A tool in LS-PrePost for Buzz, Squeak and Rattle analyses

A frequency domain approach using Ansys LS-DYNA software and LS-PrePost

Overview

- What is BSR?
- Analysis of BSR
- The E-line method
- BSR Evaluation in LS-PrePost
- An application example
  - The Toyota Camry IP (based on a public FE-model by Center for Collision Safety and Analysis at the George Mason University, their original work is gratefully acknowledged)
- Summary and outlook

Buzz, Squeak and Rattle

- Buzz and rattle noise is basically the same thing: Two structures repeatedly collide with each other, emitting noise. If the noise is perceived as buzz or rattle is subjective. The limit when noise goes from rattle to buzz may be somewhere in the range of 30-60 Hz. Think of the humming sound of a bad 50Hz electric transformer to a fluorescent lamp. Most people would probably consider that as buzz sound. Rattle snakes can on the other hand make tail vibrations up to 90 Hz.

- Squeak sound may occur when two parts are rubbed against each other and a relatively complicated stick/slip phenomena occurs in the contact interface. The stick/slip squeak sound is in the range of 200-10000 Hz but may be induced by oscillations at a *much* lower frequency. Consider that a single speed bump can cause a squeaking noise in a car.

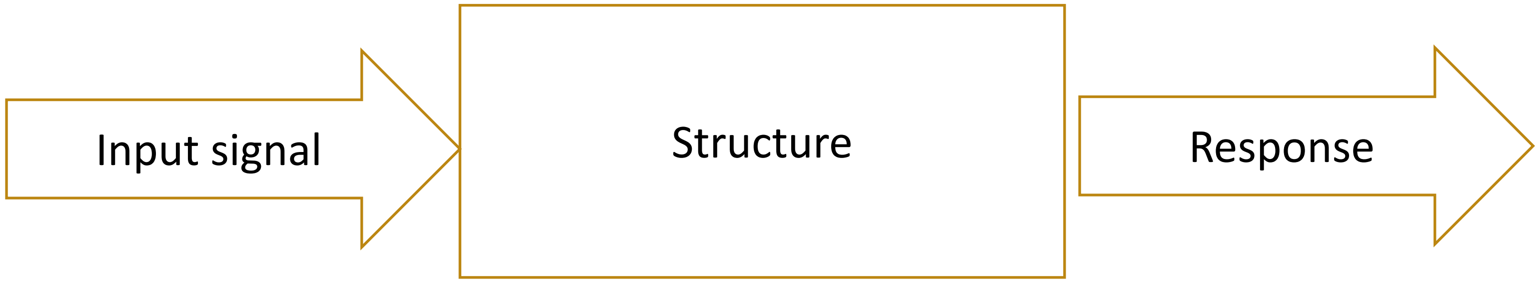
Buzz, Squeak and Rattle

- Vehicle / automotive applications, often comfort related
  - Parts in the Instrument Panel rub against each other, causing a squeak
  - Parts in the interior trim shake and collide, causing rattle
  - Or in a city bus where the whole interior starts to shake and vibrate

- Annoying, irritating noises
- Causing unhappy customers
- If a premium product is the target, it's important to avoid BSR

- Other types of squeak
  - Brake squeal
  - Belt transmissions (engine)
  - Squealing in for example railway applications (normally not included in BSR)

Buzz, Squeak and Rattle Analysis

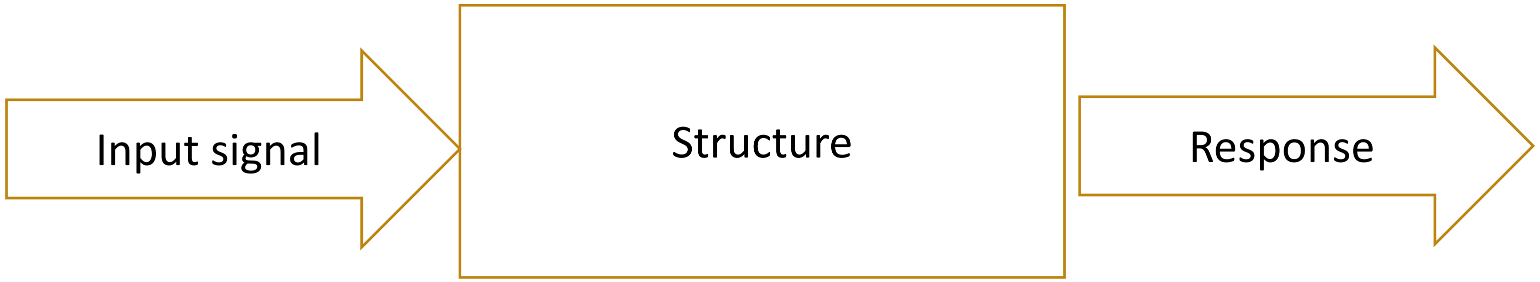


- Road-induced vibration
- Engine vibrations
- Aerodynamic loads
- ...

- Suspension system
- BiW
- Trim
- Instrument panel
- Seats
- etc.
- Non-linear contacts

- BSR Evaluation based on the structural response

Buzz, Squeak and Rattle Analysis Challenges

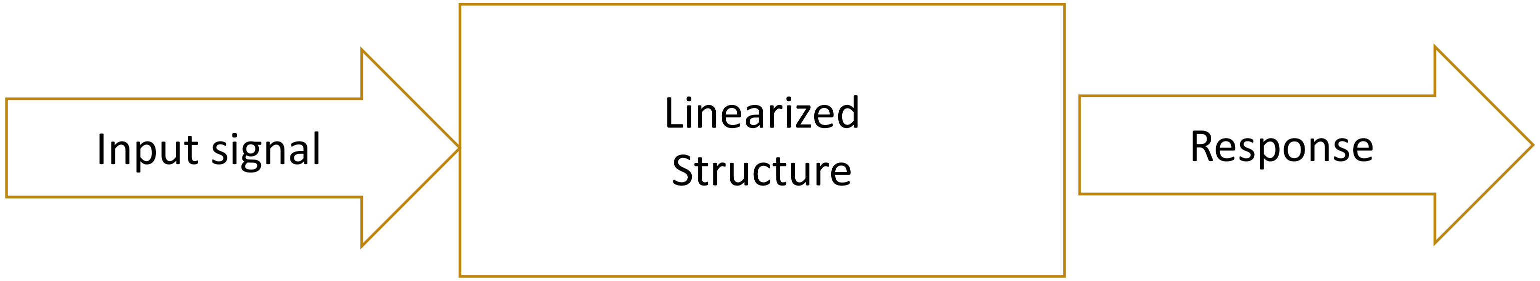


- Unknown input signals
- Variations
- Long duration

- Variations in geometry (tolerances)
- Non-linear transient analysis including contacts may be very time consuming
- Input to friction models may require testing

- BSR Response depends on surface texture, surface treatment, friction etc.

