汽车/新能源车CAE/CFD 仿真
RoadShow 2016

ANSYS 气动诱发乘员舱内噪声仿真方案
~Aero-Vibro-Acoustics Approach~

2016.06

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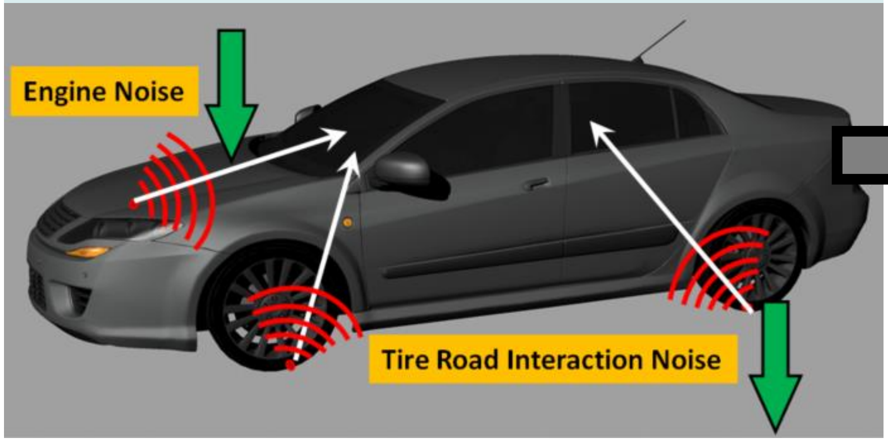
Outline

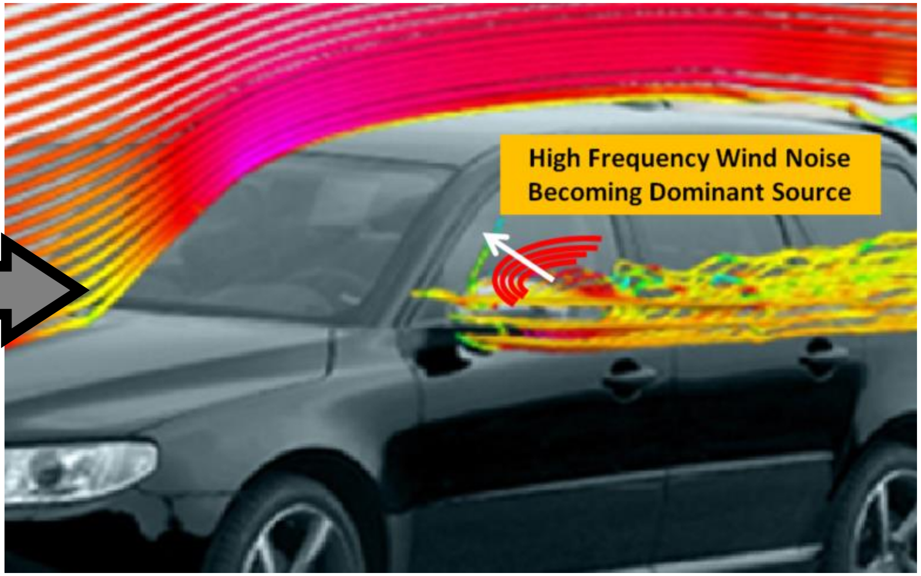
- Motivation
- Problem Description
- Simulation Methodology
- Setup
- Results
- Solution Performance
- Summary
- Outlook
- References

Motivation (1)

Wind noise is aerodynamically generated noise perceived in the vehicle interior. Important quality concern for car makers.

Advances in Sound packaging & Design improvements



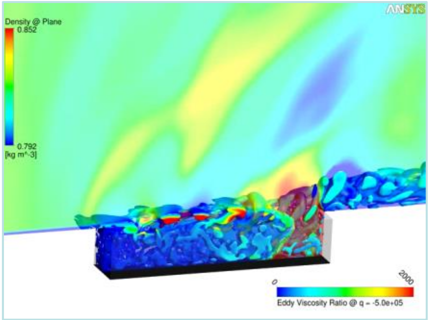


J.D. Power 2014 U.S. Vehicle Dependability Study report lists <u>Excessive Wind Noise</u> amongst the top 5 problems most commonly experience by vehicle owners

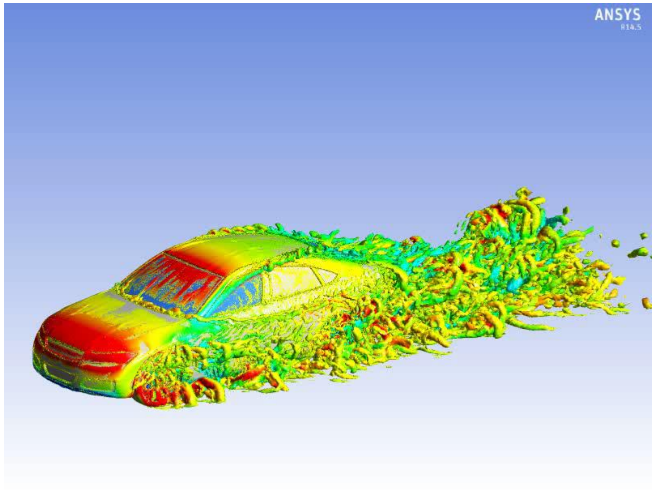
Noisy Breaks, Engine Noises, Excessive Fuel Consumption, Engine Loses Power

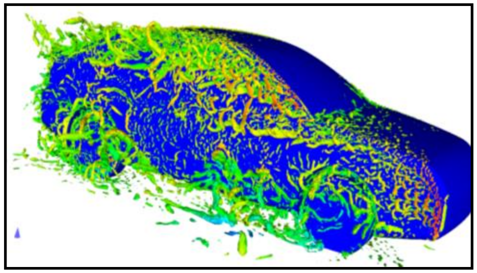
Motivation (2)

- Aerodynamic Noise Generation

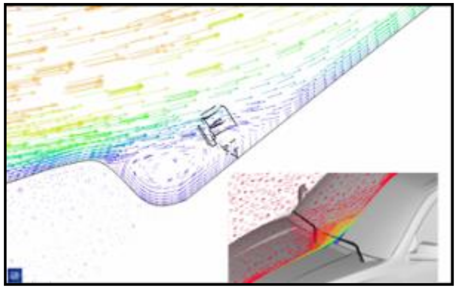


Cavity Resonance

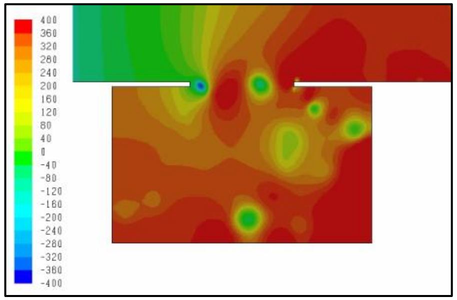




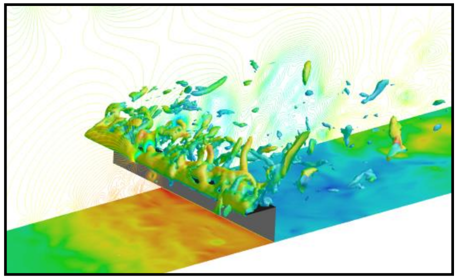
A-Pillar Vortex



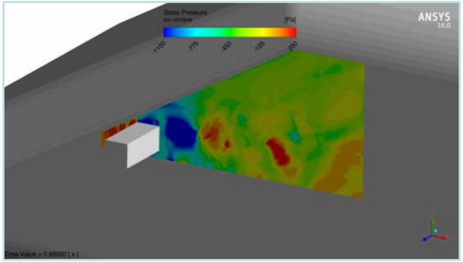
Flow Separation/
Vortex Shedding



Cavity Resonance



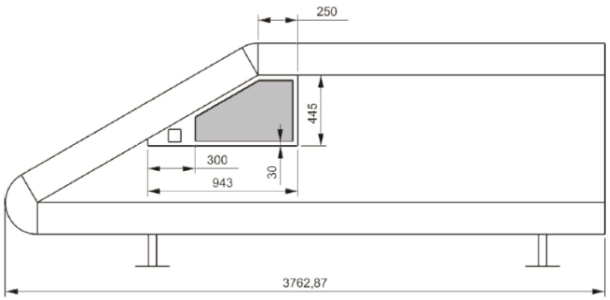
Flow Separation/
Vortex Shedding

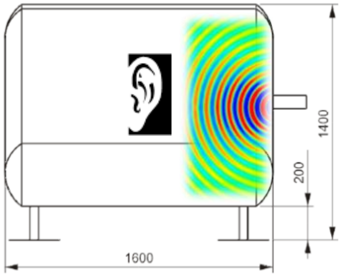


Side-View
Mirror Vortex

Problem Description

- Demonstrate aero-vibro-acoustics coupling to predict noise at SAE-Body with mirror by means of a deterministic method
- Validate with extensive experimental data [1] from Friedrich-Alexander University in Erlangen/Germany





