Squeak & Rattle Simulation
A New Approach to Support the Complete Development Process of Interior Parts

Squeak & Rattle performance has become increasingly important regarding customer satisfaction. Normally Squeak & Rattle performance in a new car is tested during the validation phase prior to the start of production. In order to reduce the number of Squeak & Rattle issues during validation a robust design is required. To achieve „right first time" design for GM projects, thus avoiding unnecessary development loops, a Squeak & Rattle simulation tool was required.

1 Introduction

Squeak & Rattle (S&R) in the vehicle is a very complex phenomenon. A wide range of factors can cause this: material pairs, surface finishing, assembling, relative displacement, tolerances, road load, manufacturing etc. Only one of these factors can always be related to S&R issues. This factor is the relative displacement [1]. Therefore it is important to focus on the relative displacement when trying to simulate the S&R phenomenon. In the vehicle the instrument panel, **Figure 1**, has normally the highest complexity of all interior assemblies due to the number of different parts mounted together. In order to avoid S&R problems the relative displacement between all these parts has to be controlled.

When studying the instrument panel more in detail a number of parameters can be identified, which have to be represented in the simulation model in order to calculate the relative displacement, **Figure 2**. These parameters are valid for all interior assemblies regarding the S&R simulation. First of all the global stiffness has a major impact on the relative displacement. This impact is strongly related to the number and position of internal mounting points. The local stiffness together with the clip and snap stiffness is also important for the relative displacement. In addition to the stiffness the local geometry, in the area where two parts can come in contact, has to be considered in the simulation. The load definition has a decisive influence on the S&R performance. A load level which is too low will probably not cause any S&R issue. A load level which is too high will always cause problems. Therefore it is important to define a realistic load. The relative displacement is finally the simulation output, which is processed both in global and local coordinate systems.

Different types of analyses are applied during the development process. In the beginning the modal analysis is performed on the main structural parts. When the structure becomes more detailed the transient analysis allows the study of relative displacement between the global structural parts. Finally the S&R simulation is performed on the complete detailed model. For the S&R simulation the frequency response analysis in conjunction with the software EdWare from EDAG is used. The output of these analyses is adapted to the detail level of the interior assembly. In order to identify the capability of the S&R simulation different correlation work between test and simulation has been performed.

2 Modal Analysis

The instrument panel (IP) assembly is a complex structure involving many plastic parts. Both the material data and the FE representation of these plastic parts are still uncertain compared to e.g. a BIW (Body in White) structure. Therefore the modal correlation work is performed in order to improve the simulation capability.

In **Figure 3** a physical reference model of an IP is shown. This reference model contains only the main structural parts and they are mounted on a stiff support structure in order to get straight defined boundary conditions. A number of accelerometers are used to capture the global deformation of the IP structure, see Fig-

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Figure 1: Cockpit assembly for the Opel Insignia

