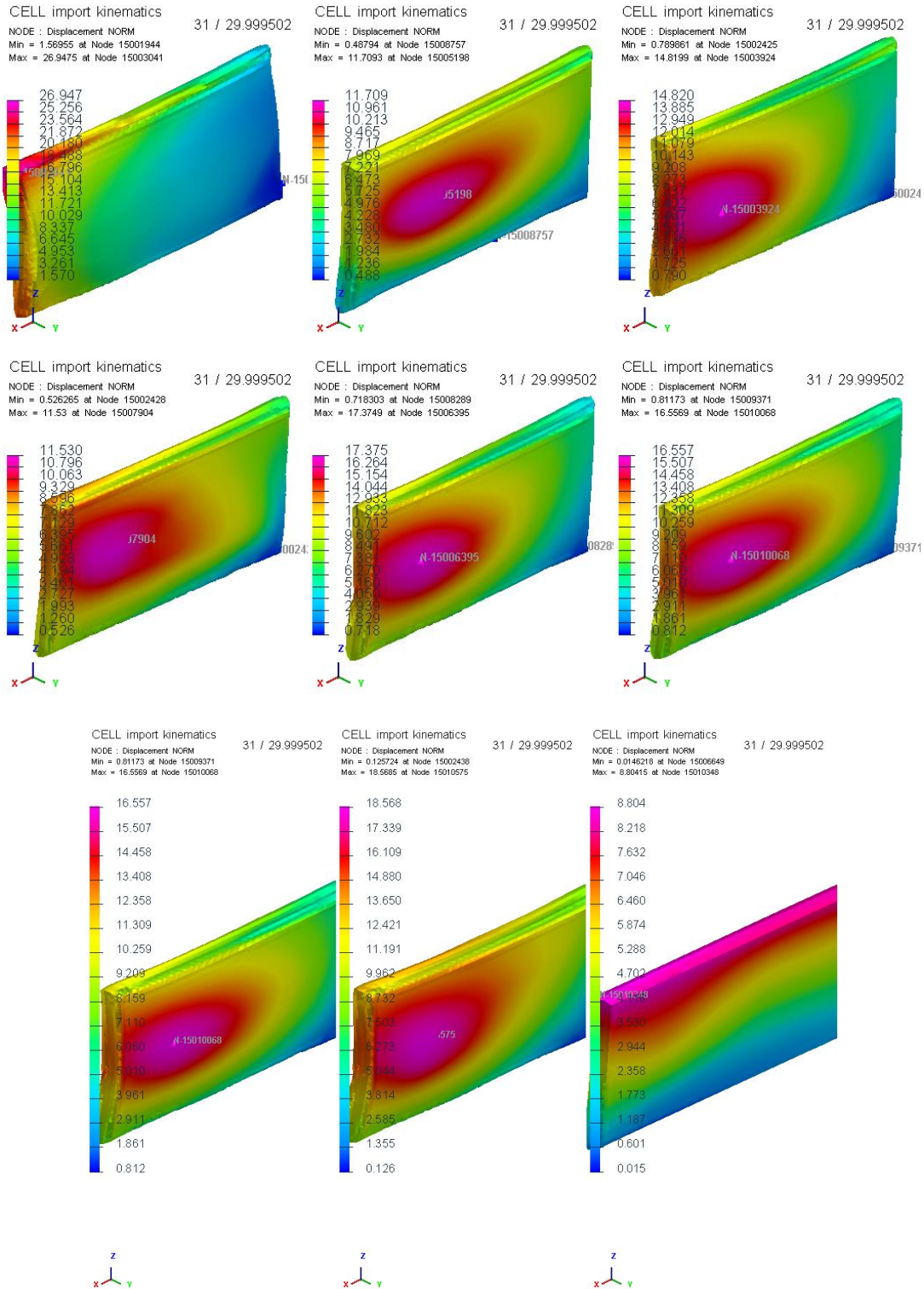


Figure 6: From top to bottom and left to right, the 9 simulations used to generate the sPGD parametric solution given in Table 25

4.2 Applied Model Reduction Technique

Using the sPGD (see section 2.2), we obtain a parametric solution for this cell, for which we can use the sliders in the ESI-Player 3.5 visualization software to observe the response of the displacement in the three directions as a function of the three parameters. Figure 7 shows the x-, y- and z-displacements for a configuration of the three parameters (impact speed increment= 6.5, pole height= 100% and pole X offset = 200) that was not contained in the original DoE.

