Analysis of the challenges of sound package definition for electric vehicles using SEA analysis

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SEA analysis of electric vehicles sound packages

Agenda

- Electric Vehicles Challenges
- Motivation for using SEA
- What is SEA? theoretical background
- SEA model within the vehicle development cycle
- Real case application
  - Overview of the demonstrator model
  - Design change analysis
    - Examples…
- Conclusions and perspectives

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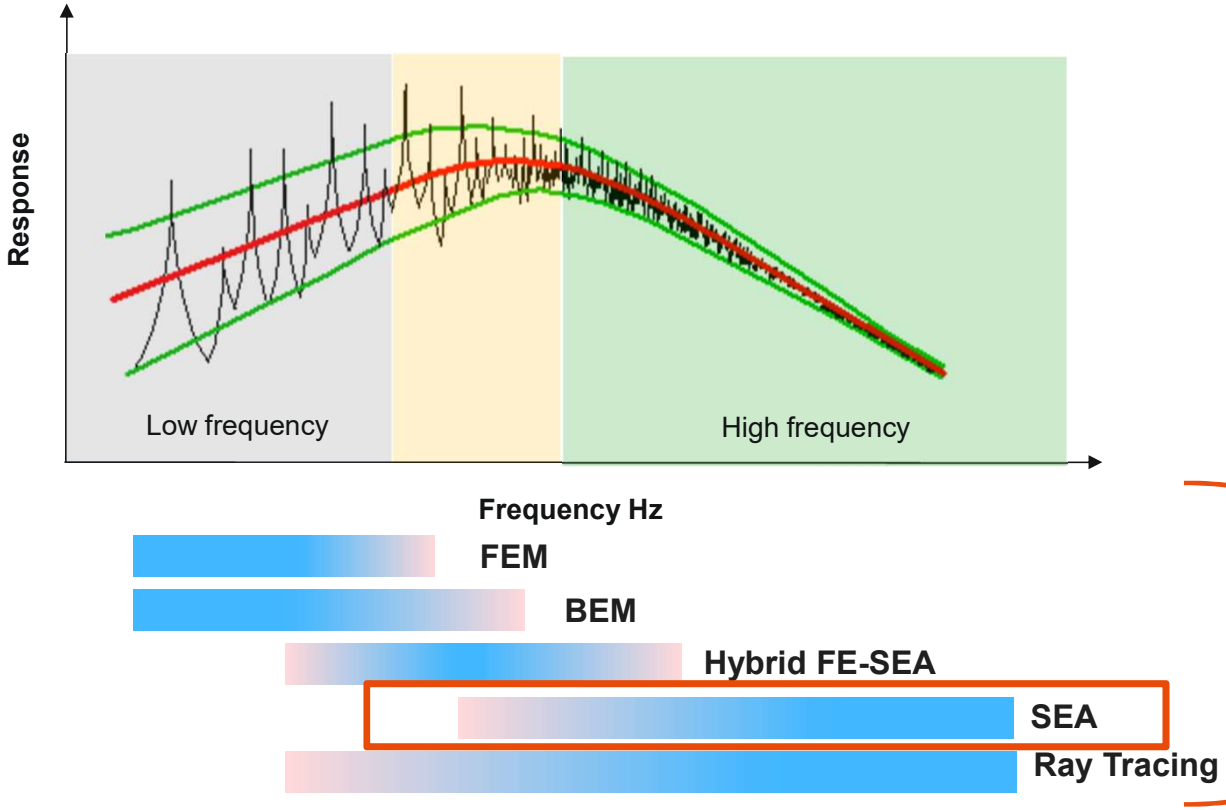
Different methods available



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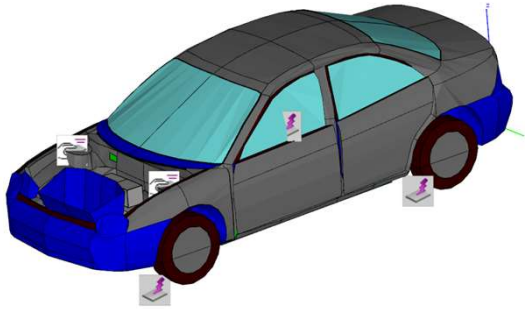
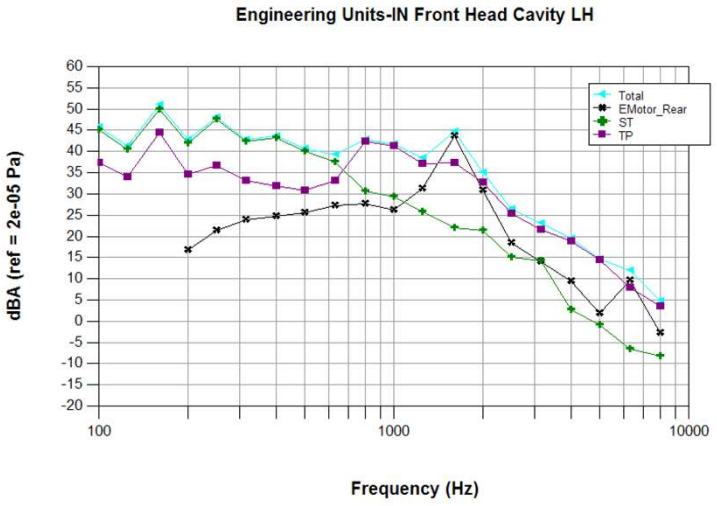
Contribution of real life excitation to the response

- Several sources are contributing to the response at passengers head
  - Motor
  - Rolling noise
  - Windnoise
- All sources have an airborne and structure-borne contribution
- Broad band contribution, higher frequencies are also important





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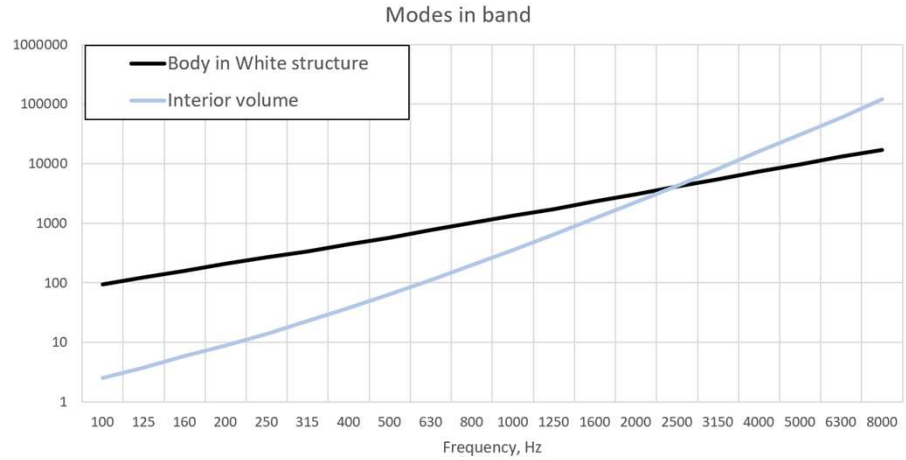
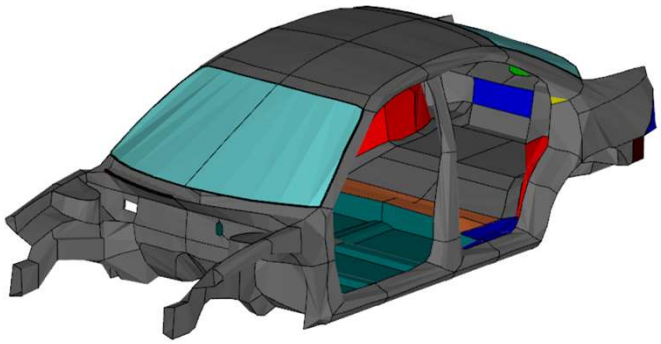
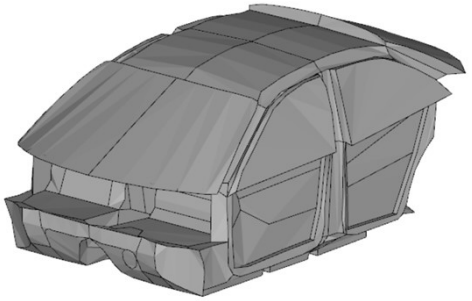
Number of modes