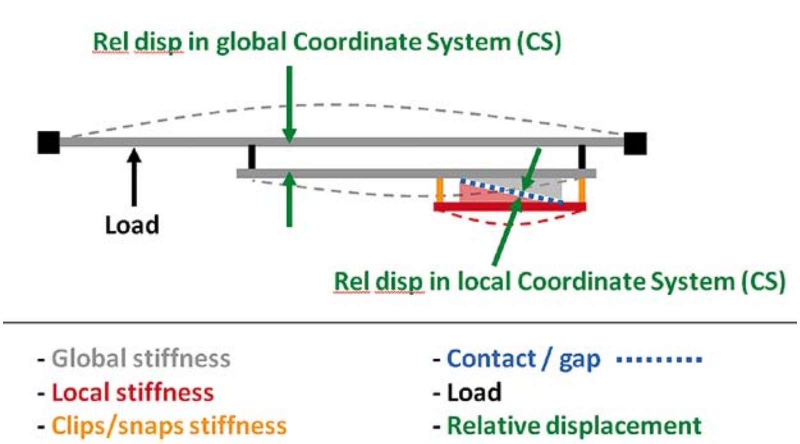

Figure 2: Parameter definition for S&R simulation model

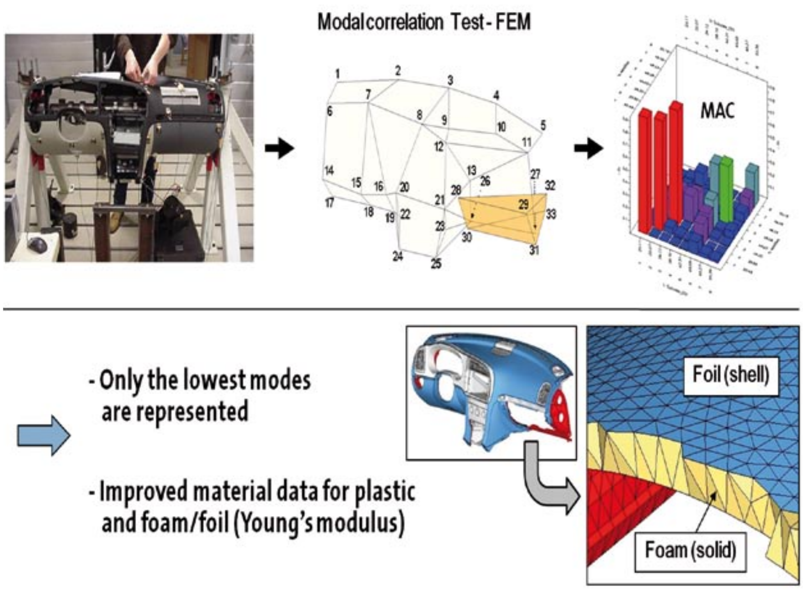

Figure 3: Modal correlation of the main structural IP parts

ure 3 in the middle. The major outcome of the correlation is that only the lowest modes are represented correctly. The MAC value (modal assurance criterion) for the first three modes is around 0.9, see Figure 3 on the right side. Higher modes do not correlate. Showing that the data for plastic material (Young's modulus) can be considerably improved. The Young's modulus based on the modal correlation can be up to twice the value from the static test depending on the kind of plastic material. The definition of the Young's modulus for foam and foil which are represented with solid and shell elements is also an important part of the correlation, see Figure 3. Since the foam and foil together with the carrier structure are acting as a composite, the data from material supplier itself cannot be used for the simulation.

In order to improve the modal correlation also on a local level a 3D Scanning Vibrometer (company Polytec) is used for measurement, **Figure 4**. There are two main advantages with this system. Instead of using relatively heavy accelerometers only a reflection tape is needed which enables also the measurement of light weighted trim parts. The second advantage is the fact, that the number of measurement points can be much higher compared to the accelerometers where the number of channels is limited. The first results of this correlation work show clearly that there is a big potential to improve the linear simulation models on a local level, because a number of simulated modes cannot be found in test. Therefore the improvement is especially related to a better understanding of how to connect the parts to each other in the best way in the simulation model.

Using the results from the correlation the modal analysis can be started as soon as a rough geometry of the main structure is available. Parts like the radio, the instrument cluster or the airbag module can be represented by lumped mass elements. The aim is to study the lowest global modes and to make sure that the first global eigen frequency matches the requirement. This first model enables also to perform side studies in an early stage to give input to design how the stiffness can be modified in the most effective way. In **Figure 5** such a model is shown, this being the first model of the Opel Insignia IP. A question in the beginning of the project, which could be answered with this model, was which parts need glass fiber reinforcement.

Not only the frequency itself is taken as design criteria, but also the mode shape continuity. By studying the mode shapes

