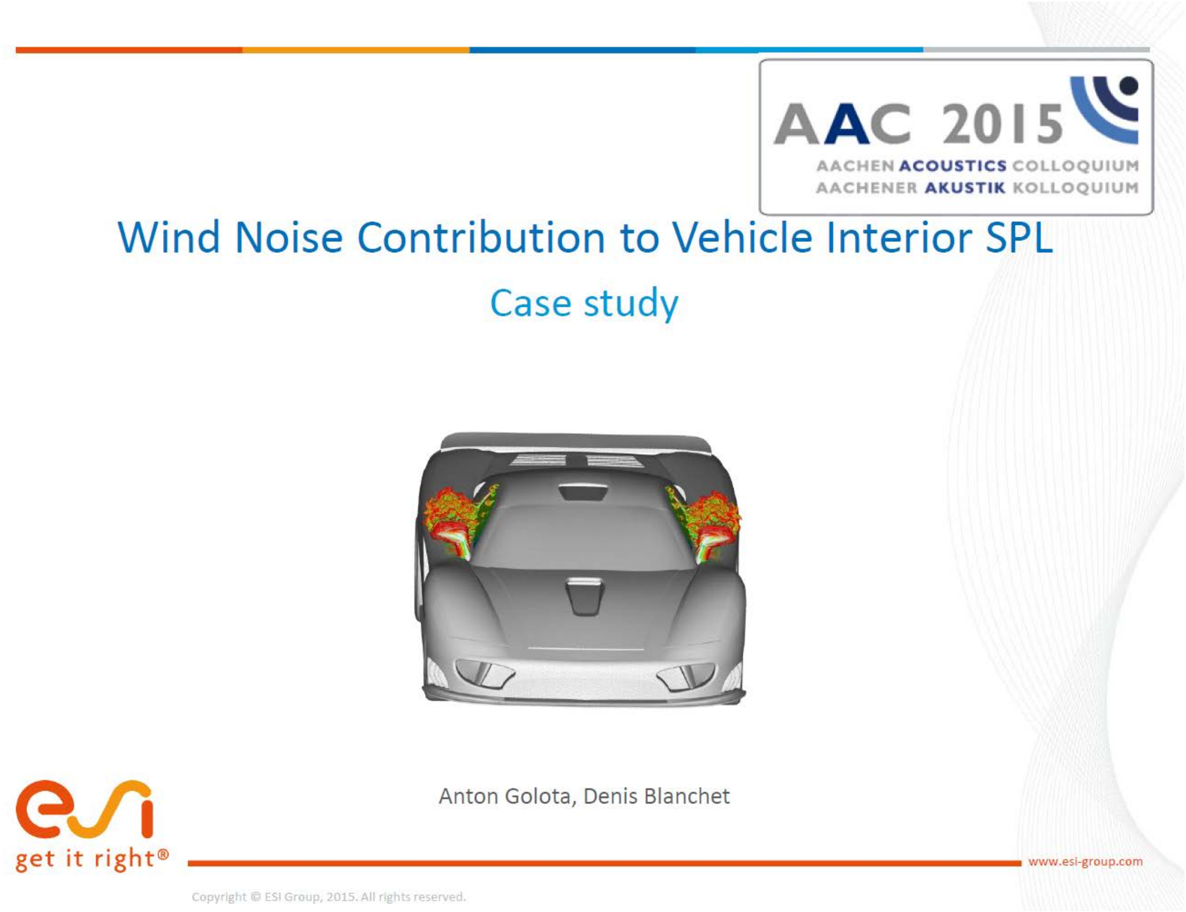
Wind Noise Contribution to Vehicle Interior SPL

A. Golota[1], D. Blanchet[2]
[1] *ESI Engineering System International GmbH, 85609 Munich, Germany, Email: anton.golota@esi-group.com*
[2] *ESI Engineering System International GmbH, 85609 Munich, Germany, Email: dbl@esigmbh.de*



Introduction

Focus of this presentation

- Overview different solutions to predict interior sound pressure level caused by the wind noise phenomena and typical work flow
- Vibro-acoustic measurements on the test vehicle and validation of vibro-acoustic numerical model
- Wind tunnel measurements and results obtained with Aero-Vibro-Acoustic simulation
- Comparison of the predicted sound pressure and structural velocity for cases with and without side mirror obtained with using FE/SEA and BEM methods

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Introduction

Acknowledgment

- Presented work was done in collaboration with German Aeroacoustics Working Group

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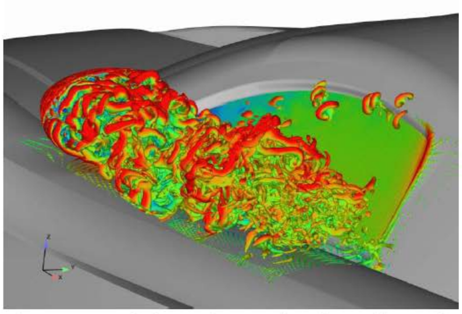
Problem description