Buzz, Squeak and Rattle Analysis in Practice



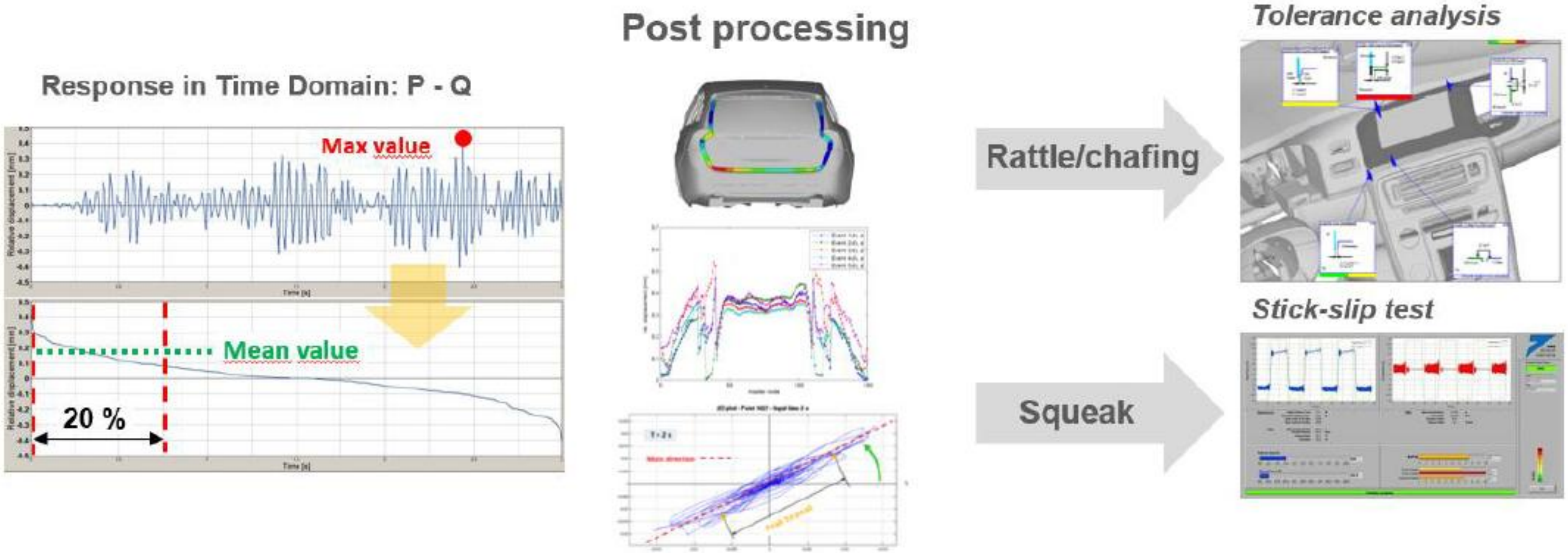
- Representative signal

- Modal basis
- Linear transient analysis, or
- Frequency response analysis

- Empirical BSR evaluation based on
  - component testin
  - previous experience

The E-line Method

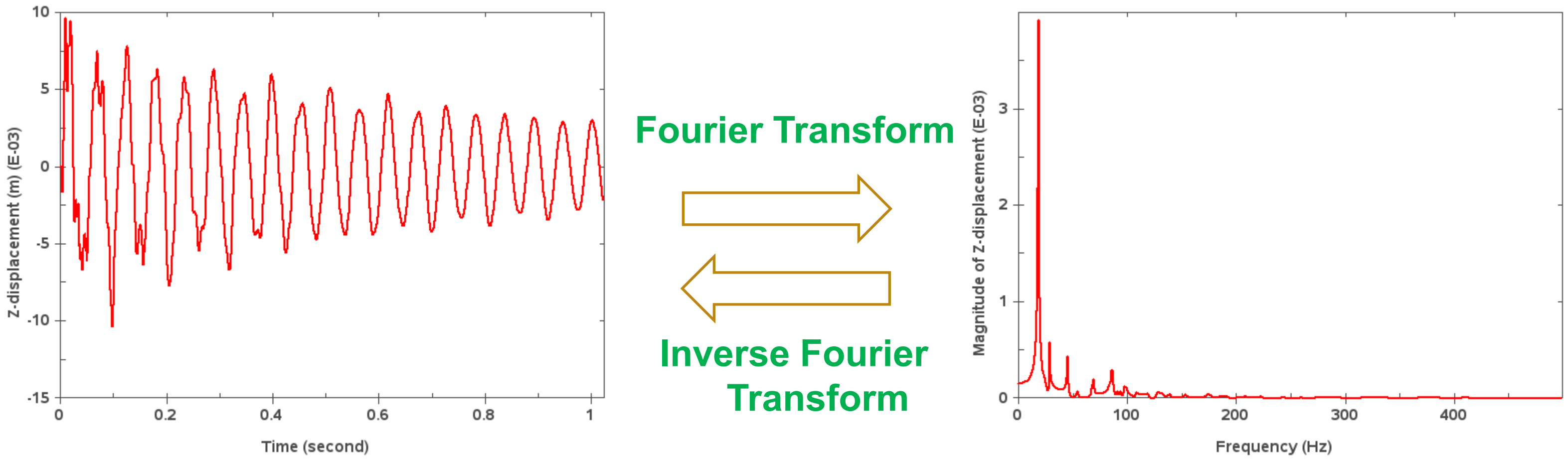
- Squeak and rattle can be analyzed in LS-DYNA using the E-line method, which is supported in ANSA and META (of BETA CAE)
  - A-priori definition of possible regions to be analyzed (E-lines, defined in ANSA)
  - Time domain, linear transient dynamics using a modal basis
  - Post-processing tools for statistical evaluations in META



From Fokilidis et al., Model set up and analysis tool for Squeak and Rattle in LS-DYNA, 14th Int. LS-DYNA Conf. 2016

The BSR Tool in LS-PrePost

- Using a frequency-domain approach, and collision detection from contact definitions

