Numerical Investigation of Porous Materials for Trailing Edge Noise Reduction

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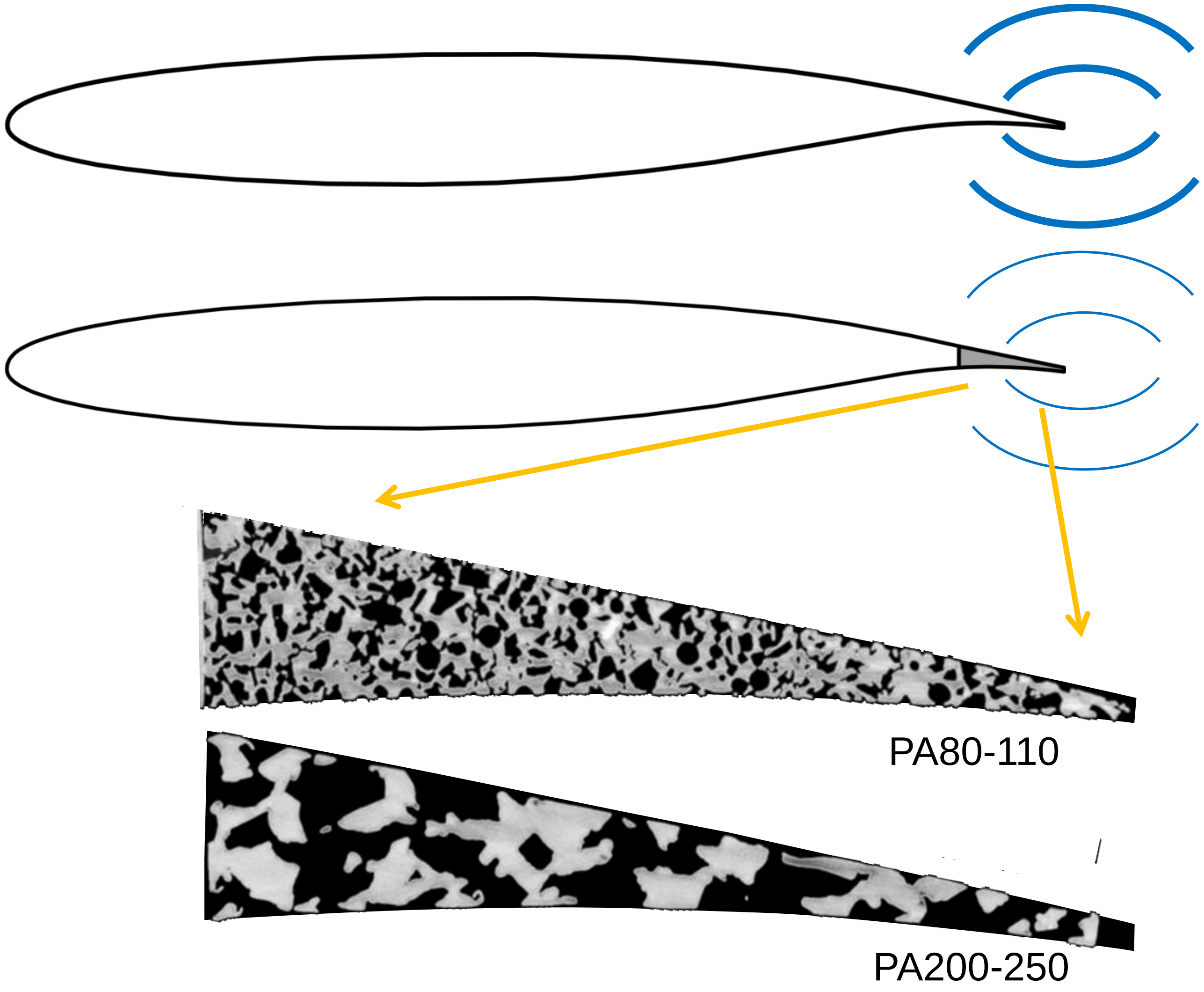
Introduction

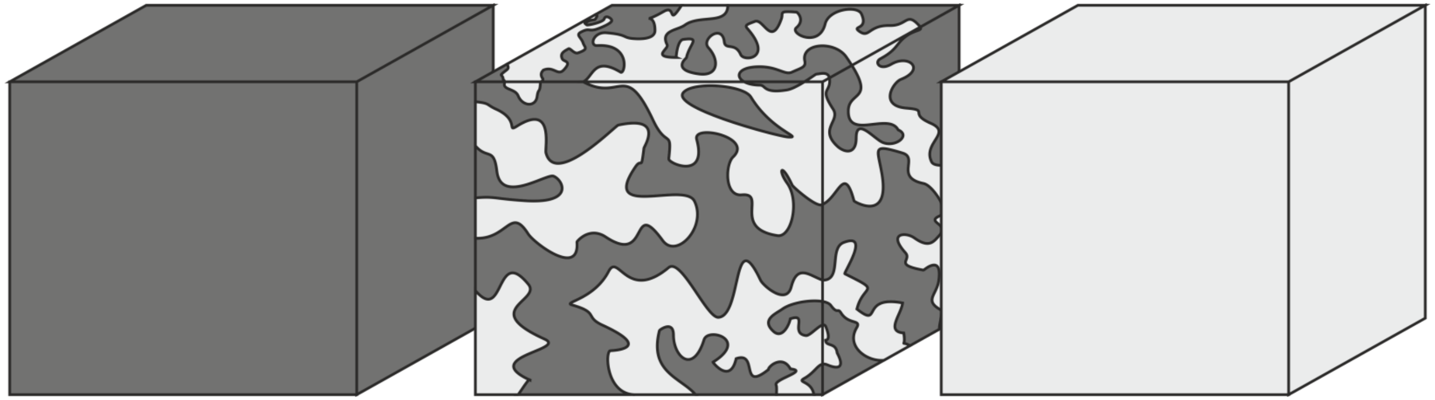
- Reduction of airfoil trailing edge noise
  - Interaction of turbulent eddies with pointed trailing edge
  - Reduction by ventilation through a permeable trailing edge
  - Effect confirmed in simulations and measurements