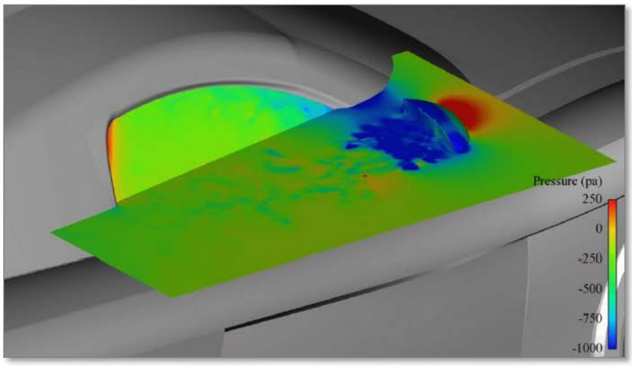
Challenge



- Interior noise level caused by the wind noise dominates over other sound sources on mid and high driving speeds
- The hydrodynamic and acoustic pressures of the turbulent flow excites the side window which radiates into the cabin
- Convective component related to the pressure field generated by eddies travelling at the convective speed
- Acoustic component related with acoustic waves travelling with the flow

Problem description

Physical mechanisms

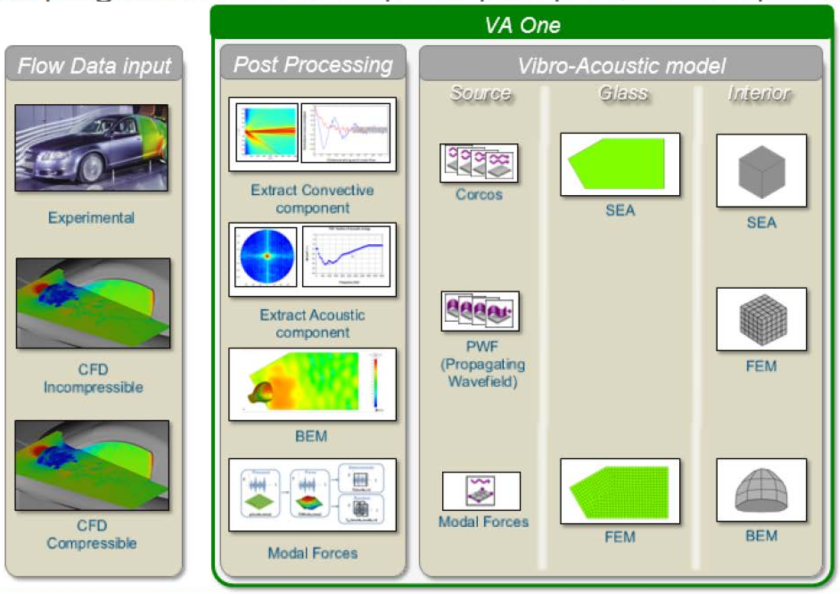


- Pressure incident on the side glass contains acoustic and convective component. Amplitude of the acoustic part is smaller than convective. Both components contribute to the interior noise.
- Pressure fluctuation on the rear face of mirror generate acoustic waves that travels toward the side glass.
- Pressure fluctuating on A-Pillar generate acoustic waves that propagates away.