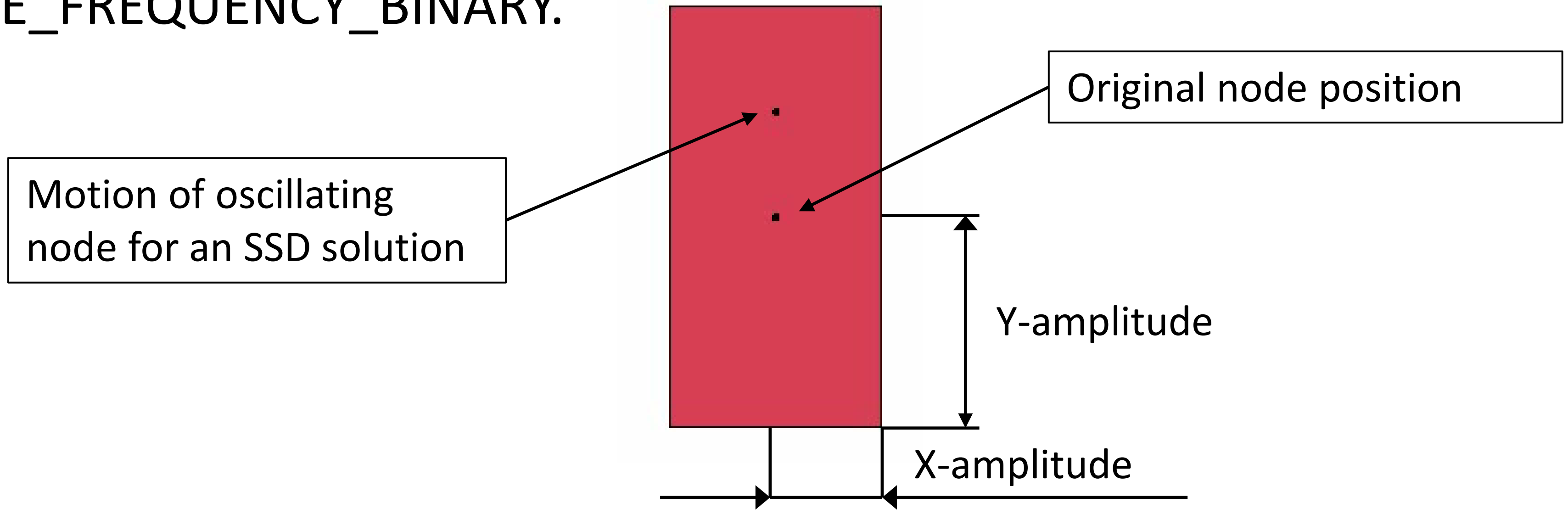


Time domain excitation **Frequency domain excitation**

- Steady-state dynamics (SSD) analysis in LS-DYNA
  - `*FREQUENCY_DOMAIN_SSD`
  - Linear dynamics analysis
  - For determining the steady-state response of a structure at one excitation frequency
  - Normally, the responses at many different frequencies are evaluated in the same analysis
  - Uses a modal basis (`*CONTROL_IMPLICIT_EIGENVALUE`)
  - Nastran: SOL 111. Abaqus: *DYNAMIC, STEADY STATE

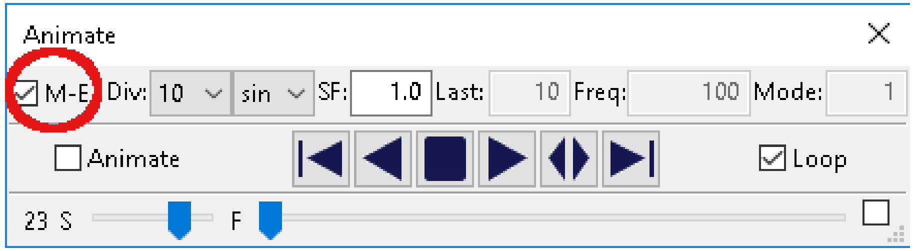
Collision Detection for One Excitation Frequency

- The steady-state dynamic (SSD) response of a forced oscillation is a linear combination of a contributing eigenmodes. The displacement for a single DOF for each contributing eigenmode *i* can be expressed as: $U_i(t) = A_i \sin(\omega t + \phi_i)$
- The sum of all modal contributions (sine functions) can for a single DOF be expressed as a single sine function with a unique amplitude and phase angle for each DOF. This is done in LS-DYNA and stored in d3ssd file if BINARY=2 on *DATABASE_FREQUENCY_BINARY.



Visualization of SSD motion

- Visualization of the steady-state motion for a selected excitation frequency can be displayed in LS-PrePost using the Modal Expansion (M-E) feature in the animation toolbar.



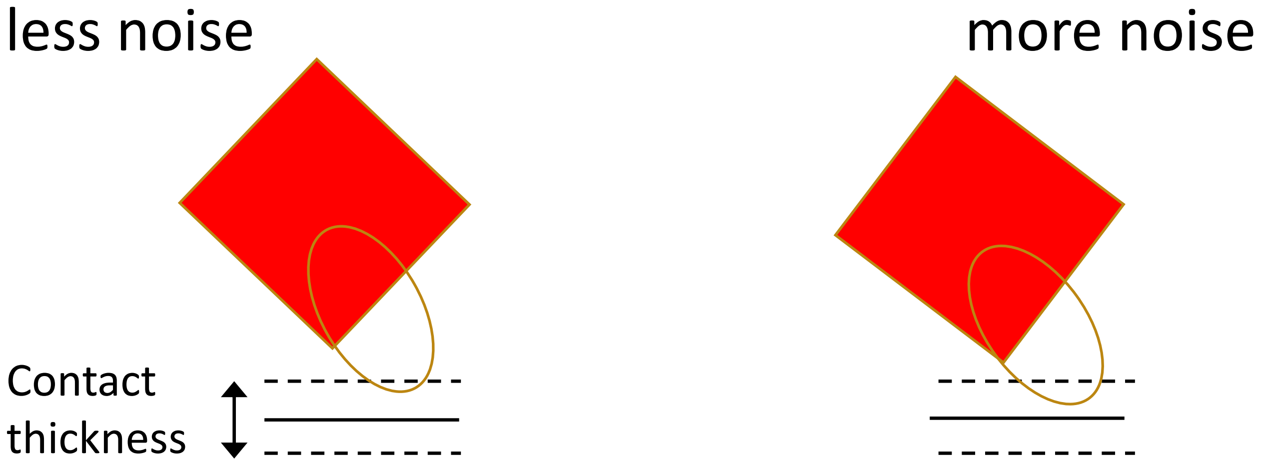
- The number of intermediate geometries to be displayed during a cycle is set using the ”Div” option.

Predicting Buzz/Rattle with CAE

- It is possible to detect if structures gets in to contact during an oscillating motion from an SSD analysis.
- The oscillating motion from the SSD analysis does however not take into account if contact occurs during the oscillation.
- The level of sound emitted from a two colliding parts depends on acoustic emissive properties and how the parts deform when colliding. These effect are not present in an SSD analysis so the *level* of emitted sound cannot be predicted.
- The *risk* of rattle noise can however be estimated.

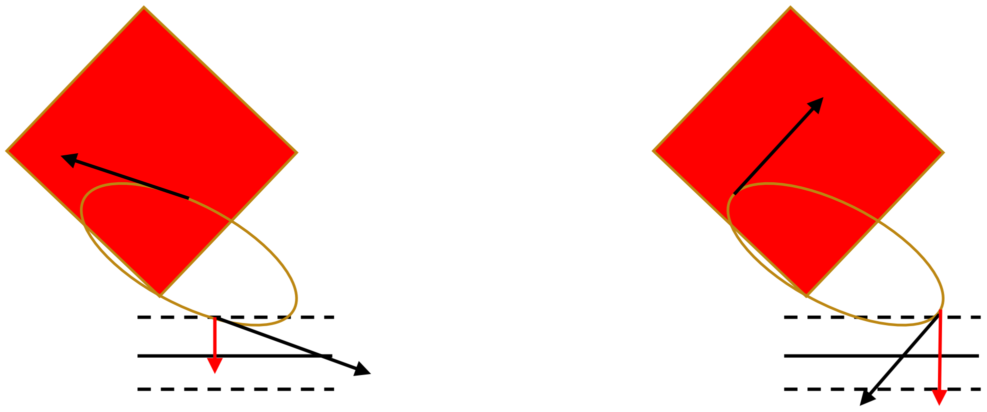
Factors that are Considered to Increase the Risk of Rattle:

- Parts get in to contact. (a presumption for noise)
- Larger penetration -> increased risk of noise as more contact energy will absorbed in each impact if the penetration is deeper.



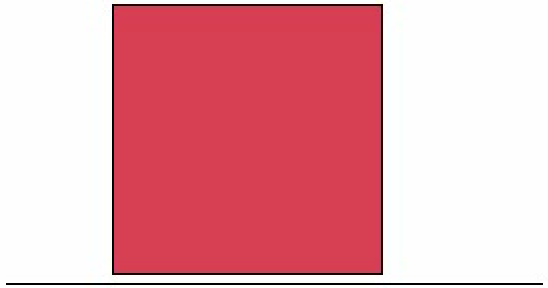
Factors that are Considered to Increase the Risk of Rattle:

- A larger relative velocity in the normal direction at the point of first contact increase risk of rattle as there is a faster change of velocity in the normal direction, which supposedly is the direction of the surface emitting the rattle noise.

