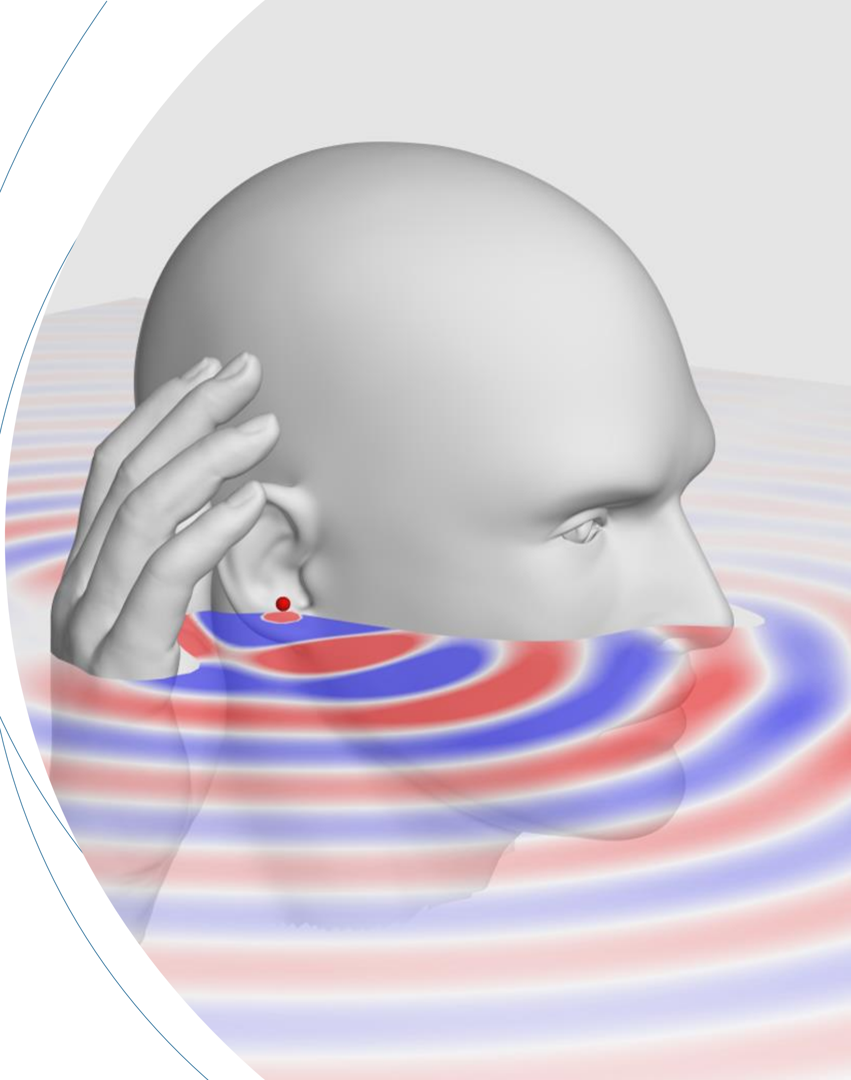
RECENT ADVANCES IN COMPUTATIONAL AND STATISTICAL METHODS

Rui Cao
Dassault SYSTEMES

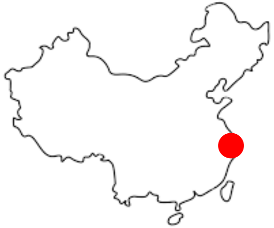
Acknowledgements:
Vincent Cotoni, David Hawes, Julien Legault, Sascha Merz, Phil Shorter, Pr. Robin Langley



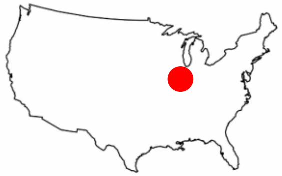
Outline

- My Background
- wave6 and Dassault SYSTEMES
- Vibro-Acoustic Analysis Methods
- Recent application examples
  - Adjoint optimization of foams and fibers for pass-by noise
  - Efficient models of high frequency windnoise
  - Audio tuning and auralization
- Summary

Rui Cao : My background



Undergrad
Shanghai University



PhD
Purdue University

with Pr. Bolton

Senior NVH Engineer

Acoustic insulation and damping material R&D and commercialization

Senior Applied Researcher

Tire noise and vibration simulation, test correlation and virtual development

NVH Simulation Manager

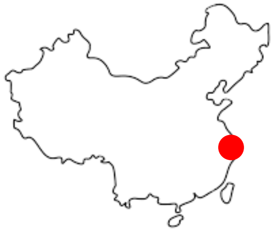
Battery Electric and Fuel-cell Electric vehicle NVH development. Cabin interior noise, pass-by noise, aeroacoustics

Senior Vibro-Acoustic Expert

Working with clients supporting wave6 vibro-acoustic software

Rui Cao : My background

Simulation of poro-elastic materials for materials supplier



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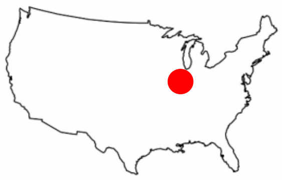

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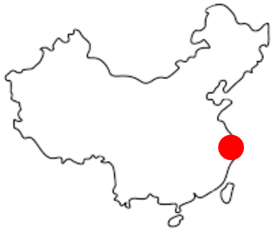

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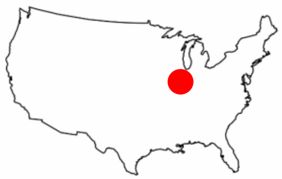

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DASSAULT SYSTEMES

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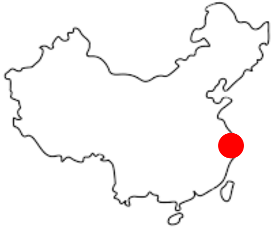
Extreme application environment

Rui Cao : My background

Simulation software provider (including Poro-Elastic materials)



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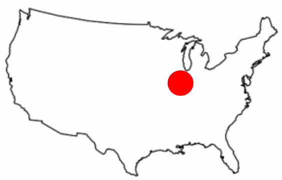

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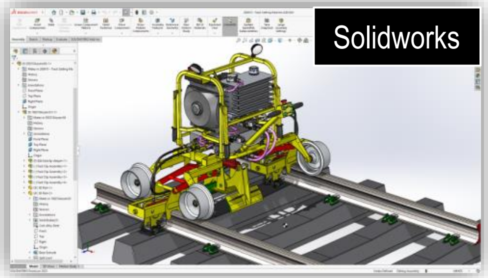
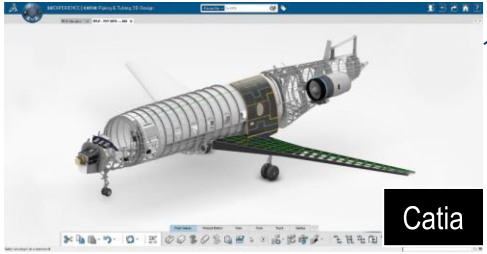
What does Dassault SYSTEMES do?