- For a typical car, number of modes till 8kHz
  - Body in White Structure ~ 100 000
  - Interior volume ~ 250 000

- FEM cannot handle this amount of modes







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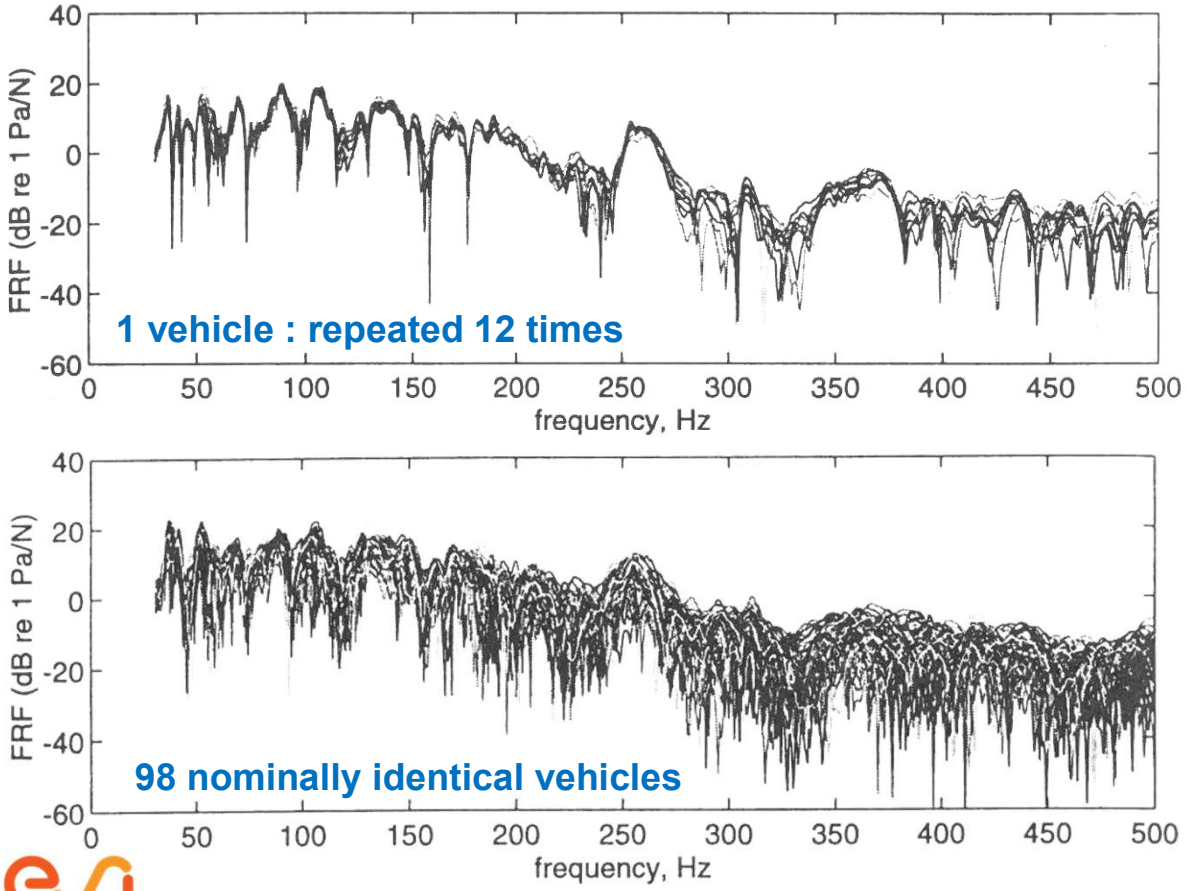
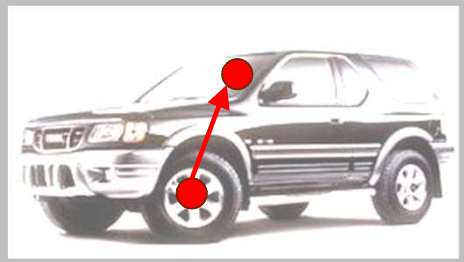
Uncertainty in measurement





3e6 structural modes
1e6 acoustic modes
< 10 kHz

R. Bernhard " The limits of predictability due to manufacturing and environmentally induced uncertainty", Proc. of InterNOISE, 1996.

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  - Examples…
- Conclusions perspectives

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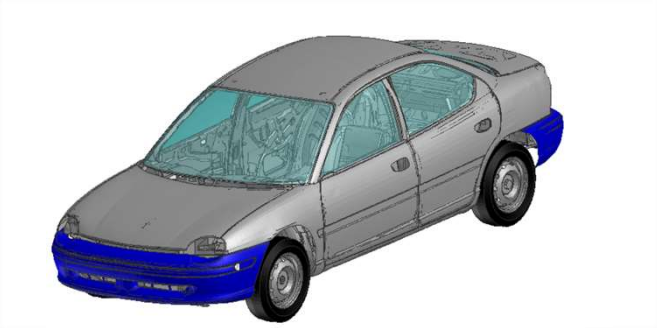
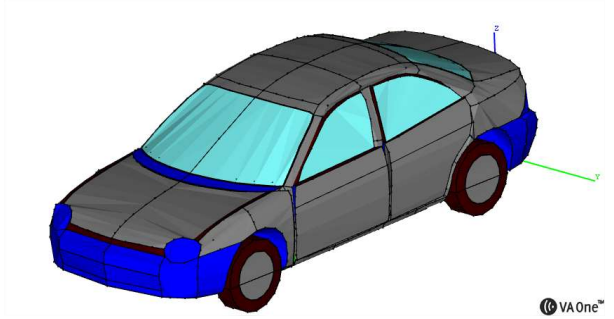
What is SEA? Theoretical background

SEA: Statistical Energy Analysis

- Method to analyse the energy flow within a vibro-acoustics system
- No small element level discretization, BUT a Subsystem level discretization
  - Door panel, windshield…



FEM model,
millions of elements



SEA model,
Several hundreds of subsystems

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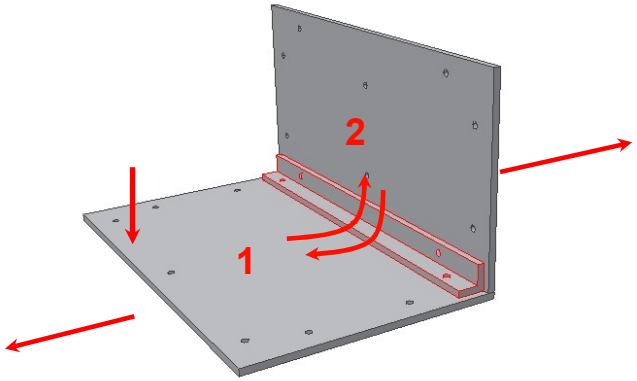
What is SEA? Theoretical background

- SEA equation
  - Based on conservation of energy equations

$$\begin{bmatrix} \Pi_{in,1} \\ 0 \end{bmatrix} = \omega \begin{bmatrix} n_1(\eta_1 + \eta_{12}) & -n_1\eta_{12} \\ -n_2\eta_{21} & n_2(\eta_2 + \eta_{21}) \end{bmatrix} \begin{bmatrix} E_1/n_1 \\ E_2/n_2 \end{bmatrix}$$



- SEA parameters
  - η_i Damping loss factor
  - η_{ij} Coupling loss factor between subsystems i and j
  - n_i Modal density of subsystem i
  - $\Pi_{in,i}$ Power injected to subsystem i
  - E_i Energy of subsystem i (unknown)

SEA basis

Junctions can be activated or deactivates to evaluate the energy flow through the different systems

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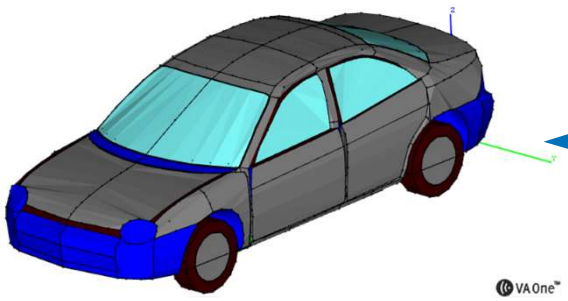
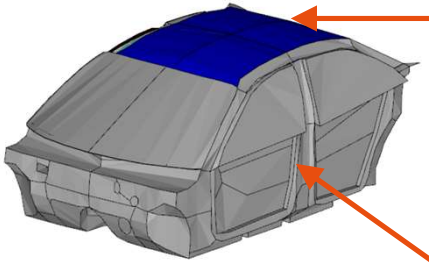
What is SEA? Theoretical background