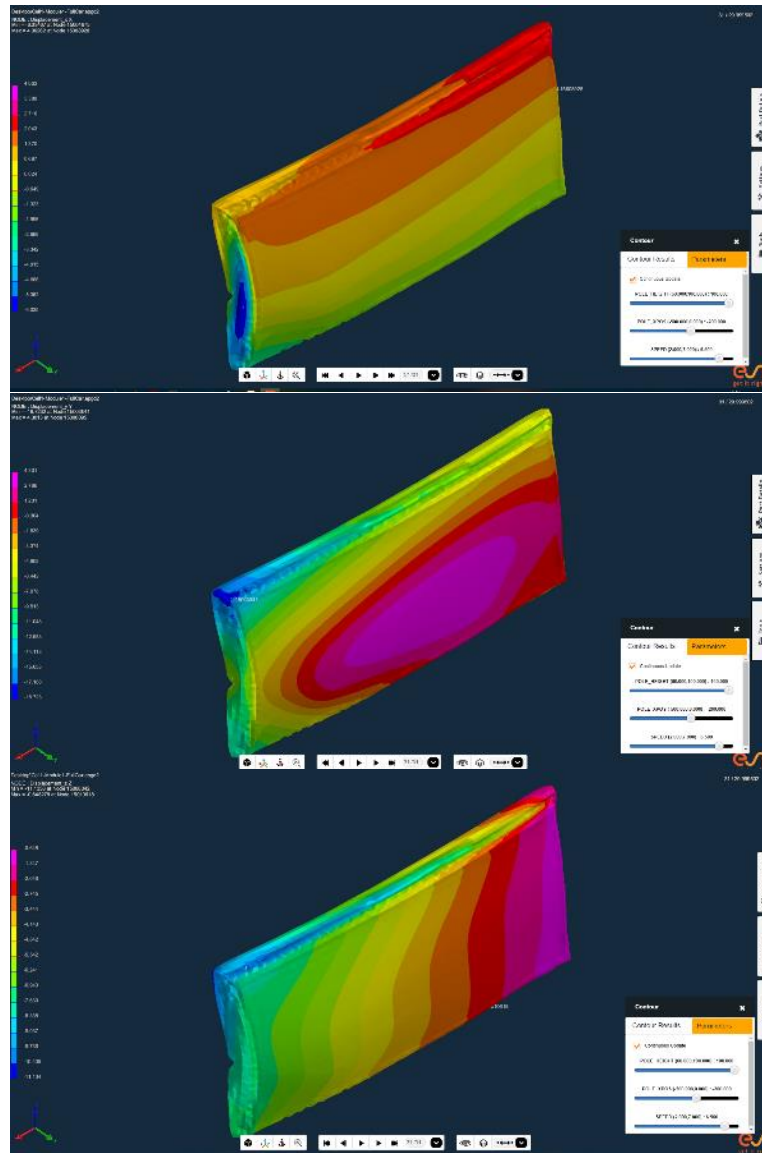


Figure 7: The predicted solution of the x (top), y (middle) and z (bottom) displacements corresponding to: impact speed increment= 6.5, pole height= 100% and pole X offset = 200.

A similar methodology can be applied for other cells of interest for rear or pole impact simulations and for other output variables.

4.3 Use of kinematic ROM

The sPGD is one of a number of model order reduction methods available in the ADMORE application on the ESI VDSS cloud platform. Within the application, a DoE is constructed by choosing the minimum and maximum values for each parameter. When using the sPGD method, as well as using the DoE recommended by the application, it is also possible to load a custom pre-existing DoE. This allows the user to use, for example, any pre-existing simulation results that they may have. Once the simulations of the DoE have been completed, the user uploads the ERFH5 results files to the application and chooses the field(s) to be reduced (displacement, thickness etc.), as shown in Figure 8.

