# NAFEMS World Congress 2025 - Shortening Airbag Model Validation Time using Reduced Order Modelling

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**Abstract**

Reduced Order Modelling (ROM) can be used to improve the accuracy of CAE models while shortening numerical parameter calibration. An industrial example for airbag deployment case illustrates the value of AI/ROM technology applied to CAE. Today extensive and time-consuming iterations are needed for the calibration of airbag model parameters such as outflow discharge coefficient, inflator heat loss, which may not be measured precisely by tests. This impacts validation quality and delivery time of airbag models for the synthesis car crash simulations. The choice of relevant airbag model parameter exploration range for validation is based on experience and trial & error approach. It is limited by the computational cost of high-fidelity CFD coupled Finite Element simulation runs. ROM based methodology reduces the airbag validation time by testing thousands of parameter combinations in a time frame of days instead of weeks. Therefore, model quality can be improved as more combinations can be tested using Reduced Order Modelling than within Finite Elements standard approach. The capability of ROM to achieve this target is shown on an industrial airbag calibration study. The available ROM methods using Proper Generalized Decomposition (PGD) are explained as well as the choice of DOE (Design Of Experiments), together with the number of Finite Element simulations required for training the Reduced Order Model. The ROM results are then compared to the Finite Element simulations, for parameters outside the training set, and a good match is demonstrated. This shows that the parametric ROM model can be used for the calibration study. A series of linear impactor experimental tests has been conducted, by changing the airbag vent size, impactor mass and velocity. Time history curves of impactor acceleration, displacement and airbag pressure obtained by the ROM model are compared to the experimental results for each

set of parameters using ISO Score (CORA) ratings. The process for finding the best parameters sets among the more than 1000 combinations is fully automated and takes less than one hour. A final validation using a standard Finite Element simulation with the updated parameters is conducted and the results are compared and rated with each experimental test, including the above-mentioned time history curves and the airbag deployment kinematics.

## 1. Introduction to the ADMORE PGD Reduced Order Model

Proper Generalized Decomposition (PGD) belongs to a family of Model Order Reduction (MOR) techniques that allow to generate parametric solutions of a given problem. A parametric solution is a separated representation able to provide the response of a system to any combination of parameter values within a parametric space of interest in a very fast time. Thus, the computational time required to compute the solution through high fidelity classical solver for any new set of parameter values is saved, enabling an almost real-time response of the system. This reactivity is the key feature of parametric solutions, allowing real-time usage of complex physical systems in many different contexts such as parametric space exploration, design, optimization, inverse approaches, Hybrid-Twin building.

The generation and usage of a parametric solution through PGD in AdMore follows a two-phase workflow. A first time-consuming phase, also called the “offline” phase, where the user generates the training data and the corresponding parametric solution, and the usage of this solution in a real-time fashion in the above-mentioned context, being called “online” phase.

The offline phase begins by defining the parametric space of interest (parameters and their ranges). The user then specifies a list of parameters combinations, or Design of Experiment (DOE) depending on the choice of the PGD method, each of the training set of the DOE shall be simulated with high-fidelity physical solvers.

The parametric solution is computed using related interpolative functions from the training data. The result is a parametric result file with the capability to display in real time kinematics, contours and time history curves.