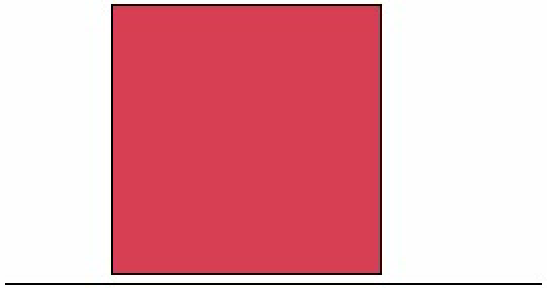


Factor that are Considered to Increase the Risk of Squeak

- Squeak is often related to material characteristics of rubber performing a very rapid stick/slip sliding motion.
- If the sliding distance is not long enough, the rubber part may not slip at all. The risk of squeak (slip action) is considered to be larger if the contact force and sliding velocity is large.
- These situations have the same ”penetration” but different sliding velocity.



short sliding



long sliding

Computation of Risk for Buzz/Rattle and Squeak

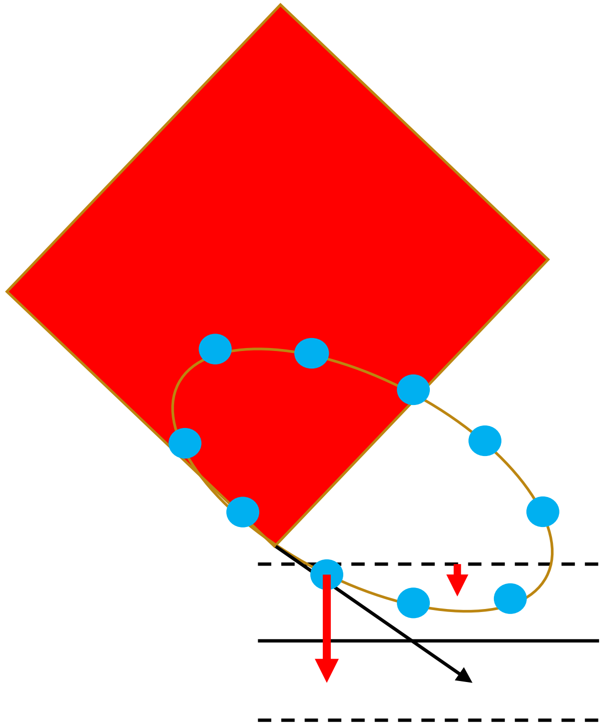
- An oscillation cycle is discretised with **ndiv** number of states.
  Default: ndiv=10.
- The number of discrete states can be modified to for instance 20 with the command ”bsr ndiv 20”.
- Penetration analysis is performed for each of these ndiv states using the definition of all *CONTACT keywords present in the keyword file. This means that. **d3ssd + keyword file with *CONTACT definition has to be loaded in order to plot rattle and squeak**

A Good Estimate of the Risk for BSR Noise?

- The energy added to the structure in the contacts during forced oscillation will dissipate as air pressure waves (sound), material damping, friction energy (heat), …
- It is reasonable to assume that the more energy absorbed in the contacts, the more sound energy will be emitted.
- A large sound volume means high energy/time, (Joule/sec, Watt), so the computed BSR value should be proportional to this.

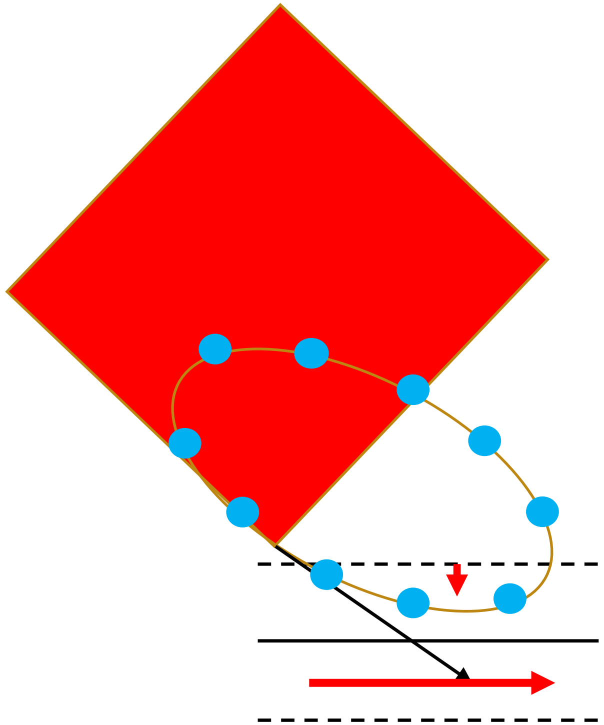
Rattle

- Average penetration in the contact is considered to be proportional to the amount of force.
- Rattle_value = average_penetration_depth * collision_speed_in_normal_direction



Squeak

- Squeak_value = average_penetration_depth * total_sliding_distance_when_node_is_in_penetration /time_in_penetration



MateRial Compatibility Factor Matrix

- Some combinations of materials are more prone to produce rattle or squeak sound than others.
- For instance: Steel-to-steel is more likely produce rattle compared to rubber-to-rubber. Rubber-to-steel is more likely to produce squeak sound compared to Rubber-to-fabric.
- A scale factor can be added to the computed rattle and squeak values in LS-PrePost depending on which two parts gets in to contact.

Part Material Compatibility Factor Matrix

- The factor is retrieved from a compatibility factor matrix. Every combination PART_X-to-PART_Y gets an associated scale factor value.

	Part 100	Part 117	Part 118	Part 142
Part 100	default	2.4	default	default
Part 117	2.4	3.5	2.5	default
Part 118	default	2.5	default	default
Part 142	default	default	default	default

Example of a part compatibility matrix for a model with 4 parts
”default” value can be set by user.

Part Material Compatibility Factor Matrix

- Example commands for setting scale factor between parts:

Set default scale factor for all part-to-part collisions:

bsr defaultsf 1.

Set scale factor 9. for collisions between PID=4 and PID=6:

bsr sf pid 4 pid 6 9.

Set scale factor 7. for collisions between all parts named="fender" and PID=5

bsr sf pname fender pid 5 7.

Set scale factor 7. for collisions between all parts with MID=8 and all parts with material name ”rubber”

bsr sf mid 8 mname rubber 7.

Any combination of PID, PNAME, MID, MNAME can be used for specifying scale factor between: part ID, part name, material ID, material name.