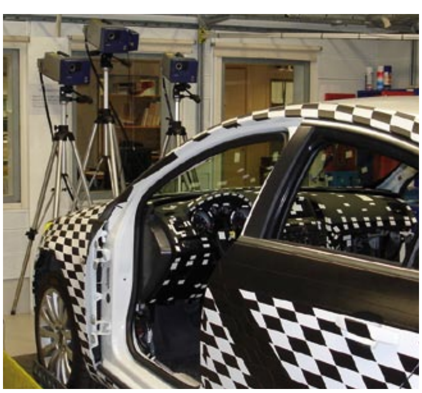

Figure 4: Modal correlation with 3D Scanning Vibrometer measurement points

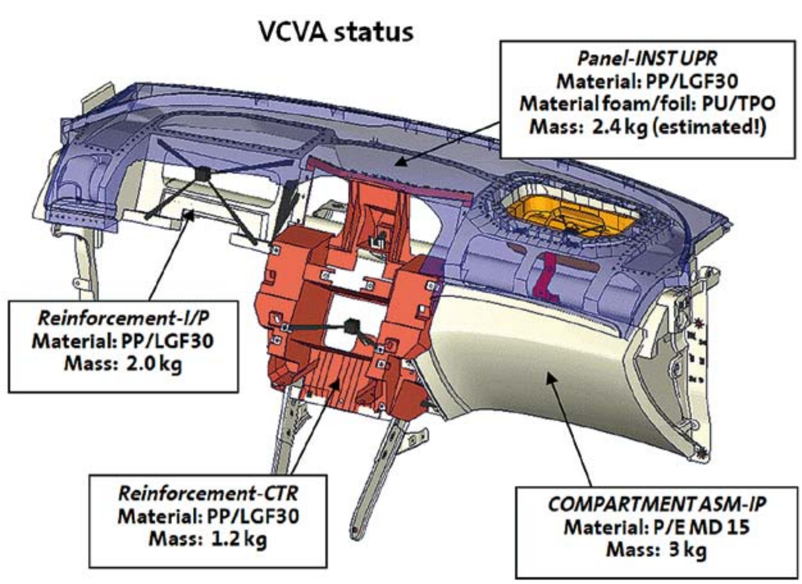

Figure 5: First IP simulation model of Opel Insignia – modal analysis

the areas for additional ribs and reinforcements can easily be identified. Since the modal analysis can start very early in the project, there are good chances to implement most of these reinforcements.

3 Transient Analysis

As the project progresses, CAD data matures and the simulation model becomes more detailed. The modal analysis is no longer capable to identify the differences between different design variants. In this stage of the design process the focus is often on the mounting points or the weld line configuration between the main structural parts in order to make sure that these parts are properly connected. When studying different mounting point concepts or weld line configurations, very often there is almost no difference either in frequency or in mode shape. However the difference can be made more clear by using the transient analysis looking at the relative displacement in the area of interest. For the transient analysis the vehicle is represented by a lumped mass, which is connected to a spring element. The spring element is grounded. The cockpit is included as a flexible model. A pulse is applied on the vehicle which gives a maximum acceleration of around 0.5 G. The deformation is calculated in time domain.

In the area of interest the relative displacement between two parts can be plotted, **Figure 6**. Even if the pulse magnitude is adapted to the normal road load (0.2 to 0.5 G) it is used rather in a sense of a unit pulse. Therefore the absolute value of the relative displacement is not of interest. This type of simulation is an A to B comparison between different design variants. The results rather indicate the percent change in relative displacement, see plot in Figure 6. The relative displacement is calculated in the global coordinate system. In that way different internal mounting point concepts or reinforcement variants can be optimized.

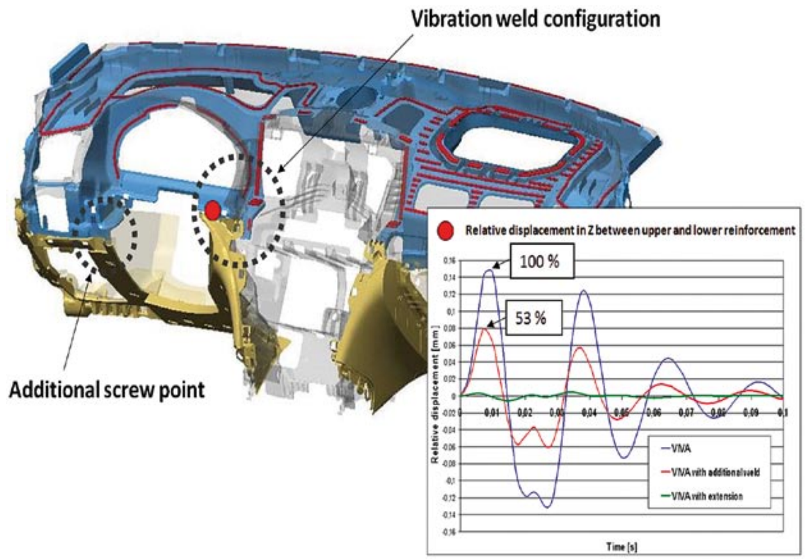

Figure 6: Relative displacement in global coordinate system in time domain due to a pulse