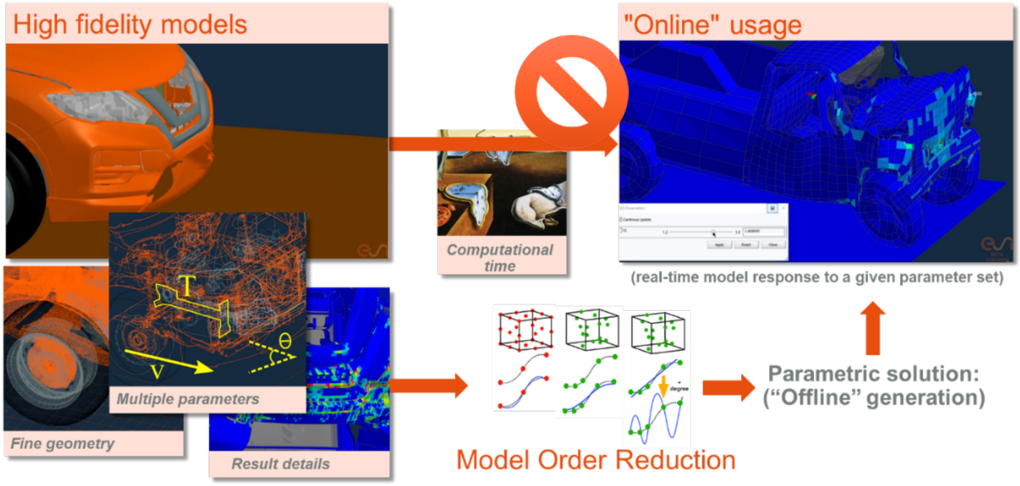


*Figure 1: Workflow for Reduced Order Modelling.*

The surrogate model allows users to interact with it using sliders to tune parameters in an interactive mode or to extract curves and values in a batch mode. The same contours and curves as those in high-fidelity Finite Element simulation results are available for postprocessing.

This method does not require any modification in the high-fidelity physical solvers and is theoretically applicable to any physical result, based on the resulting interpolated result acceptance. This makes PGD methods highly generic post process techniques, thus able to power a wide range of applications in many domains.

The SSL-PGD (Sparse Subspace Learning based Proper Generalized Decomposition) method was used for this study. SSL-PGD requires that the DOE (Design of Experiments) covers at least the minimum and maximum values for each parameter within the DOE range. The parametric model precisely matches the training results at the training points, with interpolation between these points. This model is well-suited for a low number of parameters. For example, with 3 parameters, a total of 8 training runs is required at SSL-PGD Level 0, 20 runs when using SSL-PGD Level 1, and with 4 parameters, 16 training runs are needed for SSL-PGD Level 0.

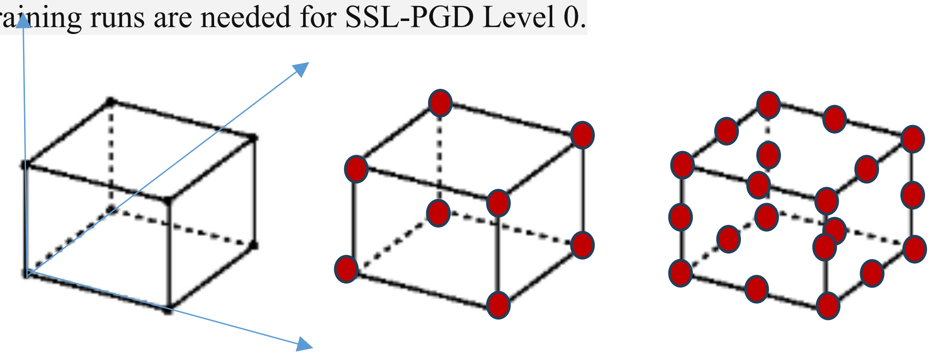

*Figure 2: a) DOE for 3 parameters b) training set for SSL PGD Level 0 c) for Level 1.*

## 2. Requirements for airbag model validation

Synthesis car crash models include multiple airbags to be validated vs. experiments individually before being integrated in the global vehicle model.

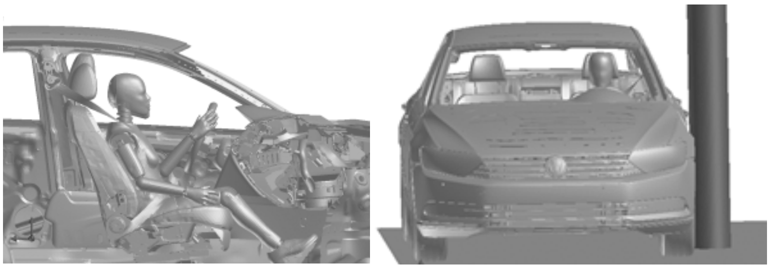

*Figure 3: a) Frontal car crash simulation with 3 airbags b) pole impact simulation with side and curtain airbags (Courtesy VW)*

The validation of individual airbags is firstly based on linear or pendulum impactor testing to quantify their dynamic restraint capability. This series of experimental tests may include in the case of a passenger airbag, an impactor plate, an instrument panel, and a windshield. The objective is to standardize airbag testing and data analysis.