- Generalisation for a complex system
  - Car



$$\omega \begin{bmatrix} n_1\left(\eta_{11}+\sum_{i\neq 1}\eta_{1i}\right) & -\eta_{21}n_2 & \cdots & -\eta_{N1}n_N \\ -\eta_{12}n_1 & n_2\left(\eta_{22}+\sum_{i\neq 1}\eta_{2i}\right) & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ -\eta_{1N}n_1 & \cdots & \cdots & n_N\left(\eta_{NN}+\sum_{i\neq 1}\eta_{Ni}\right) \end{bmatrix} \times \begin{bmatrix} \frac{E_1}{n_1} \\ \cdots \\ \cdots \\ \frac{E_N}{n_N} \end{bmatrix} = \begin{bmatrix} P_{in,1} \\ \cdots \\ \cdots \\ P_{in,N} \end{bmatrix}$$

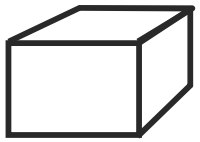
- Subsystems Energies



Roof Panel →

$E_1 = \langle V^2 \rangle_{sp}\, m$

Interior Cavity →



$E_2 = \langle P^2 \rangle_{sp}\, V/(\rho c^2)$

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Model creation process

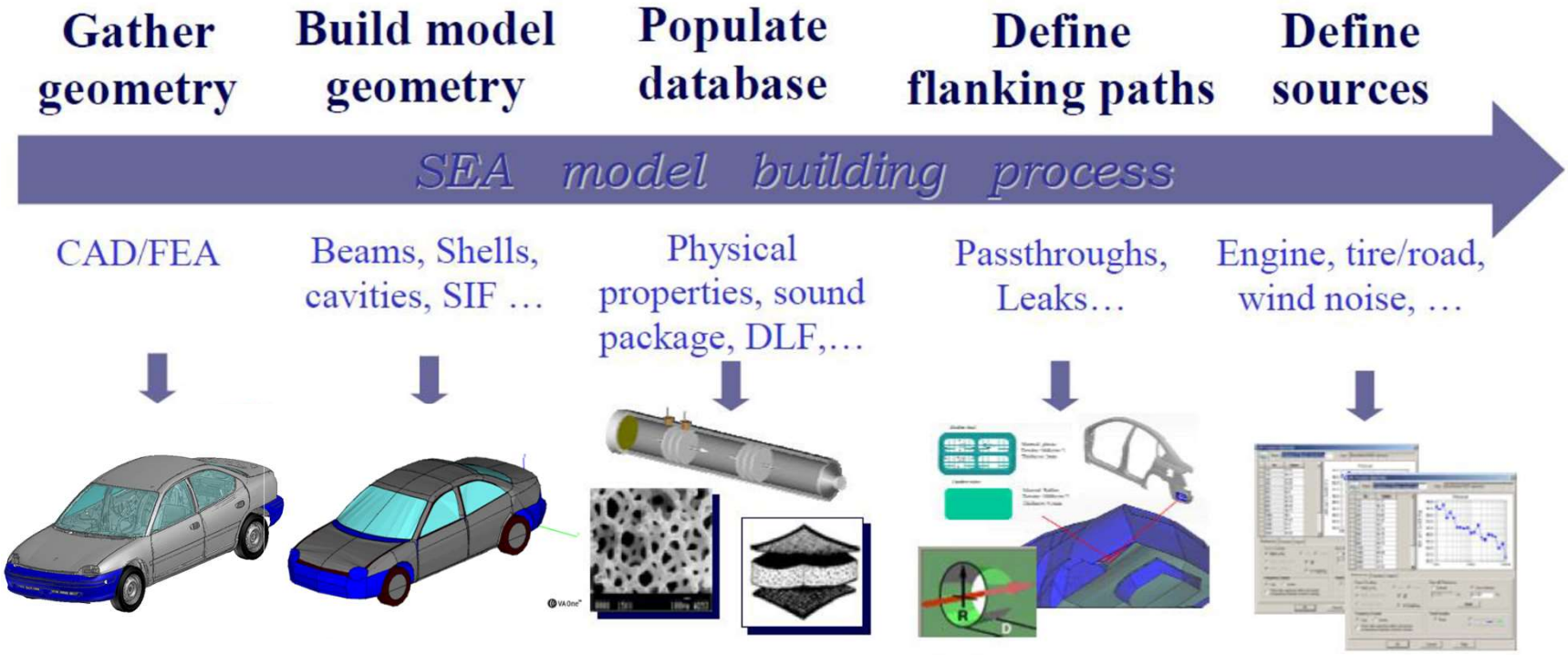

Figure 1: *SEA model building process*

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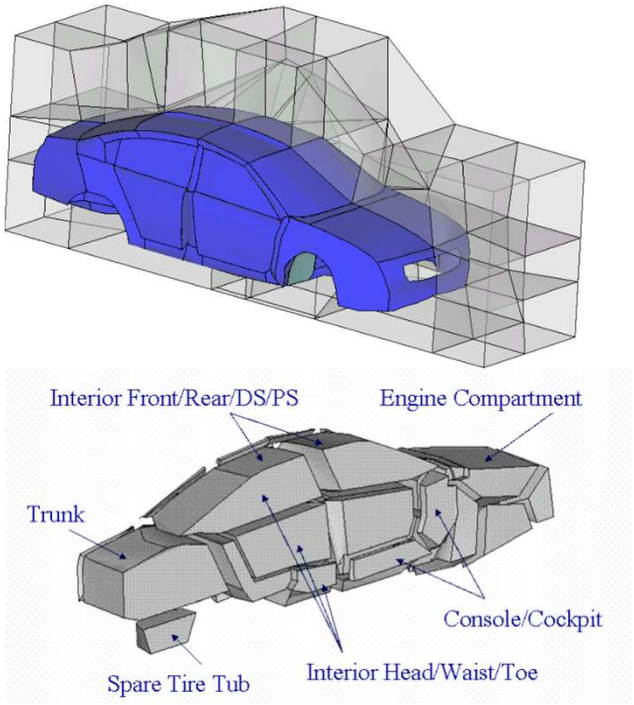
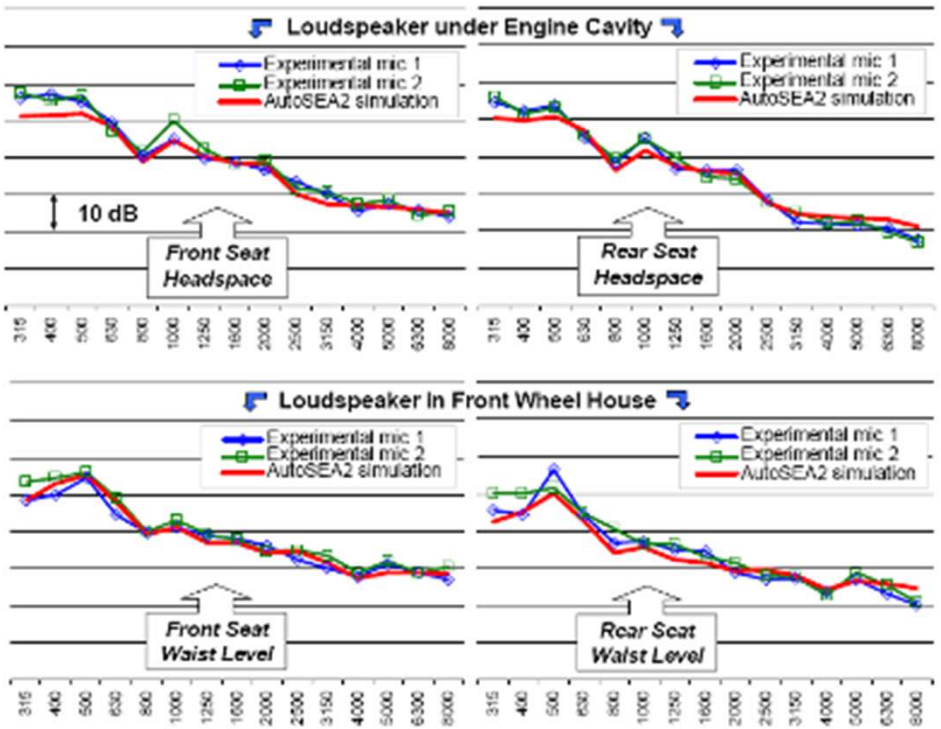
High freqency with SEA, Airborne load case investigation





