Model Set up and Analysis tools for Squeak and Rattle in LS-DYNA®

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Abstract

One of the most important quality aspects during the design process of a vehicle is the provided occupant comfort. Comfort in a vehicle is achieved, among others, through a quiet and durable interior, and through the elimination of Squeak and Rattle noises. A huge amount of different tests take place in laboratories in order to produce interior and exterior components that eliminate the occurrence of such undesirable phenomena. As a result, developing numerical models that explain and predict the behavior of a vehicle in Squeak and Rattle is important. The implementation of automated tools benefits analysts in setting up efficient and robust processes for accurate and straightforward CAE simulations.

A simulation method that is used for the Squeak and Rattle numerical analysis is the E-LINE method which focuses on calculating and evaluating the relative displacement between two components in the time domain. Based on this method BETA CAE Systems in cooperation with Volvo Cars has developed a set of special tools in ANSA pre-processor and μETA post-processor for identifying the crucial areas, setting up the LS-DYNA E-LINE model definitions for them, and finally evaluating the corresponding LS-DYNA implicit results.

The current paper dives deep in E-LINE method by showing both interior and exterior examples. In addition, it presents the BETA CAE Systems automated tools that offer a complete and effective solution in Squeak and Rattle analysis using LS-DYNA, minimizing simulation time consumption and human interaction.

Introduction

Squeak and Rattle are two undesirable phenomena that directly influence the acoustic comfort for car passengers and consequently the premium perception of a car. The main cause for S&R is the relative displacement between two components and in order to decrease the risk for S&R, simulations are performed during the virtual phase of the vehicle development.

There are many examples for S&R noises in a car such as the typical door panel rattling, due to a loud speaker excitation, or the door sealing squeak noise, due to the body twist e.g. when driving over a sidewalk edge.

For the squeak noise, a huge amount of stick slip tests is performed in the laboratory to provide useful data regarding the material compatibility on squeak level. Yet, the relative displacement due to static/dynamic excitation needs to be evaluated in order to assess the risk for the squeak.

To identify the rattling risk, many hours are consumed on the CAD data to identify all the interfaces where the rattle noise can occur. This work however, covers only a part of the real rattle issue because the excitation into the system, when driving the car can close many gaps which have not been identified during the CAD check.

Taking into account the aforementioned, the implementation of a powerful tool during the virtual phase is required. By combining the CAD check with the S&R simulation, the input to the design department becomes more qualified and understandable during the virtual development phase when the designer needs to take the complete spectrum of requirements into account from all other attributes to find the best solution. Moreover, a number of S&R relevant load cases e.g. closure slam can be simulated during the virtual phase. This simulation task can save a lot of cost and time during the start of the production phase.

At Volvo Cars, E-LINE method is applied during the virtual phase of the vehicle development to simulate/calculate the relative displacement. Interactively, the simulation results are communicated to the designers to improve the structure and finally produce a better result in terms of S&R performance.

This paper partly focuses on E-LINE theory method as well as on a detailed description of setting up the model in ANSA, solving the modal transient analysis using LS-DYNA, and the various post-processing features available in μETA post for evaluating the time domain data.

E-LINE Method

E-LINE is a simulation procedure which can be applied on different finite element solutions to calculate and evaluate the relative displacement in the time domain due to any signal [1]. In addition, the method can be used for the evaluation of static S&R. To enable an effective evaluation of the relative displacement, node pairs are defined along a 3D curve, which is located between the two parts. Each node pair has its own local coordinate system in order to capture the local gap geometry, see Figure 1.

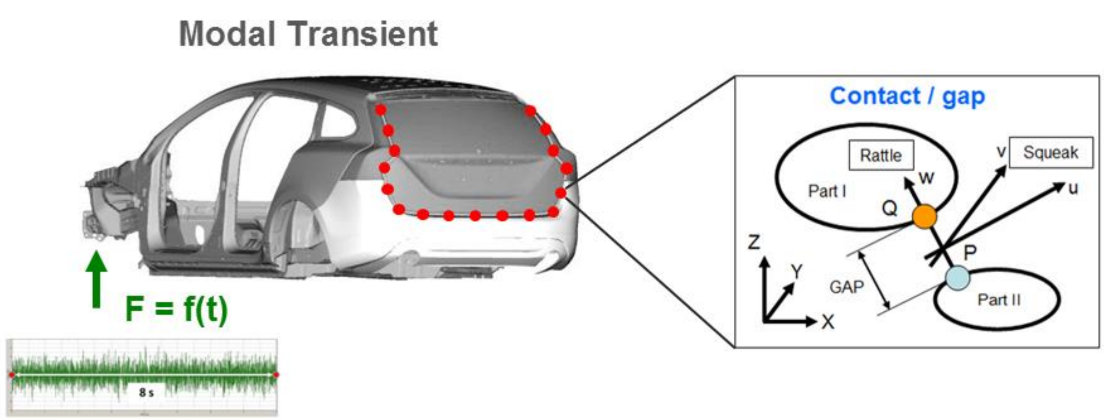


Figure 1. E-LINE for the Modal Transient Analysis

The Rattle direction w is the closest distance between the two parts whereas squeak plane is the uv plane according to the E-LINE local coordinate system, see Figure 1. The advantage of using the local coordinate system is that it always follows the geometry of the gap/line which makes the S&R assessment consistent. The evaluation is performed in the time domain as both the phase and amplitude data are essential for relative displacement assessment.