From Turbulent Flow to Interior Noise

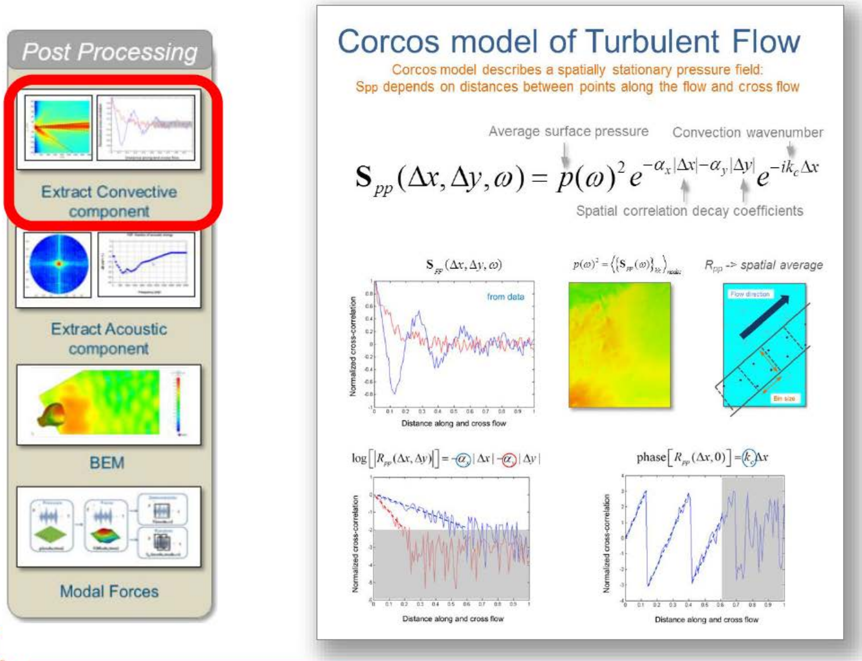
Workflow

- VA One program is used to map and post process time pressure data



From Turbulent Flow to Interior Noise

Post processing



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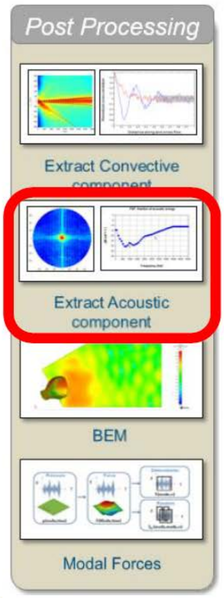

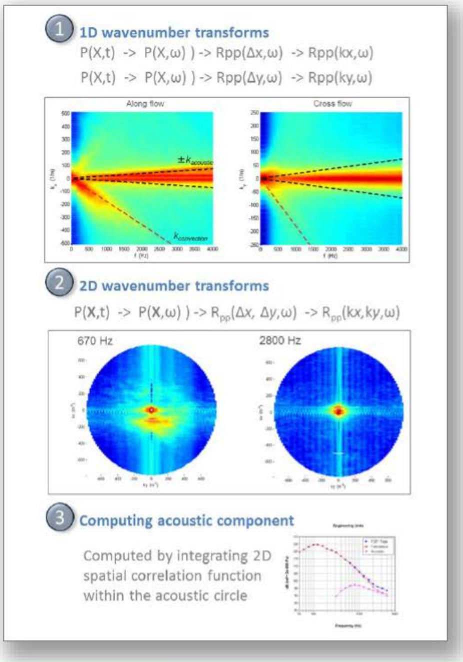

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From Turbulent Flow to Interior Noise

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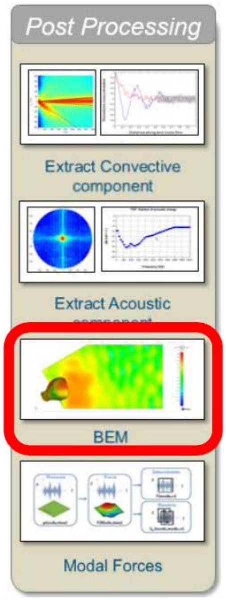

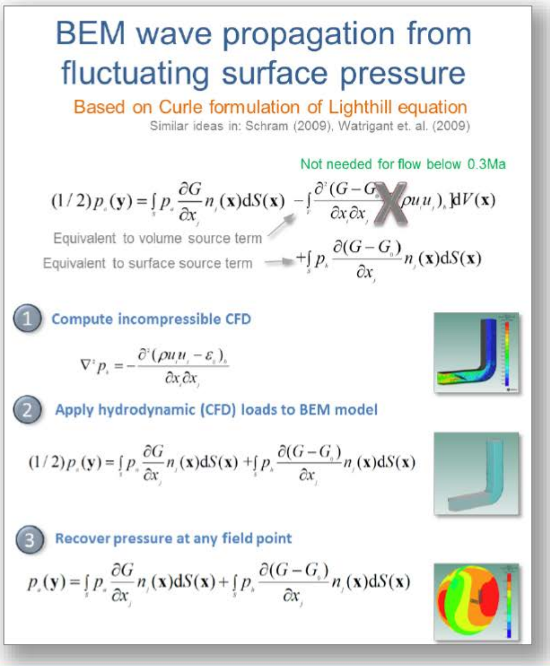

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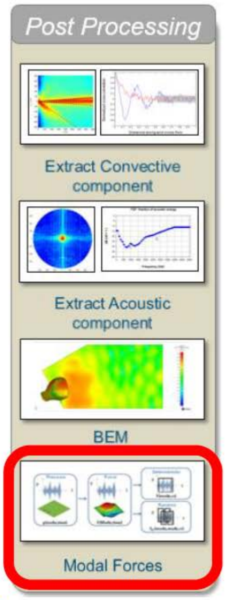
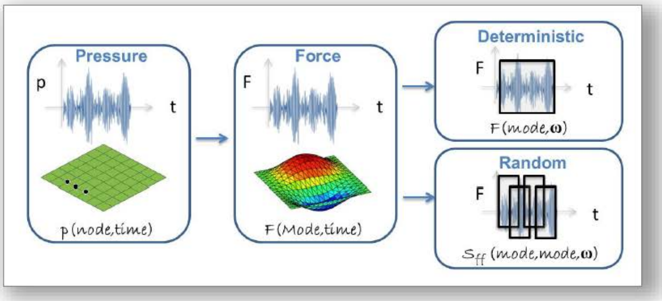
From Turbulent Flow to Interior Noise