Full Vehicle SEA Model Uses Detailed Sound Package Definition To Predict Driver's Headspace Acoustic Response
A. Charpentier, D. Blanchet and K. Fukui, Internoise 2004, Prague, Czech Republic

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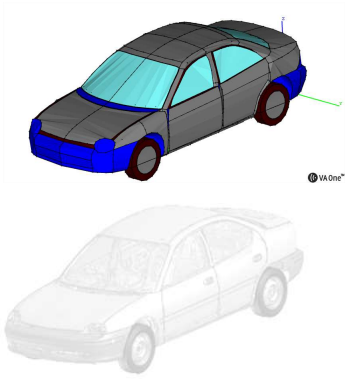
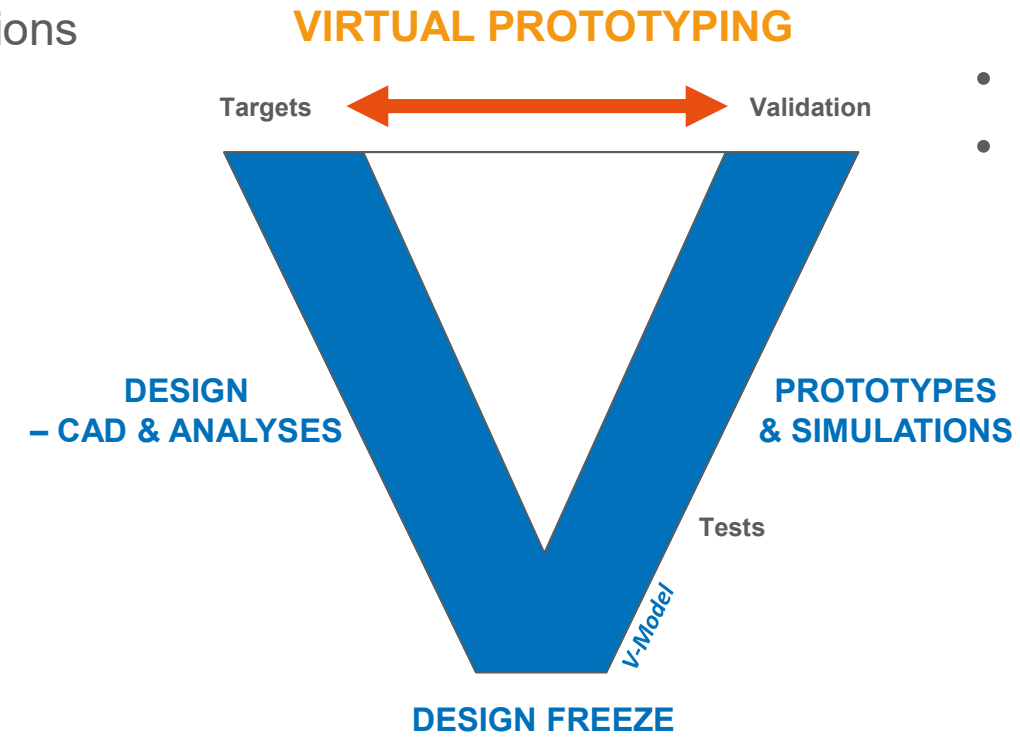
Role of the SEA model during the design process

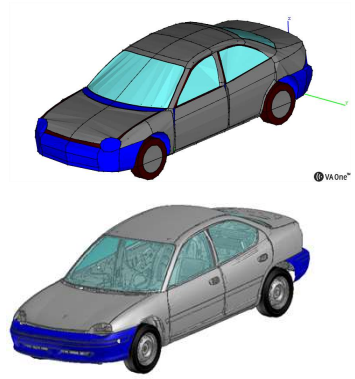
- Verify product requirements
  - Define specifications
- Aprove concepts



SEA driven process



- Verify product performance
  - Consider production impact
- Aprove designs
- Trouble shooting



SEA and FEM driven process

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  - Design change analysis
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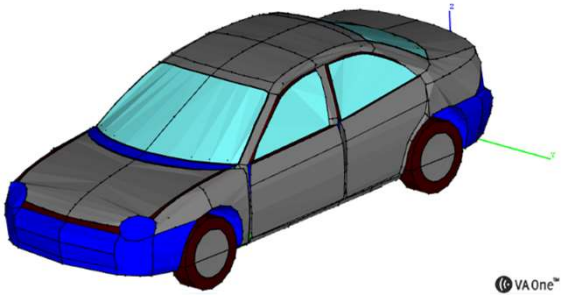
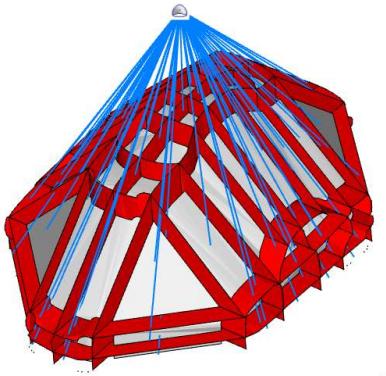
ESI‘s EV SEA model demonstrator

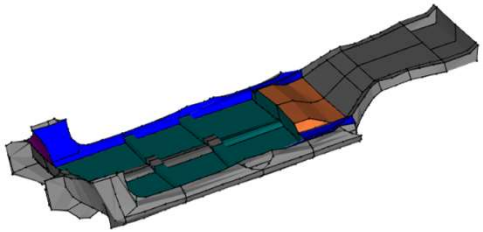
- Structure
  - Built from an actual FEM model of a real car
  - Integration of EV specific underbody architecture
- EV components
  - Fitted battery (weight=500kg)
  - Electric motors
- Sound package
  - Interior
    - Carpet, Dash insulator, Absorbers, Headliner…
  - Exterior
    - Wheelarch absorbers, Engine cover…
  - Biot parameters and TMM are used to model multilayer porous material construction
- Cavities External/Internal
  - State of the art partitioning



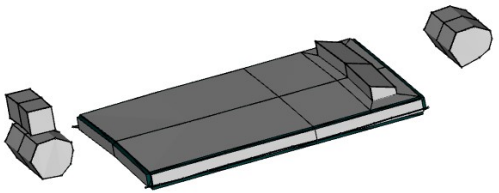
Vehicle structure model



Exterior cavities



EV specific underbody architecture



Battery and electric motors

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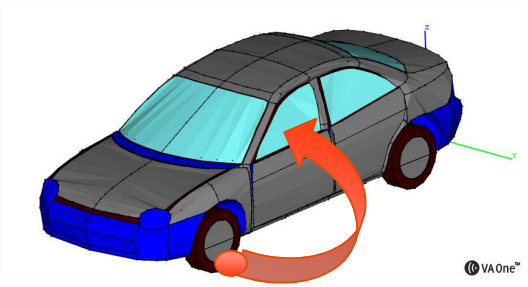
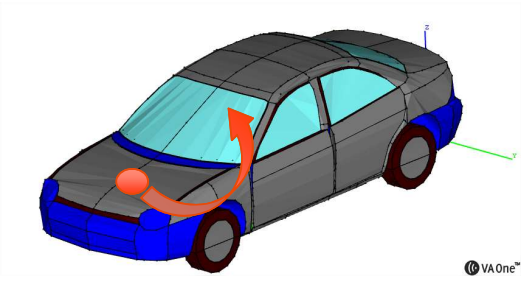
ESI‘s EV SEA model demonstrator, Load cases

