

White paper

Simulation  
enabling technologies

## Vehicle stiffness evaluation with the Opening Distortion Fingerprint (ODF) method

The Opening Distortion Fingerprint (ODF) is a method to evaluate the opening stiffness on vehicle body using dynamic results instead of static loads. It can be used to limit the distortion in the closure openings, and enable a deeper analysis of the dynamic forces acting on the body.

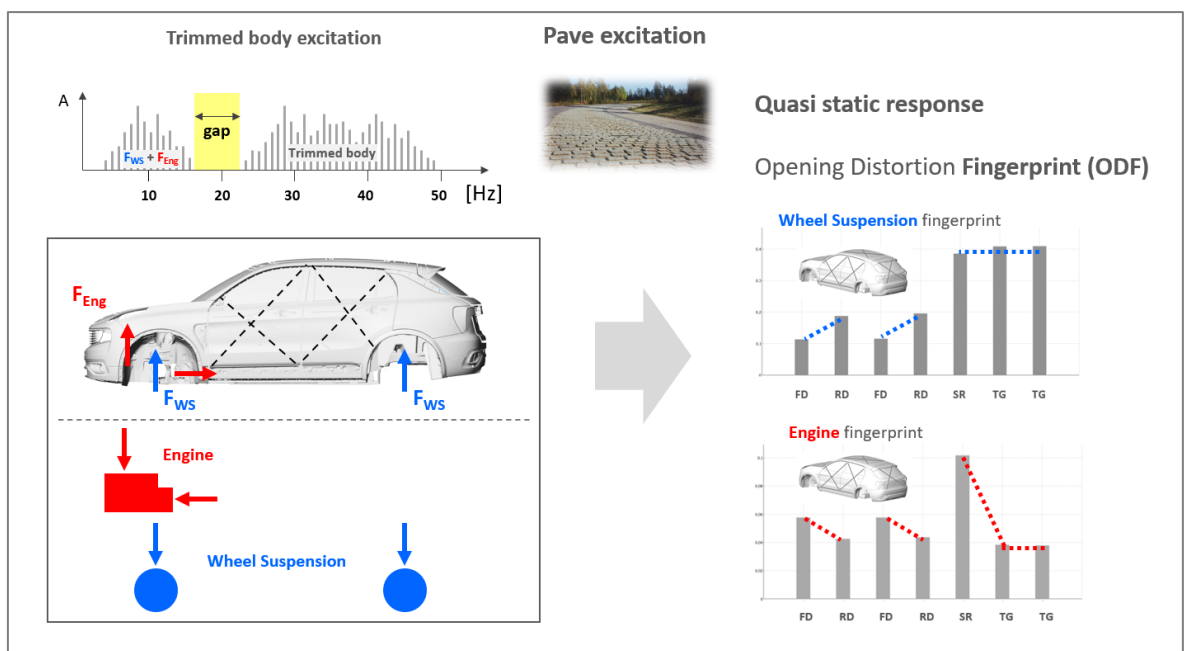


## Introduction

The increasing penetration of Electric Vehicles (EVs) in the automotive market demands for rapid reshapes in how manufacturers approach product development. Starting from the initial stages of new models design and their evaluation through simulation, new requirements and limitations require new methods, new tools, and change the focal points of analyses.

For example, the static torsional stiffness which describes the body with one value, becomes much less relevant due to the structural impact of the stiff battery package.

To achieve a comfortable ride, a common approach for vehicles is to separate the frequencies of the major body modes from the excitation frequencies. This means, there is a clear frequency gap between the forces from the wheel suspension/drive line and the body, which results in a mainly quasi-static body response.



The effect of Engine and Wheel Suspension loads

Courtesy of CEVT

By measuring the distortion in all closure openings when driving for example on a pavé road, this quasi-static response can be shown as an Opening Distortion Fingerprint, called ODF.