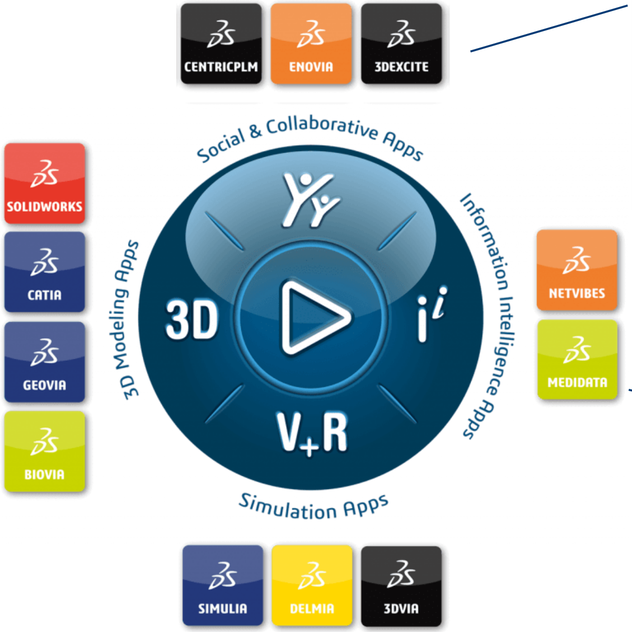
https://blogs.solidworks.com/solidworksblog/2022/10/whats-new-in-solidworks-2023-3d-cad.html

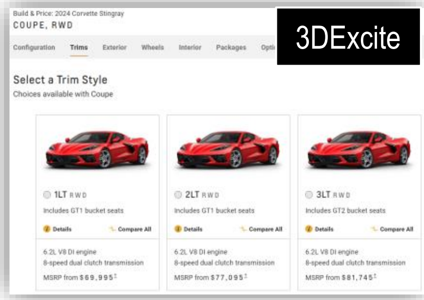
>6M users



https://3dprintingindustry.com/news/boeing-signs-1-billion-contract-with-dassault-systemes-for-3dexperience-software-119062/

World's leading solution for product design





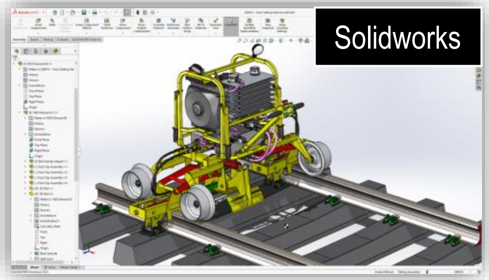
https://www.chevrolet.com/performance/corvette/build-and-price/trims> 6M users

Rendering and visualization

30K clinical trials, 9M participants

We write software that helps businesses manage their products, processes and information
20K employees in 135 countries supporting 25M users from ~300K companies, ~$6B revenues

What does Dassault SYSTEMES do?



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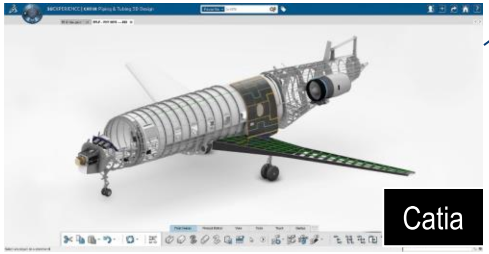

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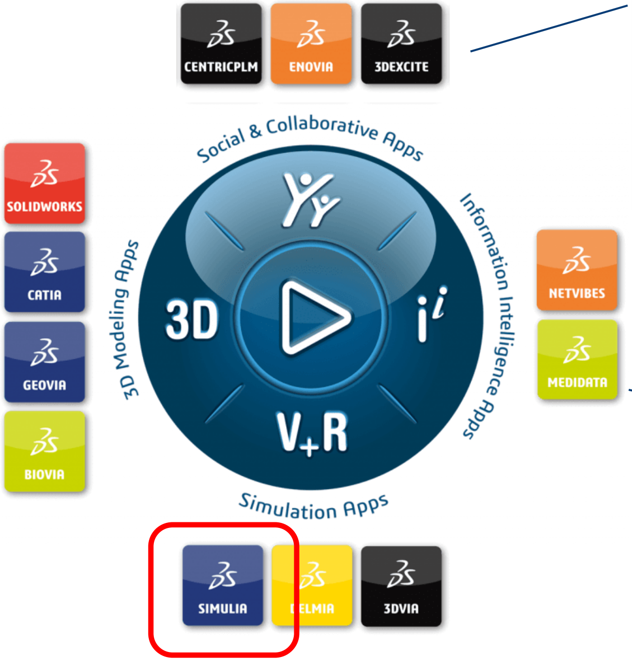

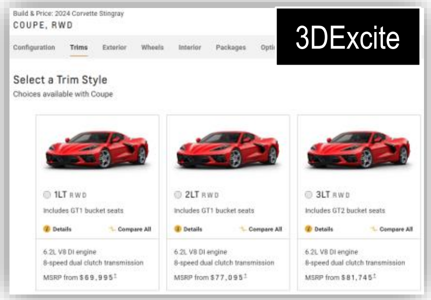

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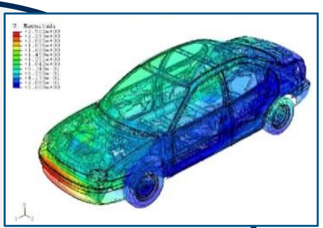
Why SIMULIA for noise and vibration simulation?

Motion : Simpack
accurate modeling of high frequency content of powertrain sources (and ride and handling etc)

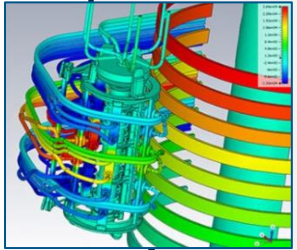


Structures : Abaqus
Explicit and Implicit Finite Elements
Best-in-class solvers and materials

SOURCES

PATHS

Electromagnetics : CST
accurate modeling of emag sources in electric machines/vehicles (and antenna design etc)



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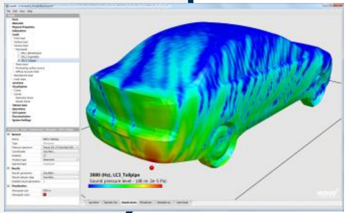
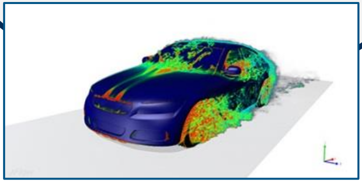


Vibro-Acoustics : wave6
vibro-acoustics and flow noise
full spectrum analysis methods

Fluids : PowerFLOW
unsteady Lattice Boltzmann CFD
accurate and fast modeling of aerodynamic sources in flow noise



Optimization : Tosca, isight

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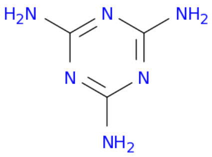
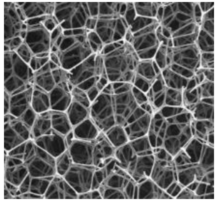
Poroelastic material modelling

Chemistry



https://www.molinstincts.com/formula/MELAMINE-cfml-CT1001755411.h

Microscopic



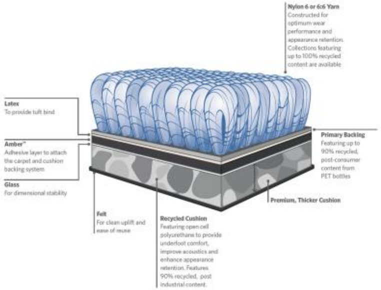
https://www.researchgate.net/figure/Melamine-foam-cell-micrograph-image-courtesy-of-BASF-BasotectV-R_fig1_350358357