Three different airbags from Yanfeng and Joyson (passenger and side airbags) were used for the validation project. This paper provides a detailed description of the two passenger airbag cases.

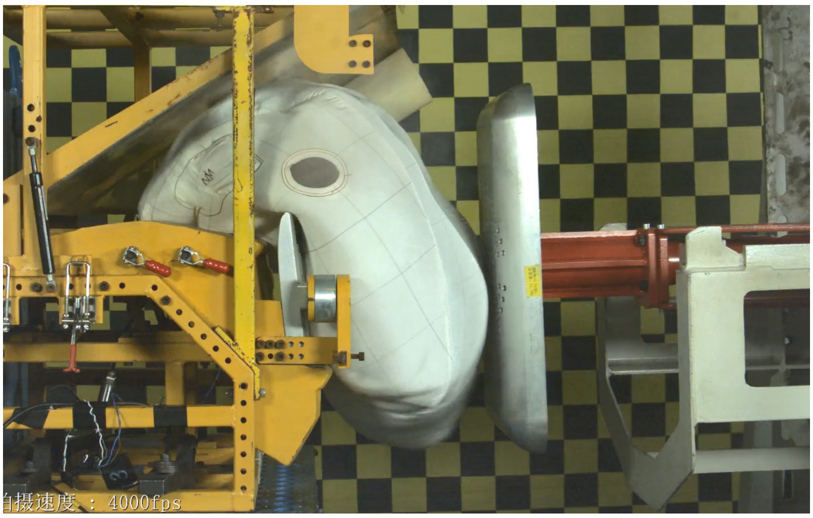


*Figure 4: passenger airbag linear impactor experimental test (courtesy Yanfeng)*

The tests can assess variability in airbag modules, optimize inflator and cushion designs, evaluate new venting technologies, and calibrate CAE models. Additionally, it can investigate out-of-position performance. Several tests are conducted to assess the accuracy of the CAE models across different scenarios.

These tests involve varying the airbag firing time, the impactor weight, the airbag trigger distance at Time-To-Fire (TTF), and the impactor velocity. Additionally, vent sizes are adjusted from a completely closed configuration to various other sizes.

**Table 1: Yanfeng PAB experimental test conditions.**

| | | | | |
|---|---|---|---|---|
| Test 1 | M1 (heavy) | V1 | d1 (medium) | Closed |
| Test 2 | M2 (medium) | V2 | d2 (close) | big |
| Test 3 | M2 | V2 | d2 | medium |
| Test 4 | M2 | V3 | d3 (far) | big |
| Test 5 | M2 | V3 | d3 | big |
| Test 6 | M2 | V3 | d3 | big |

Similar testing procedures were used for the Joyson pendulum passenger airbag test.

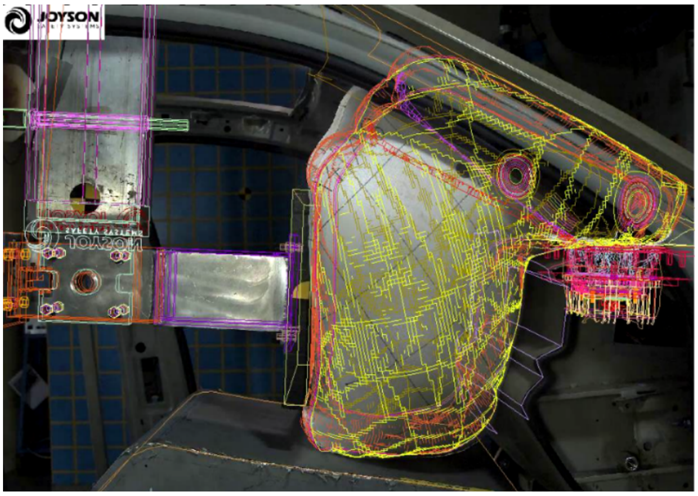


*Figure 5: passenger airbag pendulum test (courtesy Joyson)*

6 tests were conducted: 4 with Femur-Dummy plate, 2 without the plate, as shown in the figure below.