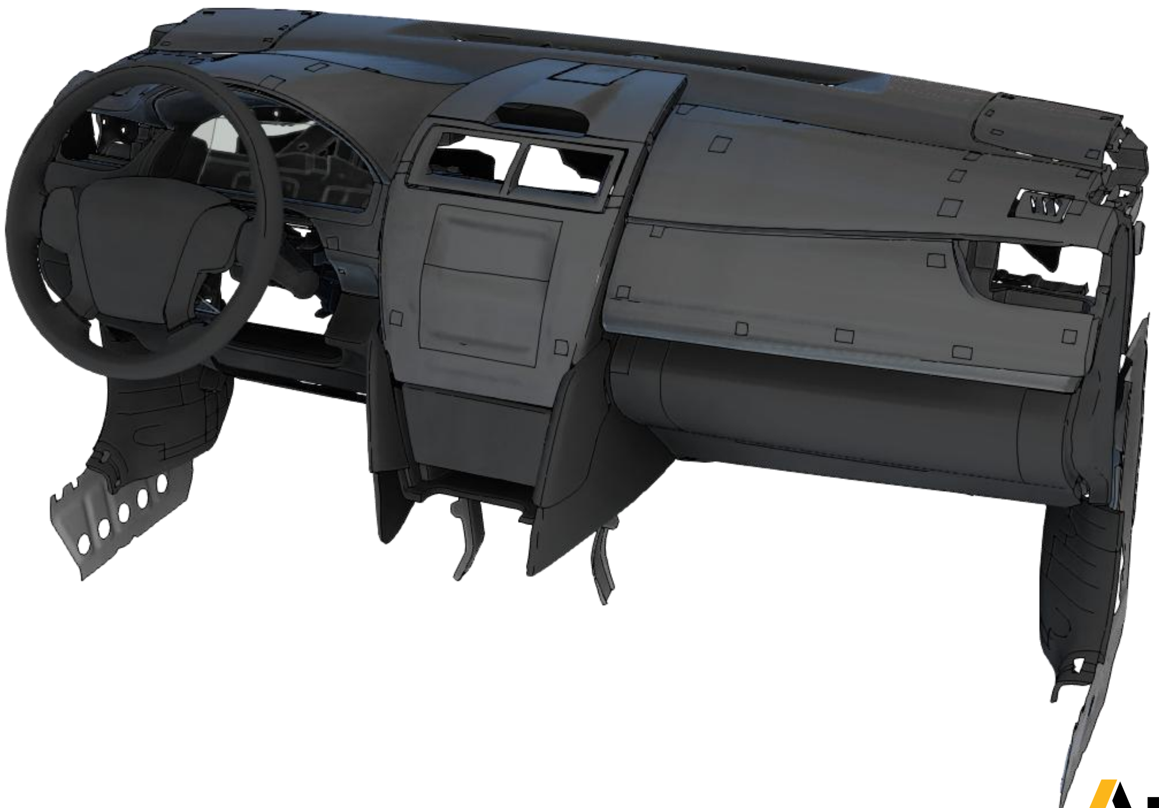
Interpretation of the Rattle/Squeak Values

- The magnitude computed value of rattle and squeak does not say if there will be a audible sound or not.
- A value of zero means that no contact occur.
- A non-zero value means that contact occur during oscillation and there is a ***risk*** of sound being emitted.
- A larger rattle/squeak value is more likely to produce sound compared to a smaller value as the value should be fairly proportional to the energy/time (power) absorbed by the collision.
- The result can be visualized as a nodal fringe plot value in the D3SSD menu.

Squeak and Rattle Evaluation - Example

- IP from 2012 Toyota Camry public FE-model developed by The Center for Collision Safety and Analysis at the George Mason University under a contract with the Federal Highway
  - The original work of the CCSA at GMU and the FHWA is gratefully acknowledged

- Model size: 114E3 shell elements
- Constrained boundary conditions at attachments to the remaining BiW and some free edges
- Control cards for linear analysis, from the "Guideline for implicit analyses in Ansys LS-DYNA"
- 1184 eigenmodes computed in less than 4 minutes on 8 cores
- Base acceleration loading
- Frequency dependent modal damping



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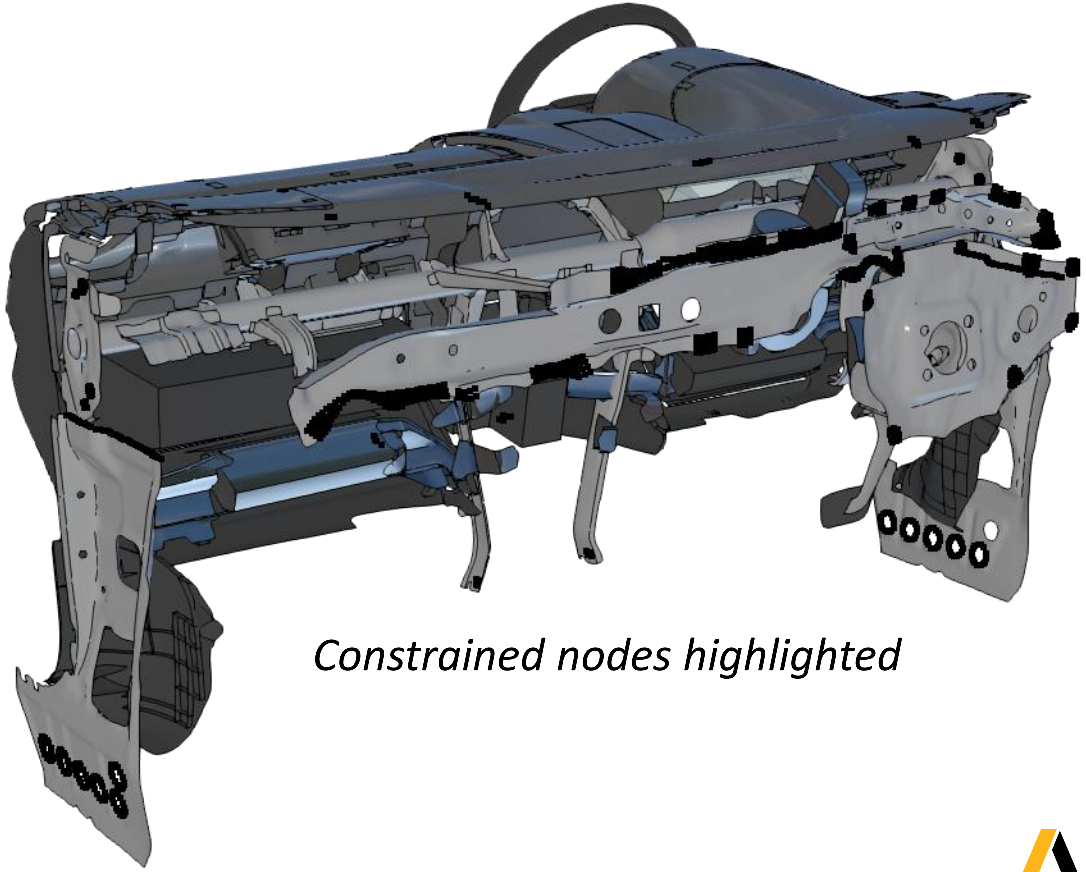