Outline

- Numerical method
  - Modelling porous materials
  - CAA procedure
- Comparison Simulation – Experiment
- Understanding noise generation at porous trailing edges
- Tailored material characteristics
- Conclusions and open questions

Porous parameters



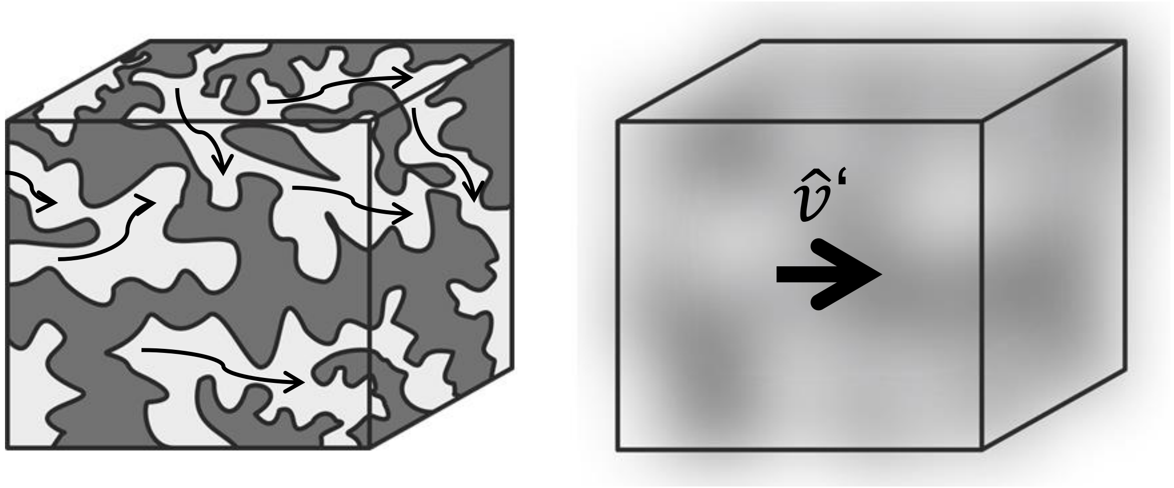
	solid body		porous body		free fluid	porous aluminium
• Porosity ϕ [-]	0	<	ϕ	<	1	0.46
• Permeability κ [m^2]	0	<	κ	<	∞	1.2e-10
• Forchheimer constant c_f [-]	0		> 0		0	0.1

- Anisotropic material

$$\kappa = \begin{pmatrix} \kappa_{xx} & \kappa_{xy} & \kappa_{xz} \\ \kappa_{xy} & \kappa_{yy} & \kappa_{yz} \\ \kappa_{xz} & \kappa_{yz} & \kappa_{zz} \end{pmatrix} \text{ and } c_f = \begin{pmatrix} c_{f_{xx}} & c_{f_{xy}} & c_{f_{xz}} \\ c_{f_{xy}} & c_{f_{yy}} & c_{f_{yz}} \\ c_{f_{xz}} & c_{f_{yz}} & c_{f_{zz}} \end{pmatrix}$$

Governing equations

- Porous volume averaged Linearized Euler Equations



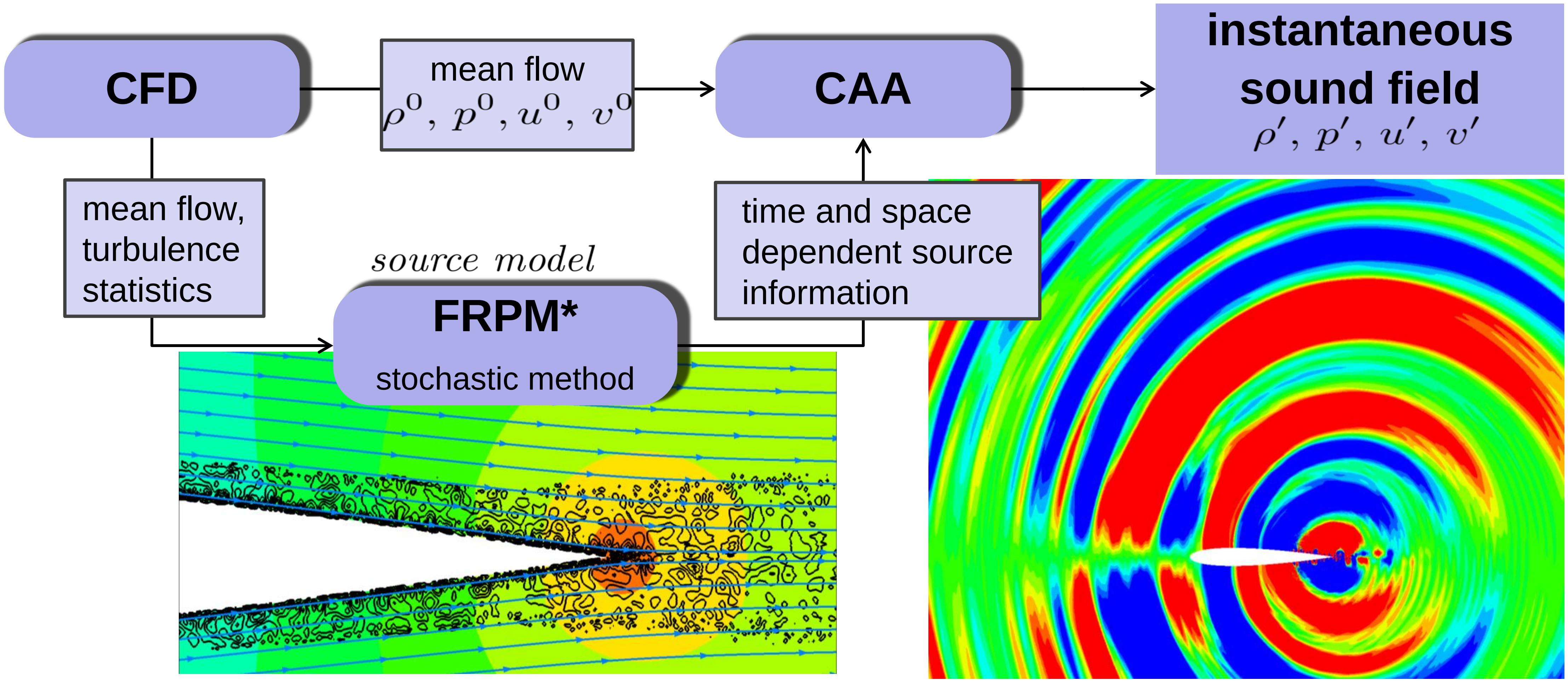
- Continuity: $\mathrm{LEE}\left(\widehat{v}', \phi\right) = S_\rho$
- Momentum: $\mathrm{LEE}\left(\widehat{v}', \phi\right) + \mathrm{D}\left(\frac{\phi\nu}{\kappa}, \hat{v}'\right) + \mathrm{F}\left(\frac{\phi c_f}{\sqrt{\kappa}}, (\hat{v}^2)'\right) + \mathrm{G}\left(\frac{1}{\phi}\right) = S_v$
- Energy: $\mathrm{LEE}(\hat{v}', \phi) + \mathrm{G}\left(\frac{1}{\phi}\right) = S_p$