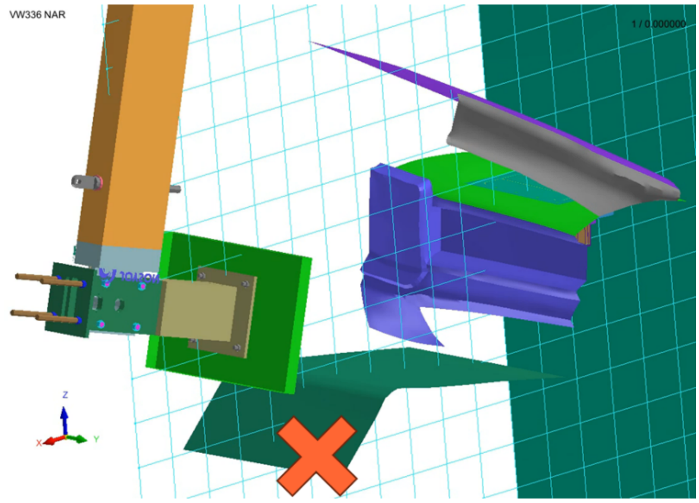


*Figure 6: passenger airbag pendulum model with and without Femur-Dummy Plate (courtesy Joyson)*

**Table 2: Joyson PAB experimental test conditions. Tests 5 and 6 without femur dummy plate.**

| | | | |
|---|---|---|---|
| Test 1 | M1 (heavy) | V1 (large) | standard |
| Test 2 | M2 (medium) | V2 (medium) | standard |
| Test 3 | M2 | V1 | standard |
| Test 4 | M2 | V2 | Active vent |
| Test 5 (*) | M2 | V2 | standard |
| Test 6 (*) | M2 | V1 | standard |

Most model parameters can be measured through experimental testing, such as the airbag sheet material properties. However, some parameters are not precisely provided by measurement data for various reasons, such as heat loss of the inflator gas interacting with the airbag module, leakage through seams, and vent discharge coefficients. These parameters must be calibrated using linear or pendulum impact test data.

The calibration and validation of airbag CAE models is a critical yet time-consuming and costly process. It often requires several weeks and numerous high fidelity Finite Element simulations, sometimes reaching a three-digit number. The goal of this project is to demonstrate how the Reduced Order Modelling (ROM) method can significantly reduce the time invested in airbag validation.