Post processing

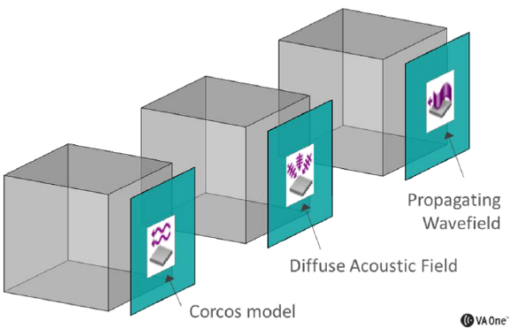


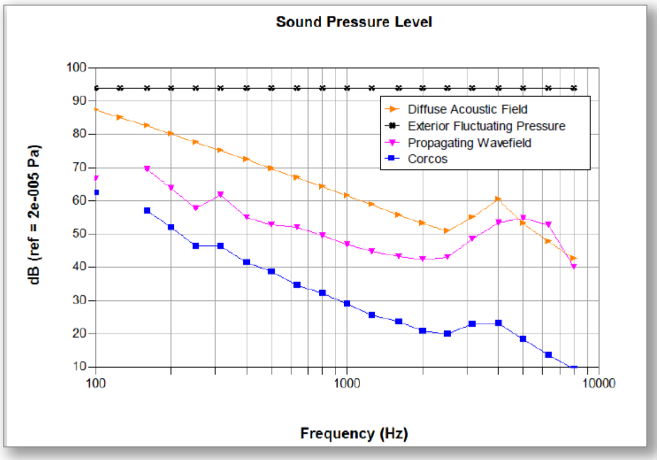


From Turbulent Flow to Interior Noise

Importance of proper cross-correlation function

Three loads with same pressure spectrum but different cross-correlation function are applied to the side glass panel which is coupled to the acoustic cavity.



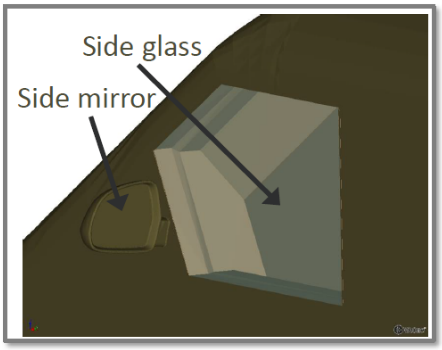


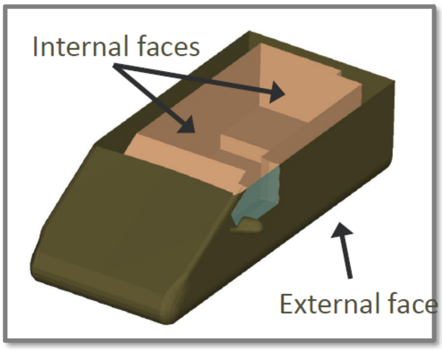
Note that the Turbulent Corcos load yield approximately 30 dB lower SPL than the DAF, and 10 to 30 dB compared to the PWF due to the different spatial correlation characteristics of each load.

Validation of Vibro-Acoustic model

Description of SAE body

- SAE body is a automotive generic shape structure used to investigate the effect of the turbulent flow on the interior SPL.
- SAE body allows to study physical phenomena without disclosing confidential information related to particular design.





- The modular design of the SAE body allows to investigate different configurations of the side mirrors or side glass position.

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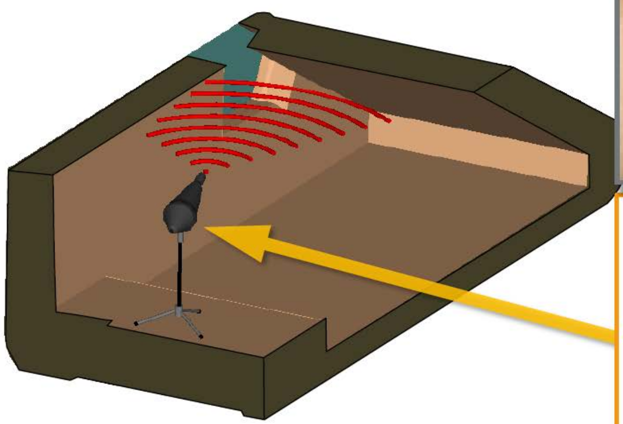
Validation of Vibro-Acoustic model

Interior measurements

Omni source is used to excite the interior of SAE body.
Five randomly distributed microphones are used to monitor pressure inside