E-LINE was first introduced in 2010 at the ISNVH conference in Graz by the name SAR-LINE with a focus on simulation. In 2012, it was presented again at the ISNVH conference but with a focus on how to correlate the simulation results to a real squeak or rattle issue [1]. Many features have been added to E-LINE since then and are elaborated below.

Time domain evaluation can be a challenging task because the time aspect for the entire signal cannot be captured considering the max value of a response. Therefore the statistical approach is a part of the E-LINE method. This E-LINE feature provides a robust evaluation on the modal transient response output by ranking the amplitudes of a certain percentage of the highest values and then calculating the mean value (statistical evaluation parameter, SEP) to be finally compared with the S&R limit. Figure 2 illustrates this process. In order to perform the rattle assessment one needs to compare the tolerance data (GD&T) with the outcome from the statistical approach from E-LINE. For the squeak assessment, the stick-slip results are compared with the max principal peak to peak result from E-LINE [2].

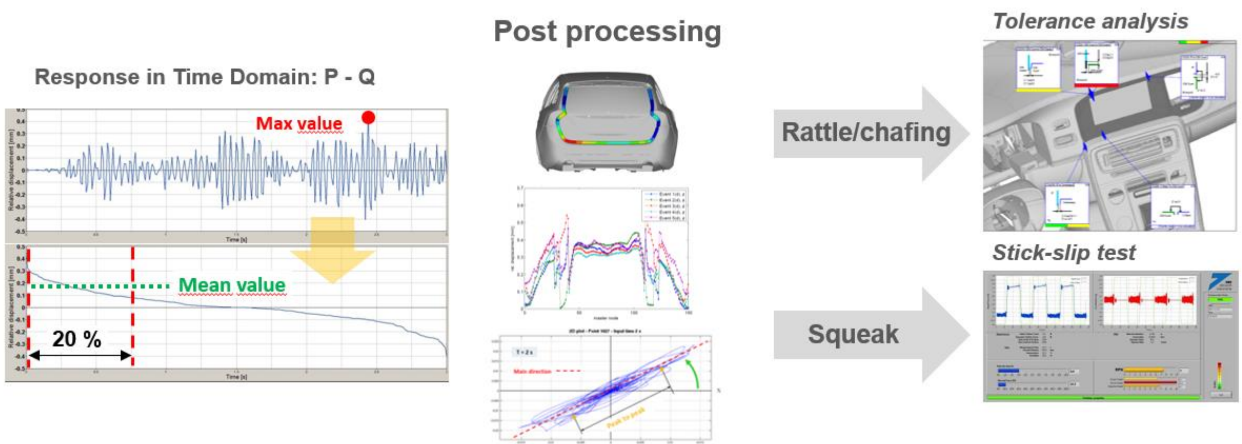


Figure 2. Evaluating the S&R using E-LINE Statistical Approach [2]

Another useful feature from E-LINE method is the relative modal contribution feature (RMC) which shows the contribution of each mode to the relative displacement and can be used on three different levels [3]:

1. Relative Modal Contribution per peak
2. E-Point Average
3. E-LINE Average

The RMC per peak helps the user to identify the most contributing modes for a single node pair of an E-LINE. The modal composition of the highest peaks in terms of relative modal contributions is presented for this single node pair.

The time average (or E-Point average) includes the statistical approach (SEP) when presenting the modal composition still at a single node pair.

The topology average (or E-LINE average) takes instead of a single point all the points along the line into account, so that the modal composition of the complete line is presented.

Complete vehicle simulation procedure

The complete vehicle simulation, which is performed to calculate the fatigue, can be integrated with the E-LINE method. Instead of outputting the stress data, the relative displacement is requested for all S&R critical interior and exterior interfaces. For this complete vehicle simulation the time history of all forces between the chassis and the body are needed. These forces can be either calculated by a Multi-Body Simulation, or recorded in a complete vehicle test on different test tracks. All the forces then can be applied on a trimmed body model in order to run a modal transient analysis. The output from this analysis is the displacement, which is the input for the E-LINE evaluation in μETA Post. At Volvo Cars this procedure is fully automated. An overview of the entire steps is presented in Figure 3.