Sound Source
Transient separated flow at side mirror

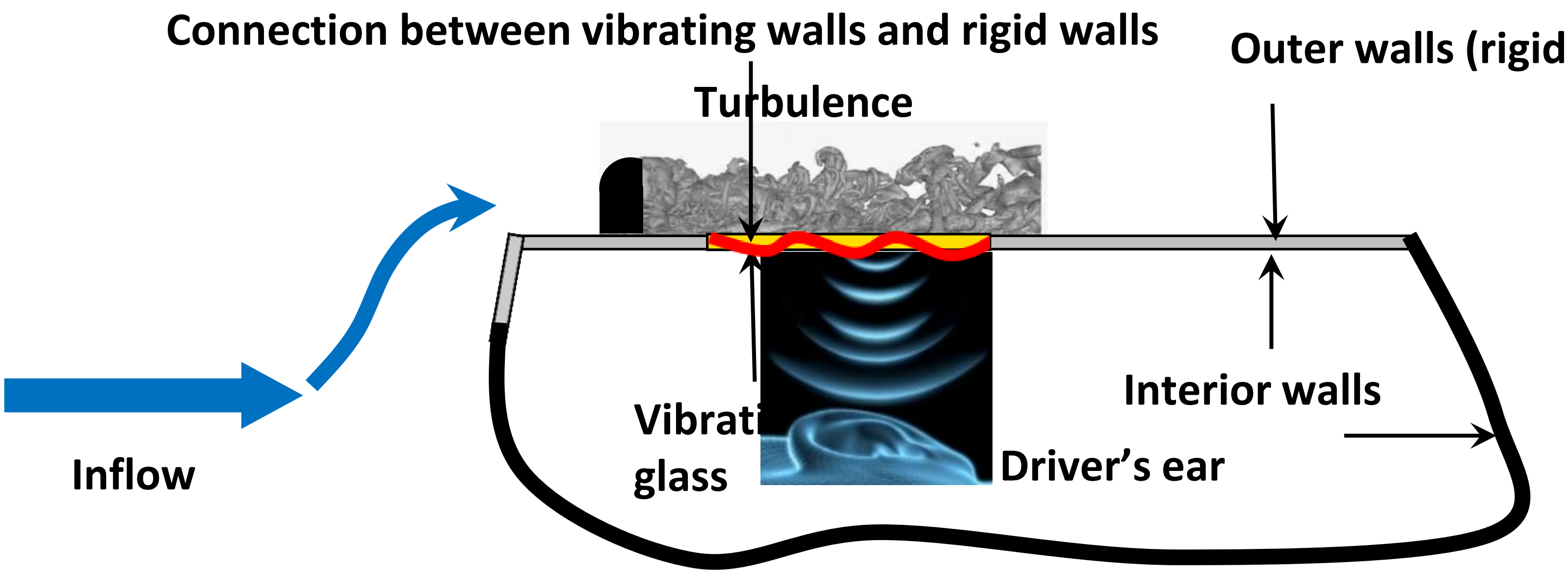
→

Transfer Path
Side glass, windshield

→

Receiver
Ear of a driver

Simulation Methodology (1)



External CFD Model
Transient Flow

→

Vibrating Surfaces
(Side Glass, Windshield)

→

Acoustics Model
(Car Interior)

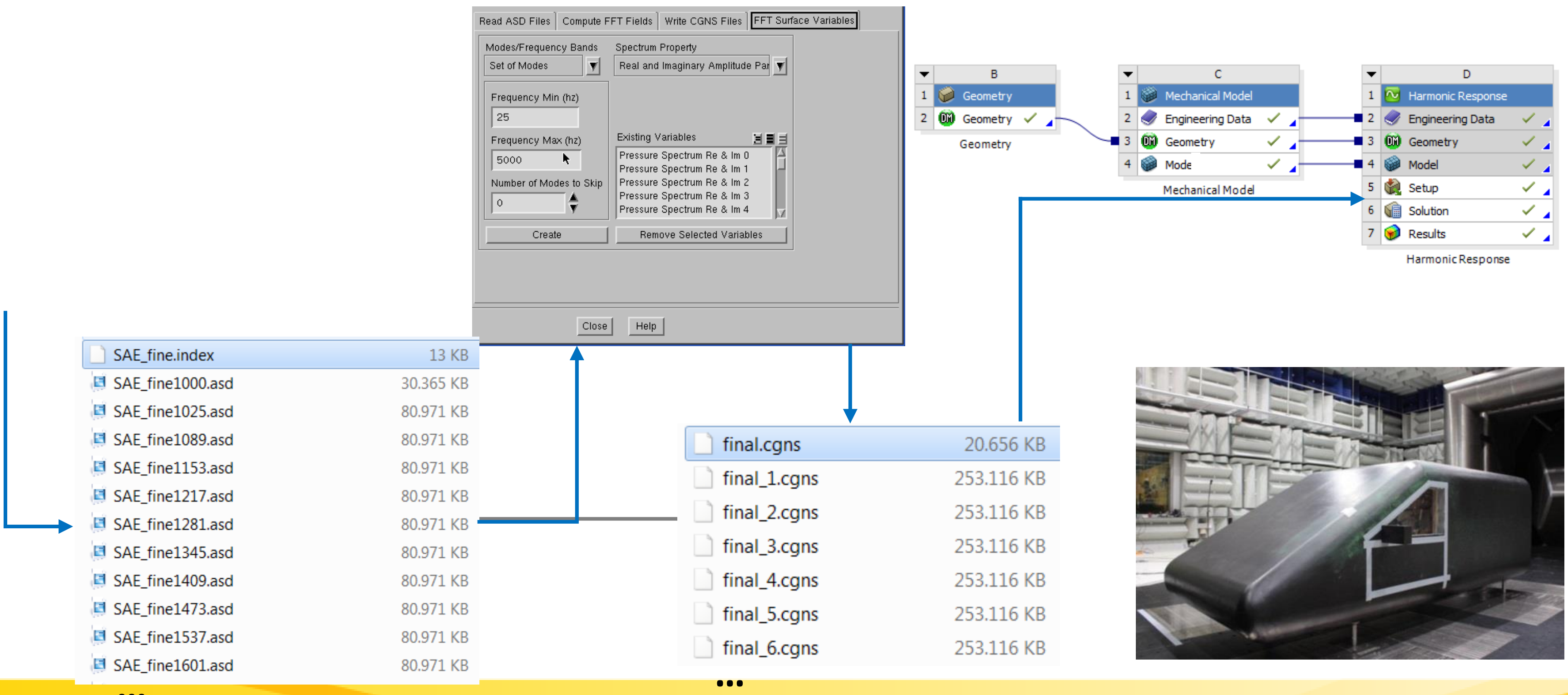
Compressible CFD modeling

Vibroacoustics Modeling

Simulation Methodology (2)

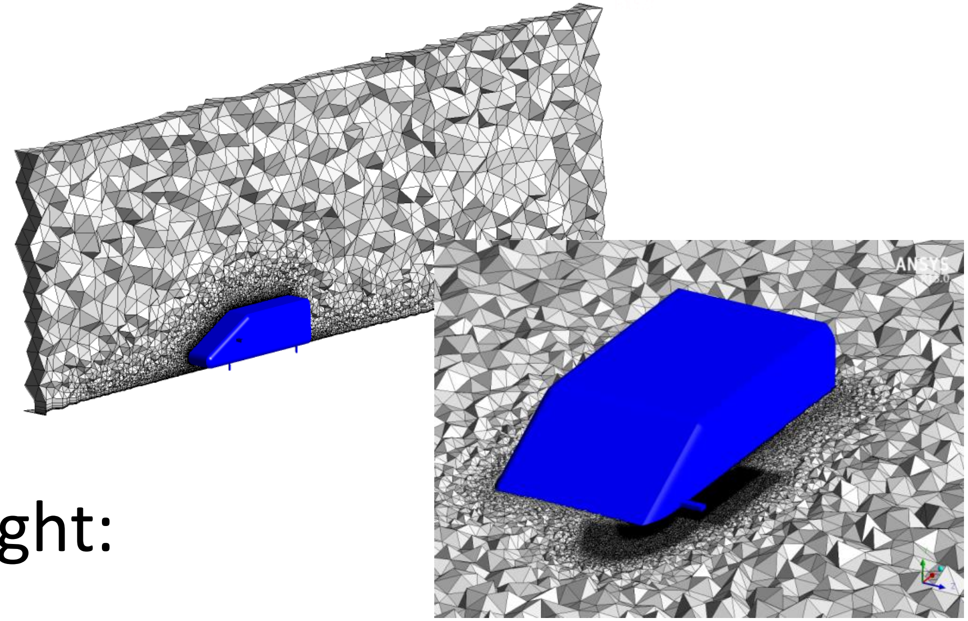
- From source to ears: SAE-Body with side view mirror

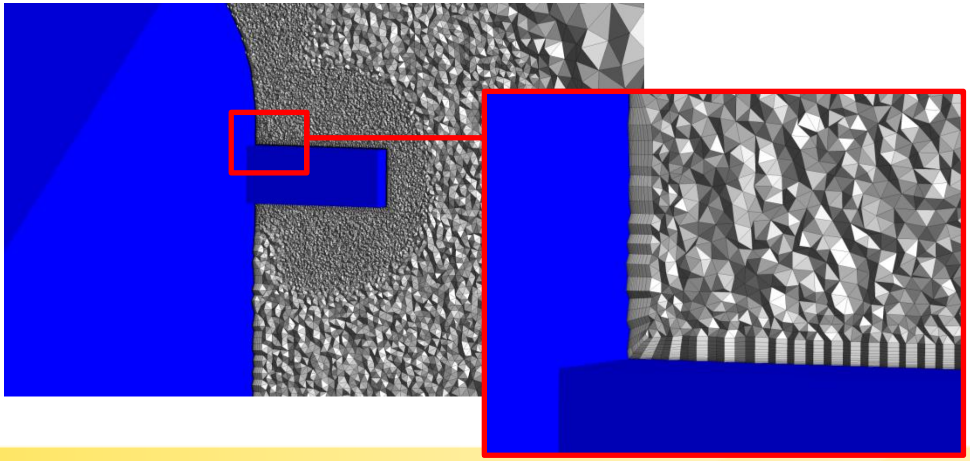
Solve Transient CFD → **Time → Freq. Domain Transform** → **Mapping Freq. Domain Pressure Loading** → **Solve Vibro-Acoustics Model**



Setup – Mesh (1)