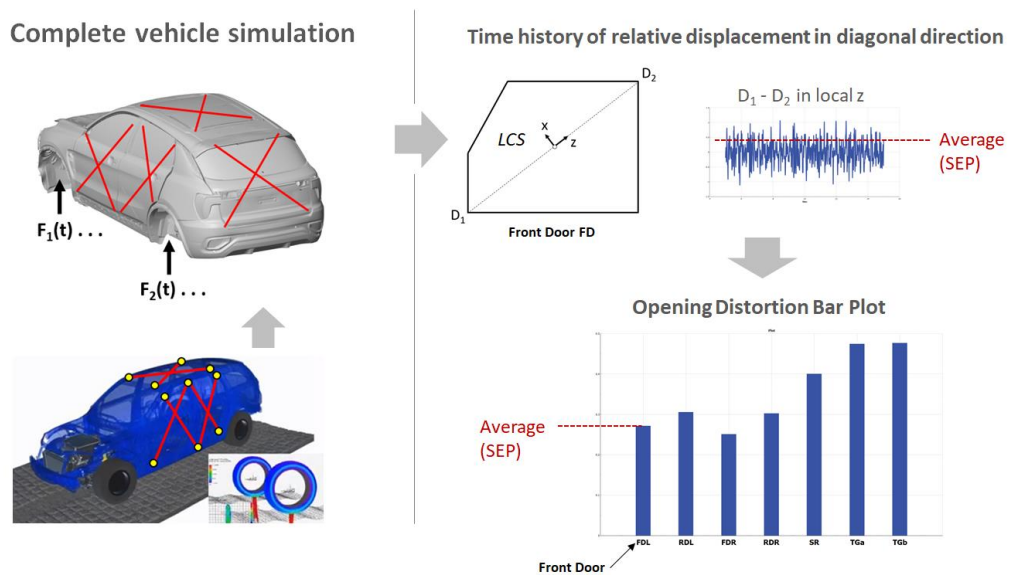


## The Opening Distortion Fingerprint (ODF)

The ODF can be used to limit the distortion in the closure openings (Solidity), and also enable a deeper analysis of the dynamic forces acting on the body (Vehicle Dynamics). For example, an ODF can be identified, specifically for the load coming from the wheel suspension or the drive line.

The distortion is measured with the E-line and the Diagonal method. The ODF method allows an evaluation in both time and frequency domains.

The ODF evaluation can be based on test data, MBS or FEM simulation.

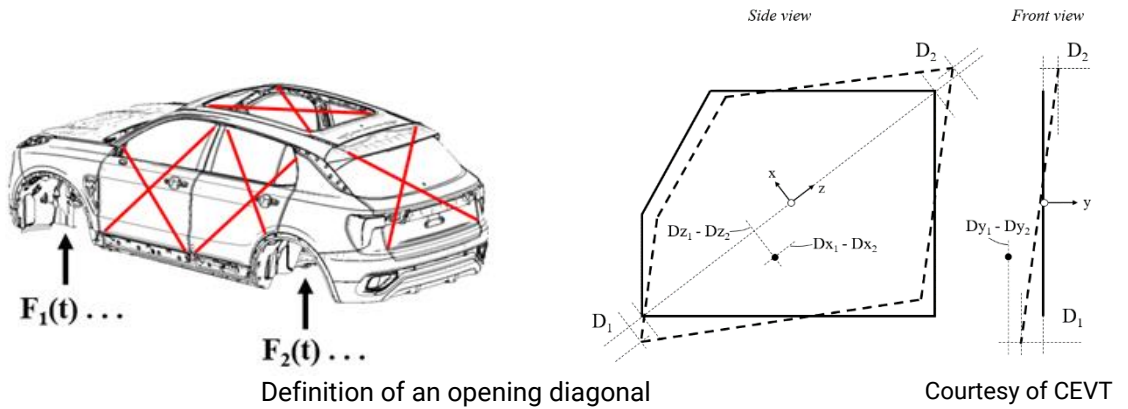


The Opening Distortion Fingerprint process

Courtesy of CEVT



## Measuring Distortion with Multi Stethoscope (MSS)

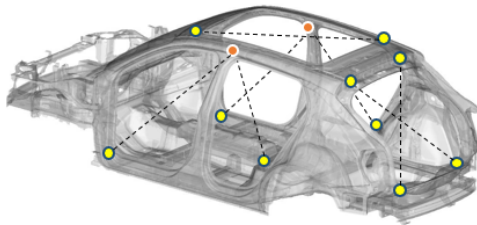


To measure the distortion in all closure openings a Multi Stethoscope (MSS) is used. Two diagonals are defined in each opening. The displacement in the endpoints of the diagonals is captured in both global and local coordinates. The relative displacement in each diagonal is used to describe the distortion