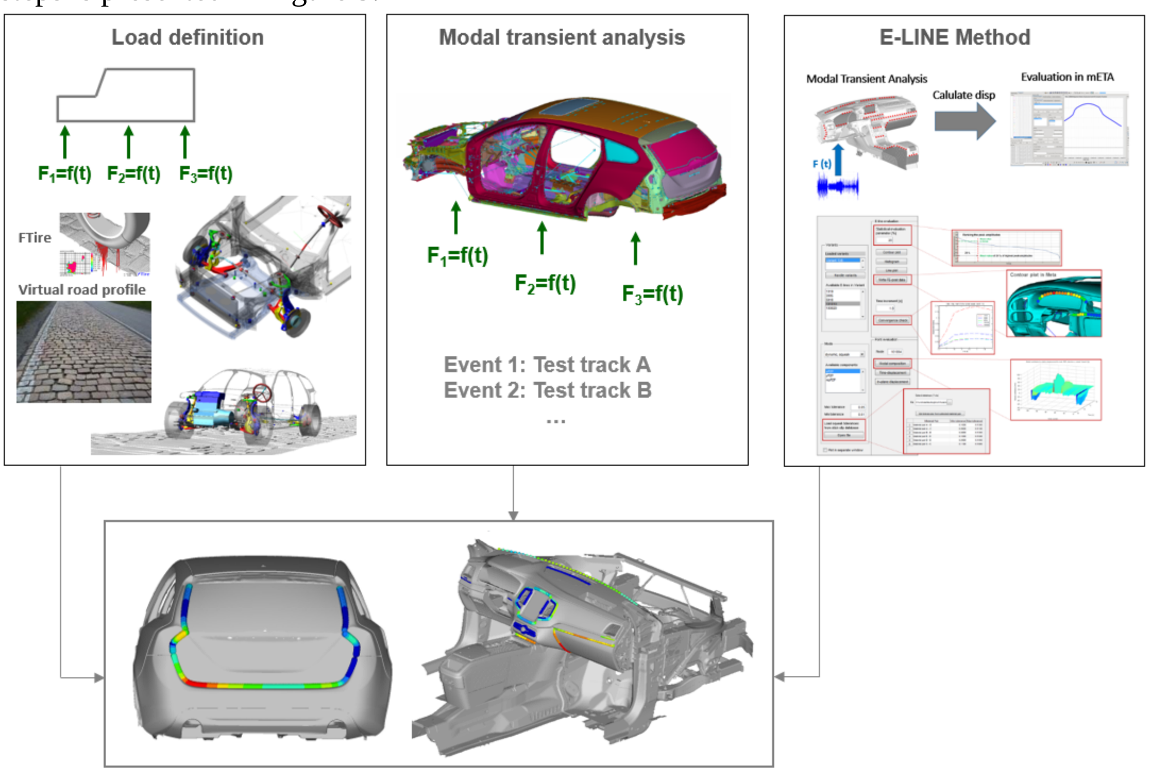


Figure 3. Complete Vehicle Simulation using E-LINE Method [3]

Besides the complete vehicle simulation, there are numerous other load cases that need to be simulated for S&R evaluation such as, static and closure slam analysis as well as simulations for the music load case and the quiet shaker table.

At Volvo Cars, the Solidity department is mainly responsible for the S&R analysis. Looking at all CAE activities supporting the virtual vehicle development, this type of analysis can be placed somewhere in between NVH and Durability. While Durability mainly focuses on evaluating stress in the time domain and NVH on calculating displacement in frequency domain, Solidity CAE is evaluating displacement in time domain. Based on collecting all Solidity relevant load cases (static, dynamic, E-LINE) a new CAE area has been established as shown in Figure 4.