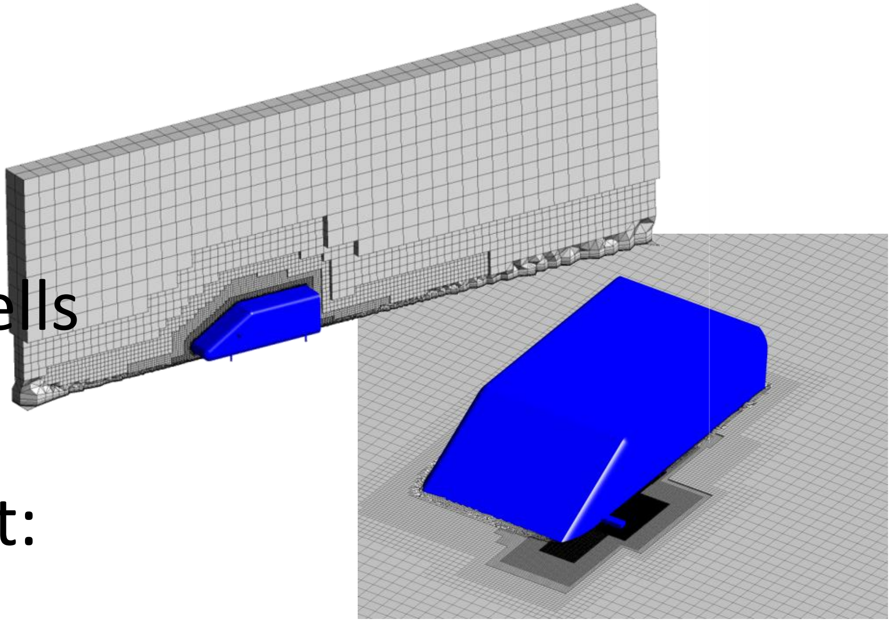
- CFD
  - FluentMeshing
  - 87M prism+tet cells
  - 15 prism layers
  - First prism layer height: 5e-02 mm
  - Surface mesh size:
    - ✓ Mirror+window: 1 mm
    - ✓ A-pillar: 3 mm
  - SIM1

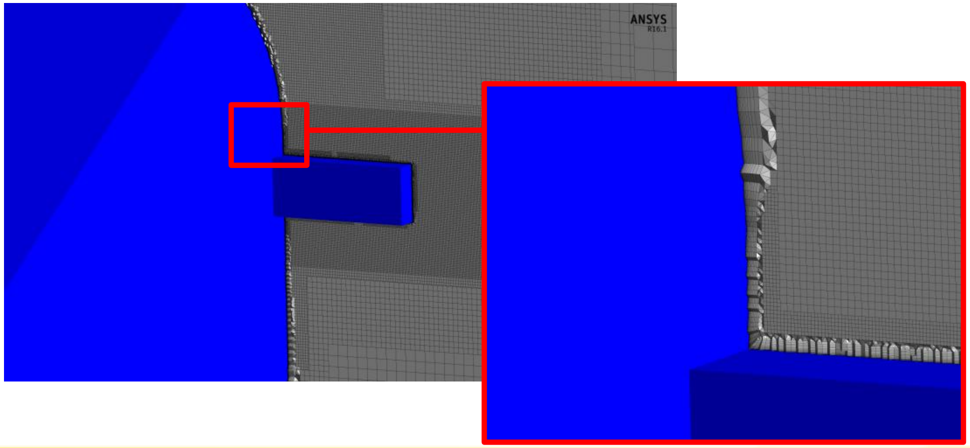




Setup – Mesh (1)

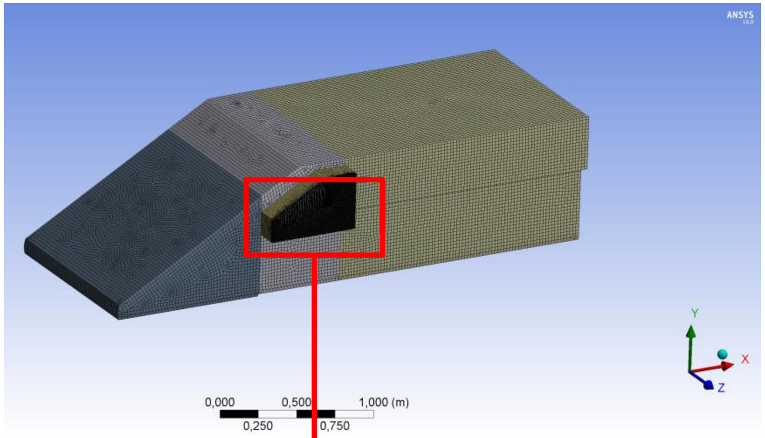
- CFD
  - FluentMeshing
  - 37M prism+hexcore cells
  - 15 prism layers
  - First prism layer height: 5e-02 mm
  - Surface mesh size:
    - Mirror+window: 1 mm
    - A-pillar: 3 mm
  - SIM2

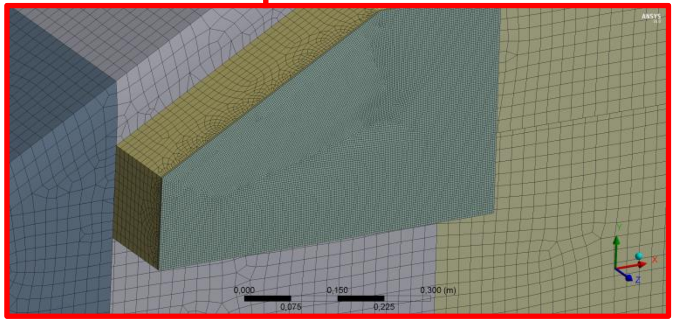


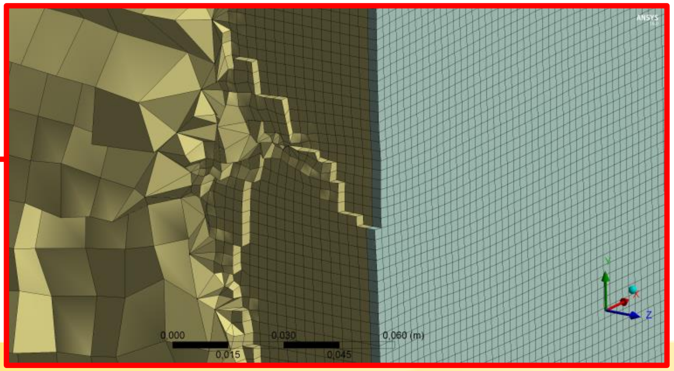


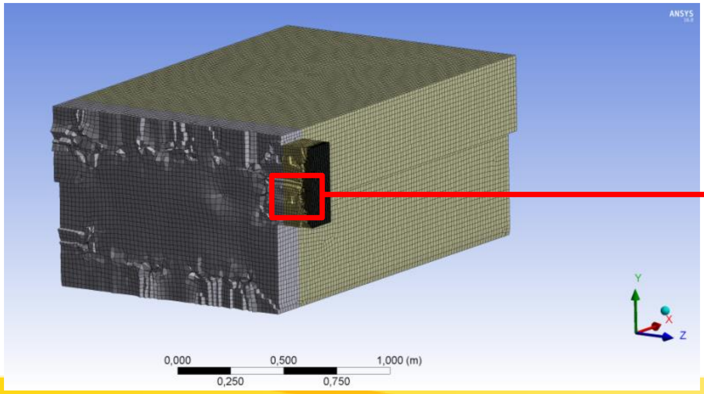
Setup – Mesh (2)

- Vibro-Acoustics
  - ANSYS Mechanical
  - 660k hex+tet+pyramid cells
    - ✓ Glass+sealing frame: 3 mm (hex cells)
    - ✓ Hex+pyramid cells for cabin
    - ✓ 12 linear elements per l inside cabin



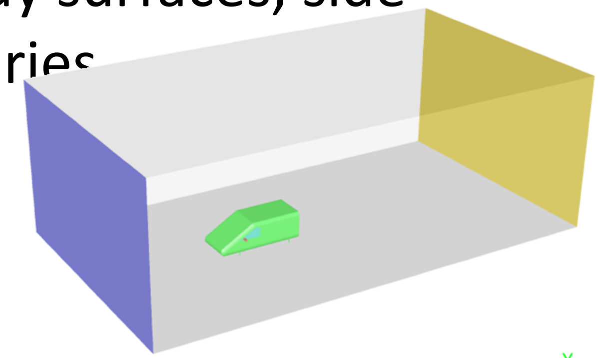






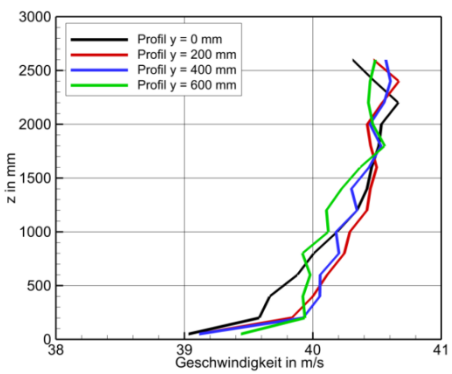
Setup - Boundary Conditions

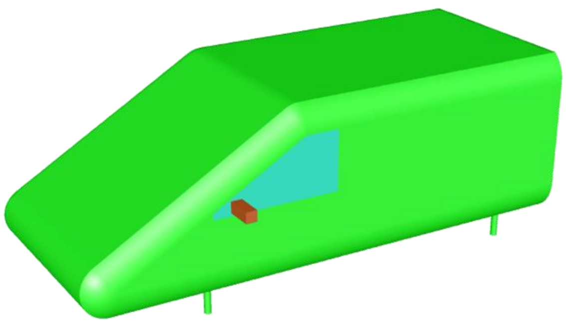
- CFD domain consists of external SAE-Body surfaces, side window, mirror and wind tunnel boundaries
- Velocity-Inlet: v = 150 km/h, Tu = 0.19%
  - Use measured profile for y = 0 mm
- Pressure-Outlet: p = 1 atm
- Tunnel top, floor, sides: no-slip walls



