Less Interior Squeak and Rattle Noise Using a Simulation Driven Design Approach

In the development of new vehicles, the PSA Group aimed to detect Squeak and Rattle (S&R) problems before availability of physical testing. This led to a collaboration between PSA's method development engineering team and Altair's domain experts.

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NUMERICAL OPTIMISATION METHODS

Squeak and Rattle (S&R) prediction using simulation is highly demanding. Numerical optimisation methods did pave the way for technical solutions.

The so called E-Line Method [1], [2] consists of calculating the relative displacement, in time domain, between components and assessing S&R occurrence. Geometrical data like gap and tolerance variations are used for rattle detection, while stick-slip physical testing data is used for squeak detection. In addition to how the E-Line method was applied to real-life projects at PSA, this article will highlight how this simulation process has been integrated into the existing Virtual Development Process (VDP) [3].

S&R PREVENTION: FROM TEST TO CAE

S&R issues have typically been addressed through Finite Element (FE) modal analysis and physical testing, **FIGURE 1**.

FE modal analysis can be useful in understanding the sub-system vibration behaviour. Design constraints are generally imposed in the model, in order to avoid local modes below a target value (usually 50 Hz for interior trim parts). This approach is a good first step, although not sufficient enough to prevent all S&R occurrences.

To achieve a risk-free vehicle, physical testing needs to be performed on all relevant components. Parts from prototype tooling are costly due to low volume and limited availability. Inaccurate materials and large tolerance variations may lead to the identification of problems that might not exist in production. In addition, production tooling modifications are costly thus limiting the design possibilities.

S&R issues can also be affected by parameters such as temperature and the aging of parts. Implementing these conditions into physical tests is costly and demanding of resources. For these reasons, PSA decided to adopt a virtual approach as a solution for the detection and elimination of S&R issues.

ENHANCED SIMULATION PROCESS

To solve S&R tasks Altair has developed the so called Squeak and Rattle Director (SnRD). Based on a standard NVH simulation model, SnRD has been used following a step-by-step approach. Those steps are described below and will be detailed later in this article using the industrial case of a closure.

- The starting point is a linear FE model used for modal analysis.
- Modelling of E-Lines using SnRD to represent S&R interfaces. E-Line consist on a set of spring elements and of local coordinate systems that will act as measurement sensors in the FE model.
- Virtual test setup: time domain excitation applied to the FE assembly.
- Modal transient analysis is solved with OptiStruct, to extract all three outputs at once, Eq. 1, at the E-Lines locations: modal displacement (m_i), modal participation factors ($\psi_i\ (t)$) for the N modes, and real displacement ($U(t)$) in time domain.

Eq. 1 $$U(t) = \sum_{i=1}^{N} m_i \times \psi_i(t)$$

- SnRD calculates the relative displacement automatically. In the case of rattle, the relative displacement is compared to the design gap and tolerance variation to assess a gap closing and how often. In the case of squeak, the relative displacement is assessed using the stick-slip test data for each specific pair of material.
- Statistical approach to assess the severity of the risks identified [2]. All in the post-processing module, the analyst can quantify S&R occurrence, or how many vehicles might fail.
- For problem areas, SnRD enables root cause analysis. It is based on the calculation of the Relative Modal Contribution (RMC) [4]: ranking of the most influential modes shapes for a specific S&R problem.
- Solution proposal phase: depending on the phase of the project and the design flexibility. Two approaches are possible: traditional iterative trial and error based on A2B comparison, or a simulation & optimisation driven approach. In both cases, SnRD is adapted for result comparisons, and assistance to setup the optimisation problem.

This simulation approach has been applied to all the interior trim parts at PSA such as front/rear/sliding doors, tailgate, roof compartments and cockpit module. The work performed on the Peugeot Partner and Citroën Cactus is presented.

FIGURE 1 S&R physical testing on interior assemblies (© PSA)