Constrained nodes highlighted

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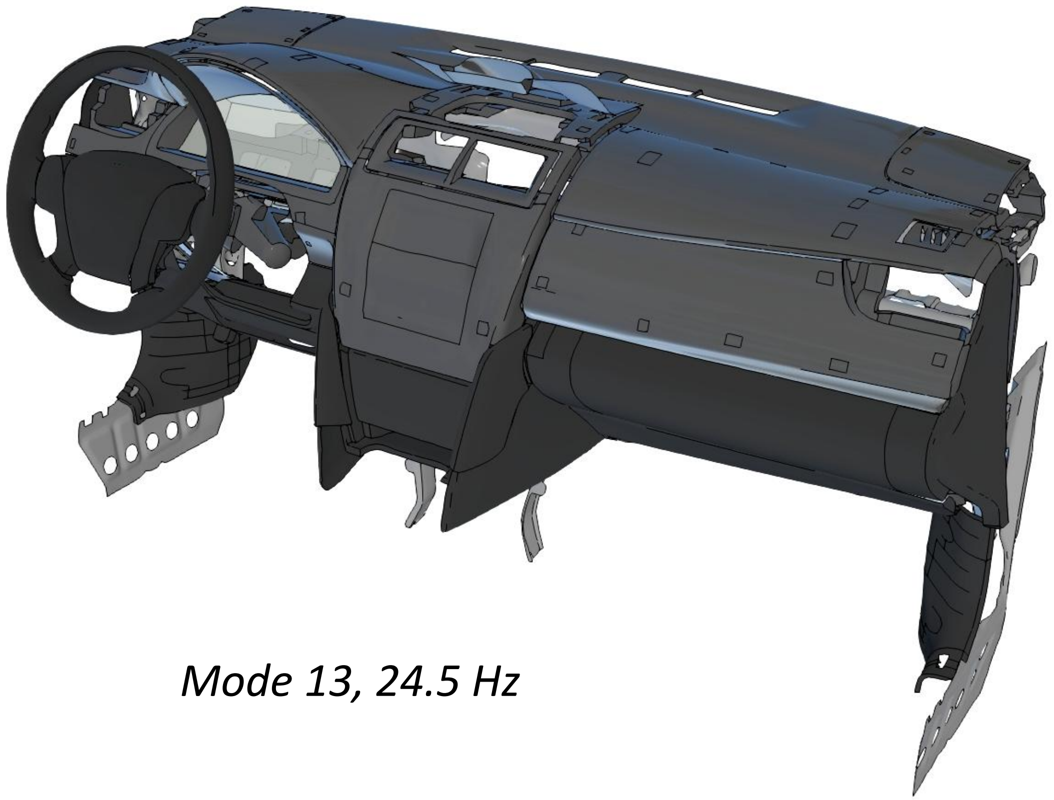
- Model size: 114E3 shell elements
- Constrained boundary conditions at attachments to the remaining BiW and some free edges
- Control cards for linear analysis
- 1184 eigenmodes computed in less than 4 minutes on 8 cores (all modes up to 600 Hz)
- Base acceleration loading
- Frequency dependent modal damping



Mode 13, 24.5 Hz

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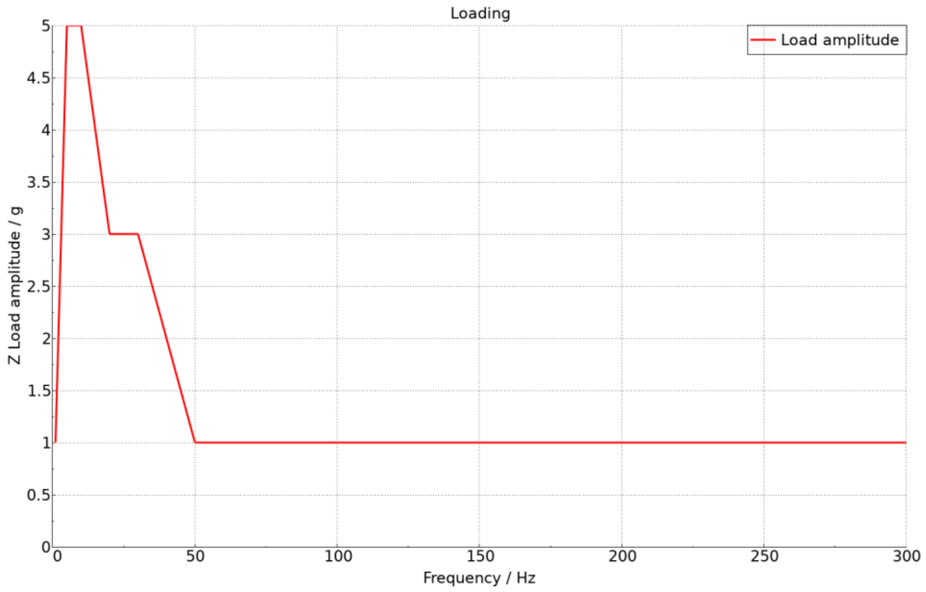
- Model size: 114E3 shell elements
- Constrained boundary conditions at attachments to the remaining BiW and some free edges
- Control cards for linear analysis
- 1184 eigenmodes computed in less than 4 minutes on 8 cores
- Base acceleration loading → (in phase)
- Frequency dependent modal damping



Base acceleration loading (g) vs. frequency (Hz)

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- Model size: 114E3 shell elements
- Constrained boundary conditions at attachments to the remaining BiW and some free edges
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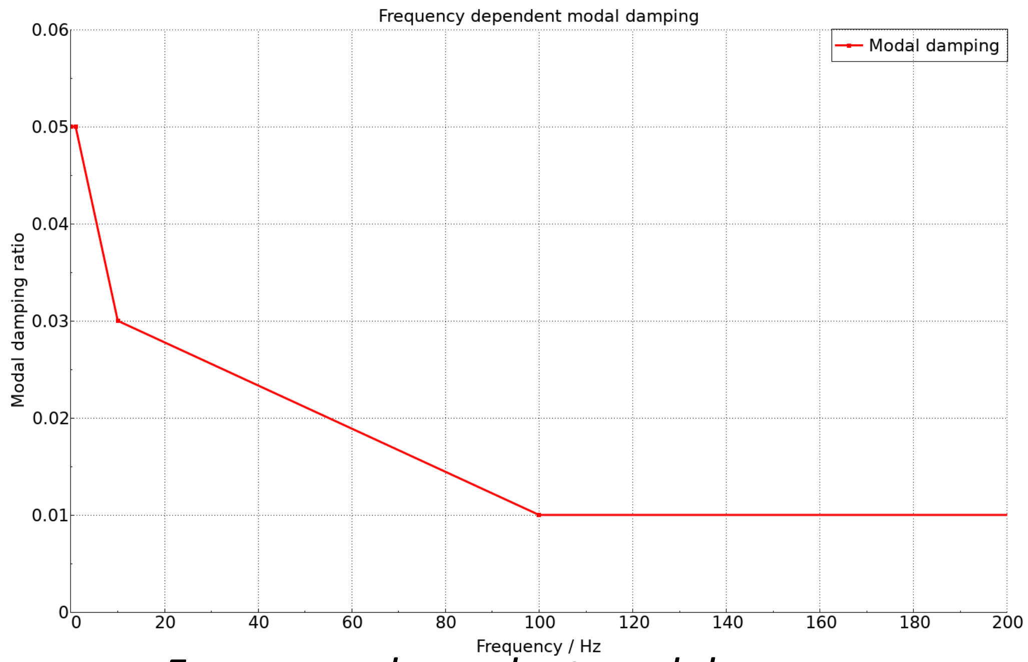
- 1184 eigenmodes computed in less than 4 minutes on 8 cores
- Base acceleration loading
- Frequency dependent modal damping
- SSD for 35 frequencies solved in less than 1 minute on 8 cores