CFD Domain

Inlet Velocity Profile





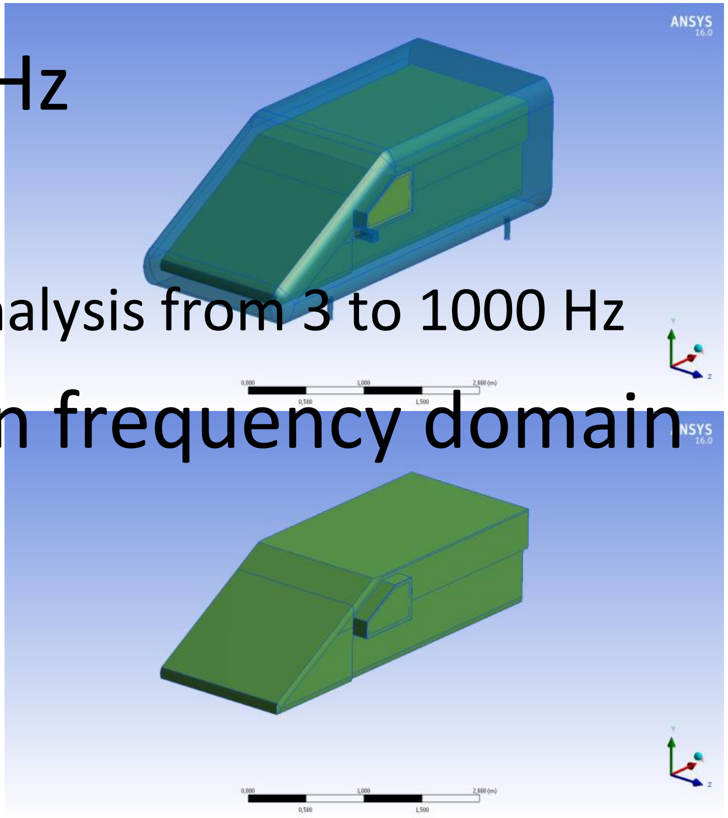
SAE–Body

Setup – CFD-Simulation

- ANSYS Fluent 16.0
- Material: Air as Ideal Gas
- Turbulence Model Steady State: SST K-Omega
- Turbulence Model Transient: DDES – SST K-Omega
- Spatial Discretization
  - Momentum : Bounded Central Differencing (for DDES)
  - All others: Second Order Upwind
- Time Discretization
  - 2nd Order Implicit, Δt= 3e-5 s
- Export acoustic data on side-window every time-step
  - Use asd-files from FW-H model; complex pressure as output[β]

Setup – Vibro-Acoustics-Simulation (1)

- ANSYS Mechanical 16.0
- Frequency resolution: 3.2 Hz
- Strong coupling:
  - Full Vibro-acoustics harmonic analysis from 3 to 1000 Hz
- Import complex pressure in frequency domain
- Setup with ACT extension



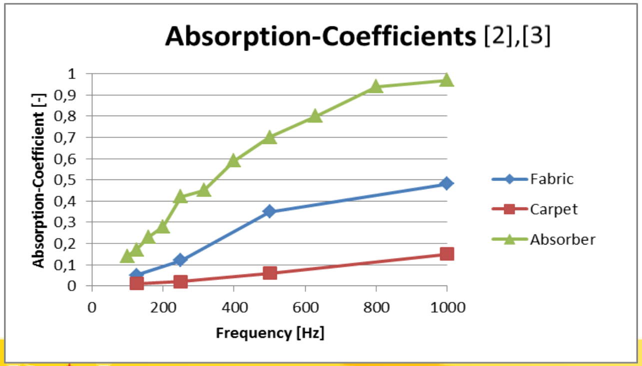
·Vibro–Acoustics Domain

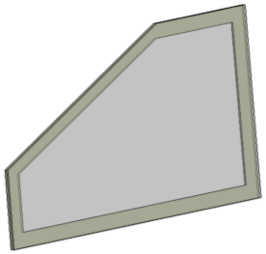
Setup – Vibro-Acoustics-Simulation (2)

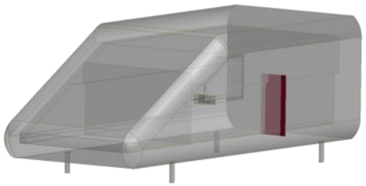
Material Properties

- Complex mounting system including sealant. Frame with high stiffness attached to synthetic rubber.

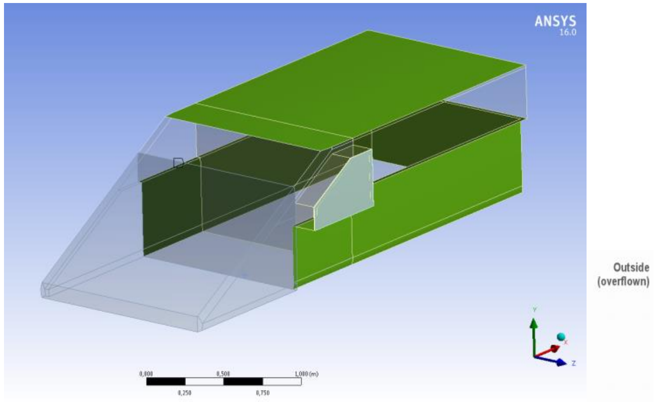
PROPERTIES	Floatglas [5], [7]	Sealant [4], [5], [6]
Density (kg/m³)	2,500	1800
Young‘s Modulus (MPa)	70,000	50
Poisson‘s Ratio	0.2	0.38
Thickness	2.85	2.85

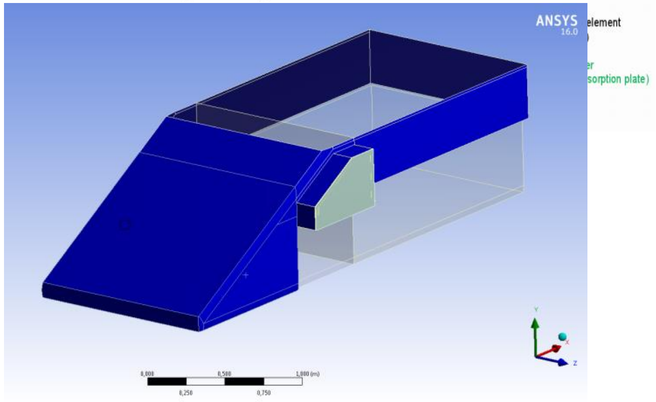


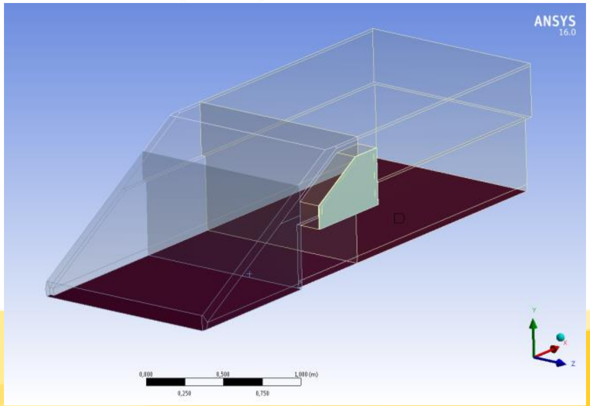




Vertical Cut

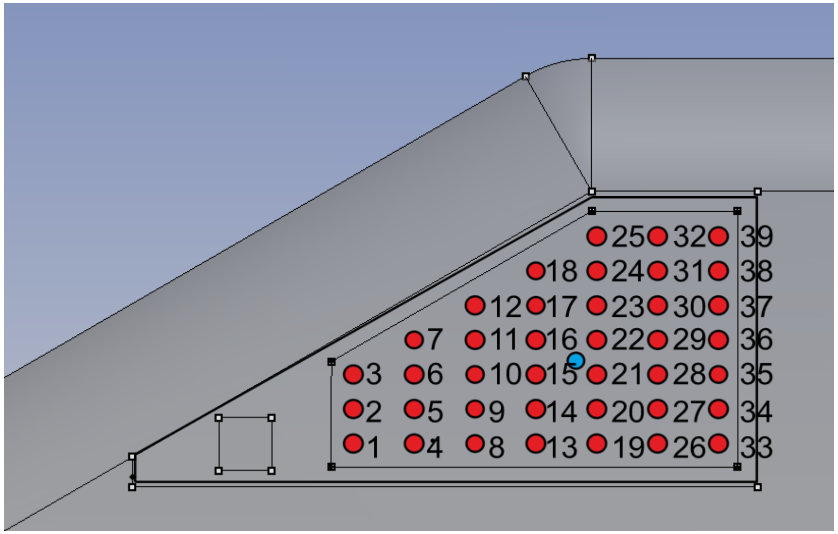






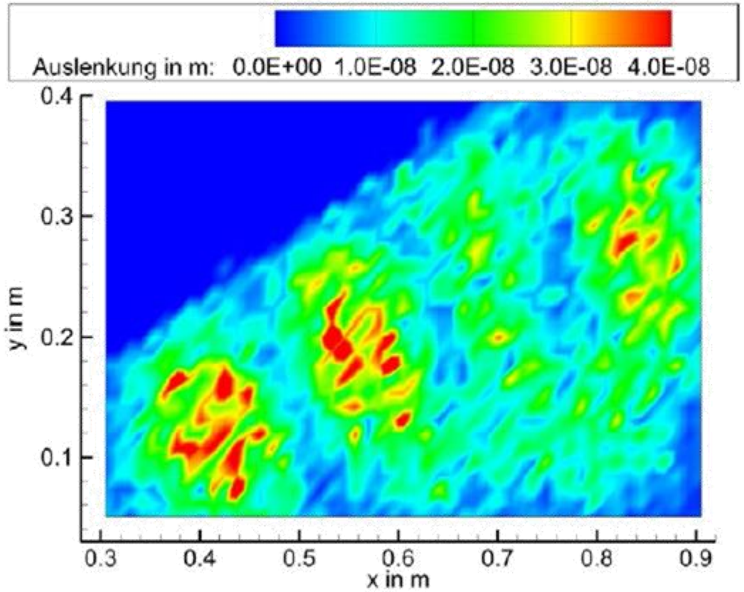
Experimental data (1)