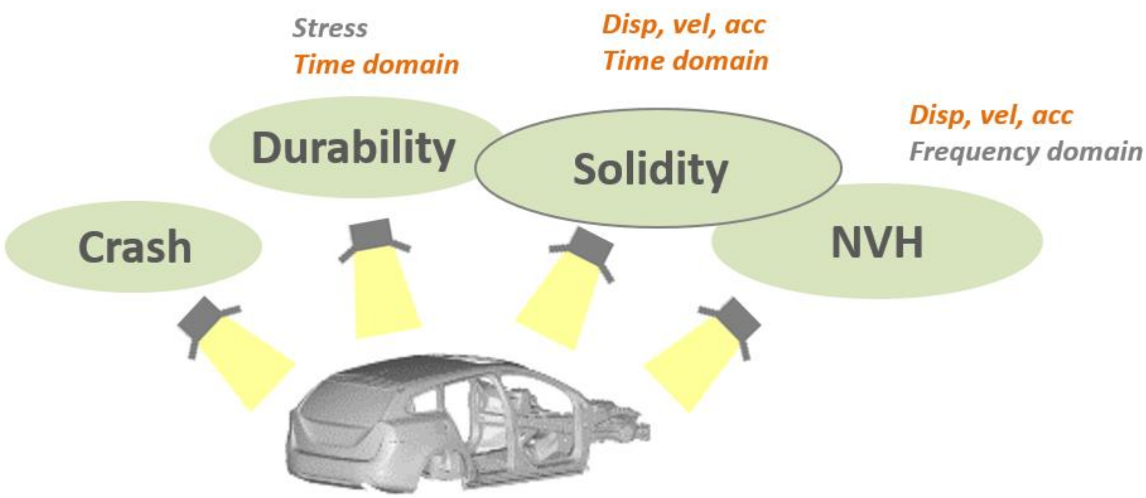


Figure 4. Solidity Department at Volvo Cars

Correlation study

To examine the reliability of the E-LINE method a correlation study has been performed. The target for the correlation study was to compare the relative displacement between test and simulation. As an example, the tailgate gap of a Volvo V60 was chosen. The displacement on both sides of the tailgate gap was measured with a 3D Laser Vibrometer (Polytec) [4], see Figure 5.

Figure 5. Measurement of Relative Displacement using the RoboVib from Polytech

Afterwards, the displacement was simulated at the same points and with the same excitation. The results from both test and simulation were used to perform a correlation in time domain by using the E-LINE approach.

Figure 6 shows a very good correlation between the test and the simulation for all three local directions of the relative displacement, which indicates the reliability of the method.

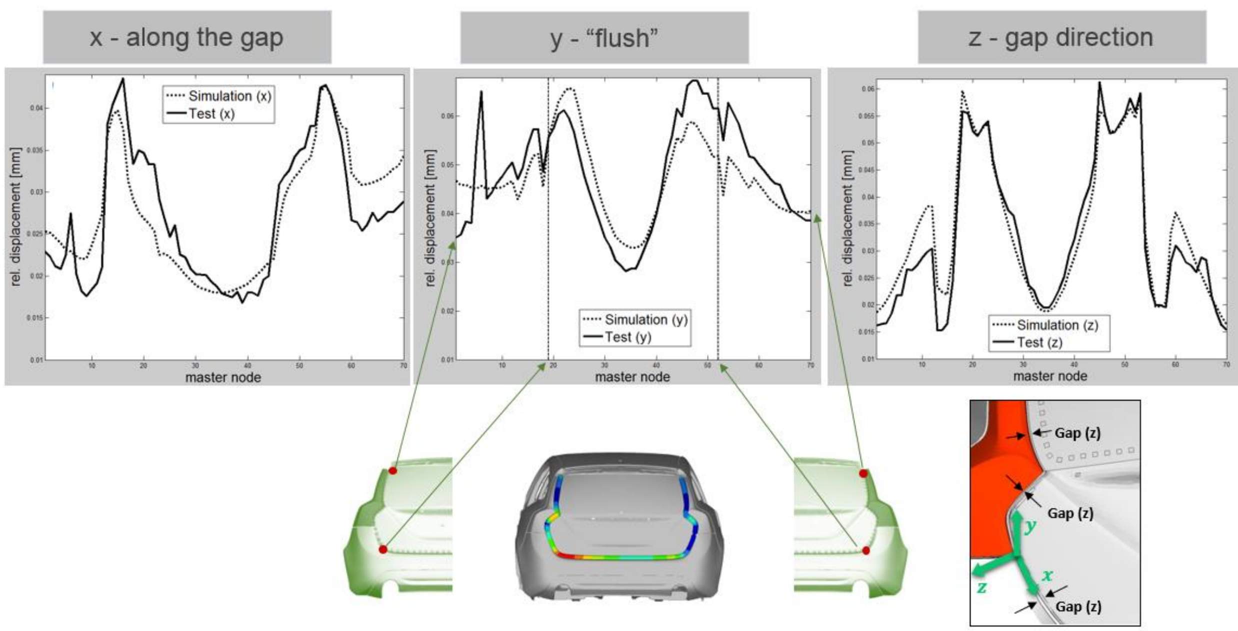


Figure 6. E-LINE correlation in all local directions for the tailgate [4]

E-LINE applications

When integrating this type of simulation into the daily design work it is important both to follow the pace of virtual development and to give a clear input to design. Based on this interaction between CAE and design, a continuous improvement during the virtual development phase can be achieved.

The relative displacement between the spoiler and the rear window has been simulated in order to calculate the minimum gap dimension to avoid rattle, see Figure 7. Several mounting concepts of the spoiler and also different temperature loads where included in the study.

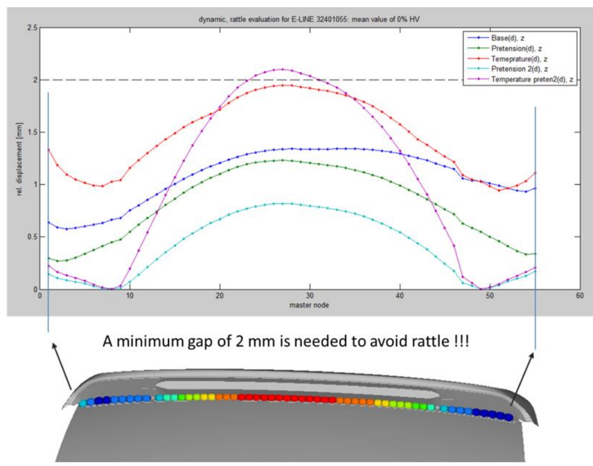


Figure 7. Critical rattle interface, spoiler versus rear window

A typical squeak example is shown in Figure 8, where the interface between the vent outlet and the decor panel has been studied. The material combination of both parts is stick-slip sensitive and by comparing it with the E-LINE results a clear risk for squeak was identified. To achieve a squeak free design a more robust reference point was suggested to insure a clear gap between both parts.