## 3. Description of the workflow using Reduced Order Modelling

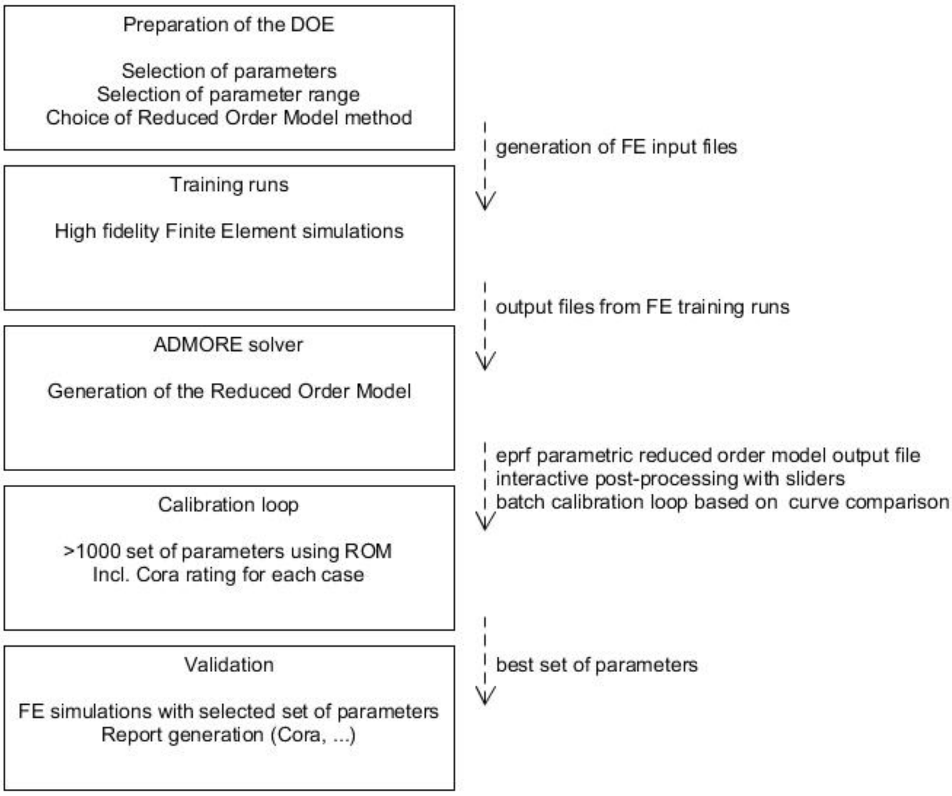


*Figure 7: Description of the calibration workflow using Reduced Order Modelling*

The steps introduced in Figure 7: are automated in batch mode once the parameters are selected:

- **Parameter Selection**: application specific. In Virtual Performance Solution (VPS), parameters are defined using Python variables. The user chooses the parameters and their value range.
- **DOE Generation**: the user selects the reduction method (e.g., SSL-PGD). The DOE is generated based on the number of parameters, the reduction method, and its level (see Figure 2: ).
- **Finite Element Input File Generation**: parameters are adjusted according to the DOE, and input files for training runs are automatically created in the appropriate format and folders.
- **High Fidelity Simulations**: performed for each training case.
- **Reduced Order Model Generation**: a parametric model for kinematics, contours, and curves is created based on the training run outputs.

- **Calibration loop**: using the fast parametric Reduced Order Model, extract relevant curves for a wide range of parameters to determine the optimal configuration based on project requirements. For airbag calibration, test results are batch-compared with interpolated curves from the Reduced Order Model using the standard ISO Score (Cora rating). Parameters delivering the best scores are selected.
- **Validation runs**: using the optimal parameters, perform high fidelity Finite Element simulations and check the results using the standard ISO Score (Cora rating).

## 4. DOE generation for airbag calibration cases

The initial step involves selecting the relevant parameters and choosing their exploration range. In our cases, the following three parameters need to be calibrated for both passenger airbag models:

- **Vent discharge coefficient**, which adjusts the gas outflow through the airbag vent.
- **Inflator temperature scaling factor**, which accounts for gas heat loss.
- **Seam leakage discharge coefficient factor**.

The Design Of Experiments (DOE) for these parameters is shown in Table 3: for the Yanfeng Passenger Airbag case. SSL-PGD level 0 was used, which requires for 3 parameters 8 training runs (minimum and maximum value for each parameter), as shown in Figure 2:

**Table 3: Training runs for the Yanfeng Passenger Airbag case DOE.**

| | | | |
|---|---|---|---|
| Run 1 | 0.75 | 0.75 | 0.5 |
| Run 2 | 0.75 | 0.75 | 2.0 |
| Run 3 | 0.75 | 0.95 | 0.5 |
| Run 4 | 0.75 | 0.95 | 2.0 |
| Run 5 | 1.0 | 0.75 | 0.5 |
| Run 6 | 1.0 | 0.75 | 2.0 |
| Run 7 | 1.0 | 0.95 | 0.5 |
| Run 8 | 1.0 | 0.95 | 2.0 |

Six Reduced Order Models are constructed, each model corresponding to each specific experimental test described in Table 1: . As a result, a total of 48 training runs (6 models × 8 runs each) are required. Similar parameters were chosen for calibrating the Joyson Passenger Airbag pendulum cases. The simulation model must also be correlated with six experimental test results (test conditions described in 0), with the last two tests conducted without the Femur-Dummy plate as shown in Figure 6:

**Table 4: Training runs for the Joyson Passenger Airbag case DOE for each test.**

| | | | |
|---|---|---|---|
| Run 1 | 0.75 | 0.6 | 0.05 |
| Run 2 | 0.95 | 0.6 | 0.05 |
| Run 3 | 0.75 | 0.6 | 0.8 |
| Run 4 | 0.95 | 0.6 | 0.8 |
| Run 5 | 0.75 | 0.95 | 0.05 |
| Run 6 | 0.95 | 0.95 | 0.05 |
| Run 7 | 0.75 | 0.95 | 0.8 |
| Run 8 | 0.95 | 0.95 | 0.8 |

As a result, a total of 48 training runs (6 models × 8 runs each) are required.