Macroscopic

Properties: Materials > Foam > Melamine

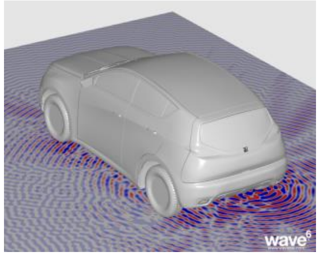
General	
Name *	Melamine
Type	*FoamMaterial*
Phase Properties	
Fluid material *	Air
Solid density	12 *kg/m^3*
Solid Young's modulus	3.0000e+05 *Pa*
Solid Poisson's ratio	0.4
Solid damping loss factor	0.1
Porous Properties	
Flow resistivity	7000 *N m^-4 s*
Porosity	0.99
Tortuosity	1.01
Viscous length	2.5000e-04 *m*
Thermal length	5.5000e-04 *m*

Layup



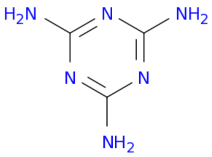
https://www.milliken.com/en-gb/businesses/floor-covering/technical/cushion-backed

System level



Poroelastic material modelling

Chemistry



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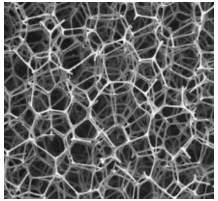

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Macroscopic

Properties: Materials > Foam > Melamine

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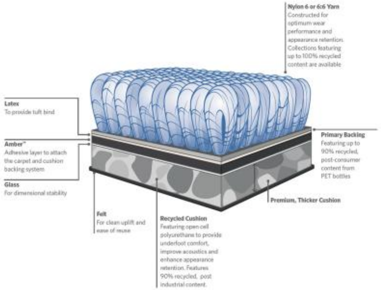

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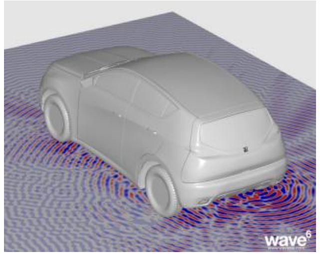
System level



This presentation

What type of systems do we want to model?

Interior noise

Exterior noise

Failure

Systems of interest are “large”

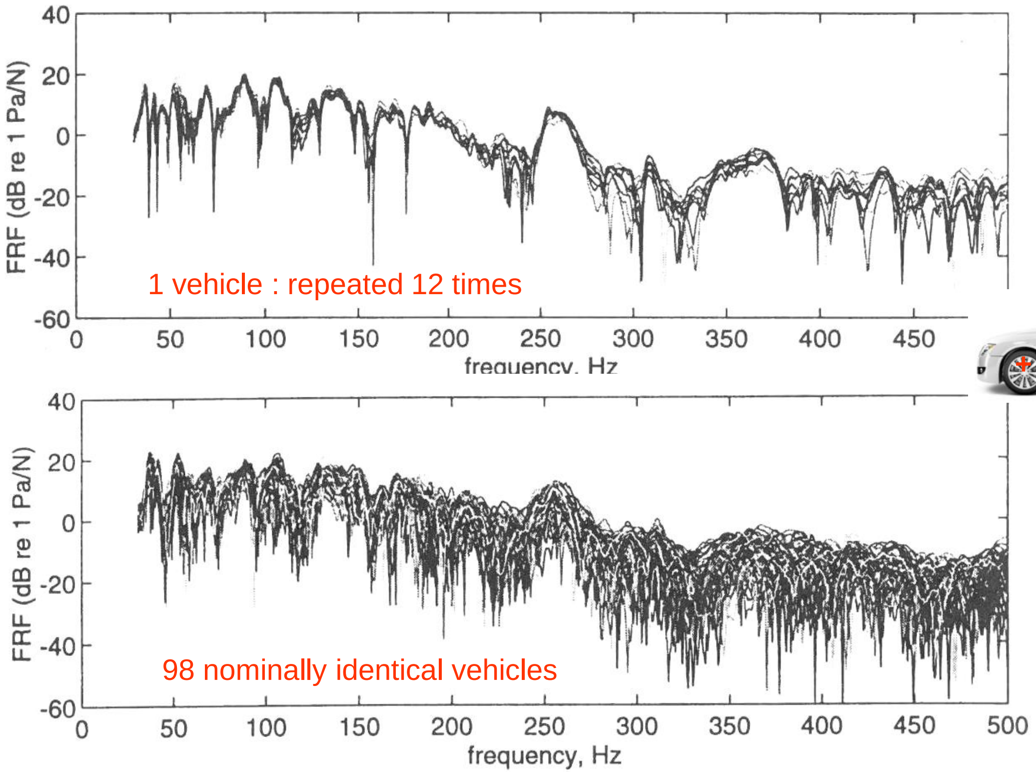
2.5m of fuselage :
5e5 structural modes
1e7 acoustic modes < 10 kHz

4e6 structural modes
1e6 acoustic modes
< 10 kHz

65 structural modes
80 acoustic modes
< 10 kHz

The systems we want to analyze typically have millions/billions of structural and acoustic modes across the audible frequency range

Systems of interest are “uncertain”



3e6 structural modes
1e6 acoustic modes
< 10 kHz

Systems of interest tend to exhibit significant variability in responses at higher frequencies due to <u>short wavelength</u> behavior

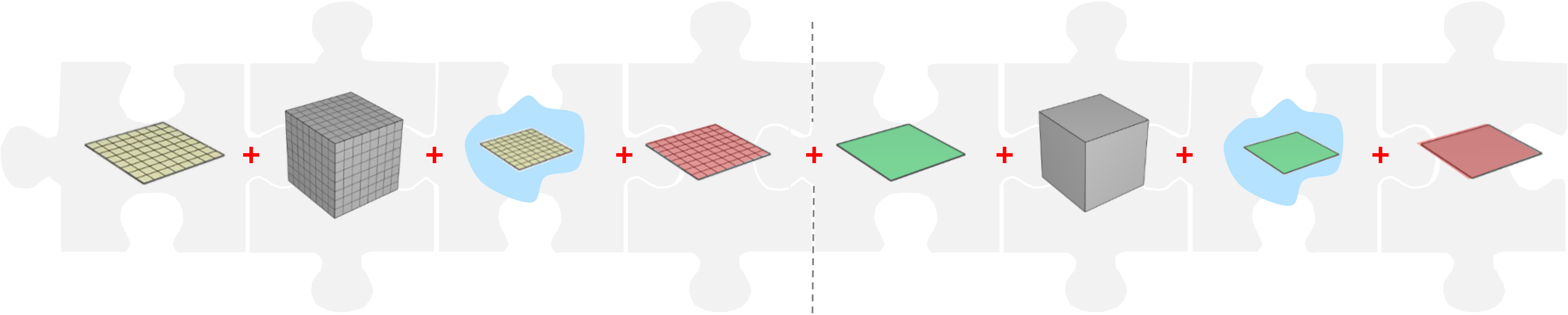
R. Bernhard “ The limits of predictability due to manufacturing and environmentally induced uncertainty”, Proc. of InterNOISE, 1996.