- SPL at 39 probe positions are available from measurement
- Sampling frequency: 44.1 kHz
- $\Delta t \approx 2.268E\text{-}05$
- Sampling time T = 180s



Experimental data (2)

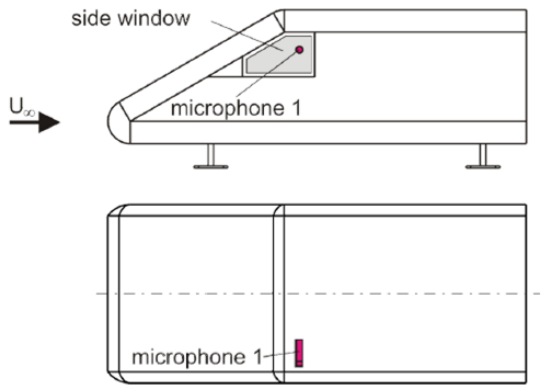
- Laser-scanning vibrometer measurements to visualize displacements
- 1426 measuring points
- Limited to frequency domain
- Frequency resolution: 1.5 Hz
- Resolved up to 10 kHz



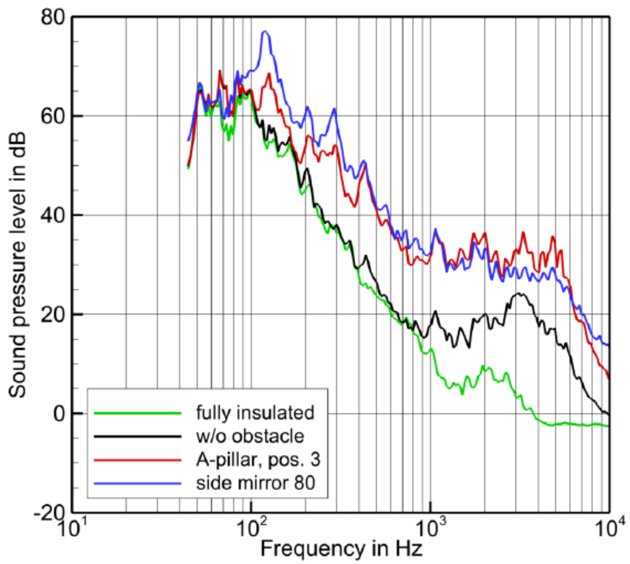
Displacements at 412 Hz

Experimental data (3)

- Sound pressure data available at driver‘s ear
- Sampling frequency: 96 kHz
  - $\Delta t \approx 1.042E-05$
- Sampling time:
  - T = 60s