D: Darcy term

F: Forchheimer term

G: Gradient term

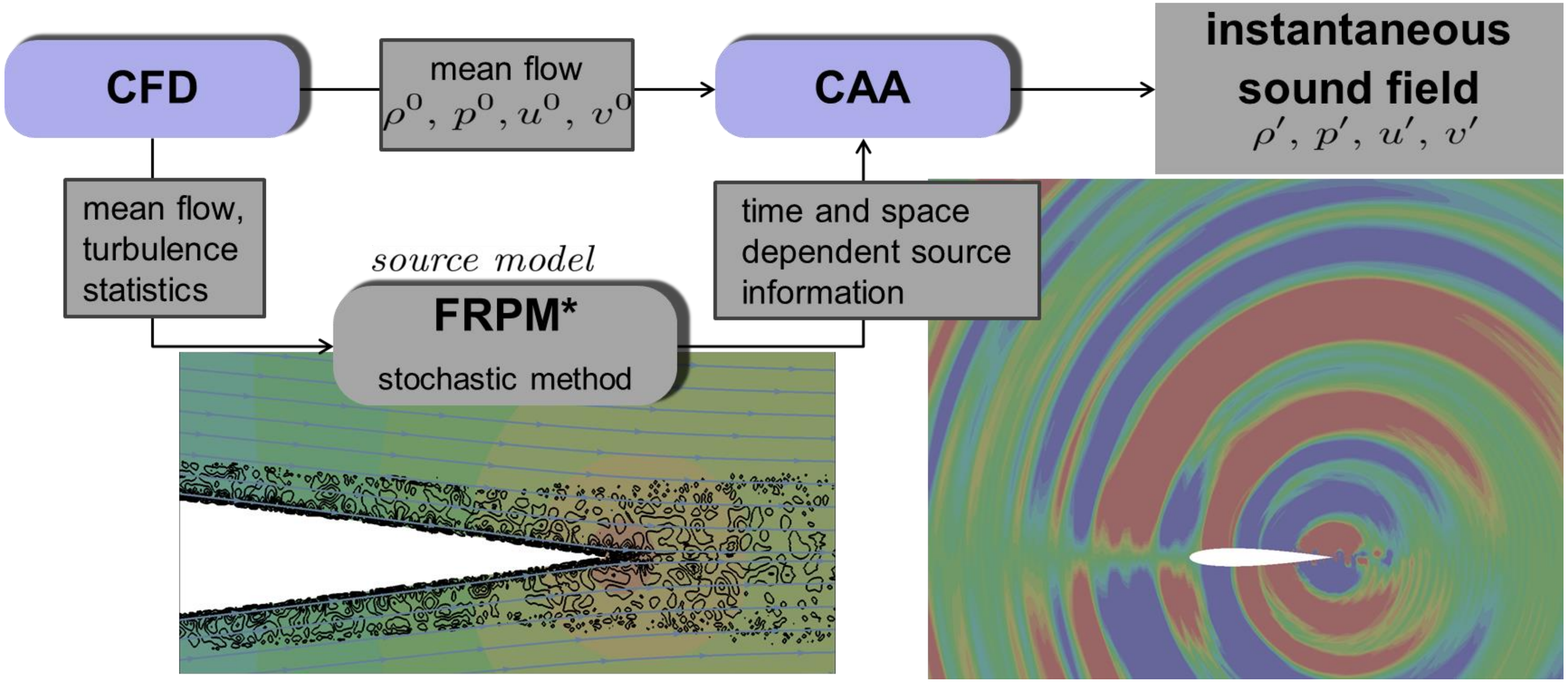
Numerical method
Hybrid CFD/CAA



AIAA 2009-3369, AIAA 2009-3175 * AIAA 2014-3053

Numerical method
Hybrid CFD/CAA: Realization of porous material

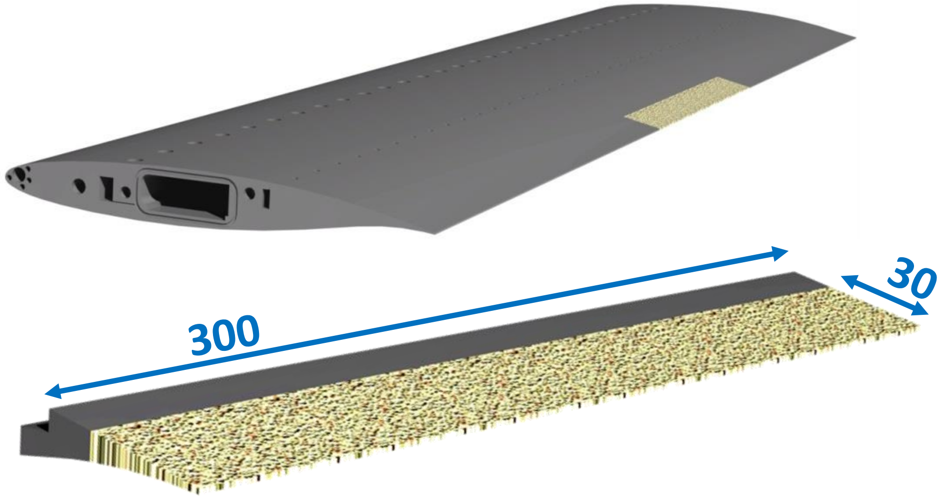
- modelling of porous materials in CFD and CAA through volume-averaging
- influence on:
  - turbulent sources
  - noise generation
- possibility to distinguish changes in:
  - sources
  - energy transfer to acoustic waves

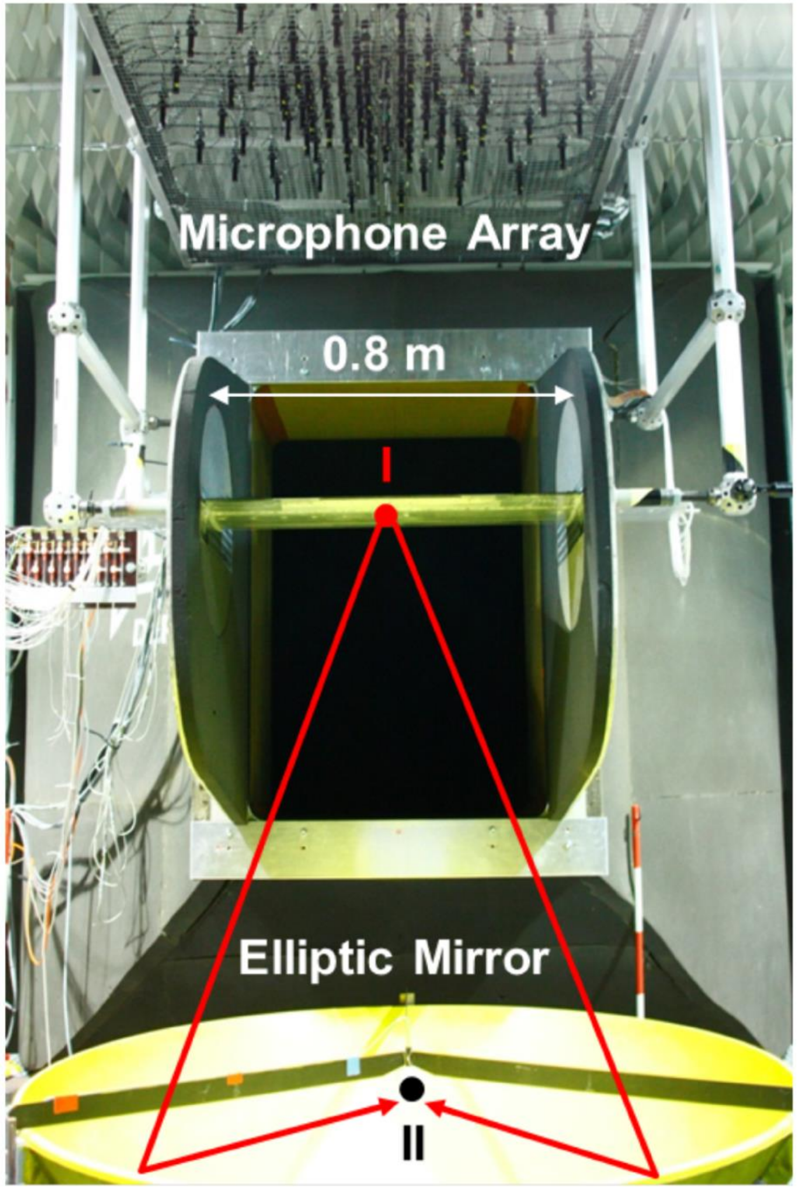


Simulation results
Comparison with measurements

- Experimental data from DLR's acoustic wind tunnel (AWB)
  - microphone data 90° below TE
  - $U_\infty = 50 m/s$
  - $\alpha_{g,AWB} = 0°$