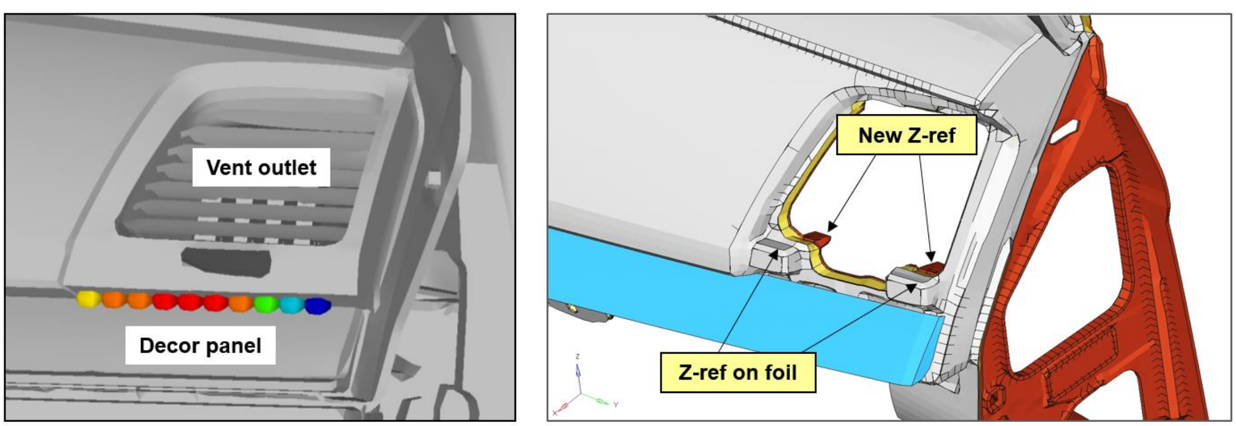


Figure 8. Critical interface for squeak, vent outlet vs decor panel

Creation of E-LINEs in ANSA

As it has been explained above, due to the huge amount of different tests that take place in laboratories, on interior and exterior components of vehicles, various numerical simulations have to be executed. The simulation for Squeak and Rattle analysis according to the method, explained in the current paper, is based on the E-LINEs. An E-LINE in ANSA is a 3D curve between two components, along which their relative displacement is evaluated under a specific load [5], see Figure 9.

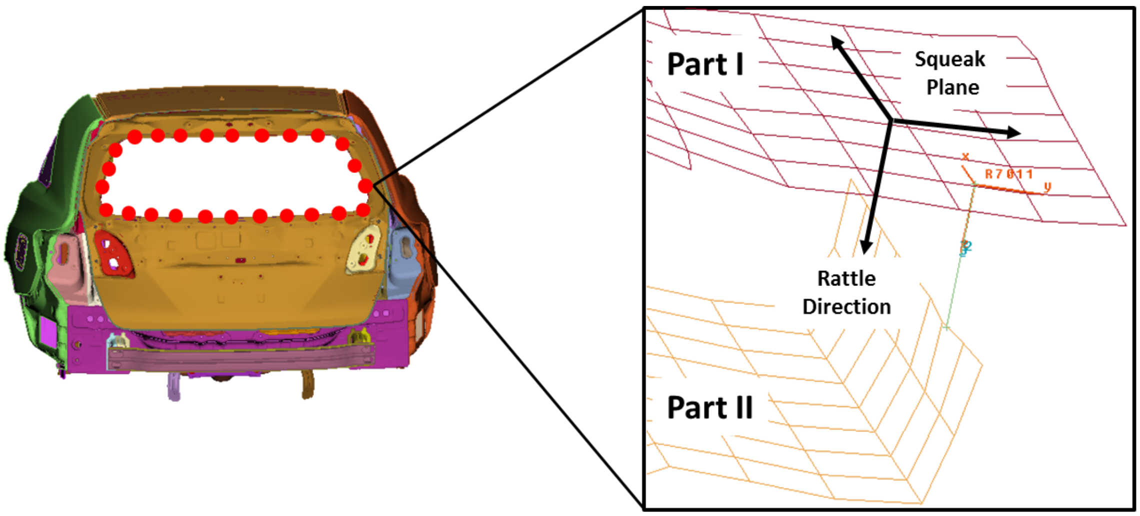


Figure 9. E-LINE detail between two components (Parts) in ANSA

The areas in a simulation model where E-LINEs are created are selected according to the areas that are mainly tested in the laboratory processes. However, the analyst may try to evaluate new areas to identify other crucial, for Squeak and Rattle components. For this reason, the ANSA pre-processor offers a functionality to select the areas of interest and build the corresponding E-LINEs manually. Moreover, analysts can employ the automated tool to identify and create automatically all possible E-LINEs in a complete model. In this way, the analyst can save a considerable amount of time from isolating components and examining each combination of components separately.