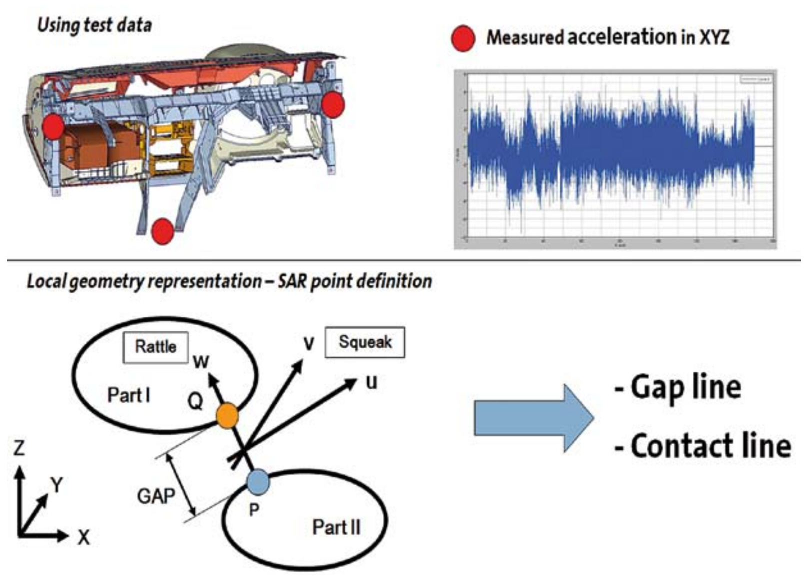

Figure 7: Using test data and SAR point definition

4 Frequency Response Analysis

The increasing detail level of the interior assembly finally enables to switch the focus to the areas where the S&R phenomenon is originated. In comparison to the transient analysis two additional steps are performed, **Figure 7**. The pulse is replaced by measured test data and instead of looking at the relative displacement in global coordinates so called S&R points (SAR point) are generated. The acceleration test data were recorded at three locations in the vehicle (right and left A-pillar and tunnel). These three points are close to the main mounting points of the cockpit assembly. The acceleration was measured in the global X, Y and Z and can be directly used in the frequency response analysis in NASTRAN (SOL 111) as input (TLOAD1). The result of the frequency response analysis is the deformation in the frequency domain, which is used as input for the S&R simulation in EdWare by EDAG.

The simulation process in EdWare contains several steps. First of all the model together with the result data from the frequency response analysis are imported. The SAR point definition is performed automatically. The SAR point describes the local contact geometry between two parts by defining a contact plane. The contact plane enables the definition of the relative displacement in