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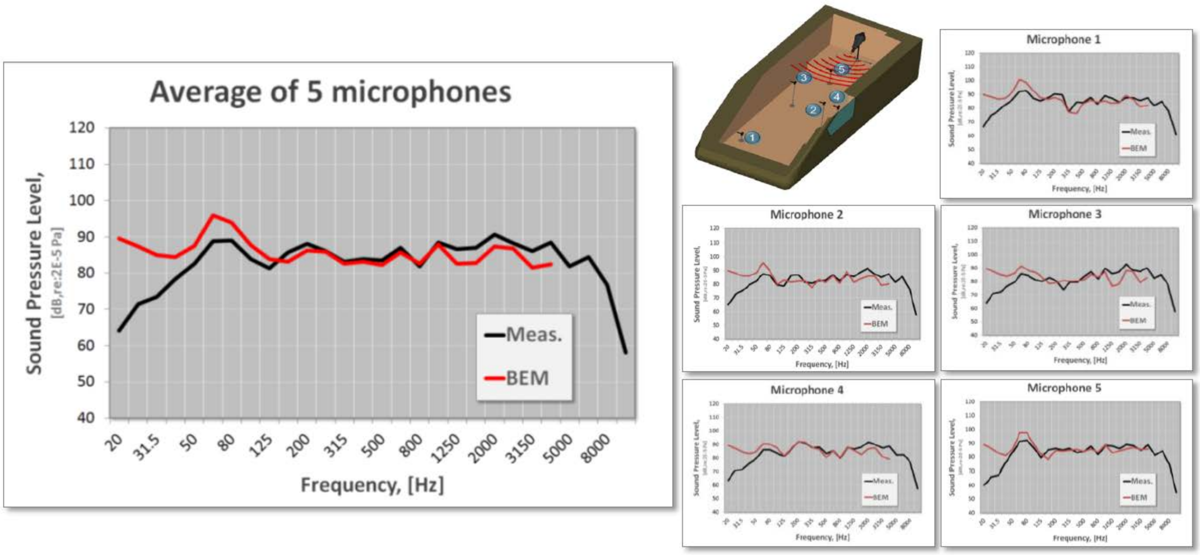
Validation of Vibro-Acoustic model

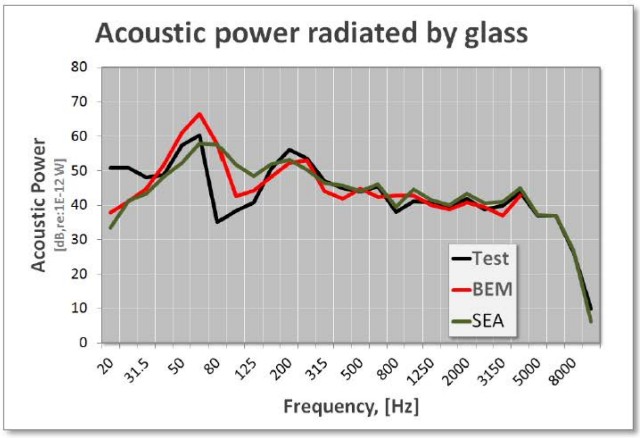
Simulation of interior measurements

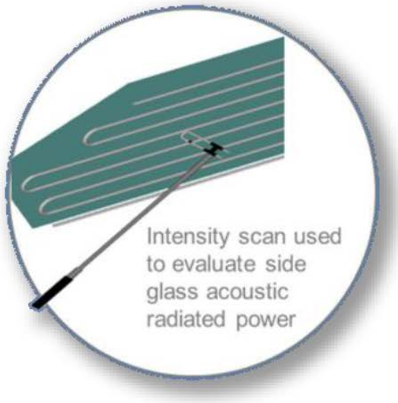


Validation of Vibro-Acoustic model

Side glass radiated power

- Intensity scan used to evaluate side glass acoustic radiated power.
- For comparison BEM and SEA method are used to predict radiated power