## 5. ROM validation and airbag calibration results

The initial step involves comparing the high-fidelity simulation results with the Reduced Order Models (ROMs) for parameter values not included in the training set. While some discrepancies are anticipated, given that ROMs are derived from interpolations of training runs, these differences should remain minimal. This ensures that parameter calibration using the ROMs yields reliable results in the subsequent validation Finite Element simulations using the same parameters.

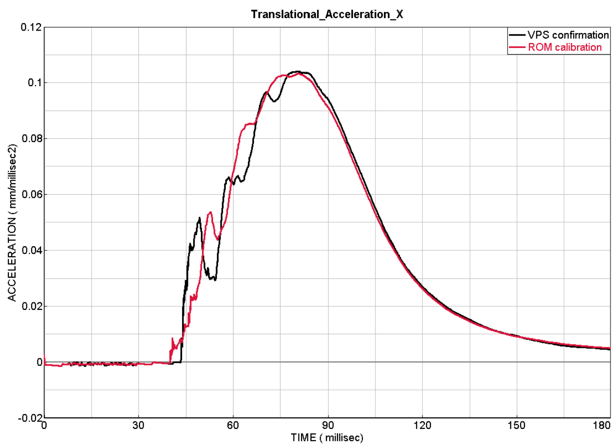


*Figure 8: Comparison between pendulum acceleration with VPS-FPM and Reduced Order Model for Joyson PAB test 5*

### CORA Rating Methods and Parameters

The CORA (Correlation and Analysis) rating methods are employed to compare simulation results with experimental curves. Volkswagen (VW) provides specific parameters to validate the following time history curves:

- **Impactor acceleration**
- **Impactor displacement**
- **Airbag pressure**

The total rating for each physical test is calculated as a weighted combination of the individual CORA ratings for acceleration (70%), displacement (15%), and airbag pressure (15%). The global rating is then determined by averaging the total ratings for all physical tests.

**Computation of CORA ratings using Reduced Order Model**

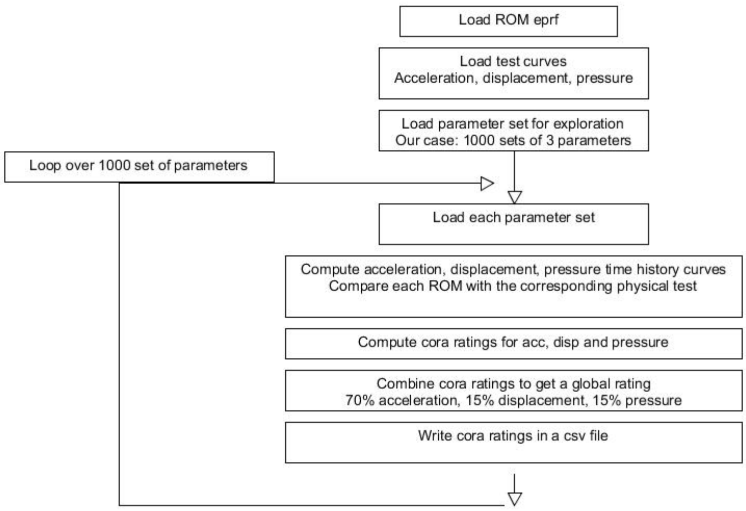


*Figure 9: Automated workflow for computation of CORA ratings between Reduced Order Model and physical test curves*

For each physical test, 1000 random combinations of parameters were provided as input data to the parametric Reduced Order Model (ROM). The pendulum acceleration, displacement, and airbag pressure time history curves were computed. Comparisons using the CORA (Correlation and Analysis) rating were then performed against the experimental test results for these three different curves.

The following results were obtained for the Yanfeng Passenger Airbag using this methodology.