Frequency dependent modal damping

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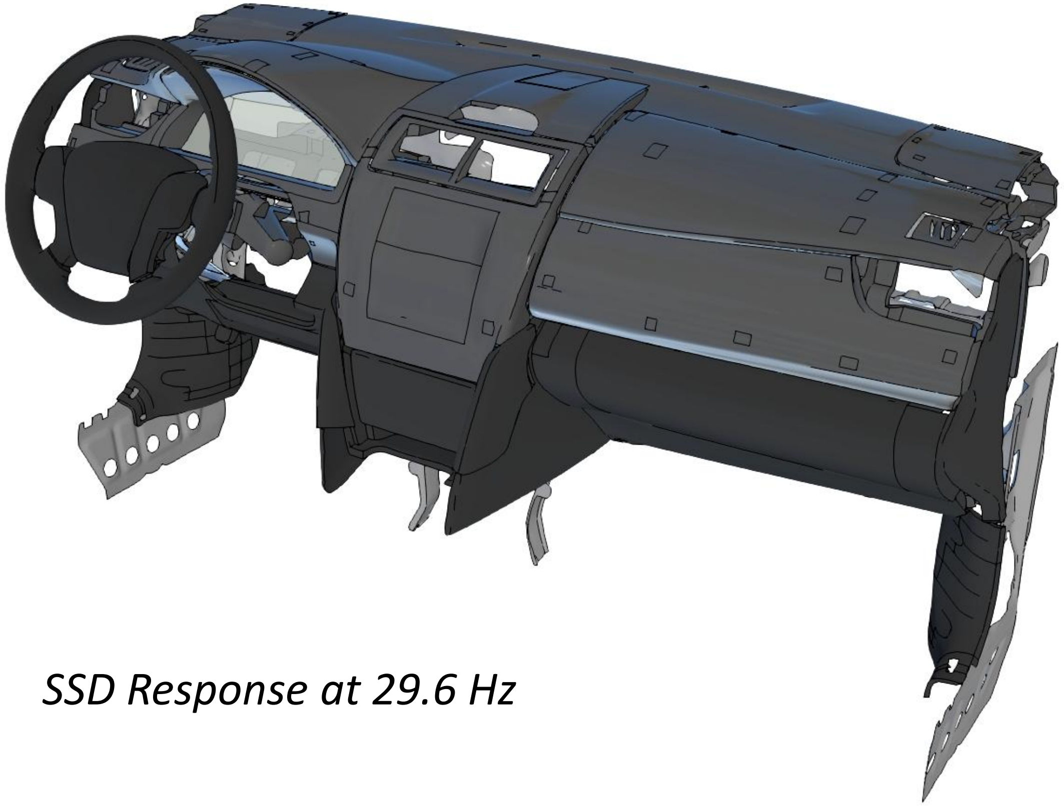
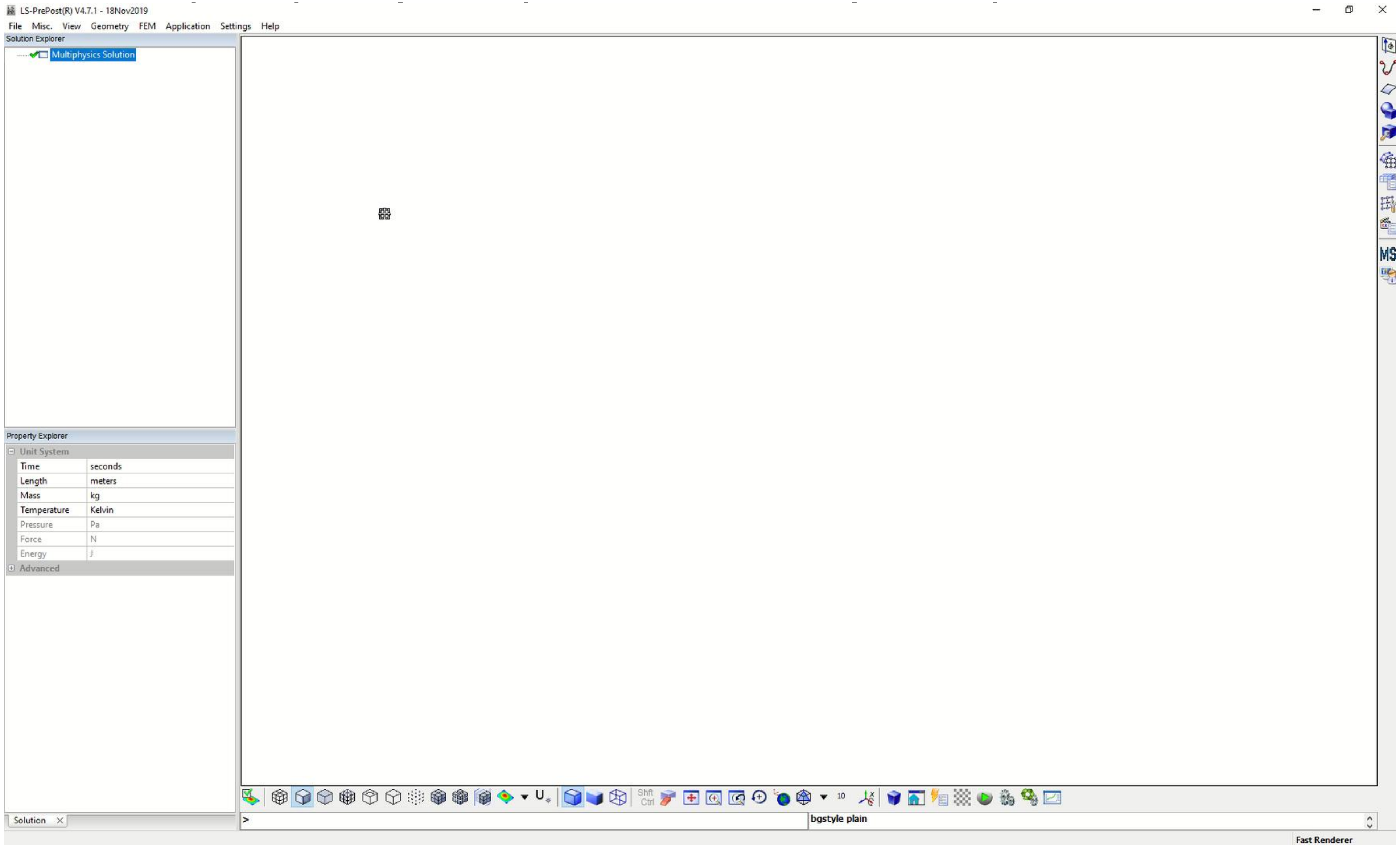


SSD Response at 29.6 Hz

Squeak and Rattle Evaluation – Set-up

- As a starting point, the control cards for linear analyses from the “Guideline for implicit analyses in LS-DYNA”: `control_cards_linear.key`, may be used
  - Download the latest version from https://lsdyna.ansys.com/knowledge-base/implicit/
- For set-up of an SSD analysis, see Section 4.7.2 of the Guideline.
  - See also https://lsdyna.ansys.com/knowledge-base/nvh-fatigue/
- NOTE: Set *BINARY* = 2 on `*DATABASE_FREQUENCY_BINARY_D3SSD`
  - Required to be able to perform the modal expansion
- LS-PrePost will perform the BSR analysis based on contact definitions (`*CONTACT_...`). This means that both `d3ssd` – files (binary results from the SSD analysis) and a corresponding keyword file is required input to LS-PrePost.
  - If Mortar contacts are used, the same keywordfile can be used for the LS-DYNA analysis as the BSR evaluation in LS-PrePost
  - Use non-Mortar contacts with caution in linear analyses