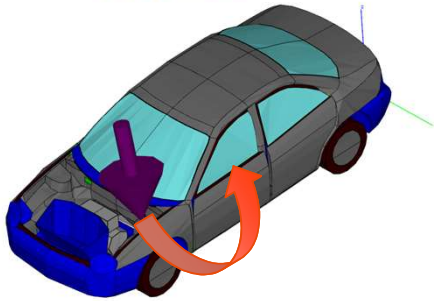
- Standardized load cases
  - Airborne
    - ENR (direct or reciprocal), TPNR
  - Structure-borne
    - NTF Front Strut, Rear Strut…
- Real life excitation
  - Example of Driving Condition
    - Constant speed
    - Full Load
    - …
  - Load description from measurements
  - Airborne and Structure-borne excitation



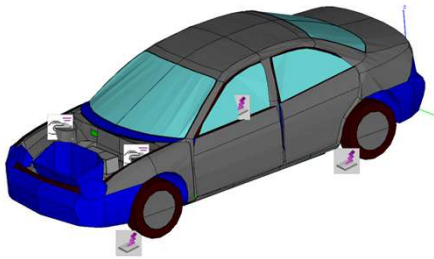
TPNR Front



ENR Front, Direct



NTF Front Strut



Real life excitation

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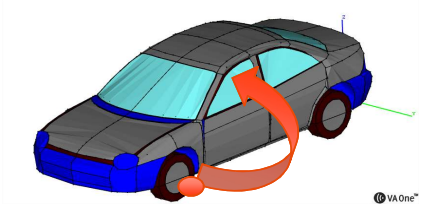
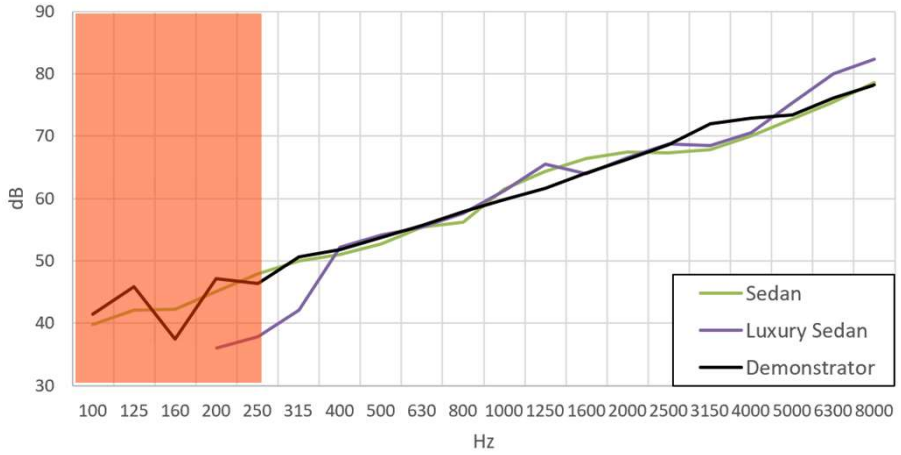
ESI‘s EV SEA model demonstrator, Sanity checks

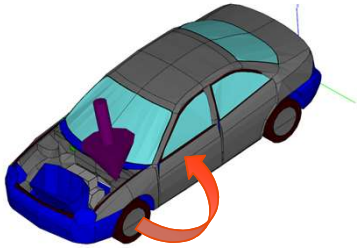
- Pure Airborne load, TPNR Front



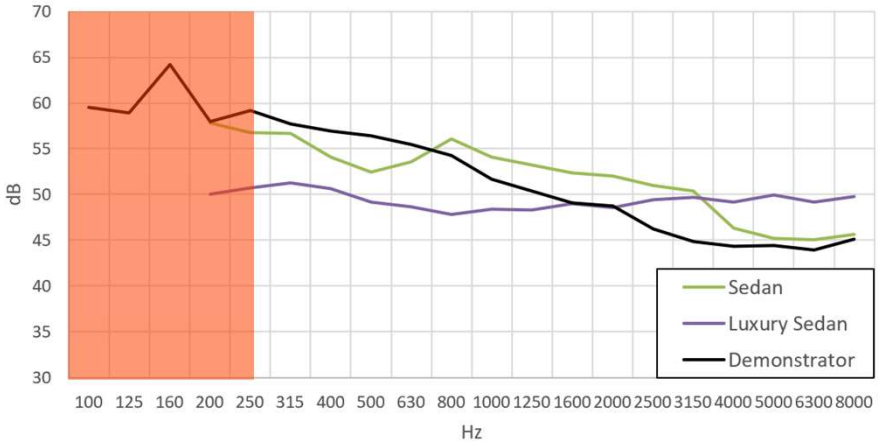
TPNR Front



- Pure Structure-borne load, NTF Front Strut



NTF - Front Strut



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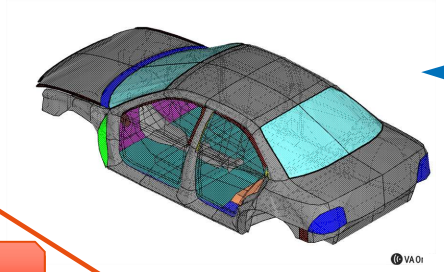
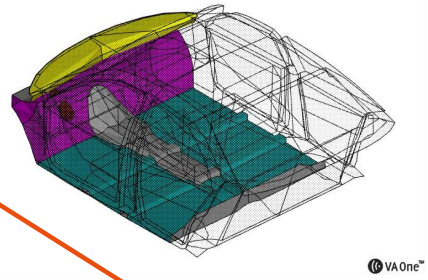
Target Cascading



Target

Competition benchmark

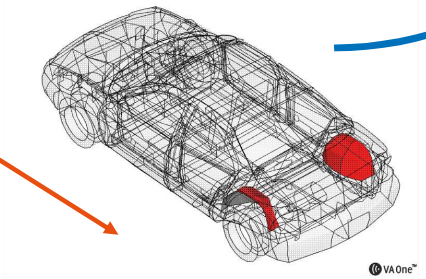
- Reach performances of competitor
- Specific load case



Identify weak paths

Cascade down to subsystems

- Contribution analysis
- Improvements needed at…



Recommendation

Evaluation of counter measures

- Delta dB plots
- Effect on different load cases
- Cost/Mass vs dB effect

Iterate different configuration to meet Cost/Performance/Mass objectives

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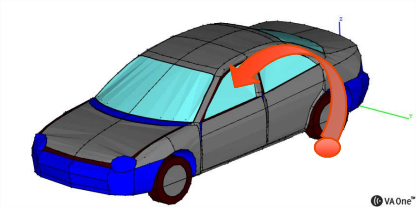
Target cascading application