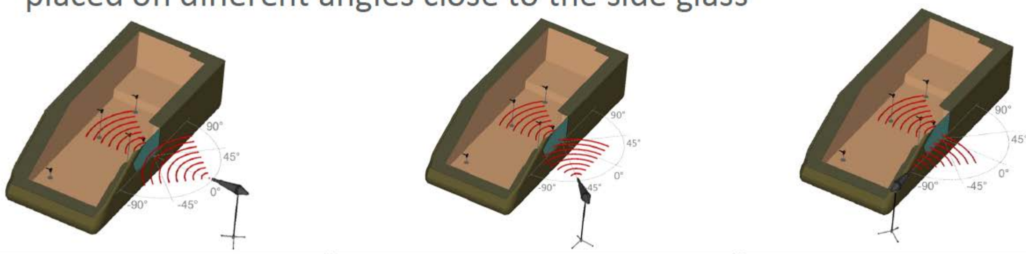


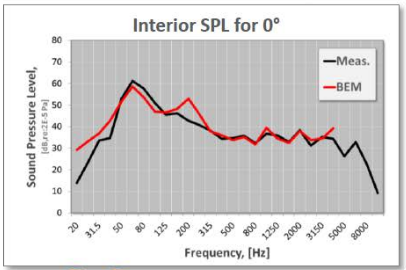


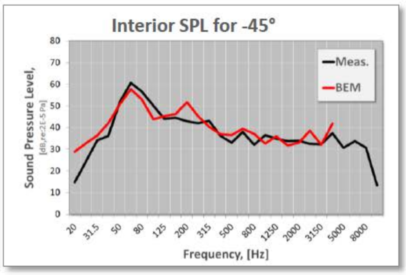
Validation of Vibro-Acoustic model

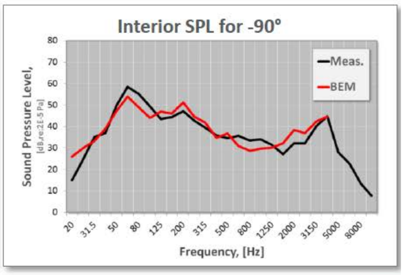
Simulation of interior pressure

- Interior sound pressure level measured for exterior directional source placed on different angles close to the side glass









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Validation of Aero-Vibro-Acoustic model

Description of test setup

- Aero-vibro-acoustic tests were performed in the Audi aero-acoustic wind-tunnel.
- Interior noise (far field, near field), dynamic pressure and vibration level on the side glass were measured.
- Different setup of the side glass and mirror were used during measurement campaign.

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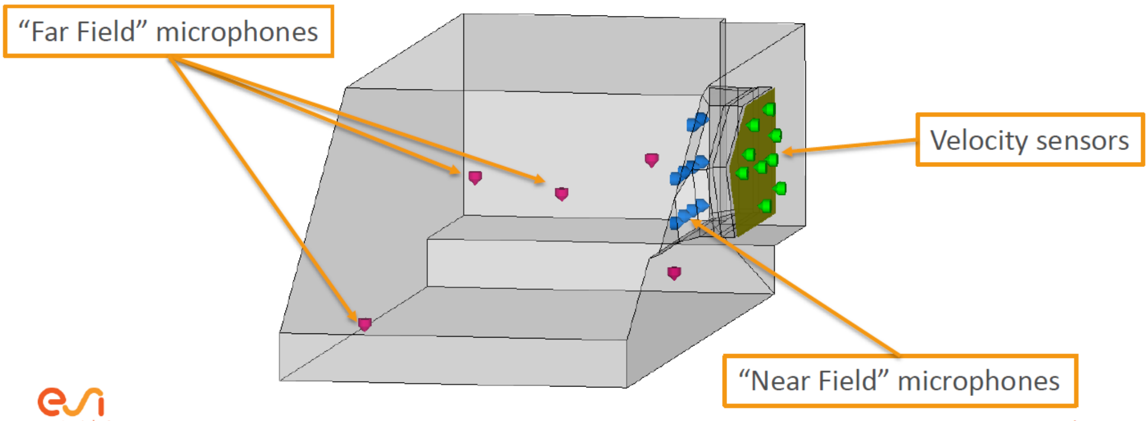
Validation of Aero-Vibro-Acoustic model

Model description

- Position of the sensors in Vibro-Acoustic model
- 10 “Near Field” microphones are located above 20 cm away from the side glass
- 5 “Far Field” microphones are distributed randomly in the interior



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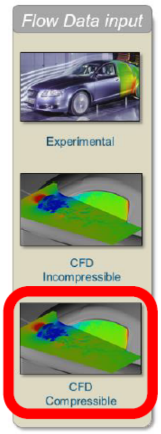
Validation of Aero-Vibro-Acoustic model

CFD details

- Compressible CFD simulation obtained with StarCCM is used as an input for Vibro-Acoustic model
- CFD simulation results are validated by GWG experts



- ❑ Half model of SAE body with and without side mirror
- ❑ Model size ~46 million fluid cells
- ❑ Compressible Detached Eddy Simulation (DES) based on Spalart-Allmaras (S-A) simulation
- ❑ Time step 2e-5 sec
- ❑ First 0.1 s of simulated physical time has been cut away
- ❑ Pressure fluctuating on A-pillar, side glass, and side mirror surfaces were saved.

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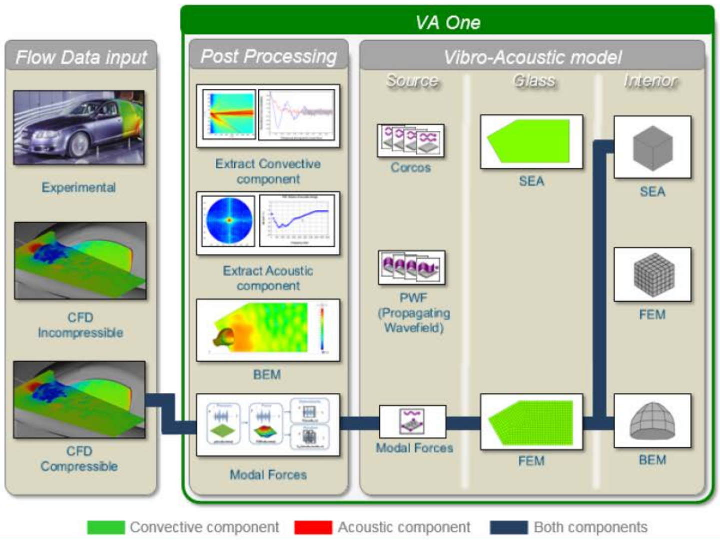
Validation of Aero-Vibro-Acoustic model