**Table 5: Calibration results for the Yanfeng Passenger Bag.**

| | | | |
|---|---|---|---|
| Test 1 | 0.85 | 0.86 | 0.86 |
| Test 2 | 0.89 | 0.91 | 0.86 |
| Test 3 | 0.86 | 0.91 | 0.86 |
| Test 4 | 0.92 | 0.96 | 0.9 |
| Test 5 | 0.92 | 0.95 | 0.89 |
| Test 6 | 0.93 | 0.92 | 0.91 |
| **Average** | **0.89** | **0.92** | **0.88** |

**Table 6: Parameter values for the Yanfeng Passenger Bag.**

| [redacted] | | [redacted] |
|---|---|---|
| Vent discharge coefficient | 0.8 | 0.8 |
| Seam leakage scale factor | 1.0 | 1.04 |
| Inflator temperature scale factor | 0.85 | 0.86 |

CORA ratings and calibrated parameter values are quite similar when using the standard calibration approach with high-fidelity simulation runs and Reduced Order Models (ROMs). However, the ROM-based methodology significantly reduces the airbag validation time by enabling the testing of thousands of parameter combinations within days instead of weeks.

The acceleration, displacement and pressure time history curves are shown in Figure 10: and compared to experimental results for test 6. The time corridor for the CORA rating evaluations is determined using the acceleration test signal.

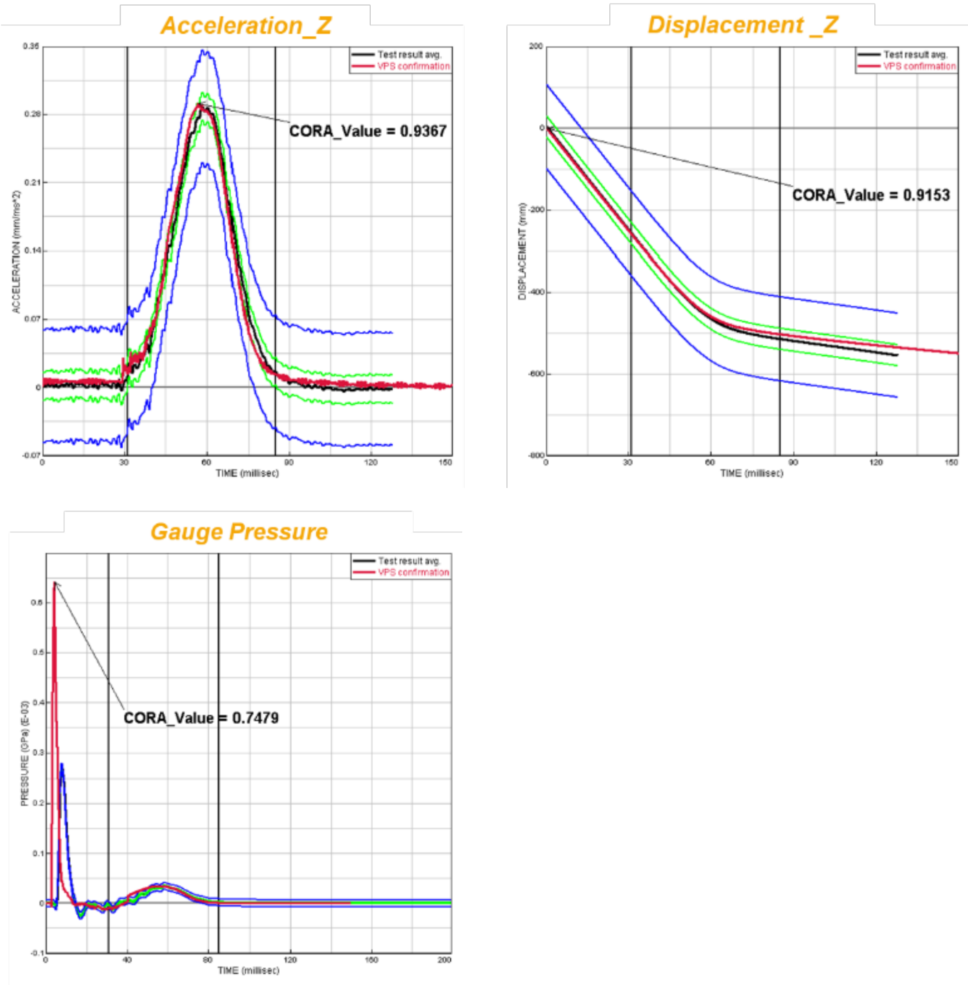


*Figure 10: Comparison between test curves and VPS simulations (in red) using the calibrated parameters for Yanfeng PAB test 6.*