- more details in following presentation



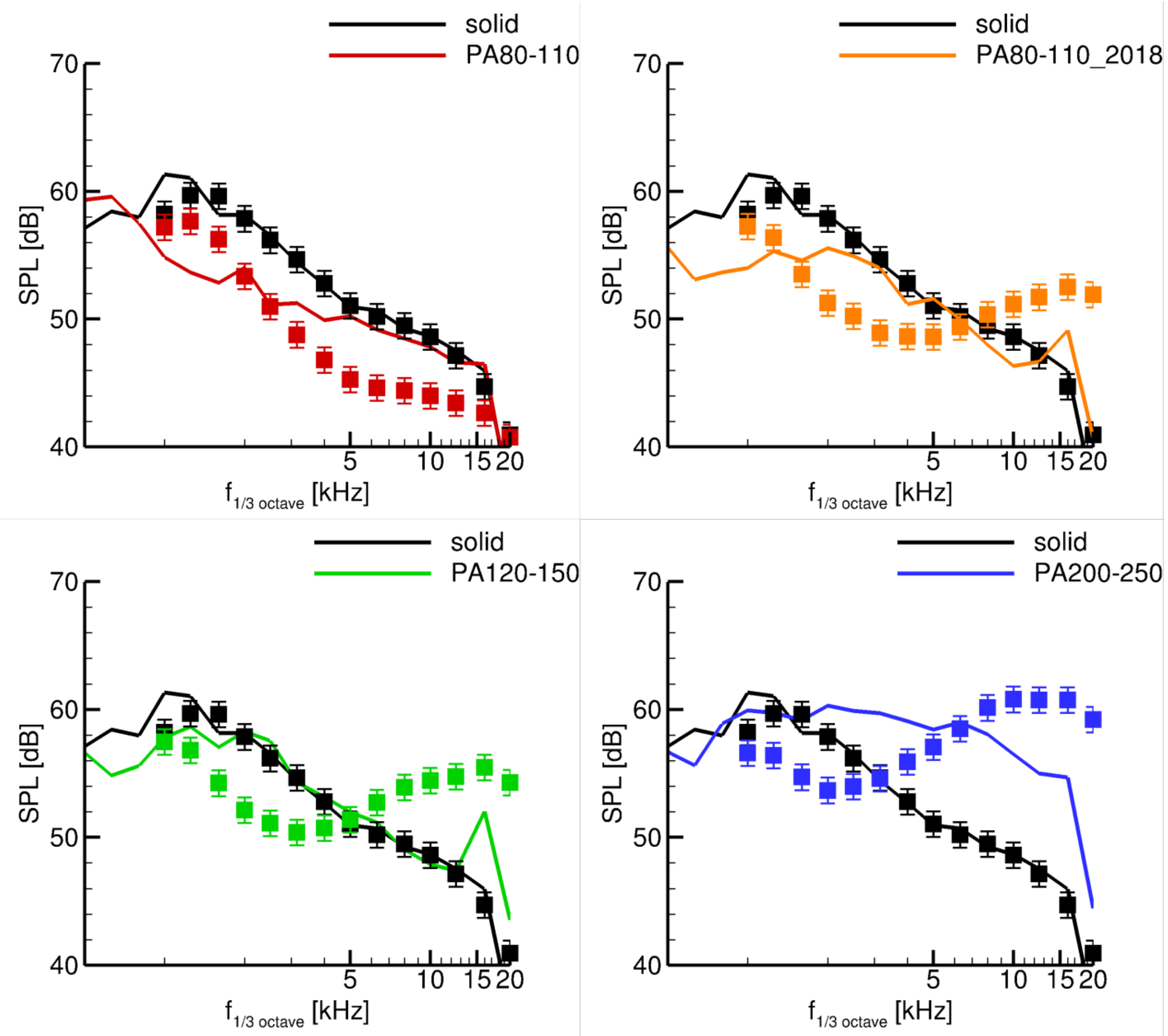


Simulation results
Comparison with measurements

- 4 porous materials (+ solid reference)
  - PA80-110
  - PA80-110_2018
  - PA120-150
  - PA200-250