Used method

- Compressible CFD data is converted to force and projected over modes of FE Structure. FE Structure is coupled with BEM/SEA interior



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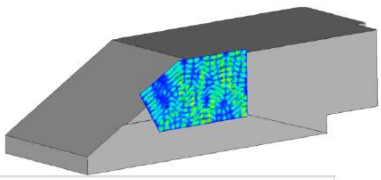
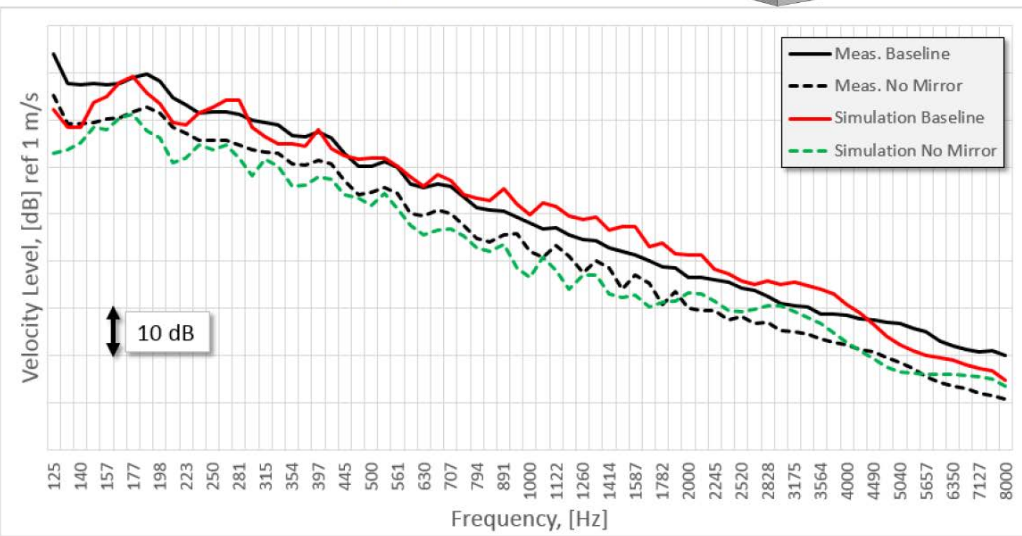
Validation of Aero-Vibro-Acoustic model

Average vibration on the side glass

- Hybrid model (Coupling FE with SEA) is used to predict vibration on the side glass





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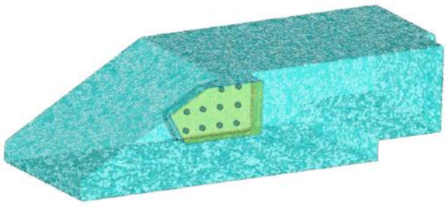
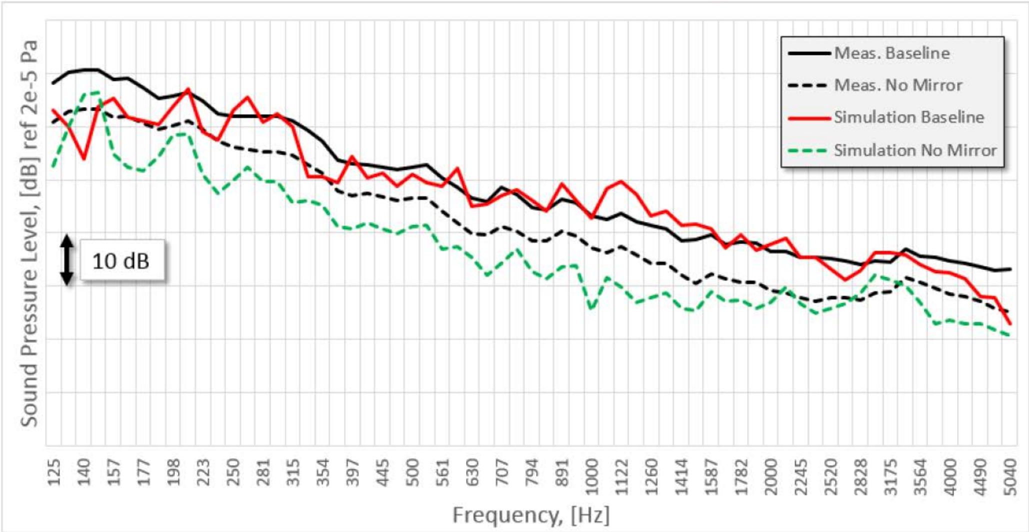
Validation of Aero-Vibro-Acoustic model