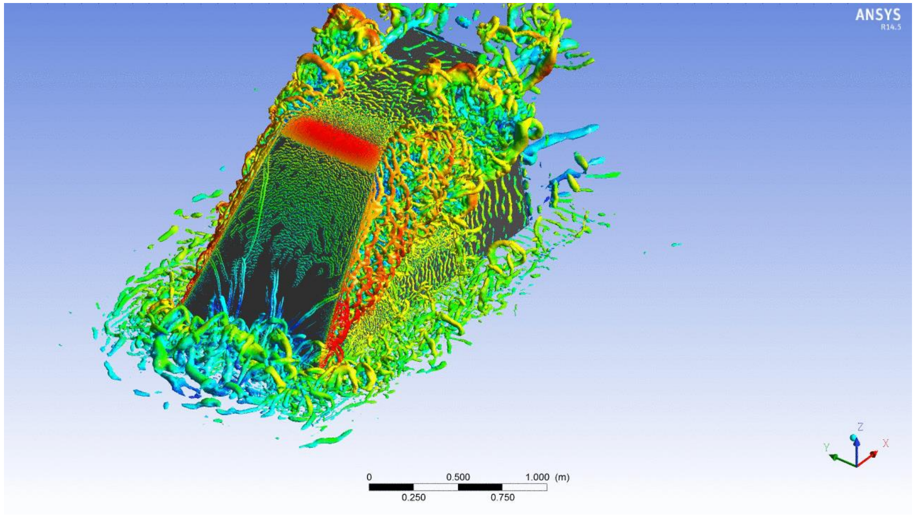


·Micro @ driver’s ear

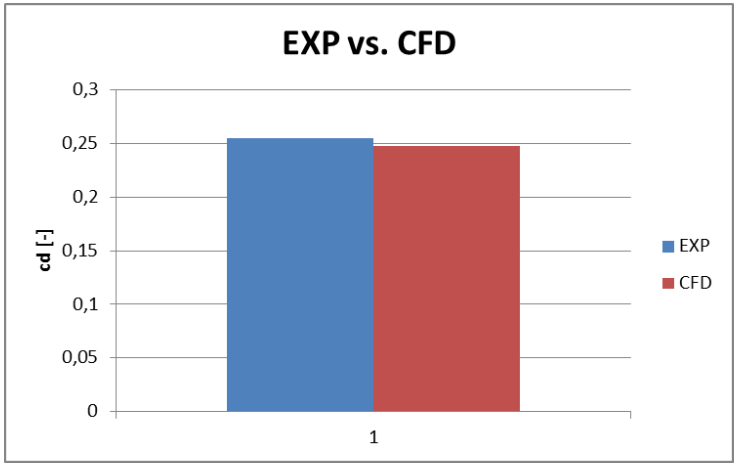


·SPL at driver’s ear

Results - Flow Field

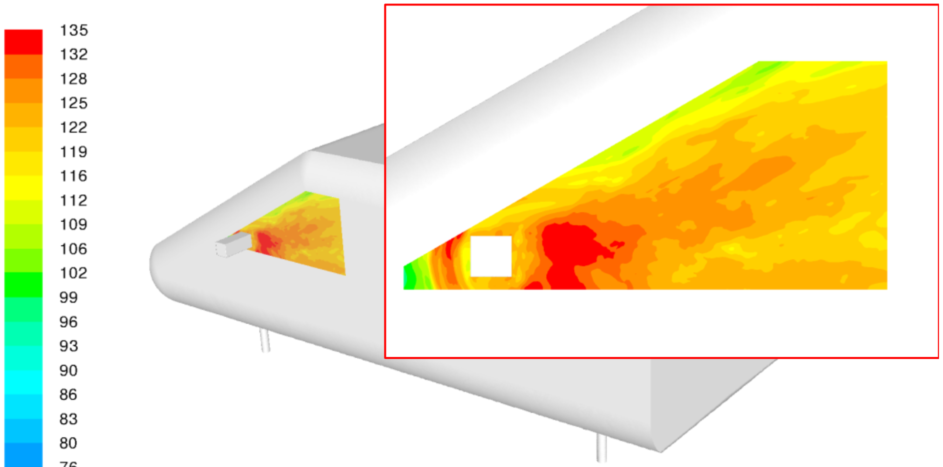


Iso-surface of Q-Criterion colored by velocity magnitude

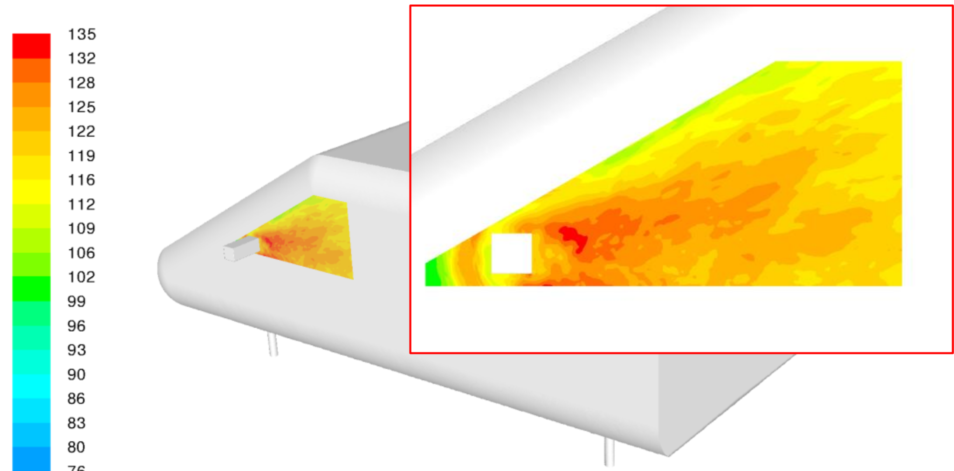


Drag validation of steady-state simulation

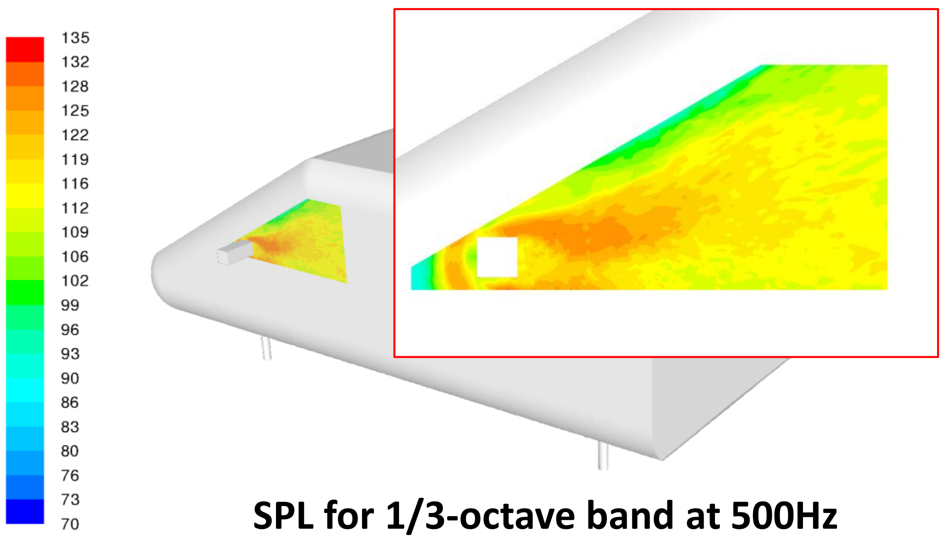
Results – Surface dB Map



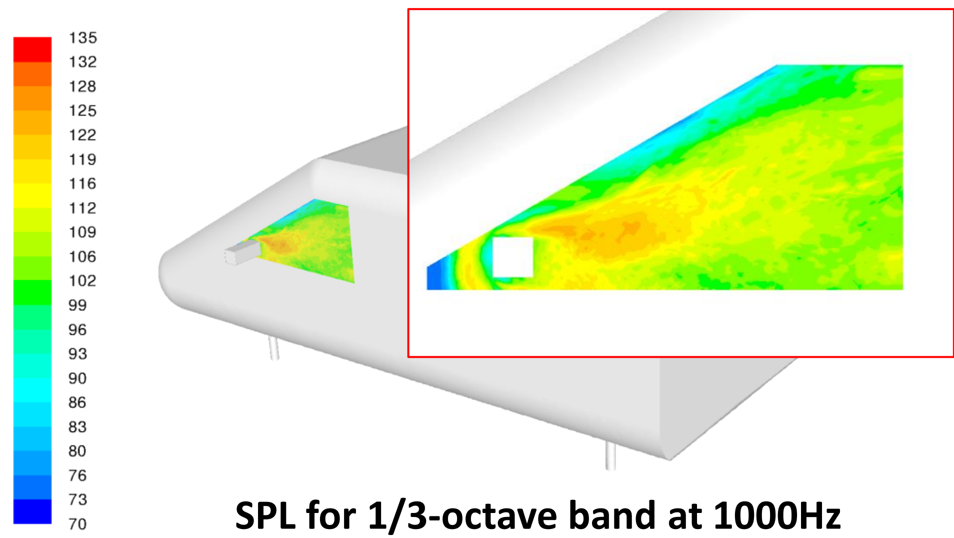
SPL for 1/3-octave band at 100Hz



SPL for 1/3-octave band at 200Hz

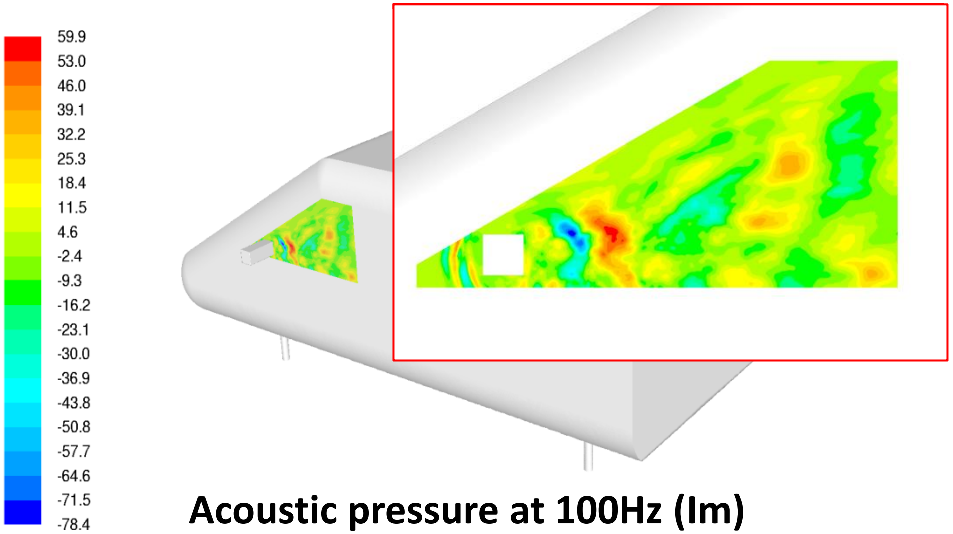


SPL for 1/3-octave band at 500Hz

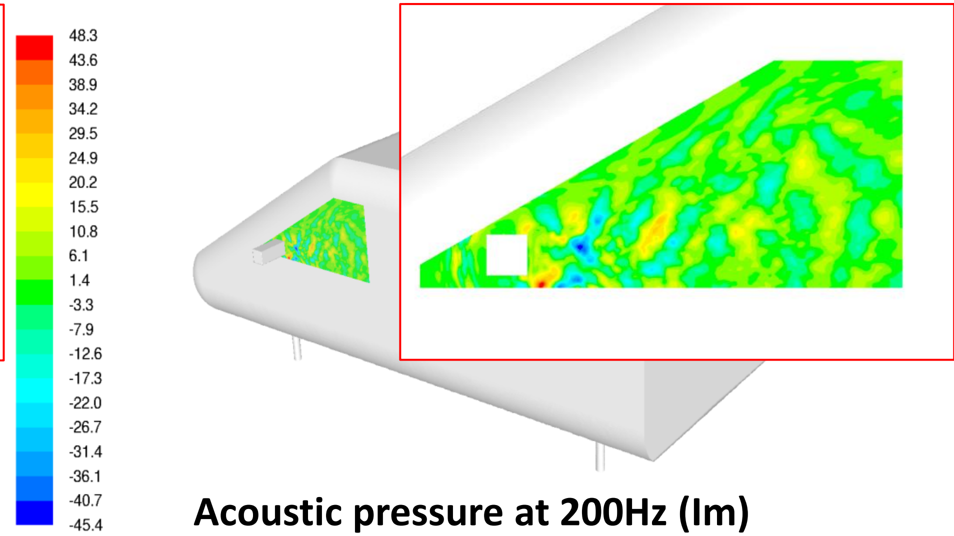


SPL for 1/3-octave band at 1000Hz

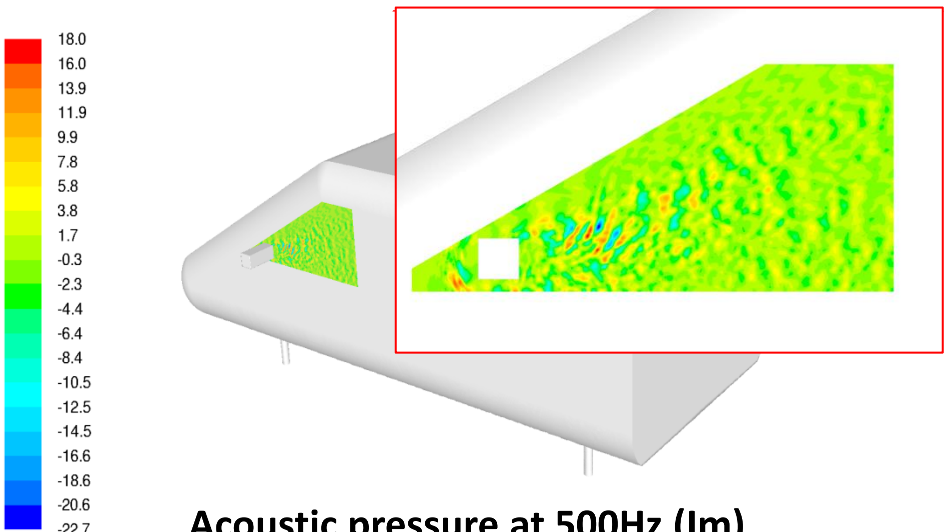
Results – Acoustic Pressure



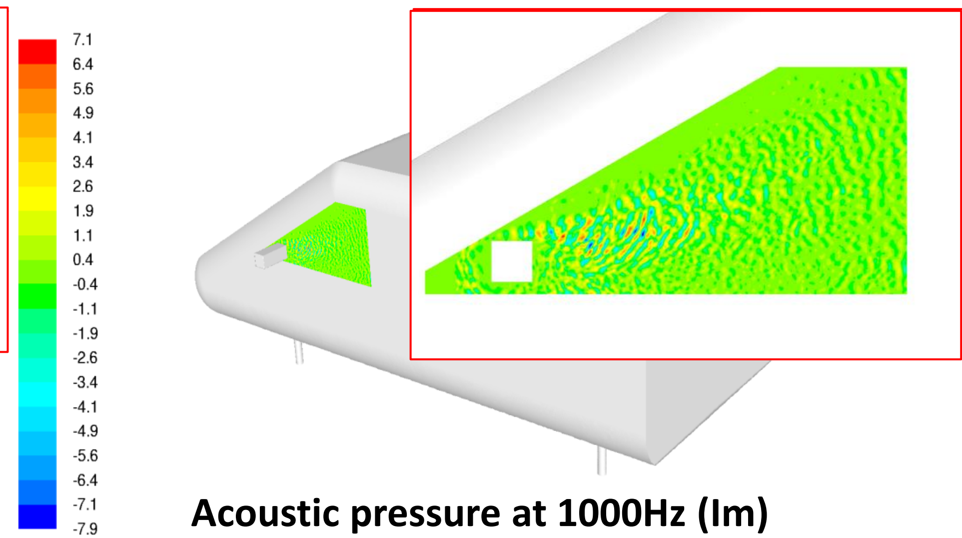
Acoustic pressure at 100Hz (Im)



Acoustic pressure at 200Hz (Im)

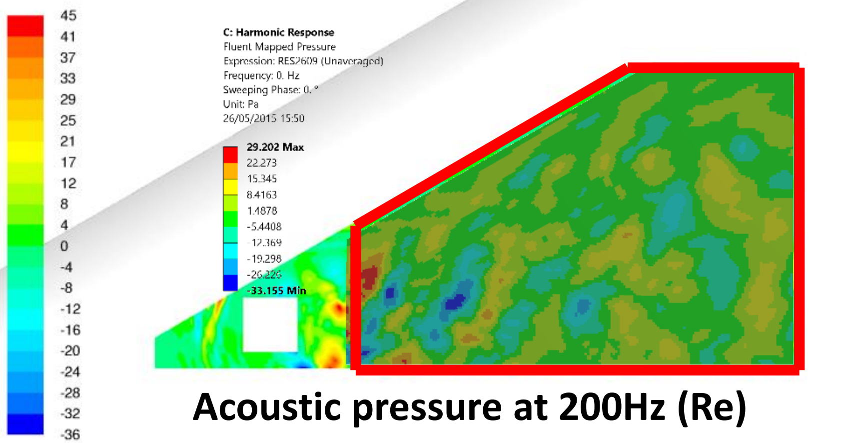


Acoustic pressure at 500Hz (Im)