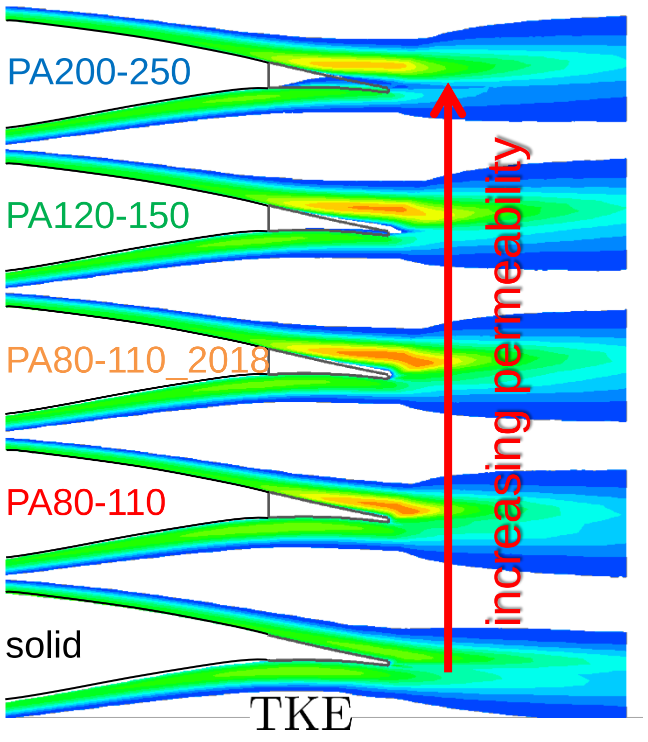
Increasing pore size and permeability

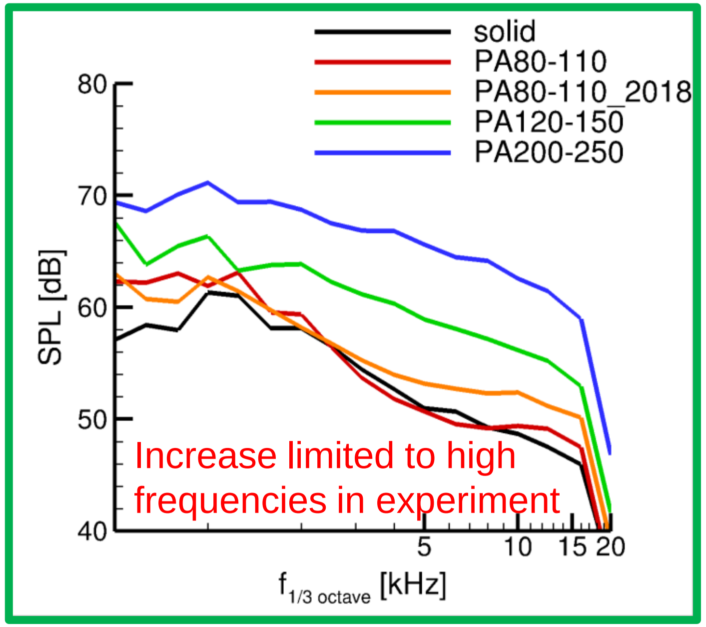
- experiments:
  - increasing high-frequency excess noise
  - small changes in noise reduction @ 1 to 2 kHz
- simulations:
  - broadband change of spectra
  - almost no noise reduction for materials with high permeability

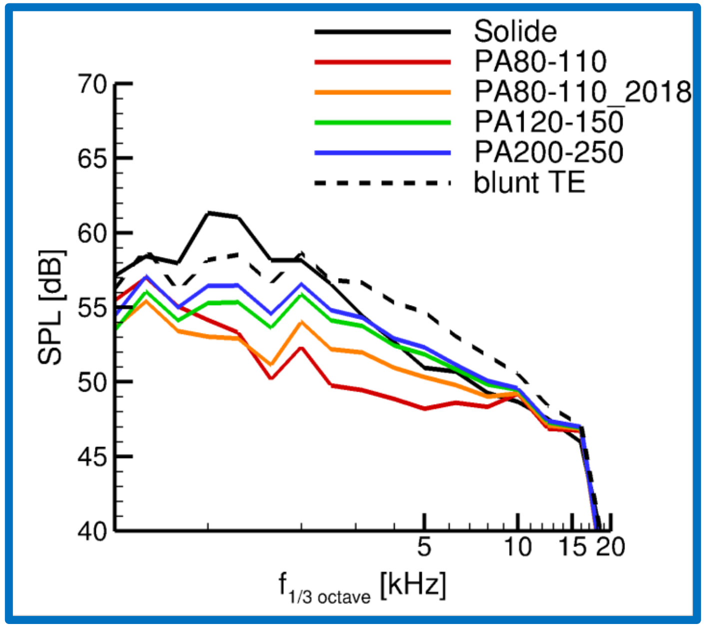


Simulation results
Understanding noise generation

- separate effects of turbulent sources and noise generation
- changed turbulence with solid trailing edge
    - significant SPL increase with permeability
- different porous materials with same turbulence
    - noise reduction decreases with high permeability
    - low-frequency domain: similar to measurements
- open questions:
    - character of noise increase: numerical model (verification by LES due)
    - limitation of noise reduction