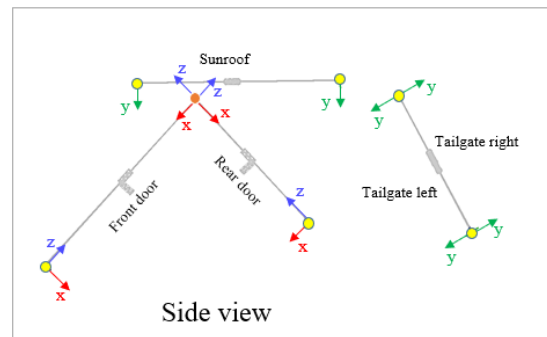
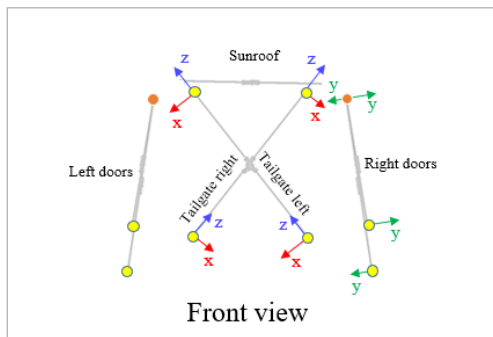
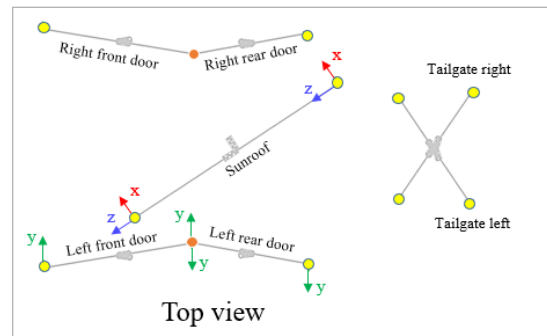
For each diagonal a local coordinate system is defined. The local z-component is pointing in diagonal direction. The local y-component is normal to the opening plane and the local x-component is on the opening plane. The x- and z-component describe the in plane distortion and the y-component the out of plane distortion.



## Multi stethoscope (MSS)



• Two coincident nodes



The Multi Stethoscope set up on vehicle closures

Courtesy of CEVT

To calculate the relative displacement, two methods can be used: The E-line and the Diagonal methods.

The E-line method calculates the relative displacement in the 3 local directions. The Diagonal method calculates the relative displacement only in the diagonal direction which is the distance between the two diagonal points.

The E-line method is only valid for cases with small displacement (linear). The Diagonal is also valid for cases with large displacement.

In the cases of small displacement, the local z-component of the E-line method is equal to the relative displacement from the Diagonal method. By comparing these values, we can identify when large displacements occur.

Furthermore, the E-line method allows for the evaluation of the rest of the local system components. When driving on pavé the vehicle is mainly twisted around its symmetry axis. This results in an out of plane distortion in the side doors (y local component is maximum) and a in plane distortion in the tailgate (x & z local components are maximum).



On the other hand, the diagonal method provides results that are directly comparable to testing with laser instruments that capture the diagonal distortion directly.

## Driving a Complete Vehicle on Pavé – Test and Simulation

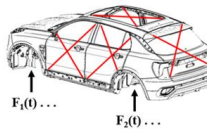
When testing a complete vehicle on pavé, 3-axis accelerometers are glued to the body in all MSS points. They are aligned to the global vehicle coordinate system. To get the relative displacement according to the E-line Method, the following two steps are performed:

- The acceleration is converted to displacement
- The displacement in global coordinates is transformed to the local coordinates of each diagonal.