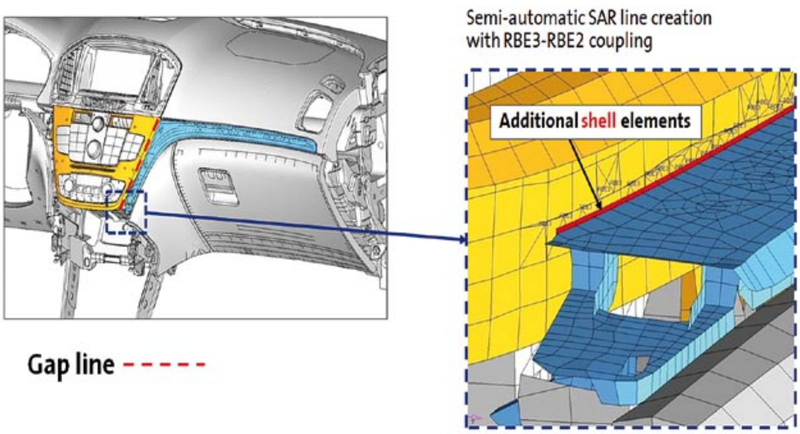

Figure 8: SAR evaluation line – local mesh refinement for the gap

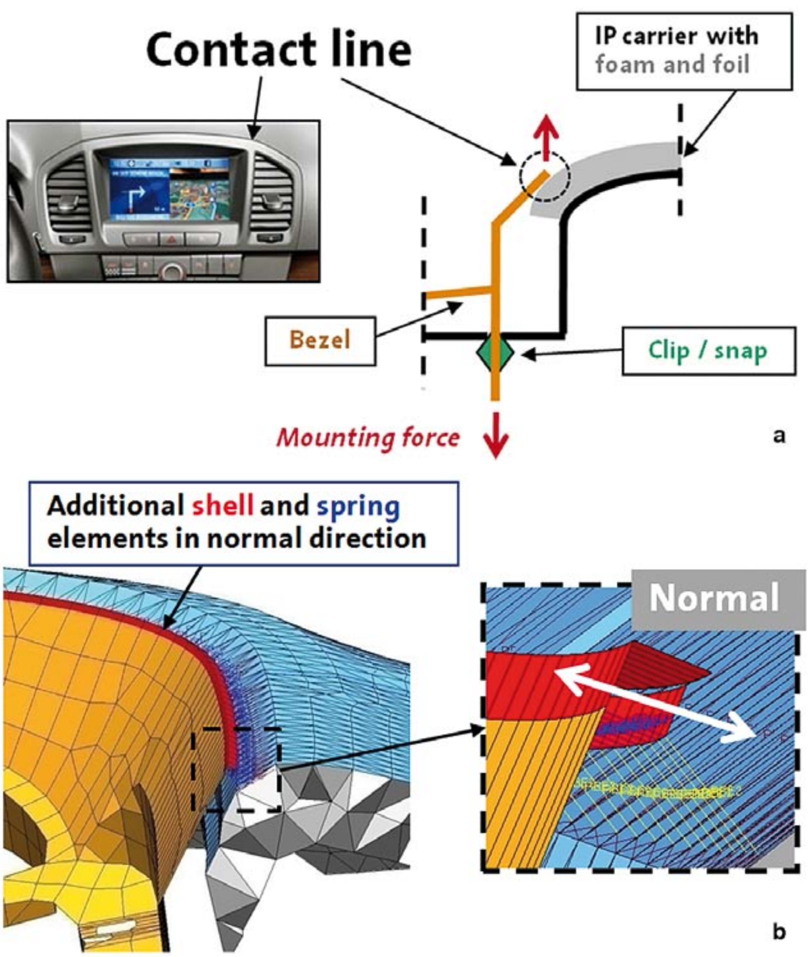

Figure 9: Mounting concept (a); local mesh refinement for contact line (b)

the plane (squeak) and the relative displacement normal to the plane (rattle), see Figure 7. EdWare calculates the imported deformation in frequency domain back into time domain, because the relative displacement can be evaluated only in time domain. Finally the SAR index is calculated for all SAR points and shown in the "Rattle contour map", where the SAR index is a dimensionless value. The algorithm behind this value is patented by EDAG. The main input values for the SAR index definition are the relative displacement, the relative velocity, the relative acceleration and the mass of the two parts. In the "Rattle contour map" the SAR index is finally normalized within the model, so the SAR points have a value between 0 and 1. The point with the Rattle index 1 has the highest risk for S&R. A ranking tool is included in EdWare in order to evaluate all SAR points in an effective way. The application of this procedure has been presented in several papers [2–4].

When using the tool for the cockpit simulation models at GME two issues became more and more clear. These issues are also described in some of the papers. The first point is the fact that it can be difficult to distinguish between relevant and irrelevant SAR points. An irrelevant SAR point is caused by the insufficient geometry representation through the simulation model. In this context it is important to mention that in case of an instrument panel even an element length of 3 mm can falsify the geometry in some critical areas. The second point is the normalized SAR index. Through this index it is not possible to compare the S&R performance between two different cockpit assemblies which is an important function when several cockpits are developed in parallel. These two issues led finally to the development of a new method called "SAR evaluation line".