E-LINEs Manager

Once the user has defined the E-LINEs in the desired areas, one of the major aspects in Squeak and Rattle analysis is the control and manipulation of those numerous 3D curves. The definition of an E-LINE has to do with the input of some important data for the measurement of the relative displacement of the respective components. The information that is stored to each of these entities explained, corresponds to the connectivity (pair of components examined), the phenomenon that is measured (Squeak or Rattle), the detail of measurement (distance between two consecutive measurements) and finally the numbering rules that are necessary for a CAE simulation model [5].

For this reason ANSA has implemented a special tool that offers analysts a compact and user friendly interface for the general handling of the E-LINEs. Specifically, the E-LINEs Manager of ANSA [5], through its interface, can guide the user to define easily the needed settings for each E-LINE. Moreover, it offers the ability of a bulk production of the respective FE-Representations, see Figure 10. These representations correspond to the LS-DYNA keywords that will be finally solved for the calculation of the relative displacement.

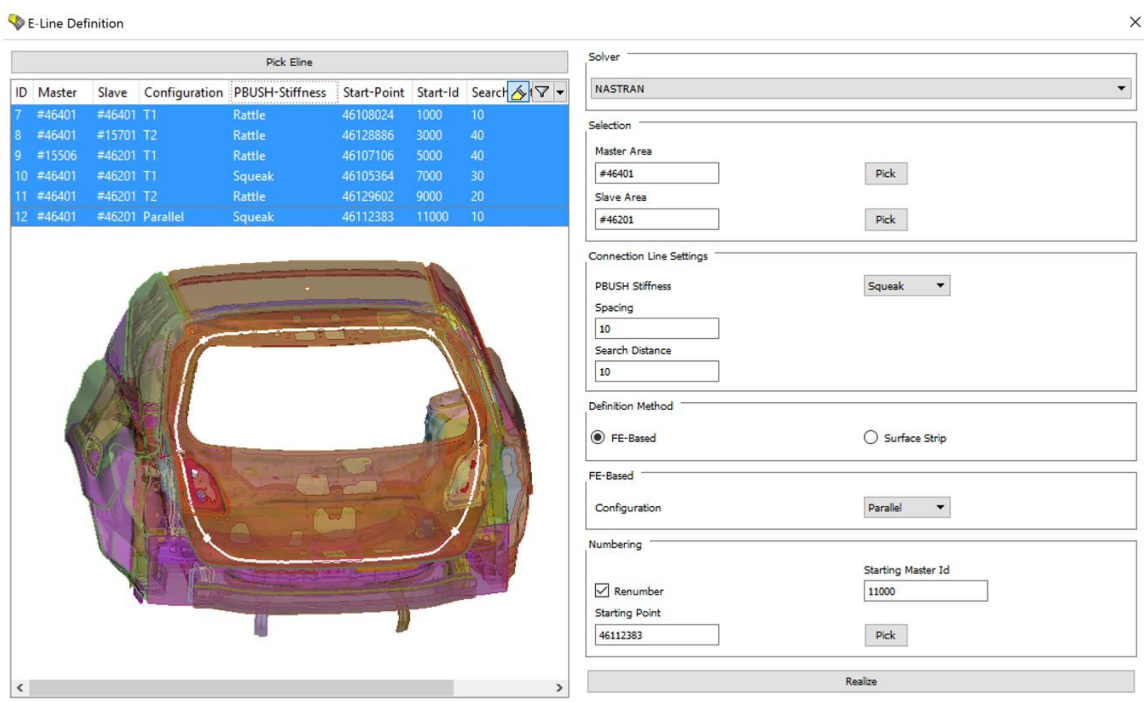


Figure 10. E-LINE Manager in ANSA

LS-DYNA keywords for E-LINE Method

The final step for setting up the CAE model for Squeak and Rattle analysis is the realization of the E-LINEs. The realization of an E-LINE is the creation of the LS-DYNA keywords which enable the analyst to measure the relative displacement between two components along an E-LINE.

E-LINEs Manager creates automatically, according to the user input, the ELEMENT_BEAM [7] of SECTION_ELFORM_6 [7] whose nodes will give the desired measurement. In order to have a local measurement, *DEFINE_COORD [7] keywords are created referencing the corresponding SECTIONs. These Coordinate Systems are oriented according to the local surfaces of the components so as to give measurements vertical to the surfaces for calculating Rattle and parallel to the local surface (plane) for Squeak respectively. The nodes of the ELEMENT_BEAMs [7] are tied on the components surfaces through a *CONTACT [7] of type TIED_NODES_TO_SURFACE [7].