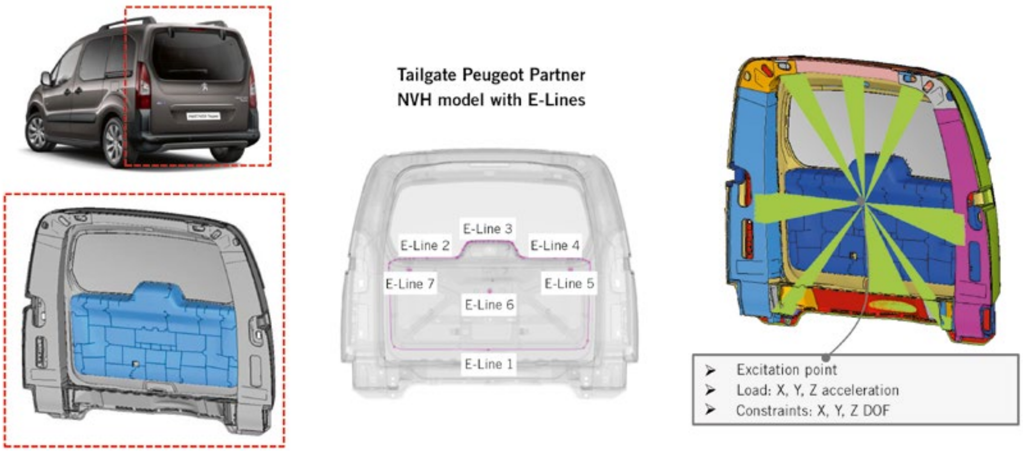

FIGURE 2 Tailgate assembly with E-Lines and loading point (© PSA)

SIMULATE – DETECT – SOLVE

Based on existing NVH-FE models, an S&R model for a tailgate assembly is built following the previously described steps.

The method allows the reproduction of the physical testing conditions. When a system is tested as a standalone, **FIGURE 1**, the fixture used is a rigid rig. This is reproduced by a rigid 1-D element, **FIGURE 2**, connecting all fixture points. The excitation can be of different sources, such as time domain Multi-body Dynamics simulation outputs, or frequency domain defined loads such as Power Spectrum Density (PSD) profiles or a sine sweep. In this case, test loads in time domain are directly applied to the model.

S&R events are based on the amount of movement that might cause a gap to close or a stick-slip condition to occur. Time domain analysis allows the determination of the number of S&R incidences.

For example, the rattle detection is based on the relative displacement crossing a maximum target gap. This evaluation is automatic for each point in the SnRD post-processing module, presenting results such as displacement magnitude or the displacement in the gap direction. **FIGURE 3** (centre). When considering the design dimensions, the risk area appears at the lower interface, highlighted in red. This is called the dynamic tolerance, **FIGURE 3** (right).

Eq. 2 $$\textit{Dynamic tolerance}_i = Gap_i - Tol_i - Rel\,Disp_{z,i}$$

The dynamic tolerance considers the worst gap ($Gap_i - Tol_i$) and the relative displacement in the direction of this gap ($Rel\,Disp_{z,i}$). Calculated with the formula in Eq. 2 the rating is as follow:

- positive dynamic tolerance (green dots): gap not close, therefore no risk, the worst gap is large enough to not get closed during a vibration state
- negative dynamic tolerance (red dots): gap closed, risk than needs investigation.

When S&R issues are identified, the project needs to priorities actions: a severity ranking is applied. Using the E-Line method and SnRD allows different investigations, two of them are discussed in this section: recurrence and robustness.

First, the time domain allows the count of how often a rattle click will occur or stick-slip will repeat. Statistical count of the peaks enables to quantify how many clicks will happen. A location or a design with larger number of clicks is rated as more severe.

Second, and still related to the dimensions and variations of produced parts, is the failure of Parts per Million (PPM). So, when simulated, a relative displacement of 1.1 mm exceeds the nominal gap of 1 mm and tolerance of ±0.5 mm, the rattle risk is obvious for the nominal design. What about the rest of the production?

The gaps and tolerances follow a normal distribution law as they depend on manufacturing, design and assembly variations. Hence, the

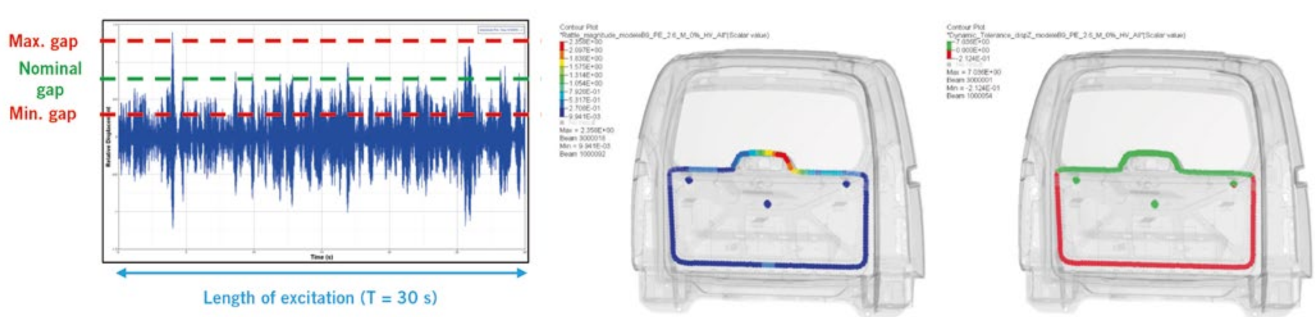

FIGURE 3 Relative displacement profile in time domain (© PSA)