5 Squeak & Rattle Evaluation Line

The SAR evaluation line contains two important points. The first one is the local mesh refinement of the gap/contact line between two parts. The second one is the usage of the relative displacement in mm as output value instead of the dimensionless SAR index.

5.1 Local Mesh Refinement

The local mesh refinement is performed by adding elements which represent the local contact geometry more exactly along the line. In that way all irrelevant points are avoided, so all points can be used for the S&R evaluation.

There are two configurations in principle when two parts are mounted together. Either there is a defined gap in between them or there is a defined contact line between both parts. Both configurations (gap and contact) have to be represented in the simulation model, see also Figure 7. On the left side of **Figure 8** a gap example between two trim parts is shown. On the right side Figure 8 shows the mesh refinement of the gap by adding shell elements. This mesh refinement enables a controlled SAR point definition along the gap line, so that all irrelevant SAR points are avoided.

Part a of **Figure 9** describes the contact line. The contact line is a part of the mounting concept. The clip force is acting in one direction and the force in the contact line is pointing in the opposite direction. The force in the contact line is a pretension force which keeps the part in place. This is a typical mounting concept for parts which are mounted in the foam and foil area. In order to represent this mounting concept with a linear model the following two assumptions have to be made: The pretension force along the contact line keeps the parts always in contact along this line. The background to this assumption is the fact, that the normal road load level is very low (0.2 to 0.5 G). The second assumption is the fact, that there is no friction between the parts along the contact line, which is a worst case assumption.

Based on these two assumptions the contact line can be modeled with CBUSH elements (spring stiffness only in normal direction). The relative displacement is evaluated in the contact plane ("squeak" direction), see part b of Figure 9. Also the local mesh refinement is shown which enables the contact line definition. Due to the coarse foam and foil mesh the contact line definition is not possible without this local mesh refinement.

5.2 Maximum Relative Displacement Along SAR Line

The SAR line definition enables the calculation and evaluation of the maximum relative displacement along the gap or contact line, which is shown in **Figure 10**. The maximum relative displacement in each SAR point is evaluated in its local coordinate system.

Since the maximum relative displacement in the contact areas has to be minimized in order to decrease the risk for S&R, this type of analysis result allows a number of interesting parameter studies.

The relative displacement can be studied as a function of the following parameters: first global eigen frequency, load set measured on different test tracks with different velocities, number and position of mounting points. An additional parameter is the relative displacement itself along the line. Beside the aim to decrease the absolute value, the equalization of the relative displacement along the line is also to prefer from a structural perspective. These parameter studies enable a much more differentiated assessment of the interior assembly. More over the relative displacement along the line as a physical output value is very easy to communicate to the project, especially to the design team and it is also very similar to the S&R physical test approach. This new output value also allows the comparison between different interior assemblies regarding the S&R performance.

Finally the relative displacement has to be related to the actual S&R phenomenon. In case of the gap line the relation is straight forward. By adding all tolerances (including tolerances due to temperature load) to the calculated maximum relative displacement the distance to the nominal gap can be identified. As long as the gap is not closed, there is no risk for rattle.

In case of the contact line the results from the physical S&R test are needed in order to define this relation. All cockpits are tested on a Z-shaker with a defined reference signal as input (power spectral density, PSD). A subjective rating of the S&R performance of the complete assembly is performed. The S&R test report shows all contact areas where a squeak or a rattle occurs. The same reference signal (PSD) used for the S&R test as defined in the SSTS can be used for the load definition in the simulation. In that way the identified S&R phenomenon in a certain area of the real assembly can be related to the calculated relative displacement in the same area of the virtual assembly. In this case it is also important to document the material pair. This information about the relation between the simulated relative displacement and the identified S&R phenomenon is a very valuable database for future interior design projects.

In this context it is important to mention that the simulated relative output data like displacement, velocity and acceleration cannot be used to describe the real S&R mechanism in detail [5]. Based on the results of the modal correlation (only the lowest modes correlate) the relation between the simulated output data and the actual S&R issues is still a "global" relation. In future when the simulation capability will increase (e.g. by using nonlinear models) this relation will become more physical.