In an FE simulation the engineer needs to simply output local displacements in the respective nodes of the structure.

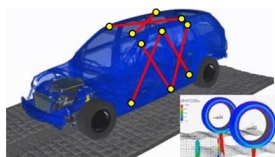
In MBS simulation either global acceleration or the total distance of the diagonal direction can be output. As long as the flex bodies are equivalent to the modes calculated by the FE analysis, transient response analysis may be omitted and MBD results can be used directly.

**FEM** - modal transient analysis



Displacement in global or local CS

**MBS** – acceleration & total distance



Acceleration in global CS and relative displacement in diagonal direction

**Test** - accelerometers



Acceleration in global CS

Source results for ODF evaluation for simulation and test

Courtesy of CEVT

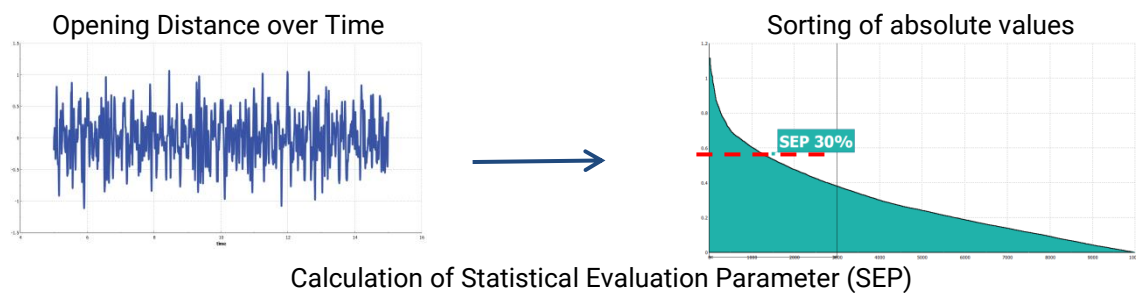


## Evaluating Dynamic Distortion

The result from both test and simulation is the relative displacement in time domain for all diagonals of the MSS. To summarize the time history in one value, the following steps are performed:

- A specific time length of the signal is selected.
- Values are sorted in a descending order.
- The mean value of a selected percentage of the highest values is calculated.

This mean value is called Statistical Evaluation Parameter (SEP).

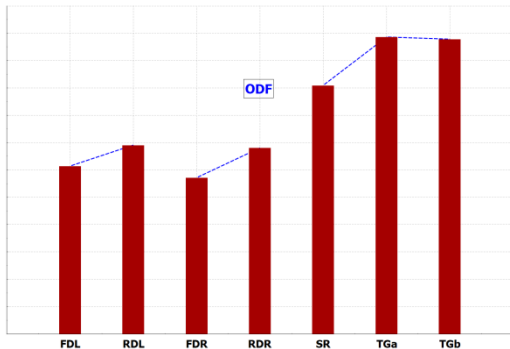


## The ODF Plots

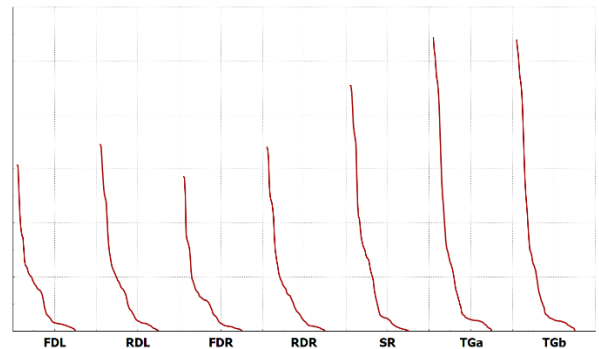
Since the body response is quasi-static, the pattern (dashed lines), which can be identified in the Bar Plot, is called Opening Distortion Fingerprint (ODF).