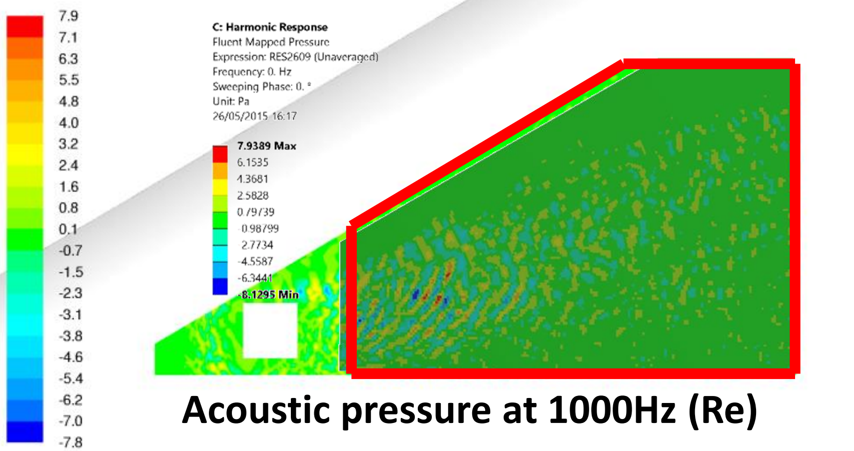


Acoustic pressure at 1000Hz (Im)

Results – Pressure Mapping

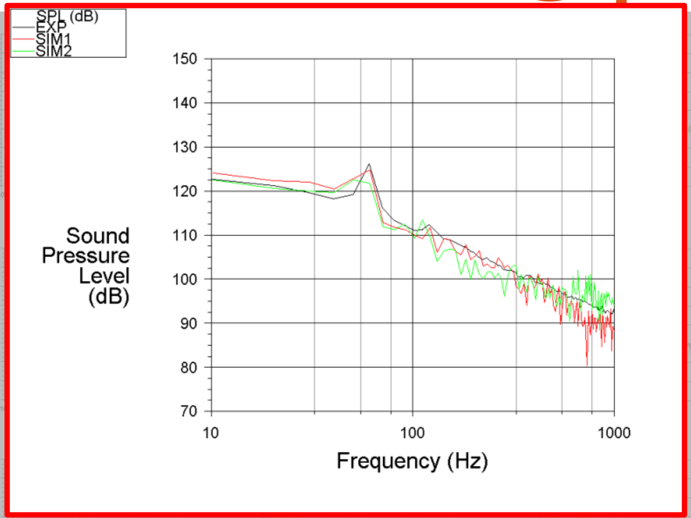


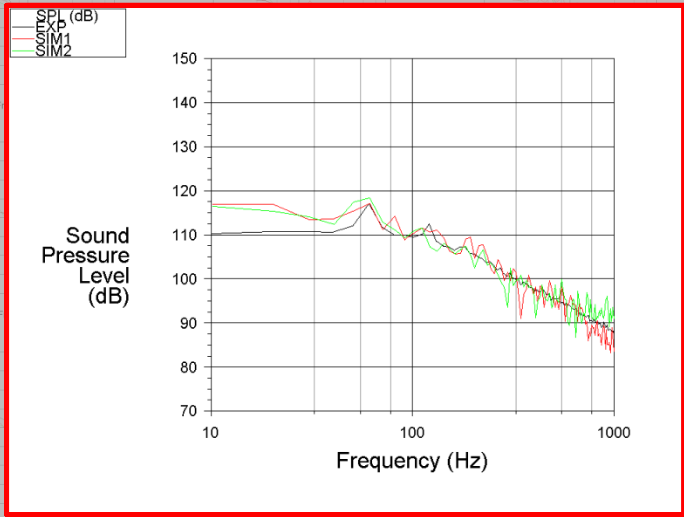
Acoustic pressure at 200Hz (Re)

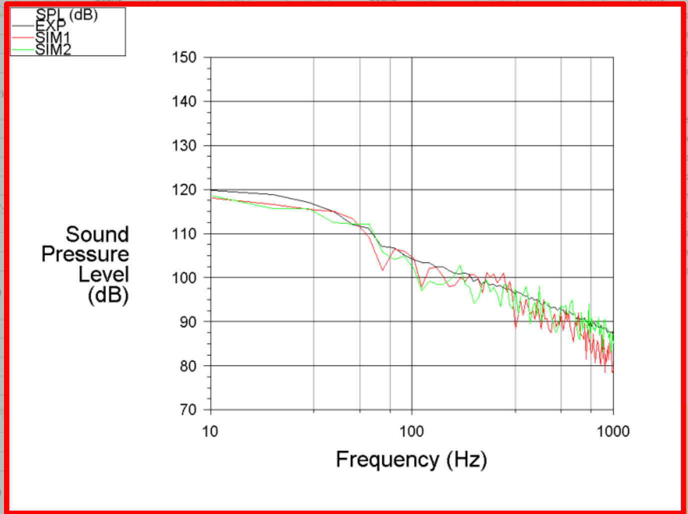


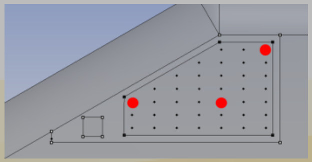
Acoustic pressure at 1000Hz (Re)

SPL @ probes


SPL (dB)
EXP
SIM1
SIM2
Sound Pressure Level (dB)
150
140
130
120
110
100
90
80
70
10
100
1000
Frequency (Hz)


SPL (dB)
EXP
SIM1
SIM2
Sound Pressure Level (dB)
150
140
130
120
110
100
90
80
70
10
100
1000
Frequency (Hz)

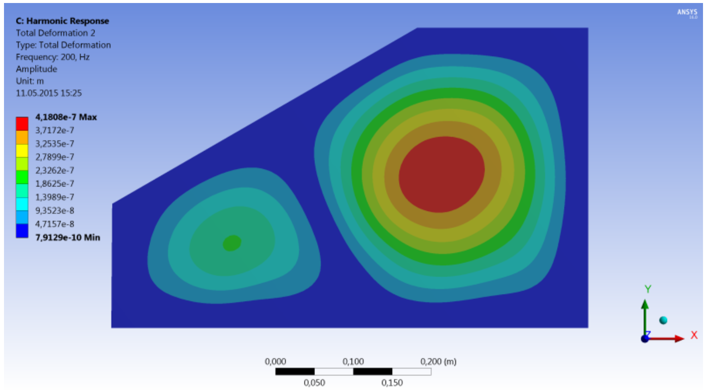

SPL (dB)
EXP
SIM1
SIM2
Sound Pressure Level (dB)
150
140
130
120
110
100
90
80
70
10
100
1000
Frequency (Hz)