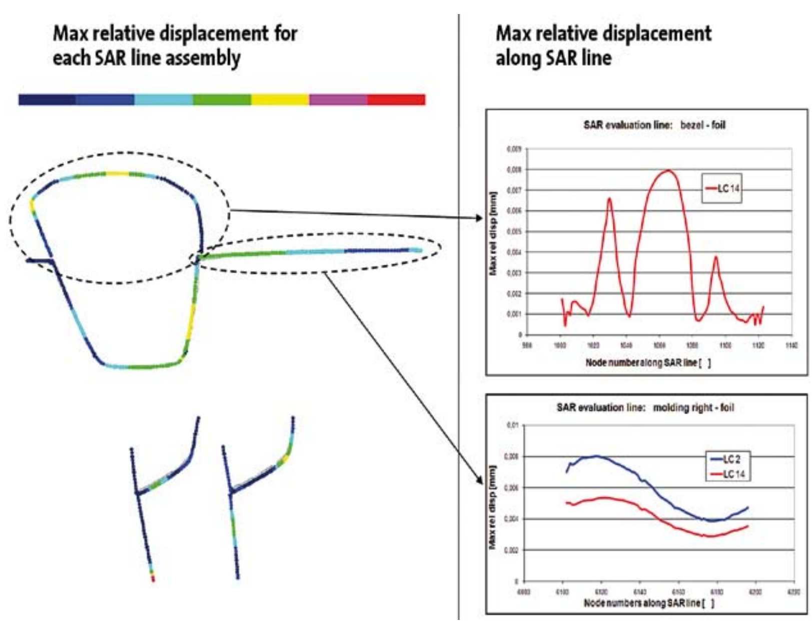

Figure 10: Max relative displacement along SAR line

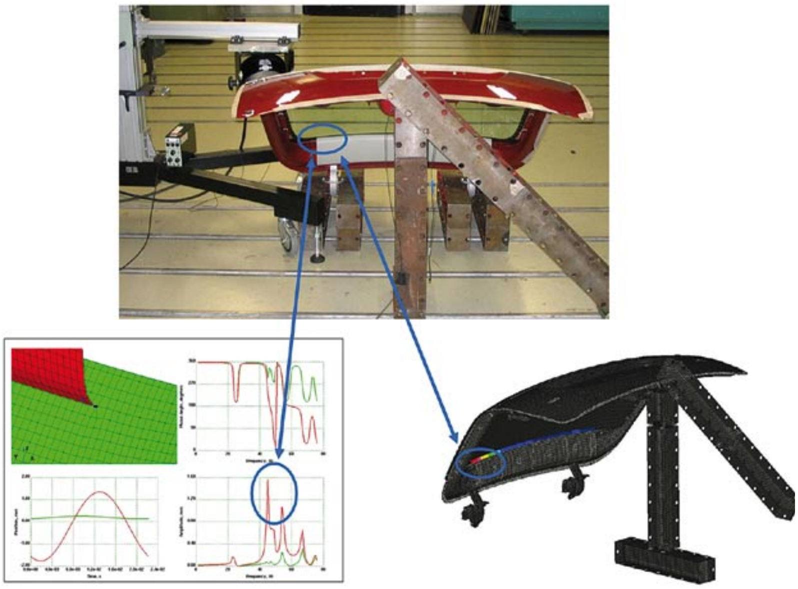

Figure 11: Squeak & Rattle correlation between test and simulation

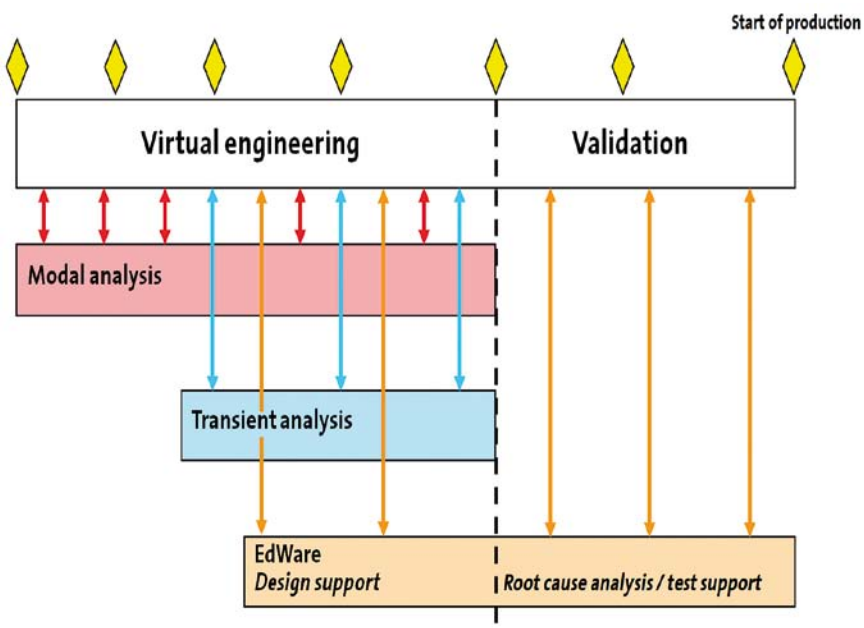

Figure 12: Squeak & Rattle simulation in the interior design process

6 Squeak & Rattle Correlation

Figure 11 shows a test installation with a tailgate and a plastic trim part. With well defined boundary conditions a clear rattle sound could be generated between the trim part and the windscreen of the tailgate. The test was performed in the same way in the simulation and it was possible to identify the correct rattle location and frequency with the simulation result [6]. The main result of this correlation was to describe and highlight the sensitivity between the S&R simulation result (location and frequency) and the simulation model quality. Therefore it is very important to represent the model parameters – as global and local stiffness, clip and snap stiffness, contact geometry, load definition (see also Figure 2) – as good as possible in order to be able to simulate the S&R phenomenon.

The presented simulation output – as modal shape and frequency, relative displacement in global coordinate system (CS), relative displacement in local CS along a SAR line and finally the SAR index – enables increasing focus on an ever more detailed FE model. The increased focus requires also an increased simulation model quality which is represented by the above mentioned model parameters, see Figure 2.

7 Interior Design Process

Three different types of analysis tools are presented in this paper. Figure 12 shows how these tools can be applied during the design process of interior assemblies. The modal analysis can be performed as soon as a rough geometry of the main structural parts is available. When the assembly becomes more detailed the transient analysis can be used to study the relative displacement in order to optimize the internal mounting point concept. Finally the S&R simulation is performed on the complete detailed model using the SAR evaluation line. The main aim of this simulation work is to get a more robust structure regarding S&R issues when the validation phase starts. The S&R issues which are identified during the validation can be solved more effectively with the knowledge of the simulation work due to a deeper understanding of the root causes.