The ODF can be either shown as a Max Bar Plot or as a Cutoff Plot. In the case of the Max Bar Plot a cutoff frequency has to be chosen and in the case of the Cutoff Plot a cut-off frequency range needs to be defined. The time signals are filtered below the specified cut off frequency for a selected frequency range. The Max Bar Plot shows only the max value of the Cutoff Plot. The cut off frequency or the low value of the specified frequency range is important for the elimination of the rigid body motion effect.

The Cut-off Plot represents the variation of the SEP value of each opening over an ascending low cut-off frequency within the specified range. The Max Bar Plot represents the maximum SEP value of the filtered signal for each opening.



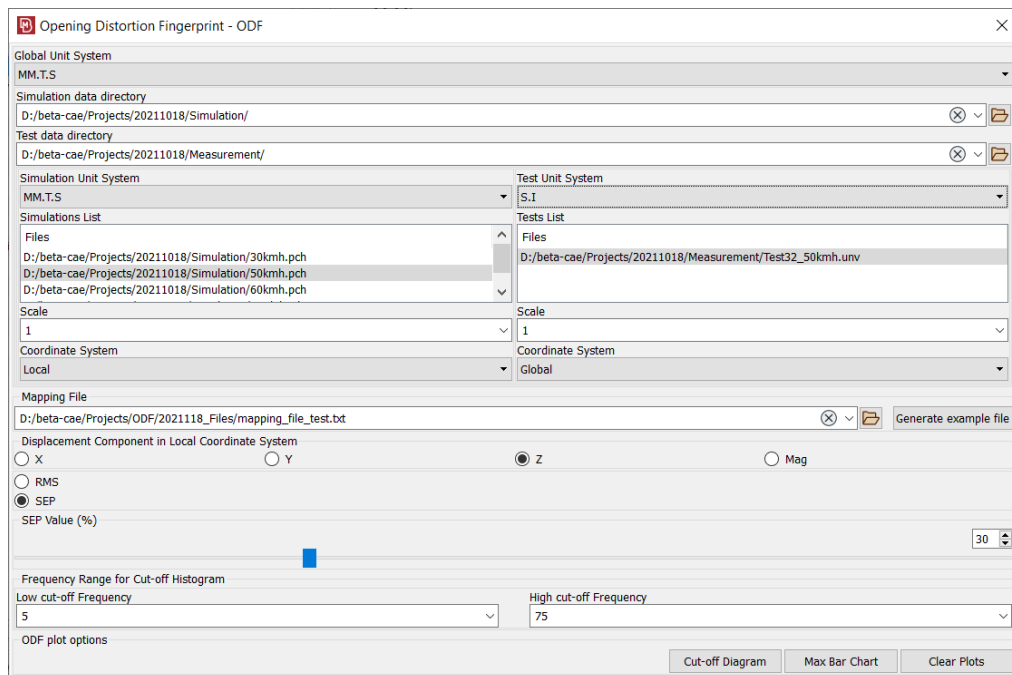
Maximum Bar Plot. The Y Axis is the SEP value of each opening



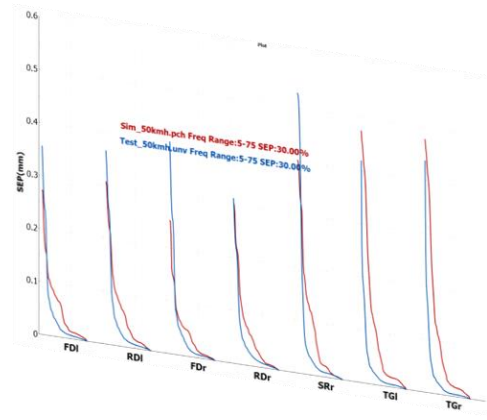
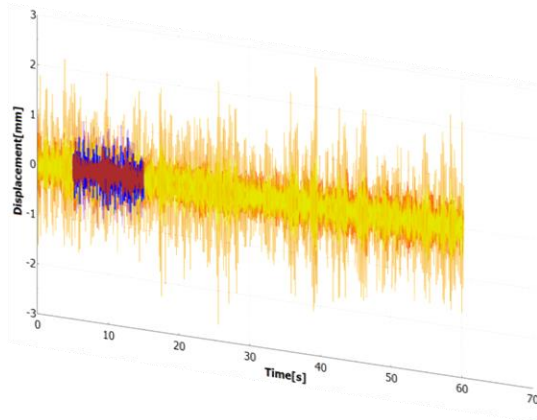
Cut-off Plot. The Y Axis is the SEP value of each opening that seems to be descending as the low cut-off frequency of the specified frequency range is increased. All openings refer to the same frequency range