## Joyson PAB results

The results obtained with the Joyson Passenger Airbag (PAB) are shown below. The CORA ratings are comparable on average between the standard and the ROM calibration methods. However, parameter values, particularly for the vent discharge coefficient and seam leakage scale factor, exhibit more differences.

**Table 7: Calibration results for the Joyson Passenger Bag.**

| | | | |
|---|---|---|---|
| Test 1 | 0.94 | 0.74 (*) | 0.86 |
| Test 2 | 0.8 | 0.96 | 0.77 |
| Test 3 | 0.91 | 0.93 | 0.94 |
| Test 4 | 0.82 | 0.85 | 0.79 |
| Test 5 | 0.74 | 0.81 | 0.81 |
| Test 6 | 0.83 | 0.87 | 0.9 |
| **Average** | **0.84** | **0.86** | **0.85** |

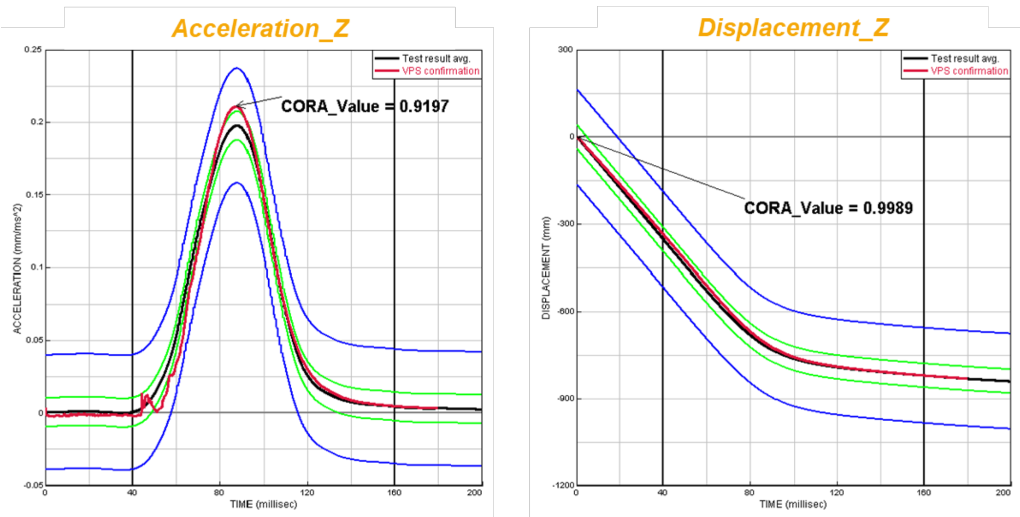


*Figure 11: Comparison between test curves and VPS simulations (in red) using the calibrated parameters for Joyson PAB test 3.*

**Table 8: Parameter values for the Joyson Passenger Bag.**

| Description | | **ROM calibration** |
|---|---|---|
| Vent discharge coefficient | 0.85 | 0.94 |
| Seam leakage scale factor | 0.5 | 0.3 |
| Inflator temperature scale factor | 0.85 | 0.82 |

## 6. Conclusion

The SSL-PGD Reduced Order Method was applied to industrial airbag calibration to accelerate the process by using real-time parametric models instead of CPU-intensive finite element simulations. Calibration could be completed in less than a week per airbag, compared to several weeks with standard Finite Element simulations, within a guided workflow. The number of Finite Element training runs required for the Reduced Order Model is predetermined by the number of parameters and the reduction method used.

This methodology was tested on several airbags, including two passenger airbags from Yanfeng and Joyson. Validation runs with VPS-FPM simulations were conducted using the parameters calibrated by the Reduced Order Model and compared with experimental results, as per the current methodology.

**Acknowledgments**

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