Vibro-Acoustic analysis methods

Low frequency (deterministic)

Mid frequency (mixed)

High frequency (statistical)



Finite Element (FE) structure

Finite Element (FE) acoustics

Boundary Element (BEM) and APML infinite acoustic fluids

Poroelastic (Foam) Finite Elements (PEM)

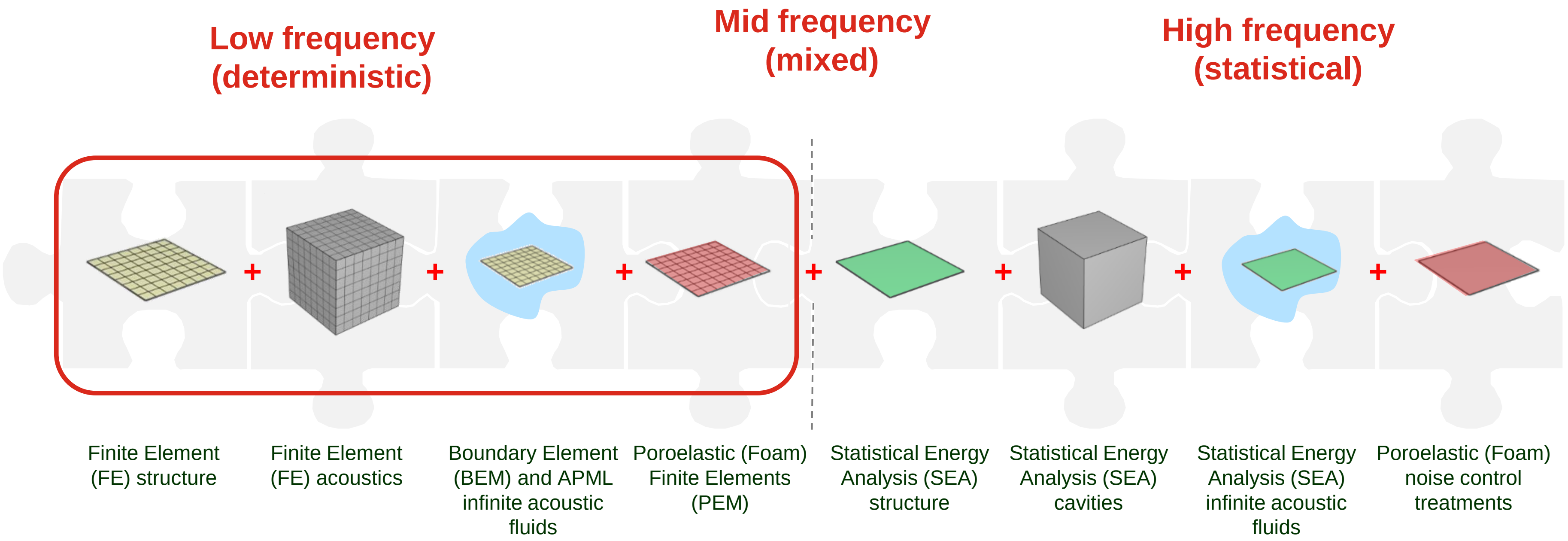
Statistical Energy Analysis (SEA) structure

Statistical Energy Analysis (SEA) cavities

Statistical Energy Analysis (SEA) infinite acoustic fluids

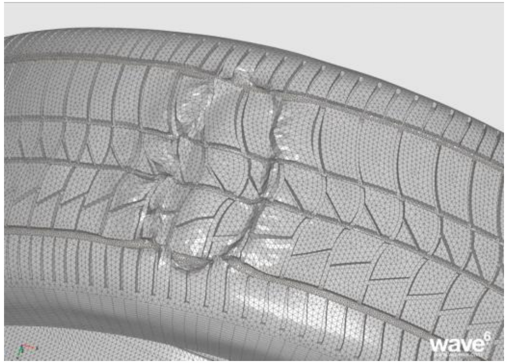
Poroelastic (Foam) noise control treatments

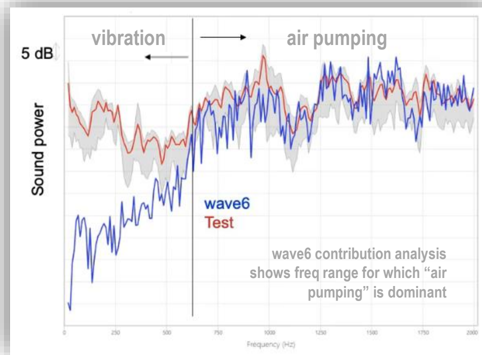
Vibro-Acoustic analysis methods



Examples of "low frequency" models

Treaded tire noise





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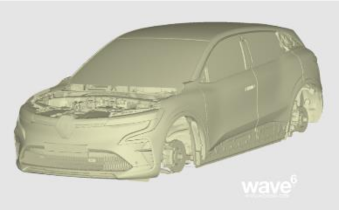
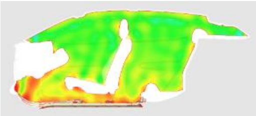
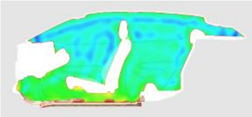
G. Del Guercio et al "Exterior noise simulation of patterned tires", Dassault ModSim Conference 2020

Trimmed body interior noise





Air-Gap



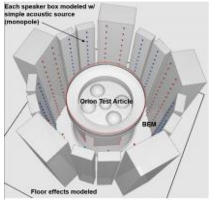
Compressed foam

RENAULT

P. Mordillat, "RENAULT Smart Cocoon Technology vibro-acoustic simulation", Internoise 2022

Acoustic testing of spacecraft

Image credit: NASA



wave6 FE/BEM model

Image credit: NASA

LOCKHEED MARTIN

NASA

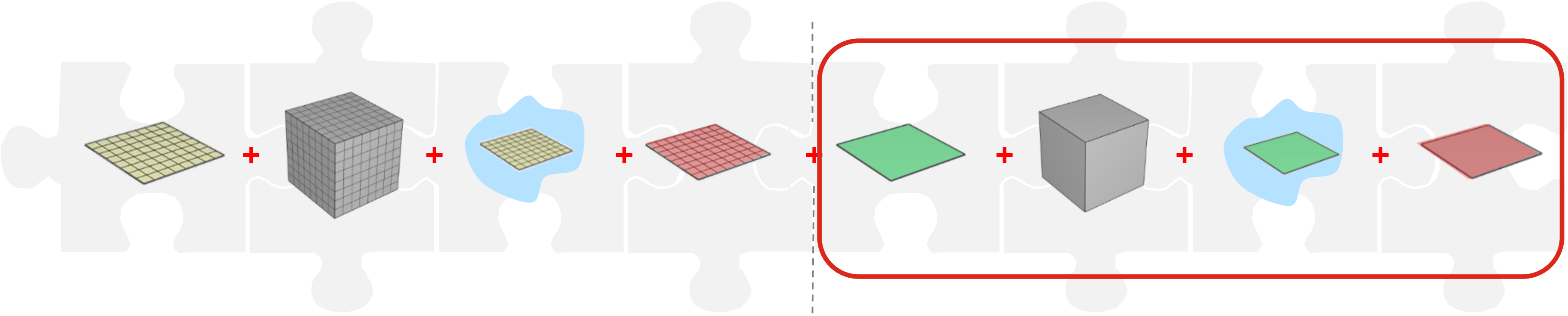
I. Dandaroy "Analytical Tool for Numerically Simulating a Direct Field Acoustic Test" Proc. SCLV 2017