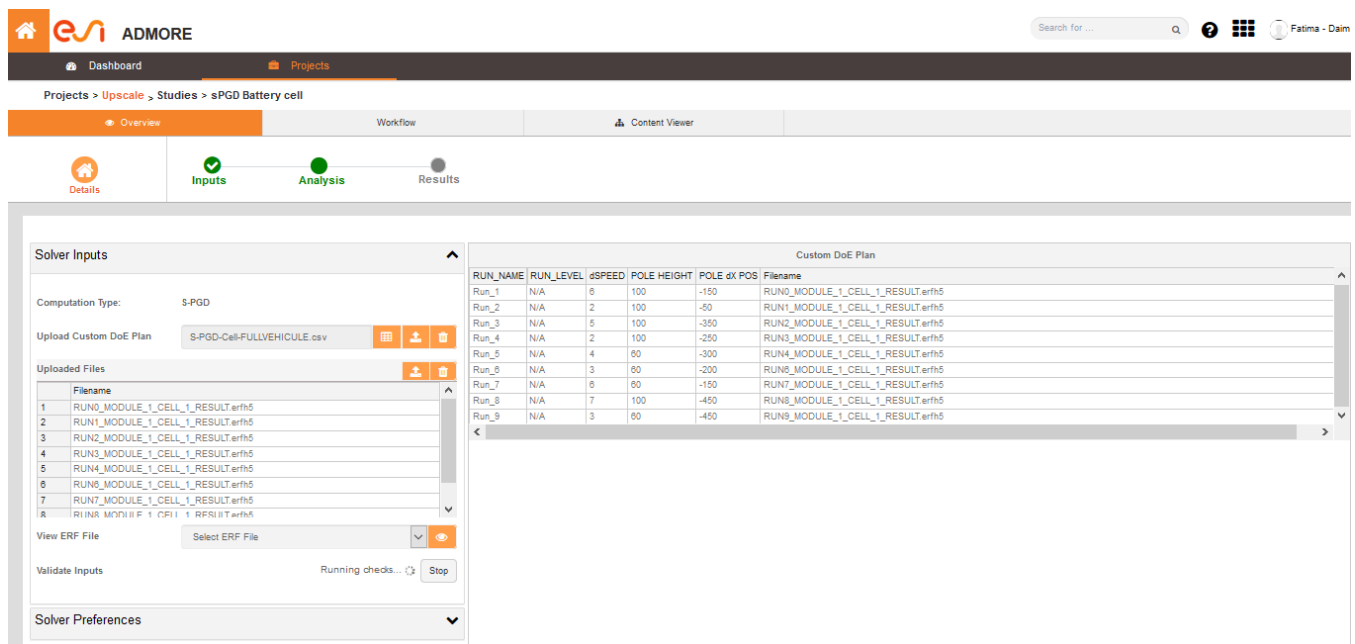


Figure 8: Screenshot of Admore application for the current study on ESI Cloud (VDSS) <https://vdss.esi-group.com/VisualDSS/web/guest/welcome>

4.3.1 Generation of submodelling file

The generated parametric file can be exported from the web application and converted to a particularized CATGEN load submodelling file in ESI Visual-Environment software. The explanation of the workflow is based on the cell spherical indentation parametric solution, see D5.1 or D3.2, which was created to show the methodology among the other UPSCALE partners. Application to different load cases is made in the same way to any cell parametric solution. The full workflow and various formats for kinematic ROM generation are presented in Figure 9.

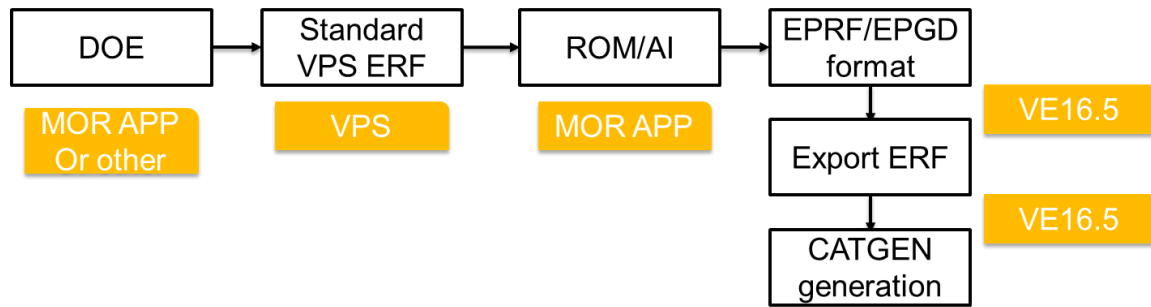


Figure 9: Various file formats and solvers used to generate kinematic ROM on cell and battery pack envelope

The epgd2 file format is used for storing the parametric solutions obtained from applying the sPGD. This file format is supported for visualization purposes by Visual-Environment Viewer 16.5 upwards. The visualization of the parametric solution in Visual-Environment Viewer is shown in Figure 10.