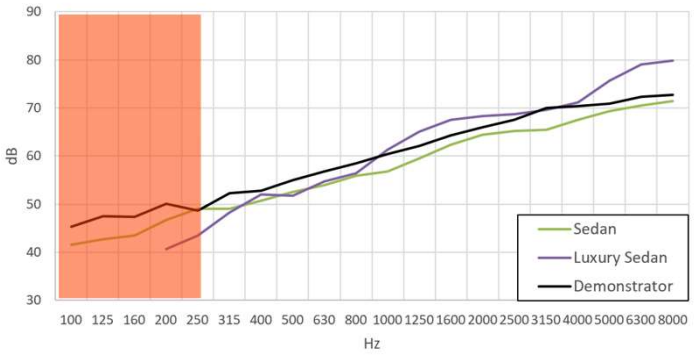
Target

Competition benchmark

- TPNR analysis



TPNR Rear

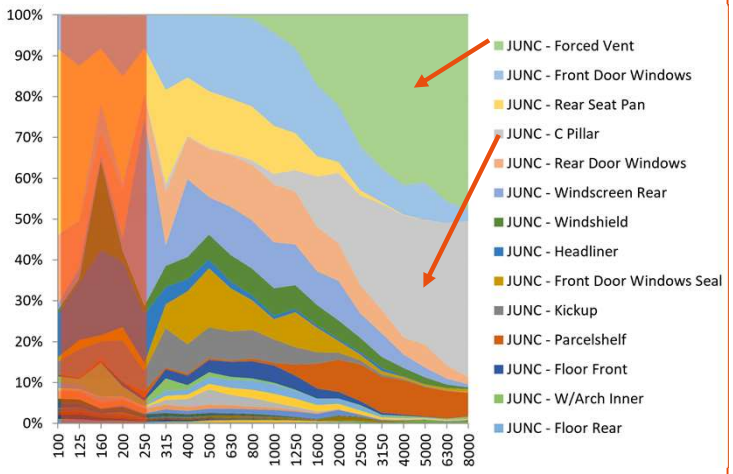


The vehicle is weak at high frequency

Identify weak paths

Cascade down to subsystems

- Contribution analysis

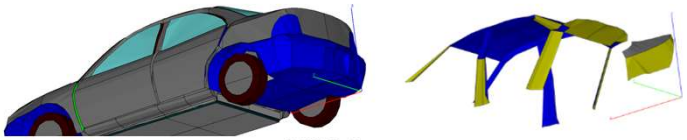


- High contribution at high frequency from
  - Air Vent
  - C-Pillar

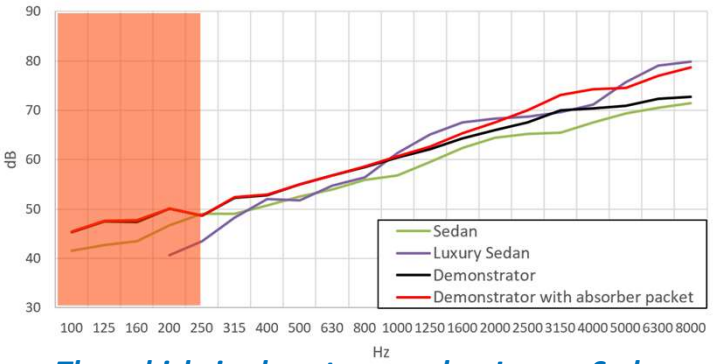
Recommendations

Evaluation of counter measures

- Absorber packet at quarter panel and pillars
  - 15mm Fiber



TPNR Rear



The vehicle is almost as good as Luxury Sedan

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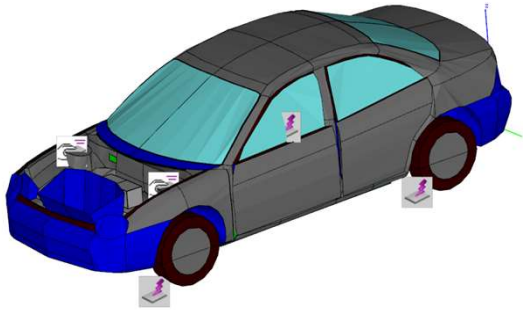
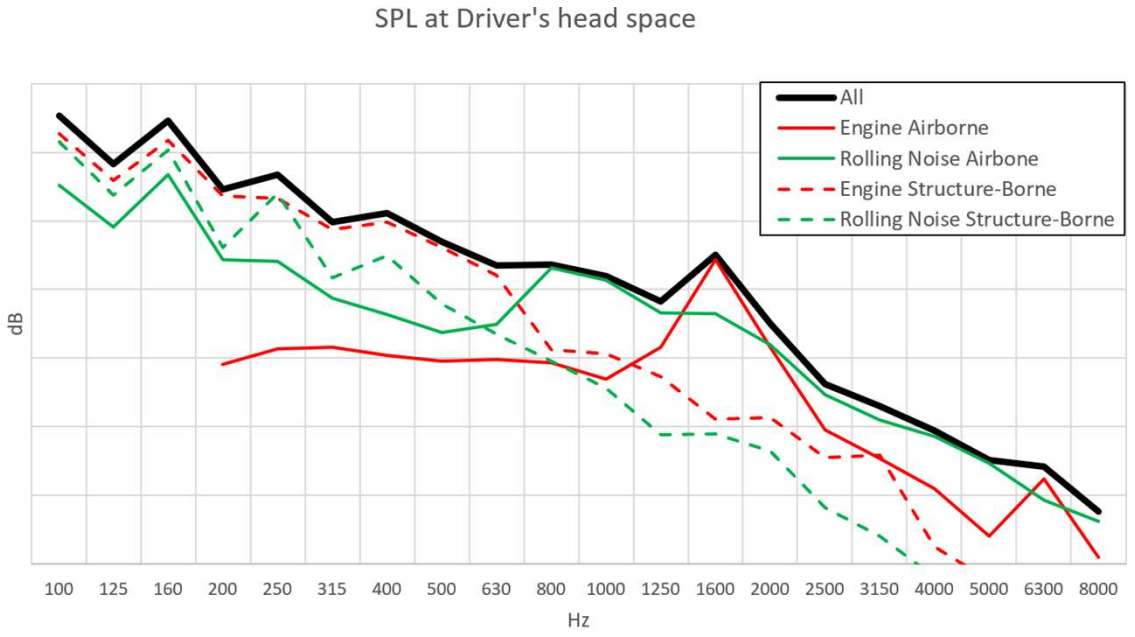
Source contribution evaluation

- Real life source is a combination of multiple inputs
  - Structure-borne or Airborne
  - Rolling noise, engine
  - Windnoise not considered

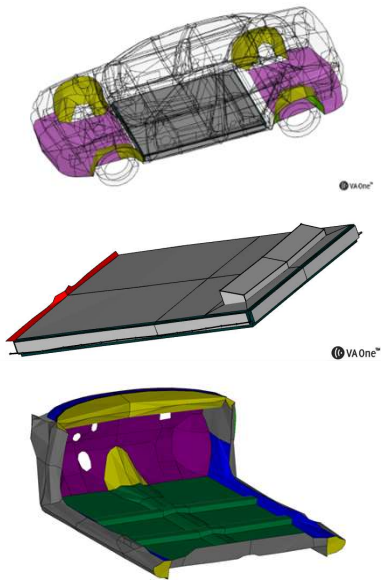




SEA analysis of electric vehicles sound packages

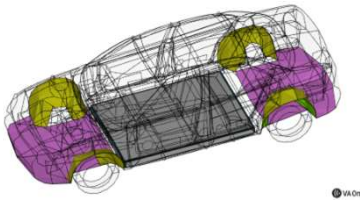
Investigation of some counter measures

- Underfloor trims
  - Battery, engine, trunk
- Battery sealing
- Heavy layers for
  - Firewall
  - Carpet