Finally, in order to be able to keep track of those local measurements in the post processing, LS-DYNA *DATABASE_HISTORY_ NODE [7] keywords are created for all the ELEMENT_BEAM [7] nodes.

Post - Processing in μETA

As soon as the solution has taken place in LS-DYNA, what follows, is the evaluation of the corresponding results. Having in mind that the ultimate goal is to measure the relative displacement along the gap between two components (E-LINE), the analyst needs to find ways of how the representation of the results will be as accurate and as informative as it could be.

The μETA post-processor offers the ability through a special tool, the Squeak and Rattle toolbar [6], to present, in various ways, the results of the solved LS-DYNA model. 2D plots and histograms of the relative displacement either for a specific pair of nodes or for the whole E-LINE can be created. Moreover, contour and vector plots offer the representation of the results on the 3D model. Finally, reports can be automatically created to inform the analyst if phenomena of Squeak and Rattle exist in the simulation model.

Plot the Relative Displacement

The first way to offer the analyst a clear view of the results is the creation of 2D-plots [6]. Using the μETA Squeak and Rattle toolbar, the analyst can plot massively for all selected E-LINEs, the relative displacement between all the corresponding pairs of nodes, see Figure 11. As a result, one can have an overview of how a specific phenomenon, either Squeak or Rattle, is developed along the gap between two components.

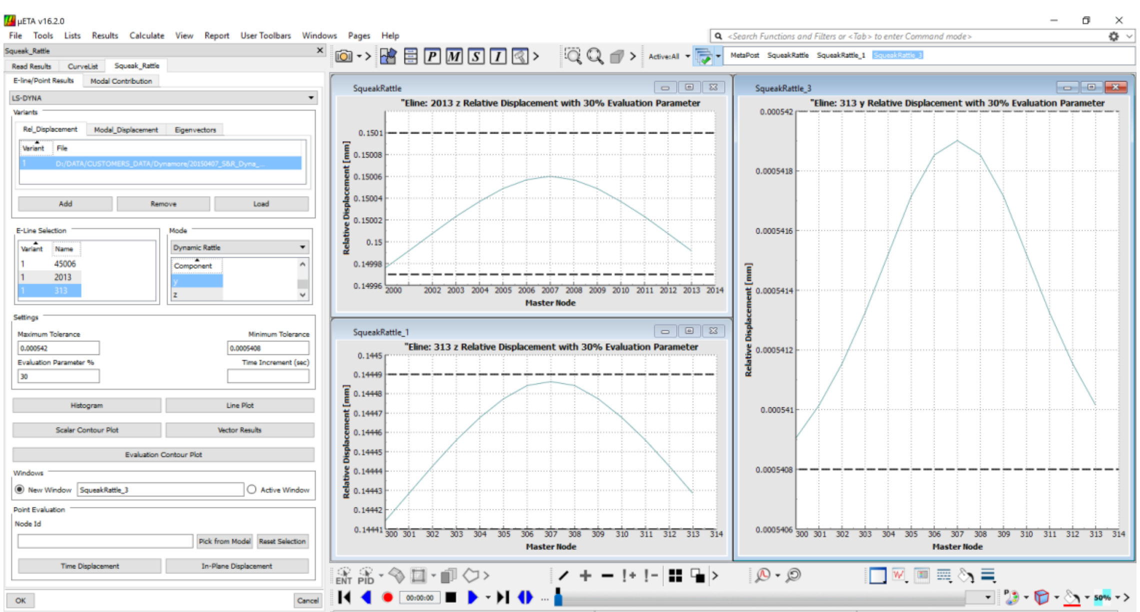


Figure 11. Plot of Relative Displacement in μETA

Contour and Vector Plots

Apart from building diagrams with the behavior of relative displacement, another functionality which is really important for Squeak and Rattle analysis is the interaction with the 3D model. Once the user has loaded the geometry of the simulation model in μETA, the Squeak and Rattle toolbar enables the analyst to select the desired E-LINEs and have the geometry in contour or vector plot [6] according to the respective results of relative displacement, see Figure 12. This way there is a direct demonstration of the results on the components of interest.