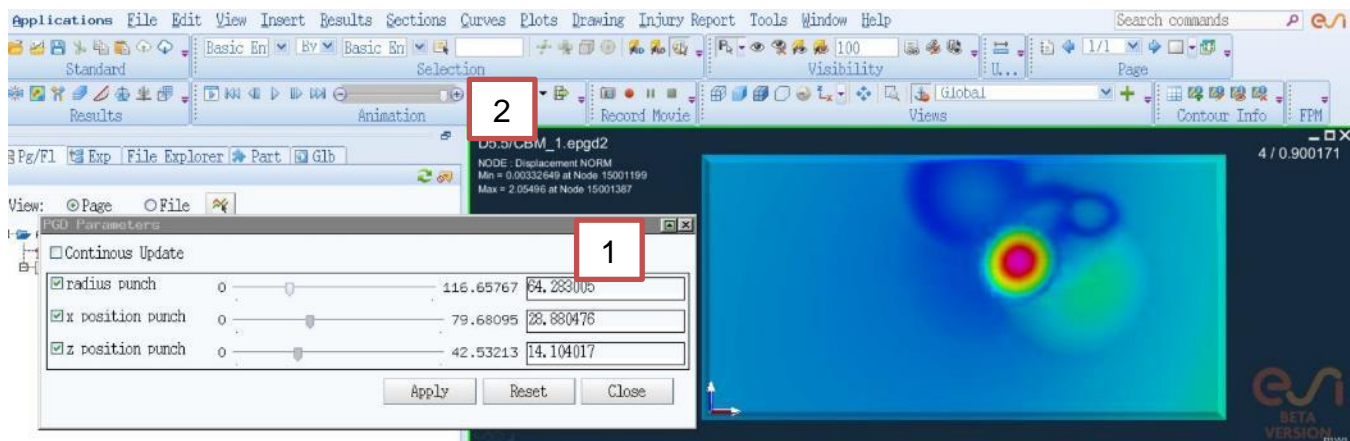


Figure 10: Visualization of parametric solution in Visual-Environment 16.5 beta version

The “PGD parameters” interface and sliders (window number 1 in Figure 10) enable the user to particularize the solution with respect to the DoE parameters. In particular, the parametric solution can be used to produce a prediction for sets of parameters which were not contained in the original DoE (see section 4.2). The animation control (menu marked 2 in Figure 10) enables the user to choose the times to be exported. Once the user is satisfied with the choice of parameter values and time state, a particularized result can be exported in the ESI standard result file format (ERFH5).

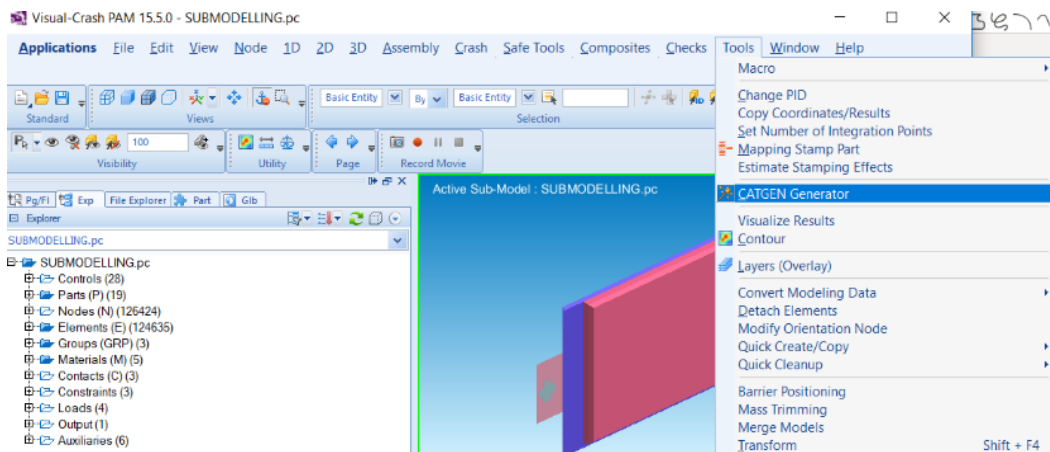
D5.5 Requirements for setting up a ROM of a full vehicle model with parametrized boundary conditions



Figure 11: Export of particularized result (ERF) in Visual-Environment 16.5 beta version

In order to generate a CATGEN load submodelling file from this result file, an additional step is necessary. In Visual-Environment Crash, open the cell envelope mesh and select *Tools>CATGEN* generator, Figure 12(a). In *Source Data*, select the result file just generated, Figure 12(b). Clicking *Export CATGEN* file will generate a submodelling file than can then be used for loading boundary conditions.