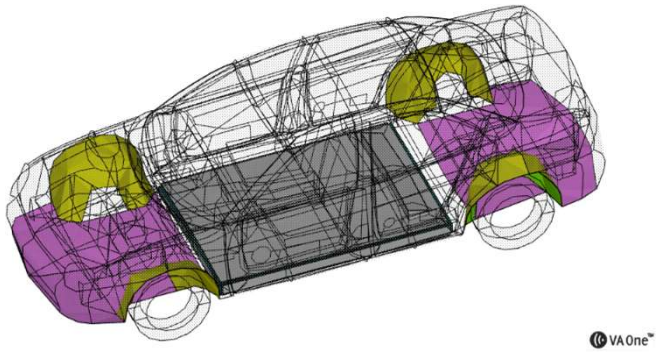


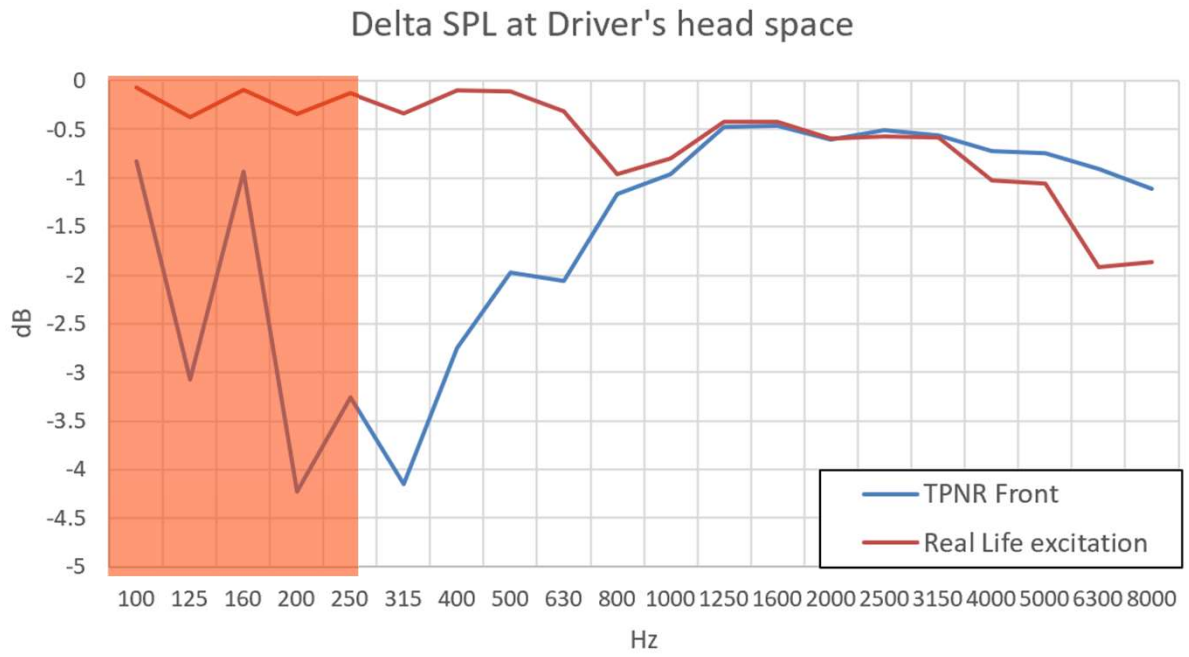
Design change influence analysis

Battery Undercover and Underfloor



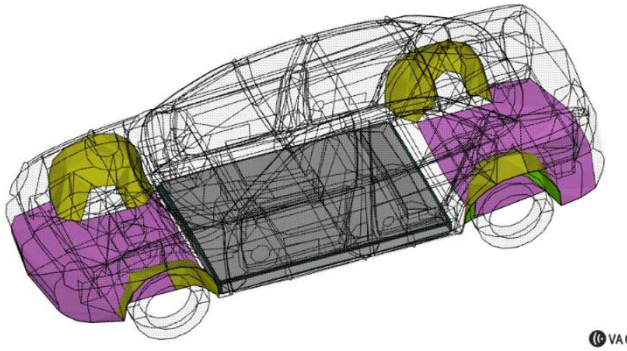
- Objective: evaluate the effect of absorptive properties used for
  - Battery undercover, Engine and trunk underfloor, Wheelhouses absorbers
  - Effect for different load cases





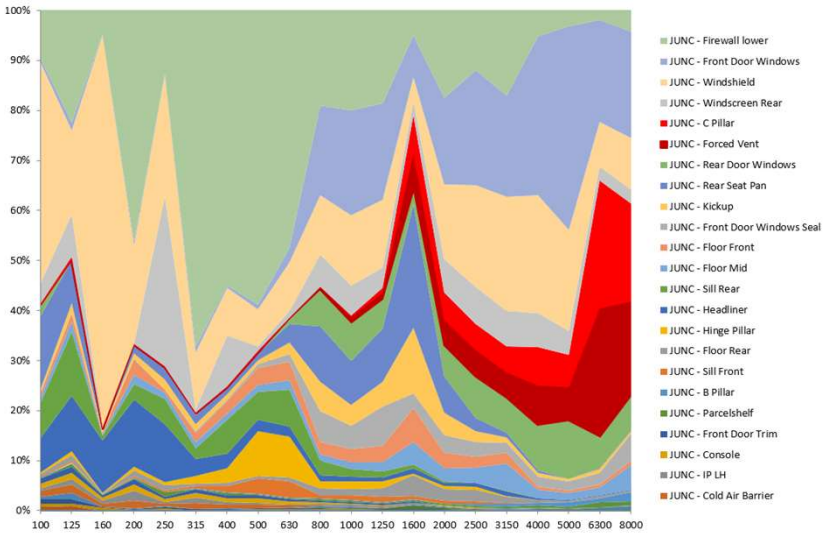
Design change influence analysis

Battery Undercover and Underfloor

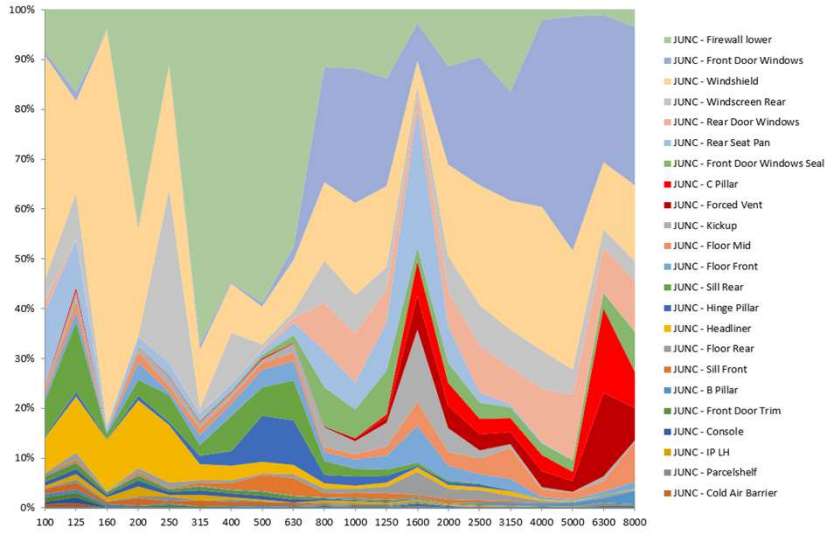


- Energy flow changes using Battery undercover and underfloor

No absorptive material



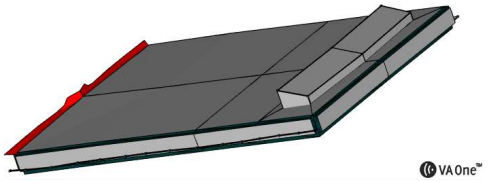
With absorptive material



Reduction of the noise propagated through the air vent. The energy is lost before entering the car!