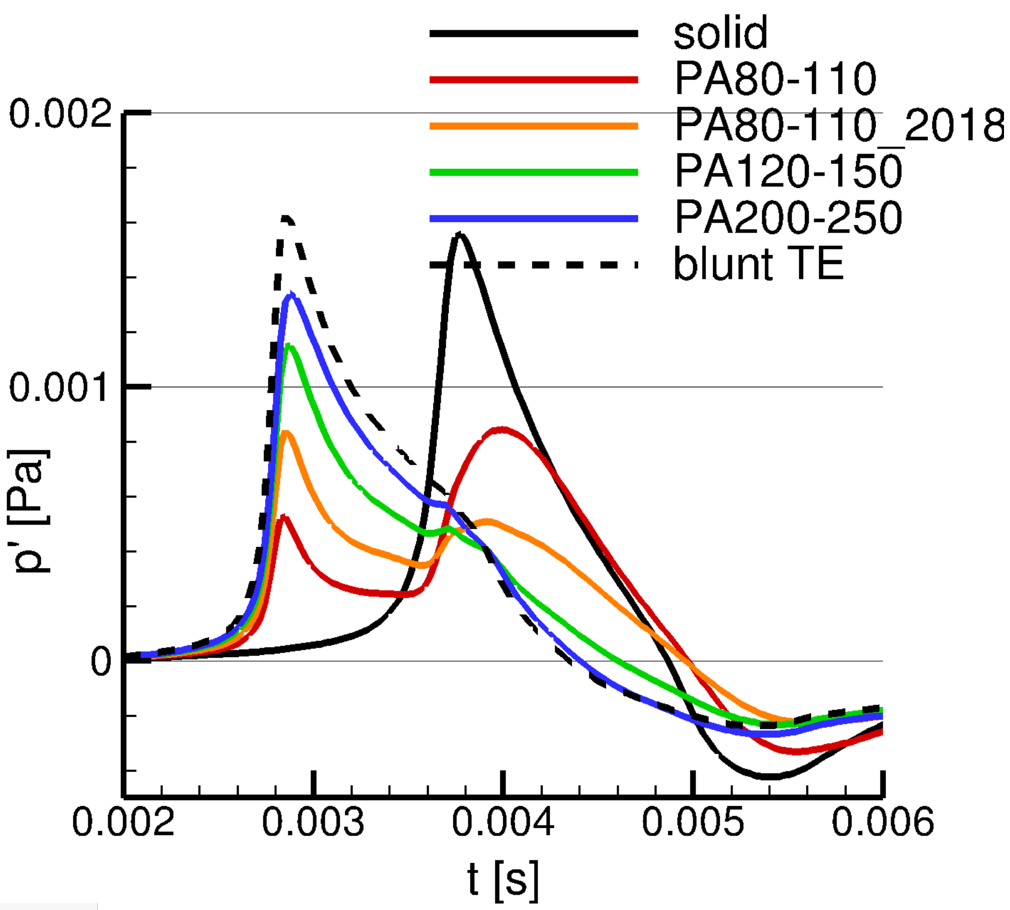


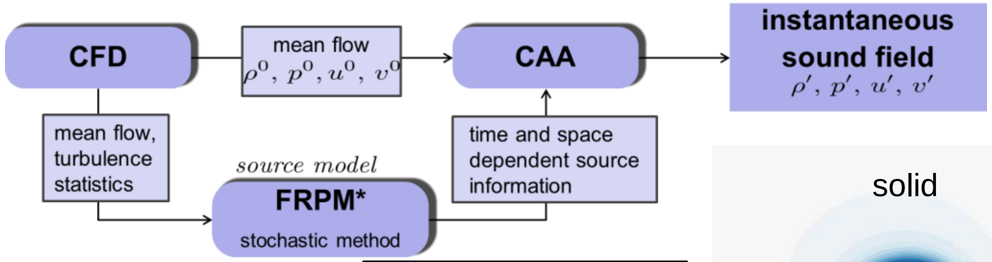
Simulation results
Understanding noise generation

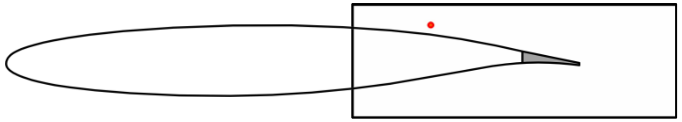
- reduce complexity from turbulence to single vortex

- trace acoustic wave generation over time
  - Distinguish between source locations

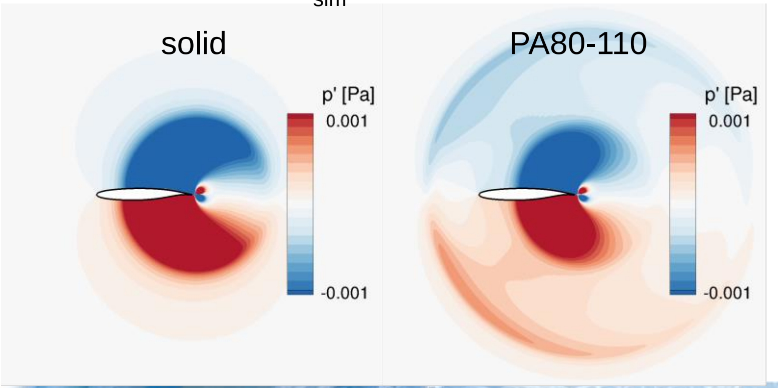
- with porous TE: secondary noise source from solid to porous interface
  - dominant for high permeability