## ODF in META

Due to the advanced features and automation capabilities of META, the ODF user toolbar can tune all of the necessary calculations for multiple variants of both simulations and tests. The toolbar interface provides all the necessary settings while all respective actions take place in the background resulting in the requested ODF and Relative Displacements plots.

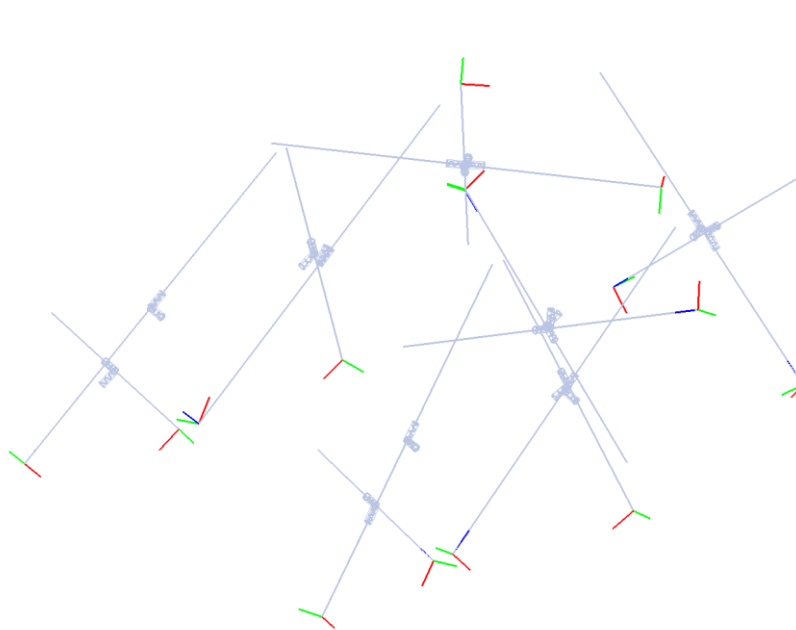






ODF in META

The user needs to specify the location of his simulation and/or test results, select the proper files and provide a mapping file with the correspondence of opening names to node/channel pairs of the simulation/test.



Geometry input file with local systems definitions

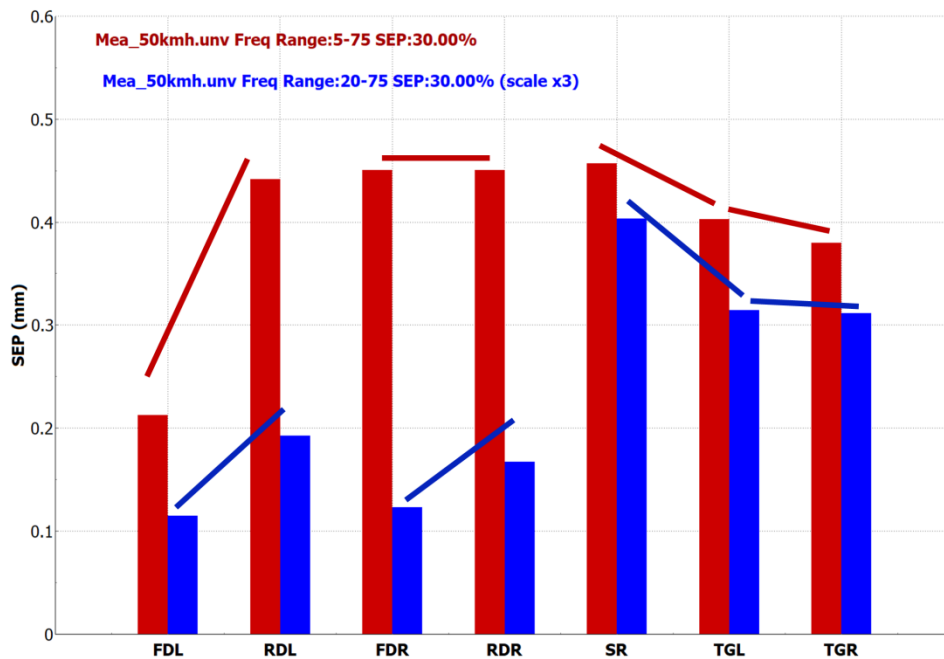
Transformations from global to local results are applied automatically as long as an FE geometry file with the respective local systems assigned to the proper nodes is provided. Unit