(a)



(b)

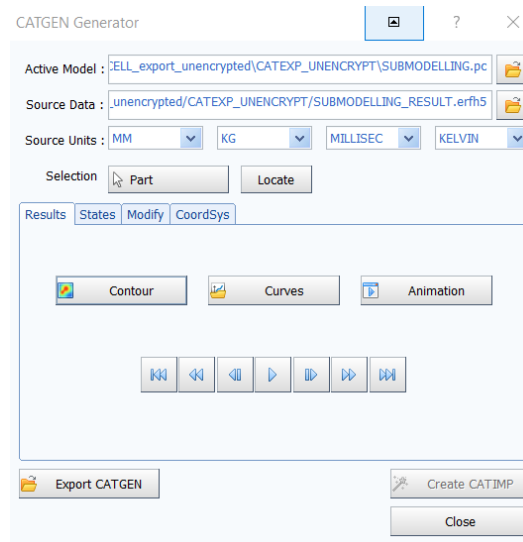


Figure 12: (a) Export of load submodelling file (CATGEN) and (b) CATGEN export interface options in Visual-Environment

The resulting CATGEN ERF contains the envelope kinematics from the particularized solution that can be applied as a load to a cell, subsystem or other. An example of ROM kinematics application on a macro scale cell model is represented in Figure 13, with visualization of the resulting plastic strain state in the cell.

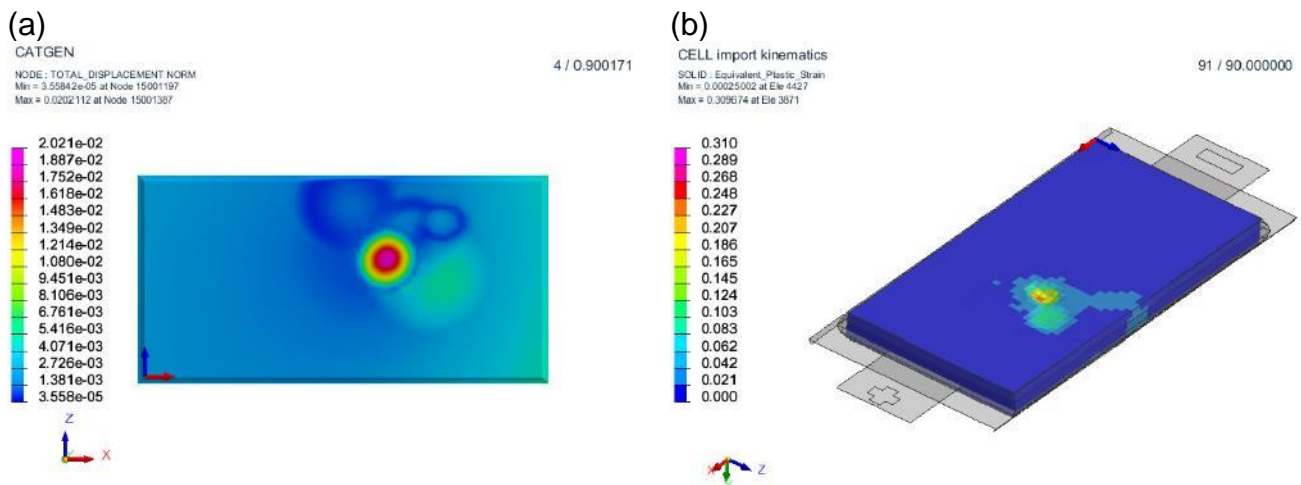


Figure 13: (a) Visualization of ROM based load submodelling file (CATGEN) in Visual-Environment and (b) Resulting plastic strain state when the ROM based kinematics is applied to the cell macro model

5 Possible risks and elaboration on the risks

The examples shown above both exhibit 3 additional load case parameters. An increased number of additional parameters will lead to larger DoEs to be performed before the training phase. Therefore the time effort for the creation of the ROM is increasing linearly and could result in an effort, that is too high for the purposes of the engineer. Possible limitations concerning the amount of parameters and the time effort for the training phase of the ROM will be investigated in the further course of the project. If the number of parameters cannot be restricted a possible strategy to overcome this issue could be to create several ROMs using only parts of the parameter set each but having each parameter in at least one of the ROMs.

Furthermore, the file size could reach a critical value, such that a post-processing is no longer possible. Here, the user needs to carefully choose the amount of parts of interest and number of input parameters and output variables. Decrease in the number of time steps stored in the result files is also a possible way to overcome this problem.