Average near field SPL

- BEM model is used to predict near field SPL





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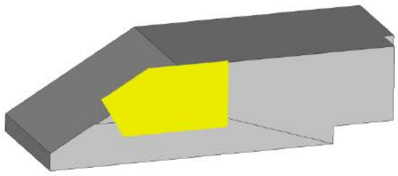
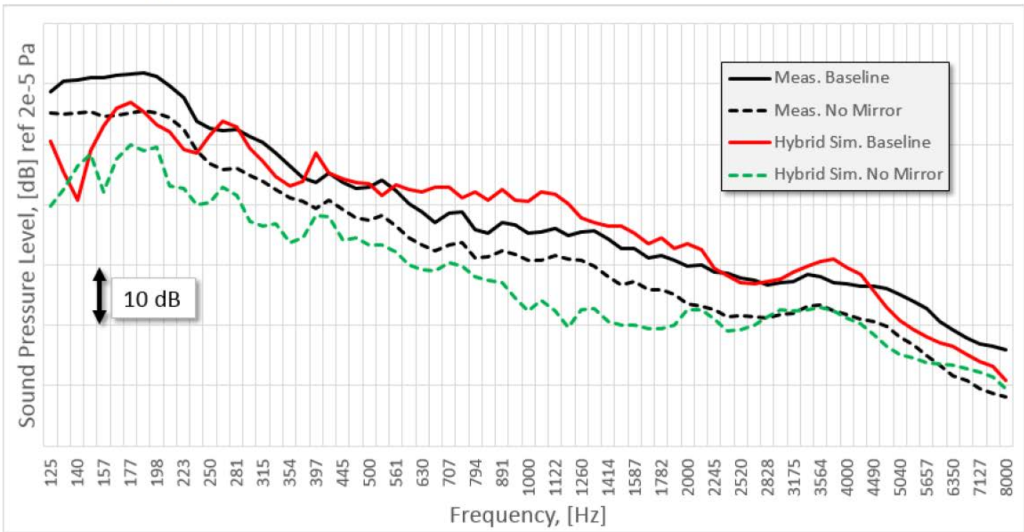
Validation of Aero-Vibro-Acoustic model

Average far field SPL

- Hybrid model (Coupling FE with SEA) is used to predict average interior SPL





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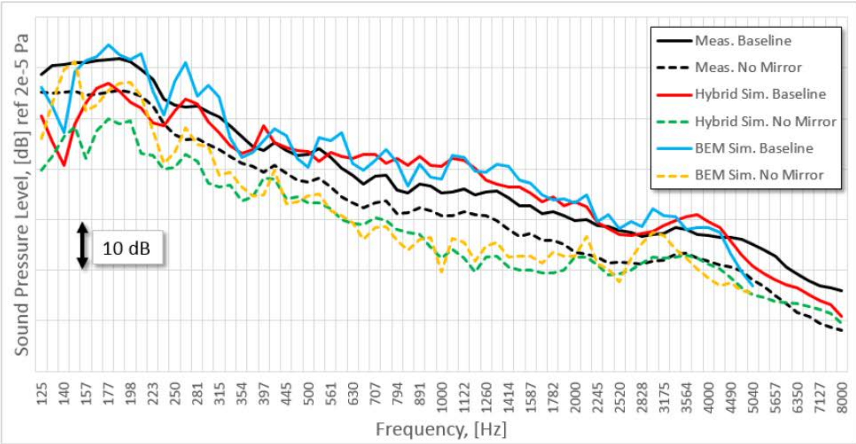
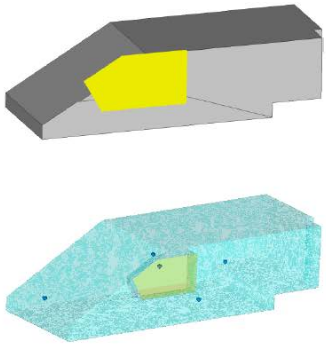
Validation of Aero-Vibro-Acoustic model

Average far field SPL

- Comparison of the results obtained by BEM and Hybrid methods





- Hybrid method has a great advantage in computation time and delivers results with same accuracy as BEM

Conclusion

- Different simulation strategies of the wind noise problem have been discussed. Choice of modeling method should be based on desired accuracy level, available time and flow data
- Vibro-acoustic models have to be validated versus measurements to give level of confidence of expected Aero-Vibro-Acoustics results
- Surface pressure-history data obtained from CFD have been successfully coupled with Vibro-Acoustic models
- Results for frequency ranges up to side glass critical frequency and above have been obtained with different modeling methods with high level of accuracy
- Converging of the results obtained using BEM and FE/SEA coupling methods show that created Vibro-Acoustic model represent the physics and capture all system properties