Vibro-Acoustic analysis methods

Low frequency (deterministic)

Mid frequency (mixed)

High frequency (statistical)



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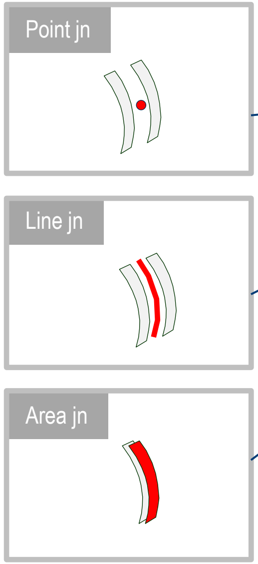
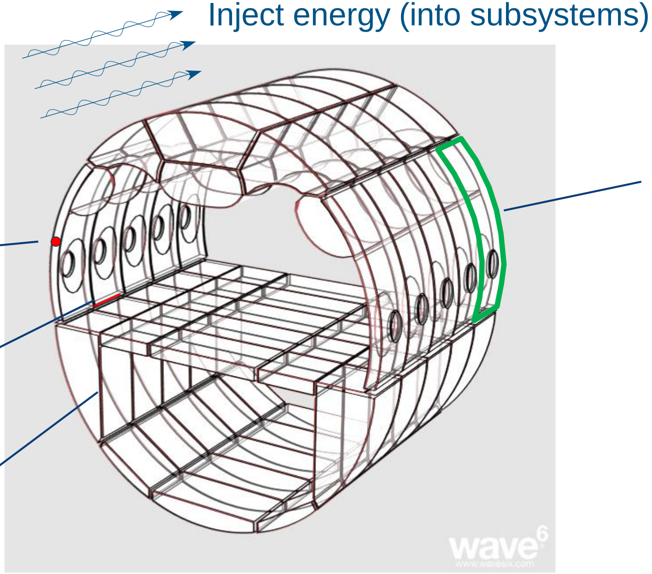
Examples of high frequency models : Statistical Energy Analysis (SEA)

"Junctions"
Transmit energy
(wave scattering)

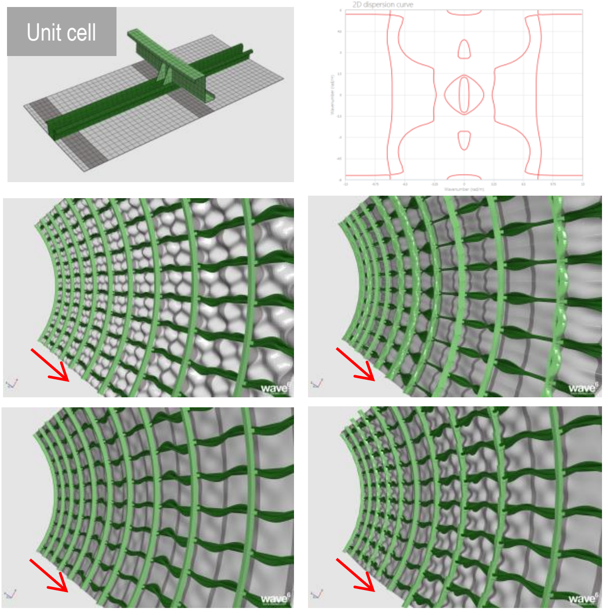


"Loads"
Inject energy (into subsystems)



In SEA a system is split into a set of coupled subsystems and "statistical wave mechanics methods" are used to describe the input, storage, transmission and dissipation of vibro-acoustic energy throughout the system

"Subsystems"
Store energy (in reverberant wavefields)



Dassault Systemes geometry and models

We have developed new generalized wave based approaches to SEA using periodic structure theory

P. Shorter et al "A new generalized approach to Statistical Energy Analysis (SEA)" Proc. Internoise 2016

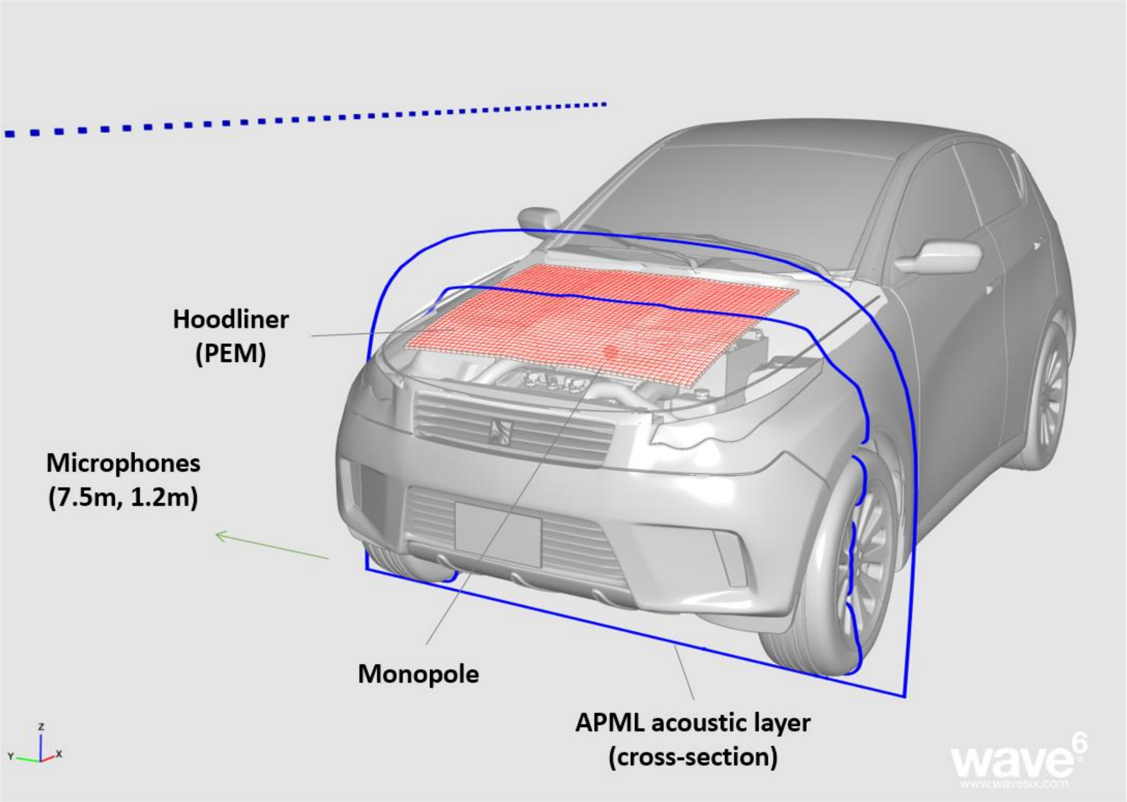
Outline

“Topology” optimization of foams (volume PEM elements)