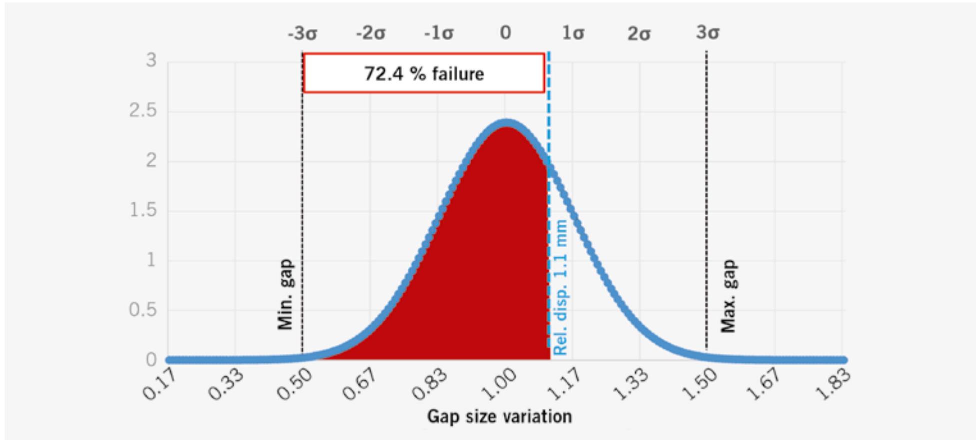

FIGURE 4 Recurrence and failure ppm (© PSA)

number of vehicles that will fail can be quantified. In **FIGURE 4**, a 1.1 mm relative displacement results in 72.4 % of vehicles rattling (gap ≤ 1.1mm). These approaches were used in the project to priorities the issues.

Once a risk has been identified, root cause analysis is required to propose a solution. Using SnRD, the analyst can extract the RMC [3] value, listing the most contributing modes.

FIGURE 5 shows the Citroën Cactus tailgate assembly rattle simulation results. Based on RMC histogram the most contributing mode to the lower interface is visualised here to the right side. These results have matched the physical test results performed on similar assembly, and all S&R zones involving the trim part analysed were identified in the simulation model.

OPTIMISATION

PSA and Altair worked closely to implement the S&R simulation process within the current development cycle. Using a simulation driven design approach, the CAE teams detected risk areas and enabled the designers to consider solutions early on in their design process. In addition to manual trialing of different ideas and dimensions adjustments, optimisation has been introduced.

There are various algorithms for optimisation. In early concept phase, topology or free-size optimisations are suitable; while for minor fine-tuning, free-shape, shape and size optimisation can be used. The example of a door assembly is presented.

Due to the advanced design phase styling constraints were applied while some design flexibility allowed solution finding. For instance, rib alteration and thickness variations were considered for optimisation.

Using the RMC calculation to identify the critical mode shapes, the objective is to minimise the relative modal displacement for a specific/range of frequency. A 1-D topology optimisation was set up in order to alter the number and location of these fixation points. In OptiStruct, the following setup was used:

- design space: existing and added 1-D connections points in the FE model
- design variables: density of the connection points
- objective: minimising the magnitude of mode shape number identified in RMC calculation
- constraint: 10 % of the connections points to remain.

The optimised design consist on an altered connection points positions. Using the existing FE model, a verification run is submitted and results are compared to the base line. S&R performance is improved without additional connection. **FIGURE 6** summarises the process.

CONCLUSION

This paper, described the analysis of a tailgate and door assembly of a Peugeot Partner and a Citroën Cactus vehicle for S&R risk occurrence. The detection pro-

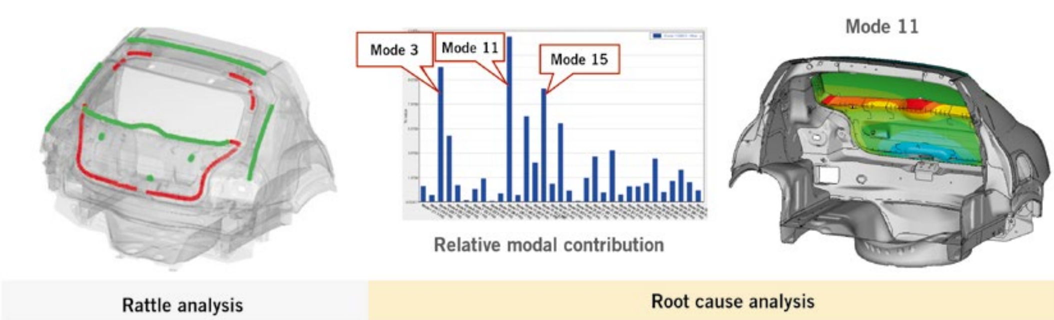

FIGURE 5 Rattle analysis and root cause analysis (RMC) in SnRD (© PSA)