LS-PrePost(R) V4.7.1 - 18Nov2019
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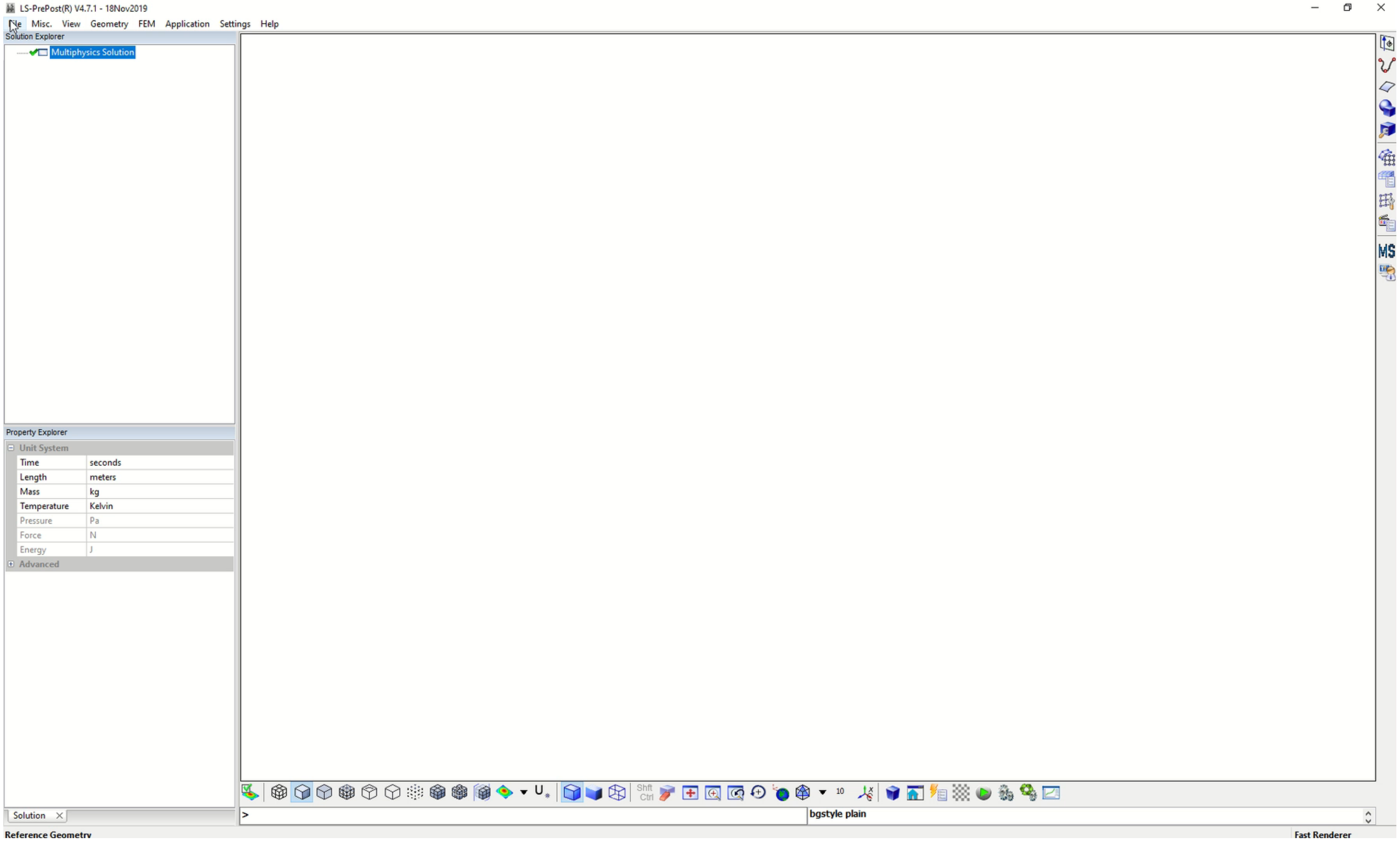
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Reference Geometry
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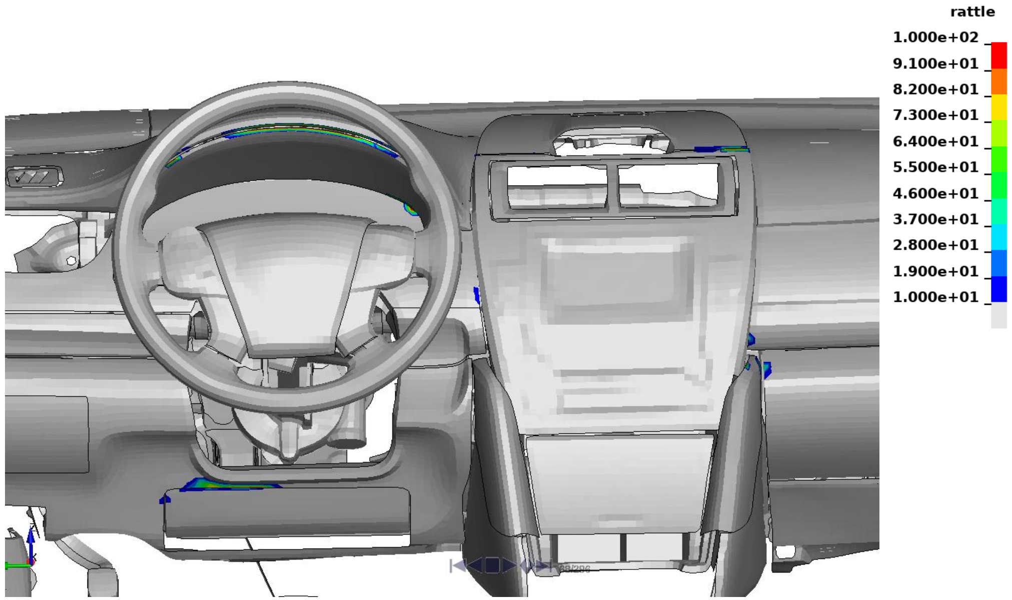
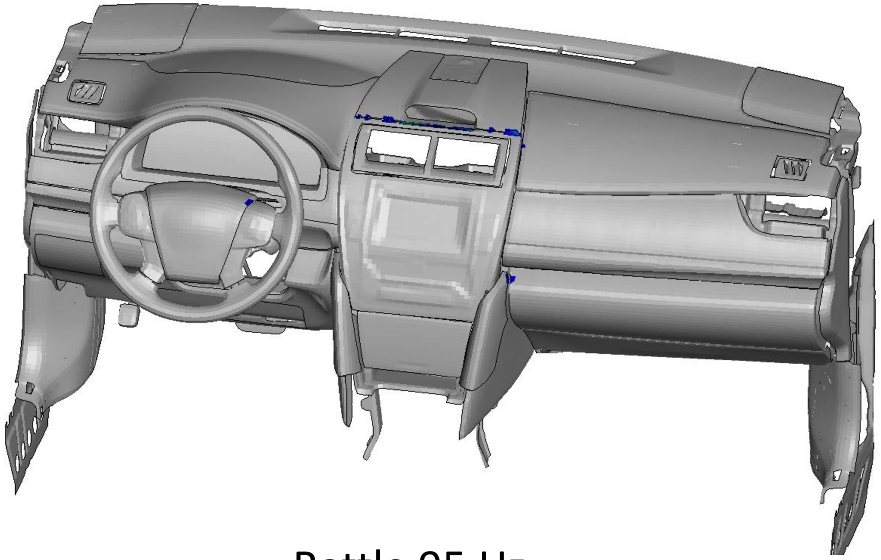
Squeak and Rattle Evaluation – Example Results



Rattle 72 Hz



Rattle 95 Hz

Summary

- A new tool for analysis of BSR has been implemented in LS-PrePost
  - Available from production version Ansys LS-PrePost 4.7
  - Can predict areas where risk for rattle or squeak may occur
  - The areas of interest for BSR evaluation are defined in the post-processing stage
- Further developments based on customer demands
  - Feedback and new requests are welcome!

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