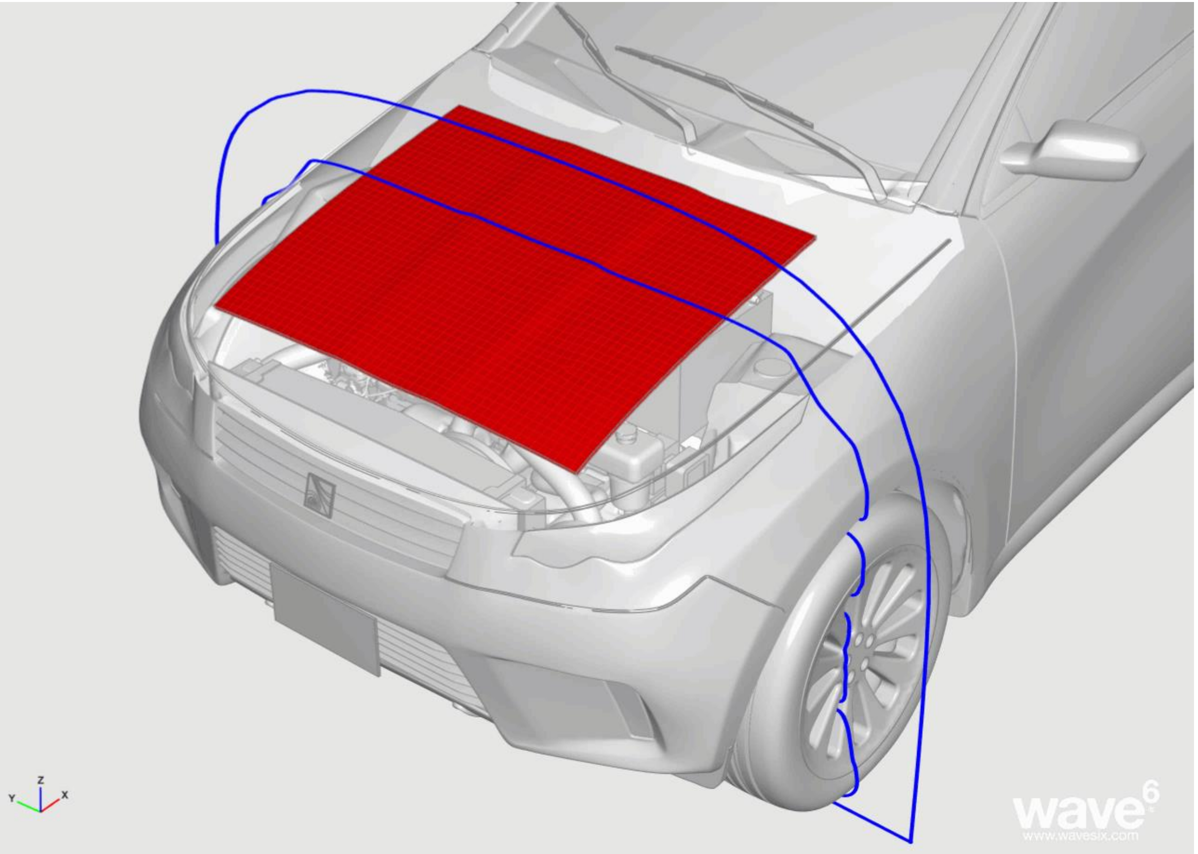
We have worked with clients to develop new methods for topology optimization of Poroelastic Finite Elements

Simplified Example : Monopole placed in underhood of vehicle, airborne paths to exterior

What is the optimal spatial distribution of foam for the hoodliner that reduces pass-by noise at 1kHz (subject to a constraint on the mass of the hoodliner)?



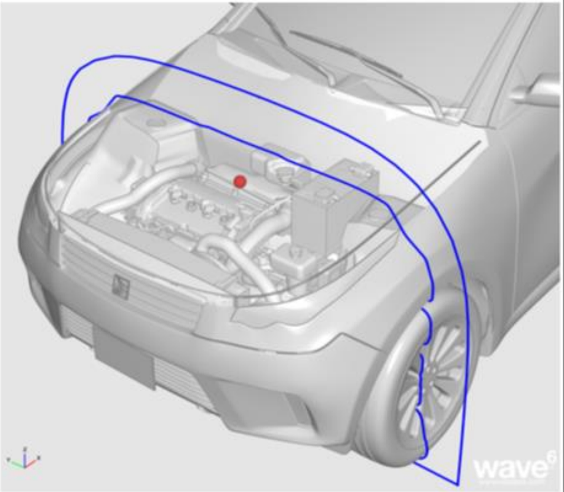
“Topology” optimization of foams (volume PEM elements)



Spatial distribution of foam at each iteration of optimization

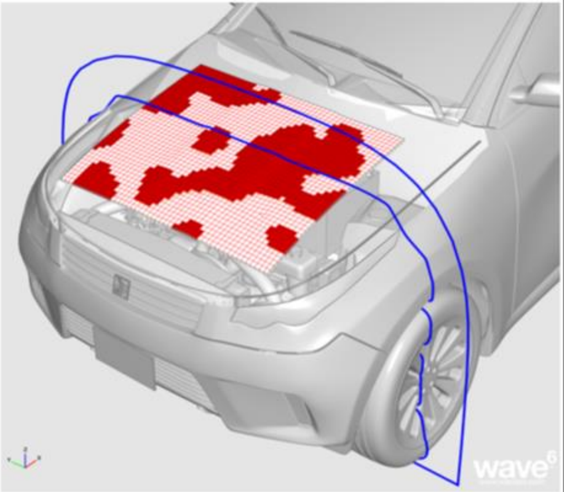
“Topology” optimization of foams (volume PEM elements)

No hoodliner



Mass = 0 kg
SPL = 75.8 dB

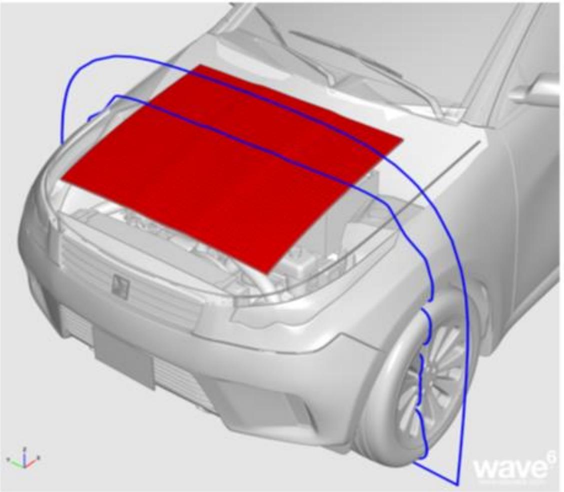
Optimized hoodliner



Mass = 0.05 kg
SPL = 71.1 dB

4.7 dB better than no headliner
1.7 dB better than uniform headliner

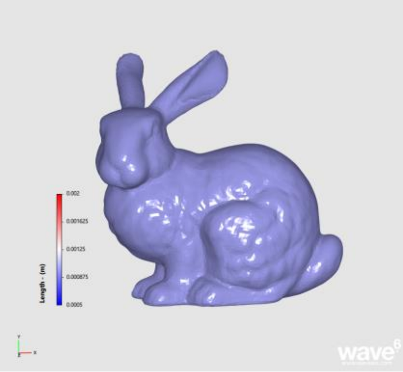
Uniform hoodliner

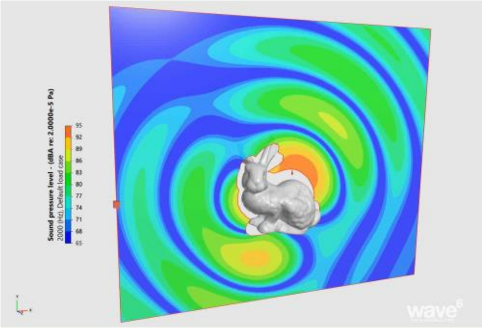


Mass = 0.1 kg
SPL = 72.8 dB

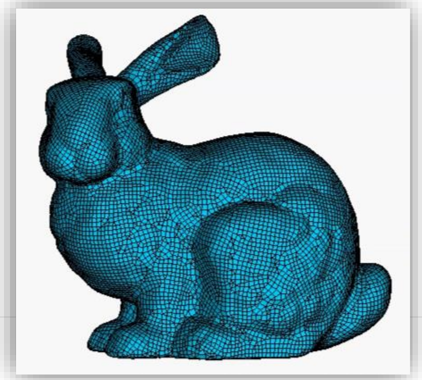
“Sizing” optimization to reduce sound radiation (or vibration)