8 Conclusions

The main aim of the S&R simulation is to represent the dynamic behavior of the interior structure as accurately as possible in order to be able to relate the relative displacement to the actual S&R phenomenon. The results of the modal correlation show that the linear simulation model is capable to calculate the lowest global modes correctly using improved plastic material data (unsatisfactory correlation for higher order modes). This capability also makes the modal analysis a powerful tool to support the interior design process at an early stage. In order to improve the modal correlation on a local level a 3D Scanning Vibrometer is used for measuring the dynamic behavior of the interior parts. This correlation will lead to a better un-

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derstanding of how to assemble the interior parts in the most correct way in a linear simulation model.

By applying a pulse (transient analysis) on the interior structure the relative displacement can be evaluated between the main structural parts of the interior assembly. This type of analysis is very useful when the design has matured but not reached the final detailed level.

The final detailed level is needed for the S&R simulation. A new method – called SAR evaluation line – has been developed by using the S&R software EdWare (EDAG). With this new method the relative displacement along a gap/contact line can be evaluated which enables a wide range of parameter studies. The relative displacement itself can be related to the S&R phenomenon. This relation is still on a global model level, but it will become more physical when the simulation capability will increase in the future. This new method allows both the definition of a clear S&R design requirement (max relative displacement in mm along a SAR line) and a considerably more differentiated assessment of the design status.

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