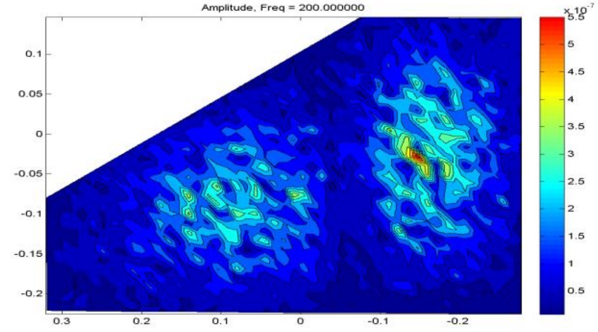
Results – Displacements SIM1

Simulation	Measurement

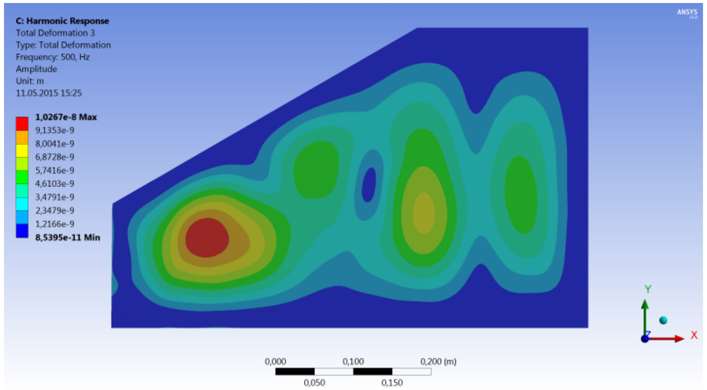
200 Hz



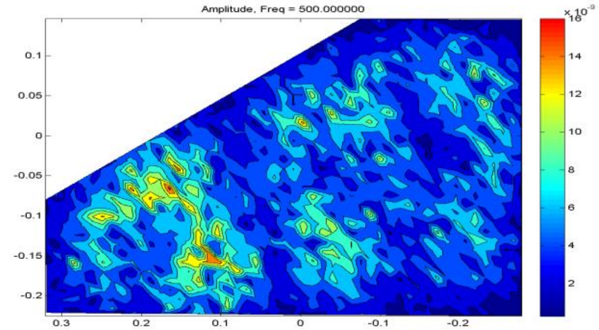
200 Hz



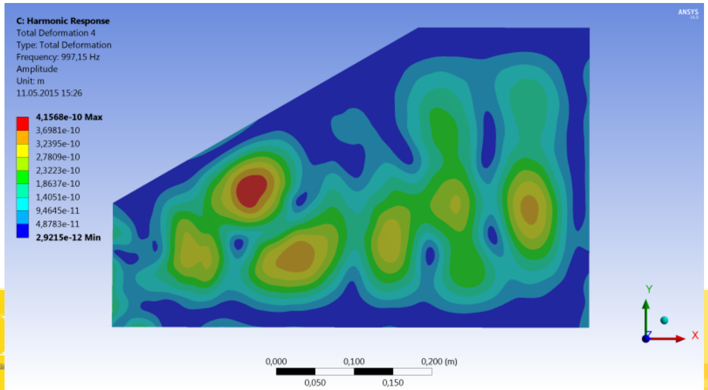
500 Hz



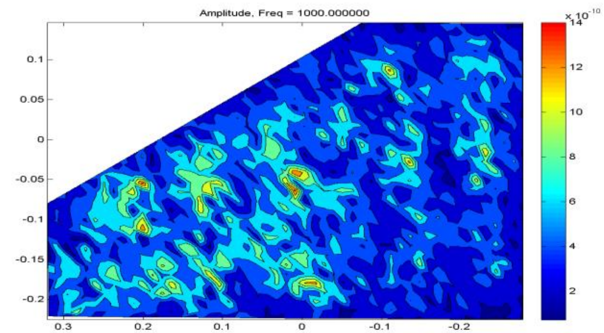
500 Hz



1000 Hz

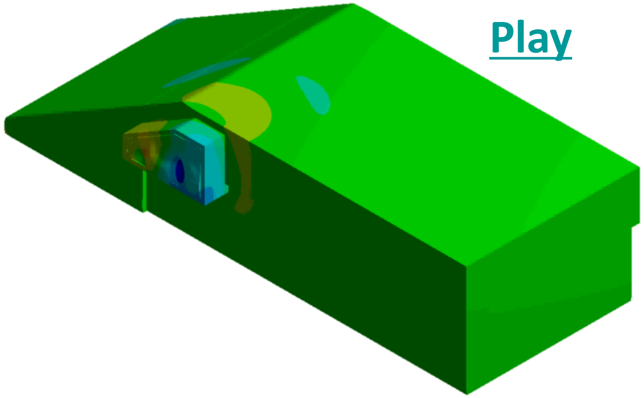


1000 Hz

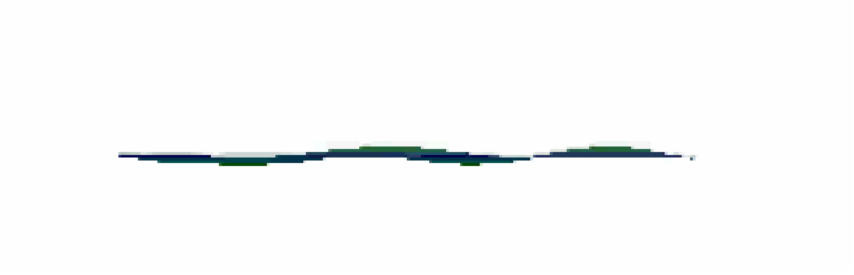


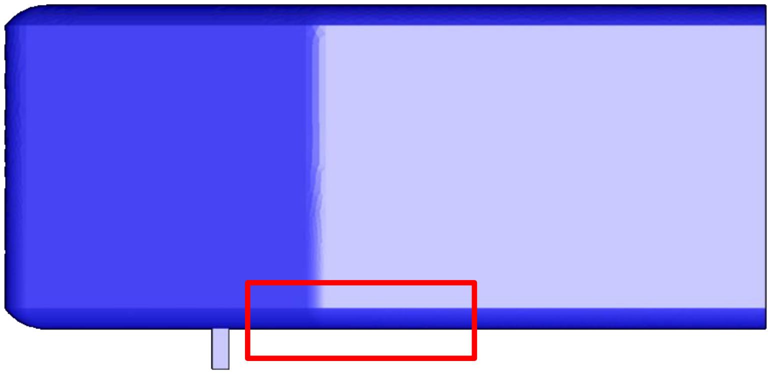
Results – Acoustic Pressure SIM1

- Deformation colored by acoustic pressure at 500 Hz



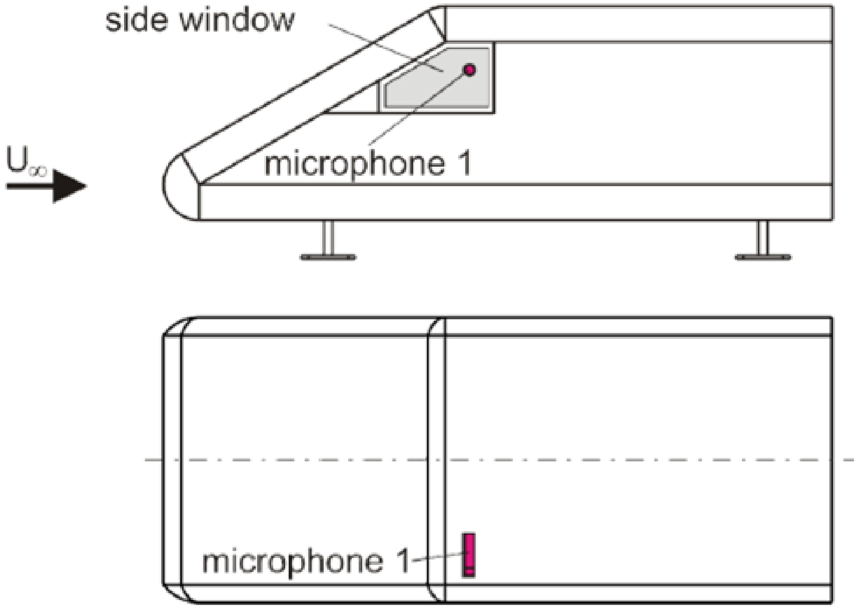
Acoustic pressure at 500 Hz

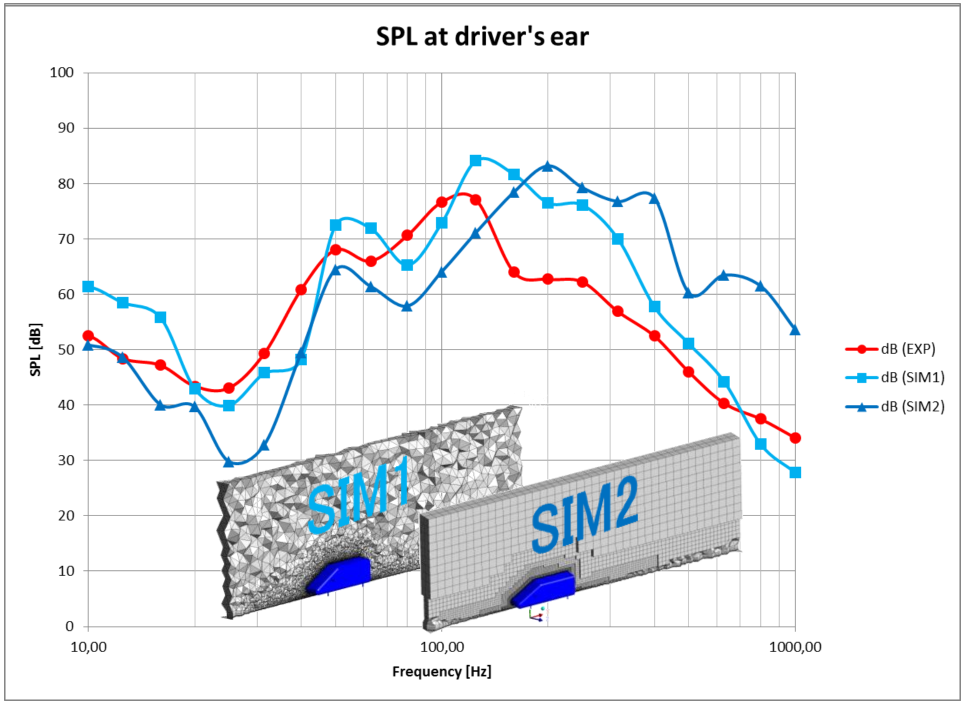




Deformations at 500 Hz

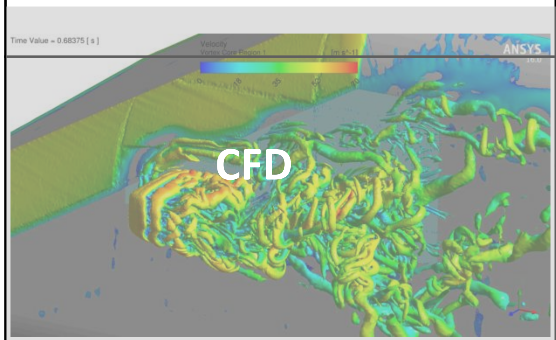
Results - SPL(dB) vs 1/3-Octave in Cabin





Solution Performance SIM1

- CFD: AMD Opteron, 2.3 GHz with Infiniband
- Vibro-Acoustics: Intel Xeon, 3.4 GHz with shared memory



Simulation procedure	Wall clock time 8 cores	Wall clock time 200 cores	Wall clock time 312 cores
Steady state (coupled solver)	-	9.3h	-
Initial transient (ramp down Δt from 1e-03 to 3e-05 for 1,000*Δt)	-	53.9h	-
Final transient (acoustic sampling for 11,000*Δt)	-	-	284.0h
Fully Coupled (3-1000 Hz)	11.1h	-	-

Summary

- Complete Aero-Vibro-Acoustics workflow
  - From turbulent compressible flow through vibrating side window to the cabin
  - One virtual environment including CFD-, Structural- and Acoustics-Simulations
- CFD results are showing excellent agreement with measured pressure spectra on the window
- Shapes of deformation can be predicted qualitatively
- Computed sound spectra inside cabin shows good trends as compared with test data up to 1000 Hz
- Structural damping and sealant can be fine-tuned

致谢

- 感谢ANSYS China提供材料

谢谢！

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