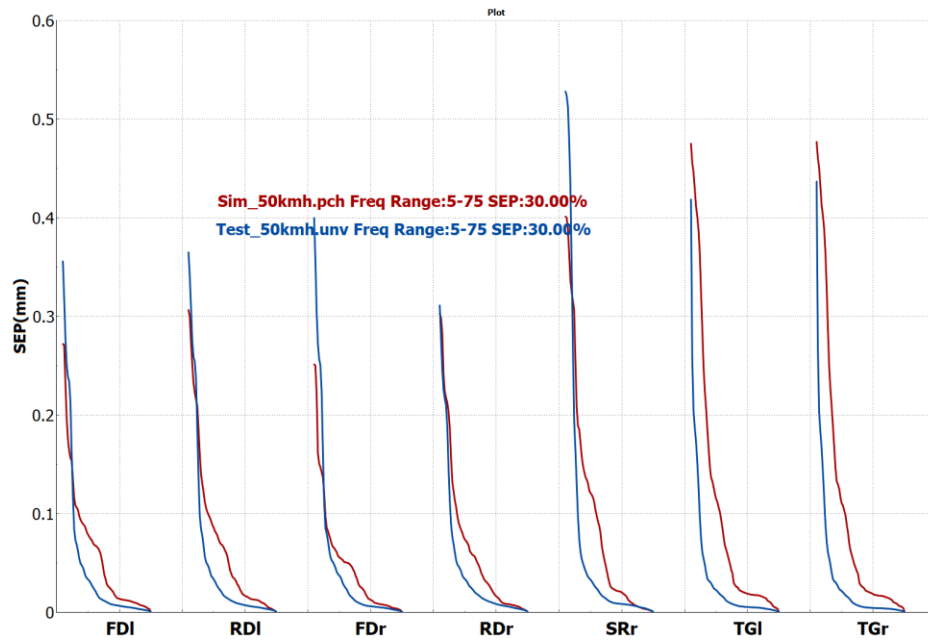
system definitions are provided in the interface as well so that results can be compared on the same basis.

## Conclusion

The ODF tool can be used to limit the distortion in the closure openings. Design changes may target the final ODF scores in an optimization loop. Furthermore, it provides a characteristic identity of the vehicle openings on the variety of dynamic forces acting on the body. The contribution of certain frequencies to the overall opening distortion can be evaluated, by examination of the low cut-off value. Furthermore, this characteristic fingerprint is a direct comparison index between measurements and simulation.



Comparison of ODF results of the same simulation for different cut-off frequencies. Results for cut-off frequency 20Hz have been scaled so that differences in pattern are highlighted instead of absolute differences. Cutting-off on 20 Hz does also exclude the engine response therefore we get a symmetric pattern between left and right door openings.



Comparison of ODF results of the same simulation for different cut-off frequencies

### **About BETA CAE Systems International AG**

BETA is a simulation solutions provider, dedicated to the development of state of the art software systems for CAE. For almost 30 years, we have been developing tools and delivering services for the front-runners in numerous sectors by listening to their needs and taking up even the most demanding challenges. For more information on BETA CAE systems, our products, and our services, visit [www.beta-cae.com](http://www.beta-cae.com)

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*physics on screen*

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