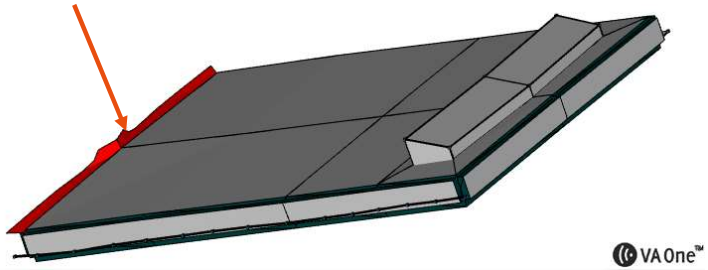
Design change influence analysis

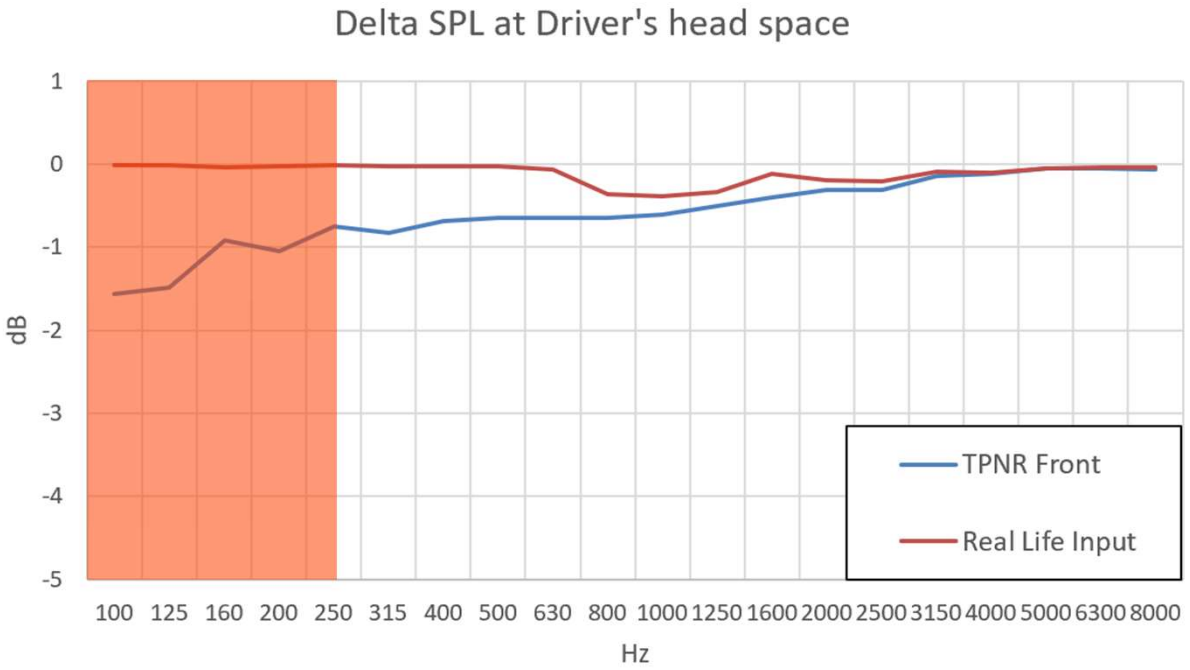
Battery Sealing



- Objective: Evaluate effect of adding a seal in front and back of the battery

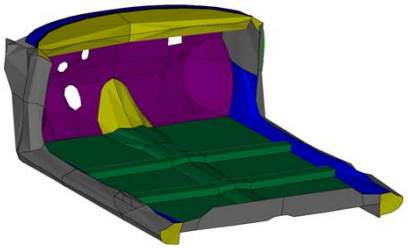
Front battery seal position





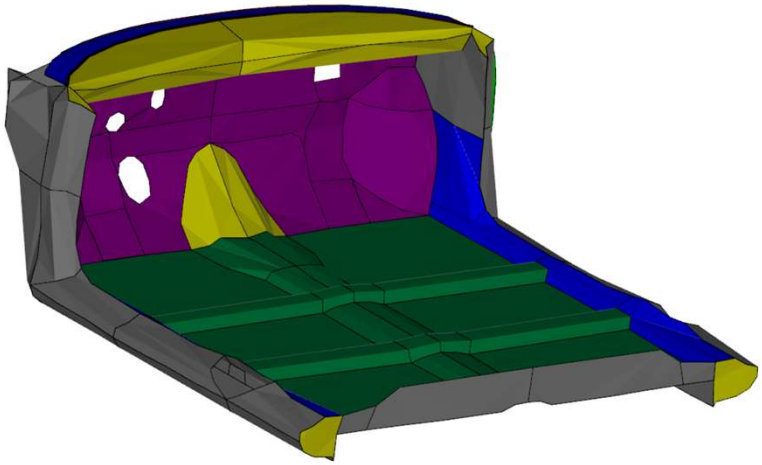
Design change influence analysis

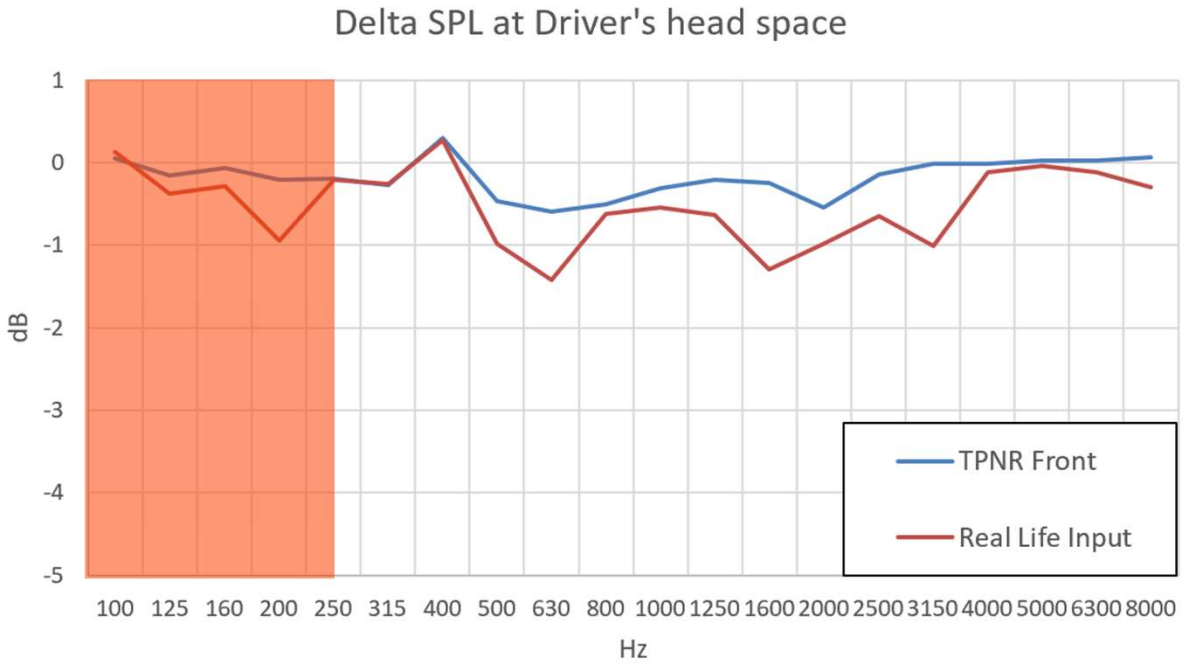
Heavy layer for carpet and dash insulator



- Objective: Evaluate effect of adding a 3kg/m² heavy layer

3kg/m² heavy layer

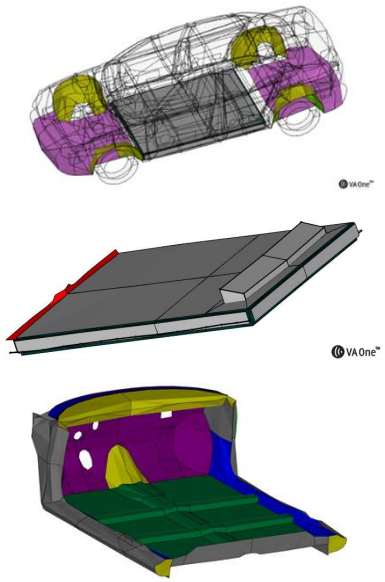


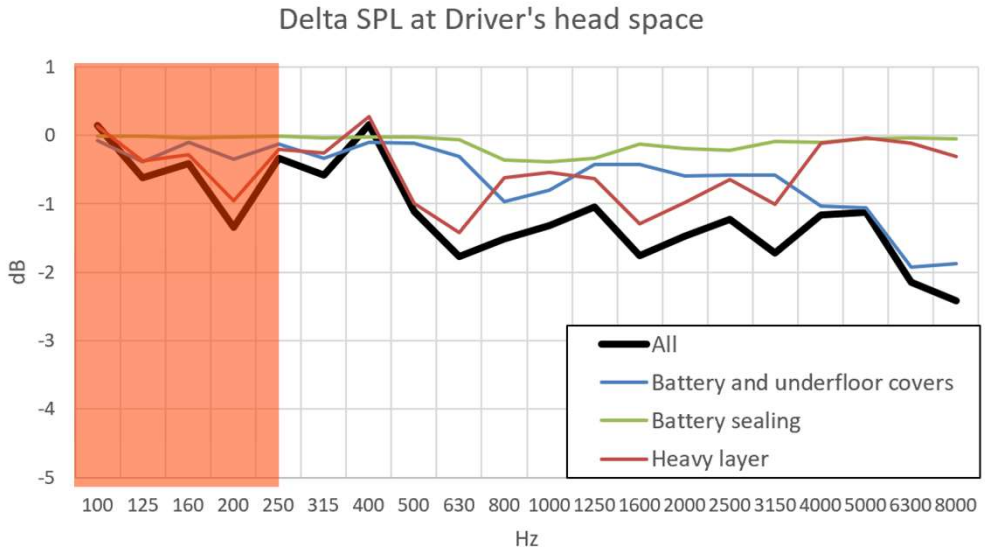


Design change influence analysis

Summary

- Effect of the different design changes for the real life excitation





SEA analysis of electric vehicles sound packages

Conclusions and perspectives

- SEA analysis gives the opportunity to:
  - Analyse the energy flow within the vehicle
  - Analyse the relative importance of the diverse sources
    - Engine/rolling noise/windnoise
    - Airborne/structure-borne
  - Evaluate effect of vibro-acoustics counter measures
  - Optimize the sound package of the vehicle in regards to
    - Vibro-Acoustics performances
    - Mass
    - Costs
- SEA is realiable, easy and quick to provide answers and test new designs

THANK YOU!