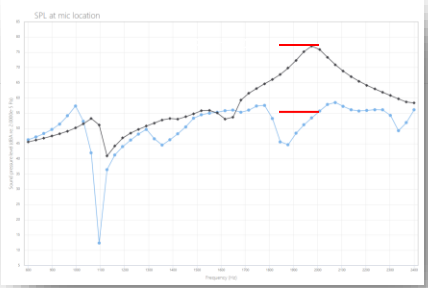
1mm thick steel



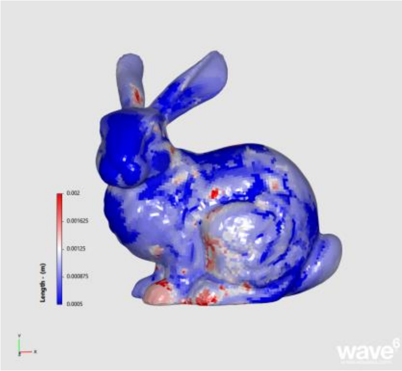


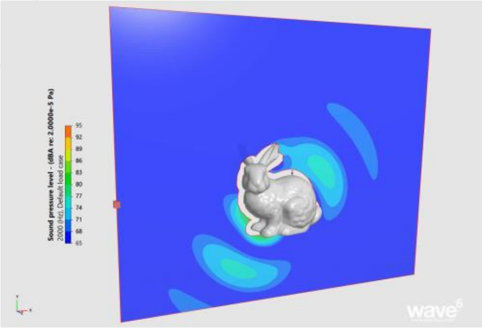
Sizing optimization (50 iterations)





Optimized shell thickness (same mass)





We have worked with clients to develop “acoustic specific” adjoint based sizing optimization (optimize thickness of sound package and shell structures for absorption, TL, acoustic radiation etc)

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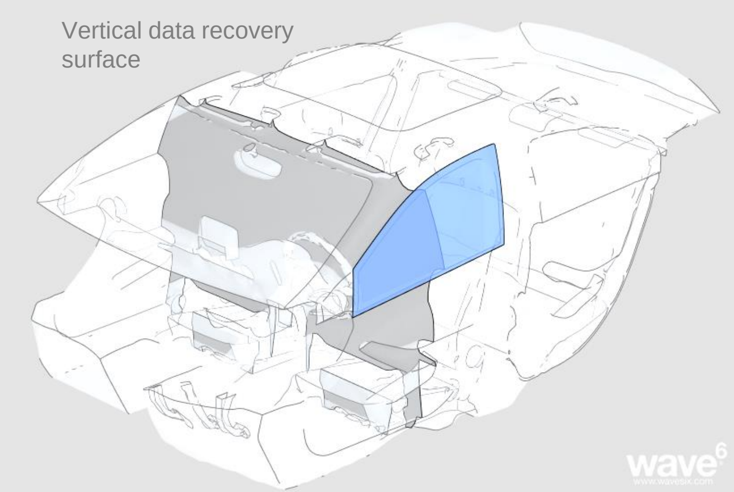
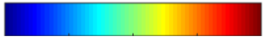
New fast (SEA) methods for mid/high frequency trimmed body



We have developed new computationally efficient methods for accurately modeling the sound pressure level within a trimmed vehicle across a broad frequency range (due to various localized sources).

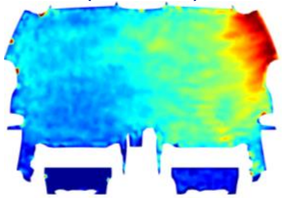
4kHz 1/3 OB

Pressure PSD
dB, re. 4e-10 Pa^2/Hz
20dB scale

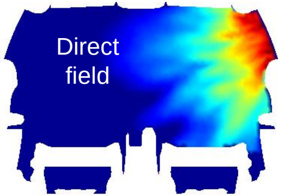


A.Traditional SEA

B,BEM model (200Kdofs)



C. New SEA approach



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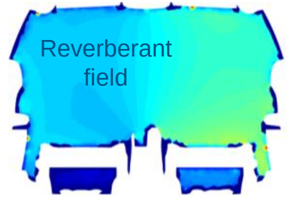

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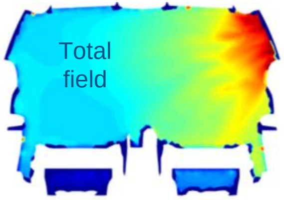


~5 minute solve time

A. Schell, V. Cotoni "Flow Induced Interior Noise Prediction of a Passenger Car", Proc. SAE 2016

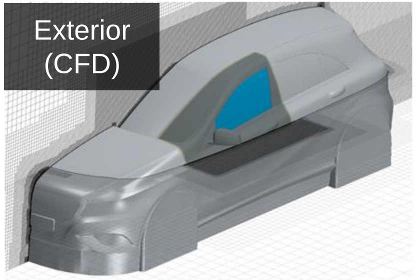
Side mirror interior windnoise : Daimler

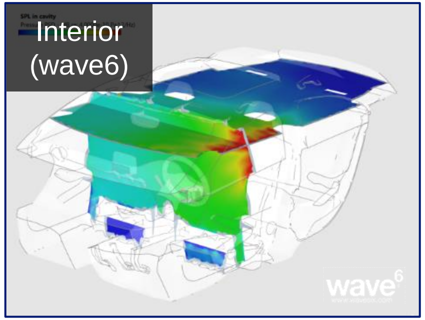
Experiment

Figure 1: Mercedes-Benz A-class with blocked underbody flow and interior microphone array

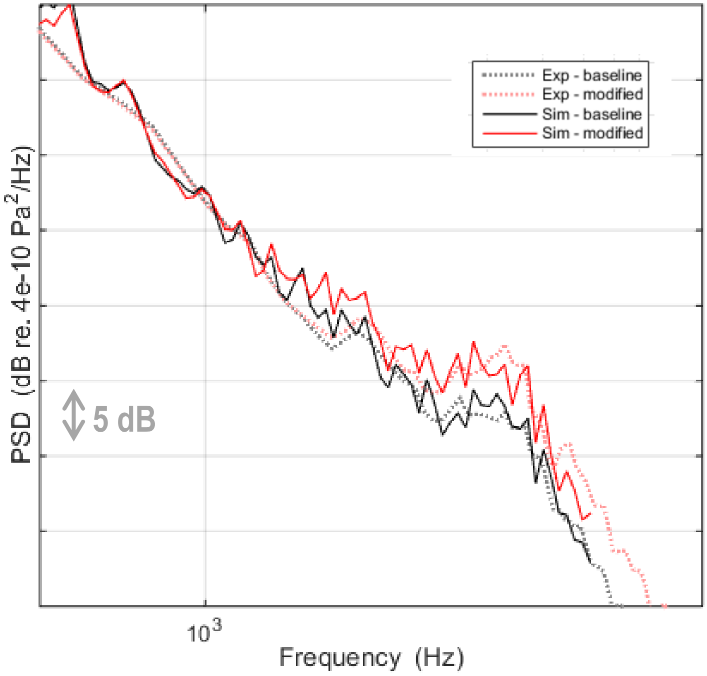
Figure 2: Side mirror modification (4 mm forward facing diffusor step)