6 Conclusion

The sPGD technology serves as a powerful tool to overcome the problem of post-processing too many simulation results. Optimization problems can be defined after creation of the ROM without the need for a specific cost function. Even visual optimization is possible. It also allows creating new simulation results in real-time. This fact, can become important in further project phases, if the amount of necessary training data needs to be increased.

7 References

- CATARC. „United Nations Economic Commission for Europe (UNECE).“ *Status of EV Standards in China*. 2012. <https://www.unece.org/fileadmin/DAM/trans/doc/2012/wp29grsp/EVS-1-08.pdf> (Zugriff am 27. 10 2020).
- D. Borzacchiello, J.V. Aquado, F. Chinesta. „Non-intrusive sparse subspace learning for parametrized problems.“ *Archives of Computational Methods in Engineering*, 26 2019: 303-326.
- D.H. Doughty, A.a. Pesaran. „National Renewable Energy Laboratory.“ *Vehicle battery safety roadmap guidance*. 2012. <https://www.nrel.gov/docs/fy13osti/54404.pdf> (Zugriff am 27. 10 2020).
- R. Ibanez, E. Abisset-Chavanne, A. Ammar, D. Gonzalez, E. Cueto, A. Huerta, J.L. Duval, F. Chinesta. „A multi-dimensional data-driven sparse identification technique: the sparse Proper Generalized Decomposition.“ *Complexity*, 2018: ID 5608286.

8 Figures

Figure 1: External module protection	9
Figure 2: Internal cell holding structure	9
Figure 3: Cell shaped holding and distancing structure copying the cell shape	10

Figure 4: Deformation reference points for the Pole impact and Rear impact load cases.....	12
Figure 5: Module layout coding for battery pack positioning.	24
Figure 6: From top to bottom and left to right, the 9 simulations used to generate the sPGD parametric solution given in Table 25.....	26
Figure 7: The predicted solution of the x (top), y (middle) and z (bottom) displacements corresponding to: impact speed increment= 6.5, pole height= 100% and pole X offset = 200.	27
Figure 8: Screenshot of Admore application for the current study on ESI Cloud (VDSS) https://vdss.esi-group.com/VisualDSS/web/guest/welcome	28
Figure 9: Various file formats and solvers used to generate kinematic ROM on cell and battery pack envelope	29
Figure 10: Visualization of parametric solution in Visual-Environment 16.5 beta version.....	29
Figure 11: Export of particularized result (ERF) in Visual-Environment 16.5 beta version	30
Figure 12: (a) Export of load submodelling file (CATGEN) and (b) CATGEN export interface options in Visual-Environment.....	31
Figure 13: (a) Visualization of ROM based load submodelling file (CATGEN) in Visual-Environment and (b) Resulting plastic strain state when the ROM based kinematics is applied to the cell macro model	31

9 Tables

Table 1: Full vehicle model information.....	10
Table 2: Overview of parameters and corresponding ranges.....	11
Table 3: Pole impact DOE parametrization	11
Table 4: Rear impact DOE parametrization	12
Table 5: Pole impact DOE results - design 0	12
Table 6: Pole impact DOE results - design 1	13
Table 7: Pole impact DOE results - design 2	13
Table 8: Pole impact DOE results - design 3	14
Table 9: Pole impact DOE results - design 4	15
Table 10: Pole impact DOE results - design 5.....	15
Table 11: Pole impact DOE results - design 6.....	16
Table 12: Pole impact DOE results - design 7.....	16
Table 13: Pole impact DOE results - design 8.....	17
Table 14: Pole impact DOE results - design 9.....	17
Table 15: Rear impact DOE results - design 0	18
Table 16: Rear impact DOE results - design 1	18
Table 17: Rear impact DOE results - design 2	19
Table 18: Rear impact DOE results - design 3	19
Table 19: Rear impact DOE results - design 4	20
Table 20: Rear impact DOE results - design 6.....	21
Table 21: Rear impact DOE results - design 7	21
Table 22: Rear impact DOE results - design 9	22
Table 23: Pole impact DOE results deformed modules with ID 0 to 17	23
Table 24: Rear impact DOE results deformed modules with ID 0 to 17	23
Table 25: The configurations used for the sPGD parametric solution	24

10 Acknowledgement

The authors want to thank all project partners of the UPSCALE project for their inputs and the positive and constructive working atmosphere in the project.