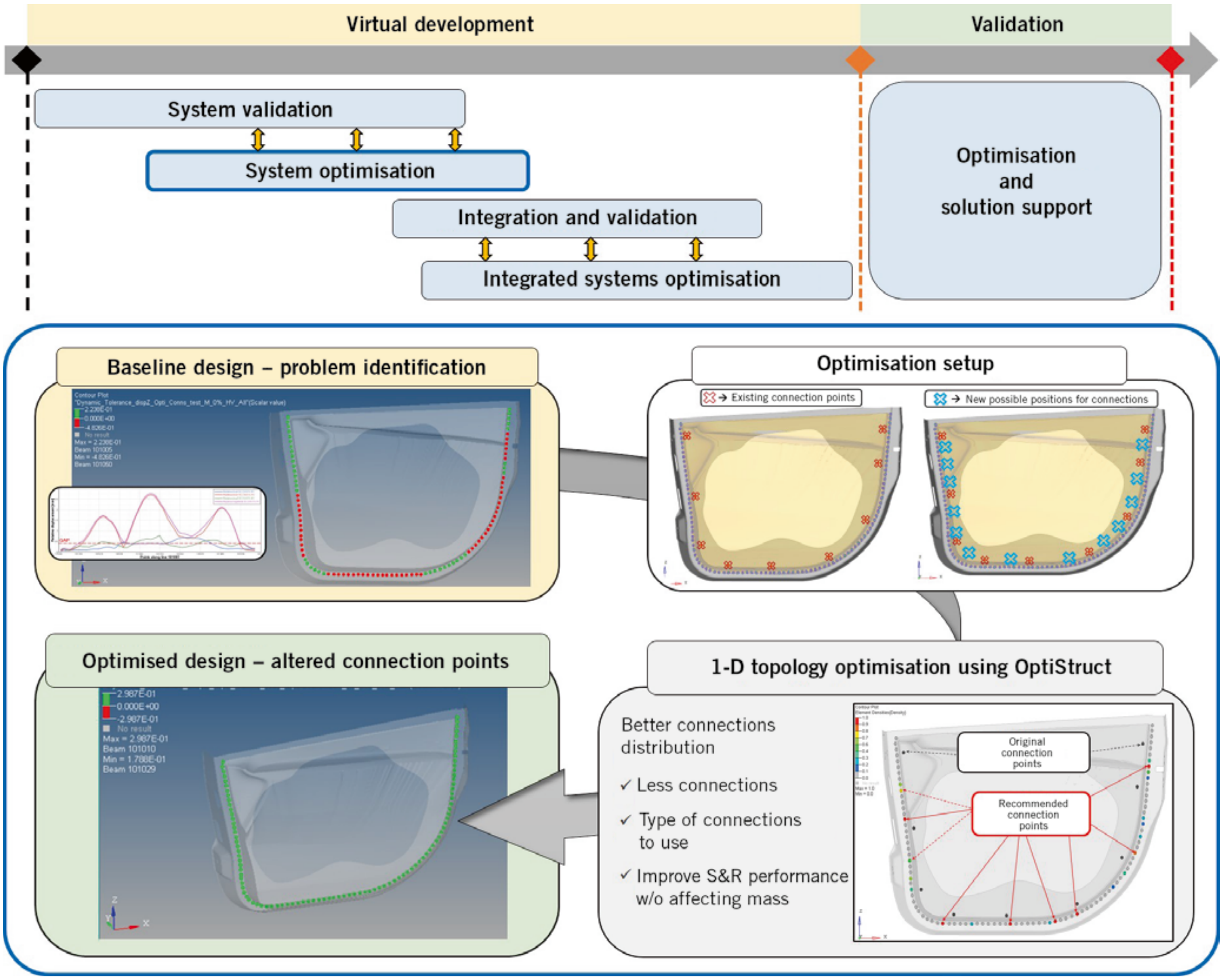

FIGURE 6 CAE based prevention of S&R problems in the VDP at PSA: topology optimisation for trim attachment points (© PSA)

cess, severity ranking and root cause analysis, using the E-Line method in SnRD, was explained using project experiences. In the case of the Cactus where physical test data were available, the simulation prediction matched 100 % with test.

Moreover, the solution proposal phase was demonstrated for clip attachments using topology optimisation in OptiStruct. Since this specific project was in the early concept phase, physical test results were not available for correlation of risk predictions.

As a result, the E-Line method is adopted by Groupe PSA project teams. As described in this article, the simulation method and the SnRD module allows PSA to use existing FE models to detect S&R risk and support the design team with solution proposals. In that sense, PSA have introduced new CAE capabilities.

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