Simulation





Drivers ear SPL (prediction vs. test)



Schell, A. and Cotoni, V., "Flow Induced Interior Noise Prediction of a Passenger Car," SAE Int. J. Passeng. Cars - Mech. Syst. 9(3):1053-1062, 2016

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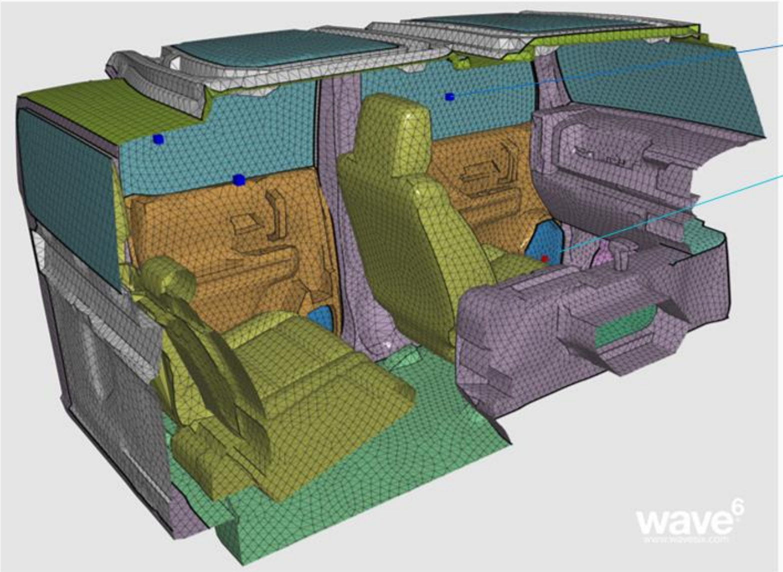
Audio tuning and auralization : GM

Objective : predict p/q transfer functions to 20 kHz

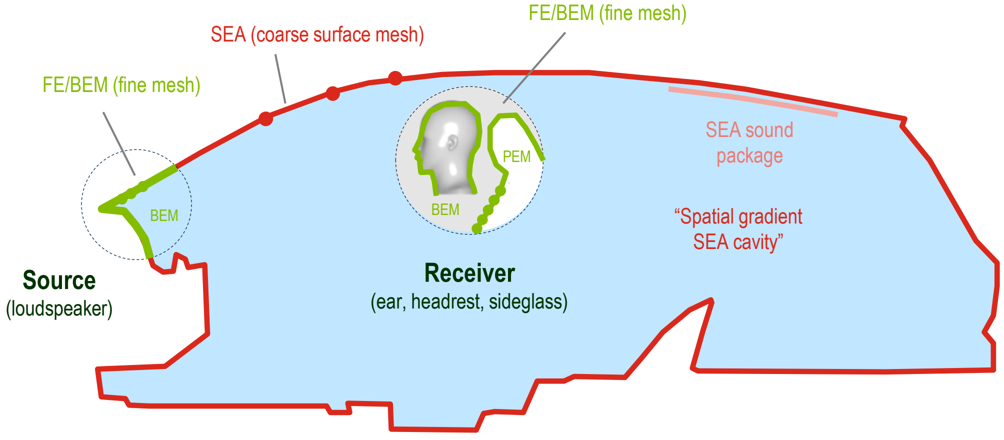
- Surfaces
  - Surfaces for cavity volume
    - ☑ *Glass surface*
    - ☑ *Seats surface*
    - ☑ *Vinyl-Floor-Front surface*
    - ☑ *Vinyl-Floor-Rear surface*
    - ☑ *Speaker surface*
    - ☑ *Wetted cavity surface*
    - ☑ *Wetted FOD surface*
    - ☑ *Doors surface*
    - ☑ *Headliner-Cloth surface*
    - ☑ *Console-IP-Garnish surface*
    - ☑ *Upper footwell*



Cavity geometry + surface impedance/absorption

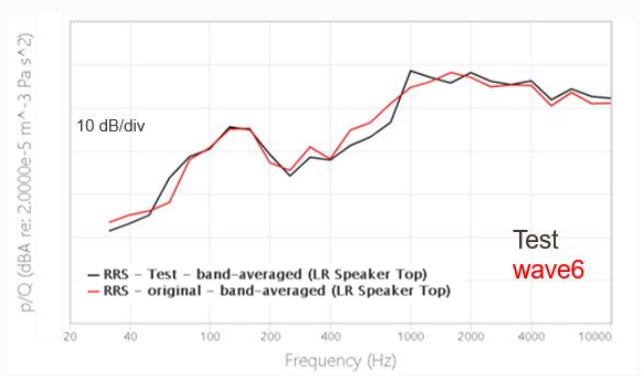
Q. Zhang et al “Full spectrum simulation of vehicle interior acoustic transfer function (ATF) using wave6”. Simulia Users Conference 2023

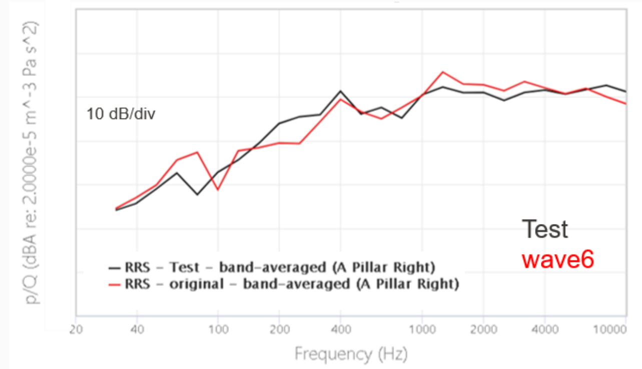
Audio tuning and auralization : GM



New computationally efficient methods that enable us to add small zones of "FE/BEM detail" in an SEA cavity model (that also accounts for cavity shape and sound package distribution). Have recently extended to transient applications

P. Shorter, R. Langley "Vibro-Acoustic Analysis of Complex Systems", JSV 288(3)
P. Shorter, R. Langley "On the reciprocity relationship between direct field radiation and diffuse reverberant loading", JASA 117(85-95)





Q. Zhang et al "Full spectrum simulation of vehicle interior acoustic transfer function (ATF) using wave6". Simulia Users Conference 2023

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Summary

- Vibro-Acoustic systems typically contain millions of structural and acoustic modes across the audible frequency range
- Combination of deterministic and statistical methods needed to analyze systems across this frequency range
- We have worked with clients on various new methods:
  - Low frequency : new methods for tire noise, large fully coupled FE/BEM models, trimmed body models, adjoint optimization for vibro-acoustics etc
  - High frequency : new generalized wave based SEA methods
  - Mid frequency : combining deterministic and statistical methods for efficient full frequency models including for windnoise and audio tuning/auralization
- Please contact me for more information

IF WE ™