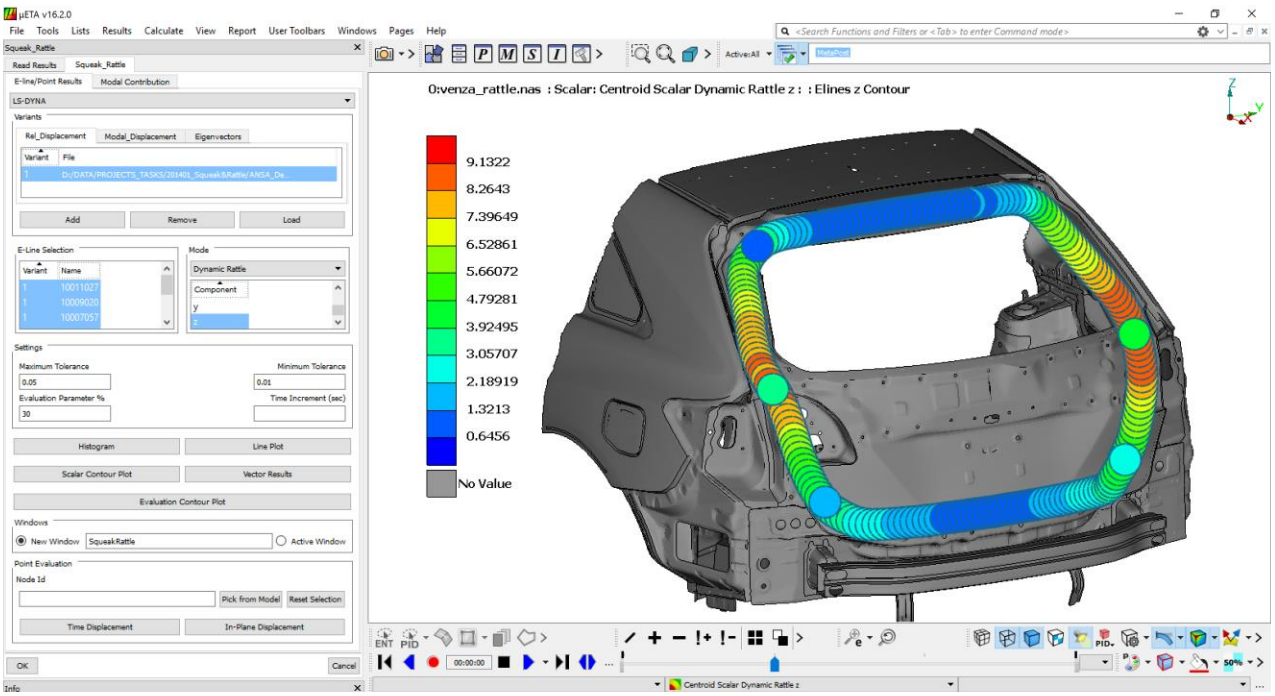
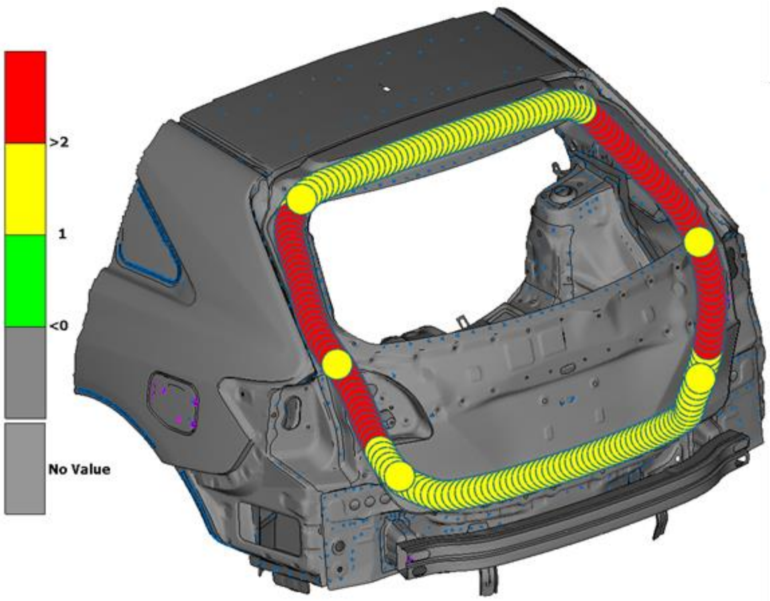


Figure 12. Contour Plot of Relative Displacement in μETA

Evaluation Contour and Report

Taking into account a full vehicle analysis, where the simulation model contains all the components of the vehicle, a huge number of E-LINEs may exist. In such cases (and not only), the analyst needs a quick way to identify which are the most crucial areas to focus on, either on the 3D model or through a compact report [6]. μETA Squeak and Rattle toolbar offers the ability to run on a full model analysis and produce a contour plot having the Squeak and Rattle limits as criteria to assess the calculated relative displacement. These criteria come from the stick-slip test and the tolerance analysis (GD&T). Based on that a green, yellow and red plot will be generated, see Figure 13. In this way, the analyst can have instantly a general overview of the results.



Evaluation Dynamic Rattle z

Eline Id	Nodes Ids	Evaluation
10011027	10011000-10011027	
10007057	10007000-10007057	
10005019	10005000-10005019	
10003027	10003000-10003027	
10001048	10001000-10001048	
10009020	10009000-10009020	

Figure 13. Evaluation Contour and μETA Report

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