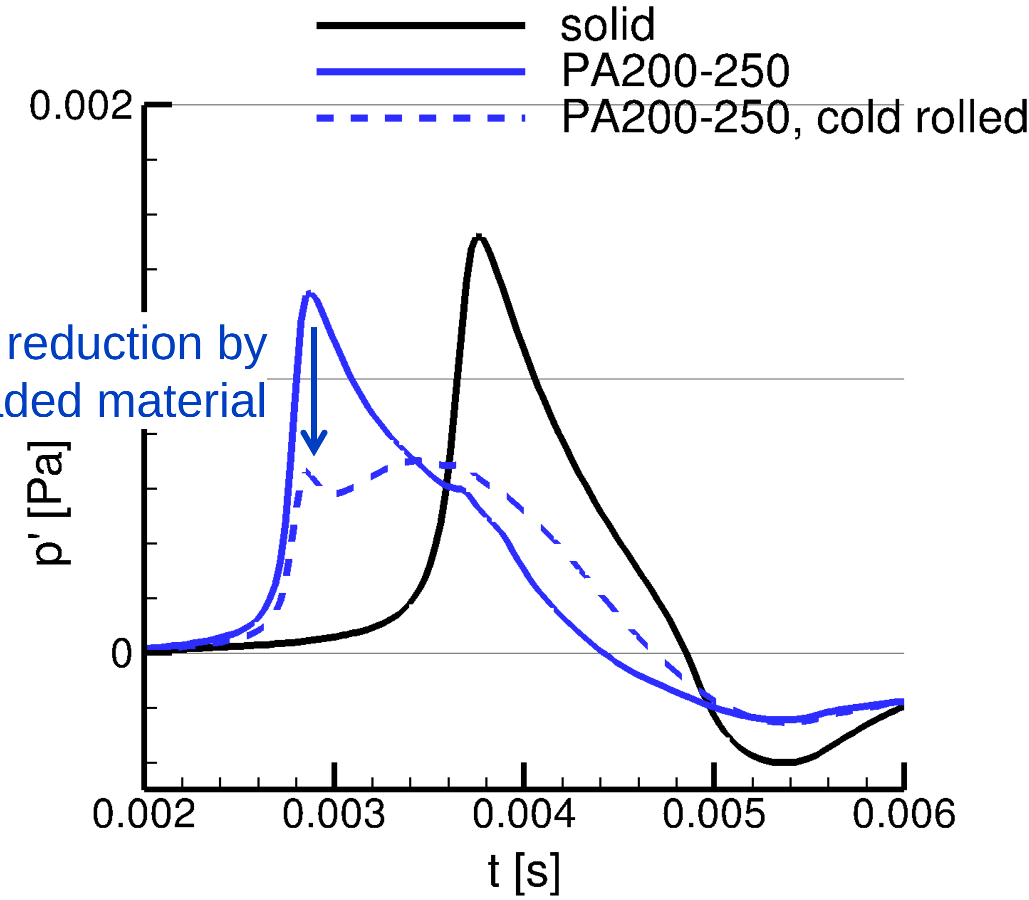


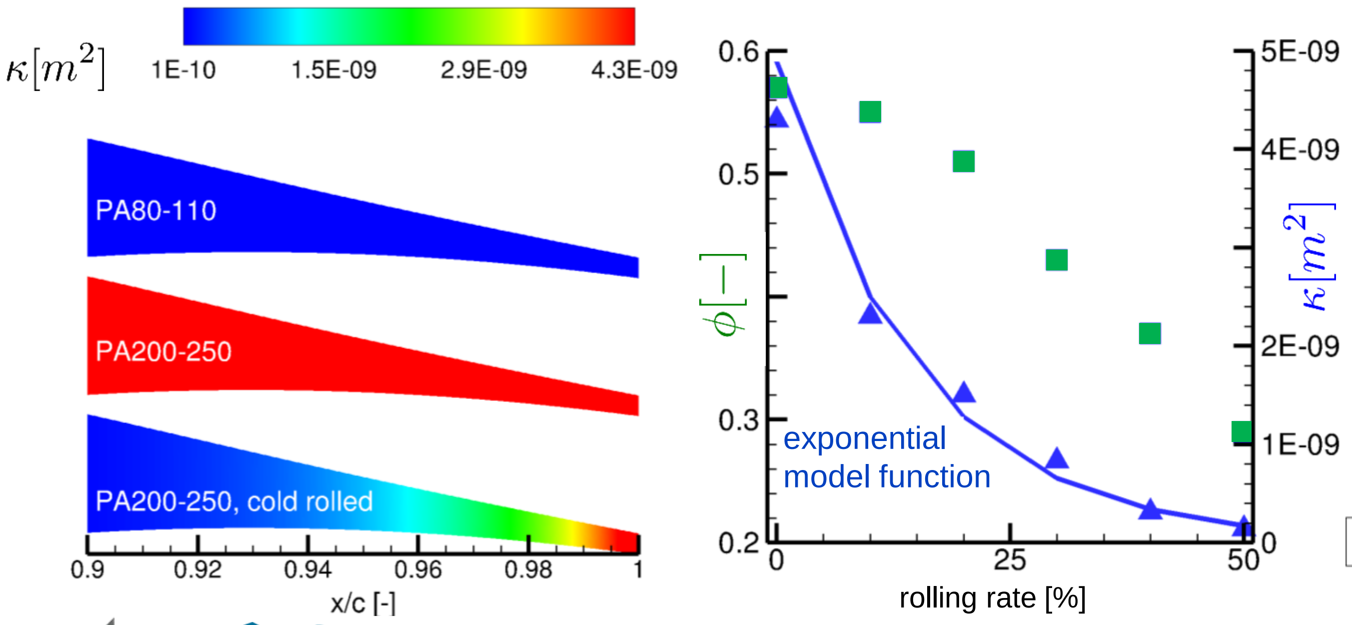
t_{sim} = const.



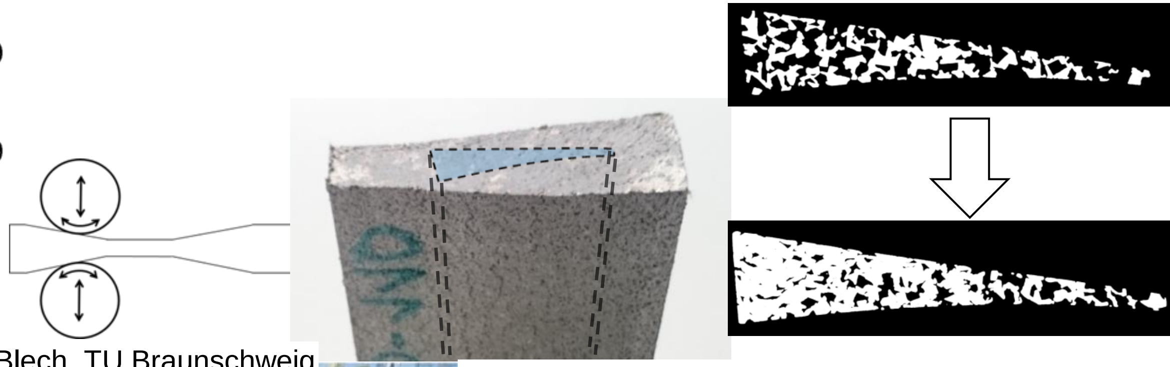
Simulation results
Tailored materials

- objective: reduce noise generation for both source locations simultaneously
- idea: combine advantages of low and high permeability by local variation





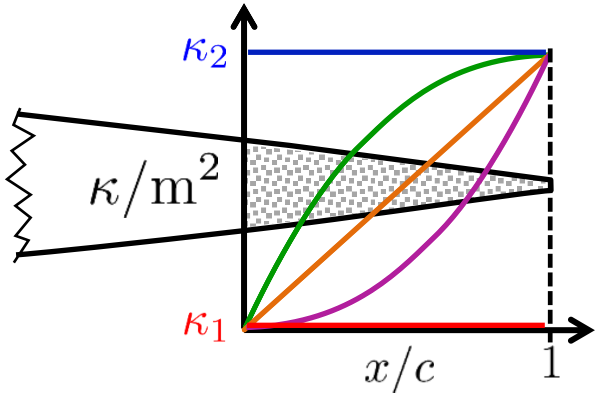
Section wise characterisation by J. Tychsen; Chr. Blech, TU Braunschweig

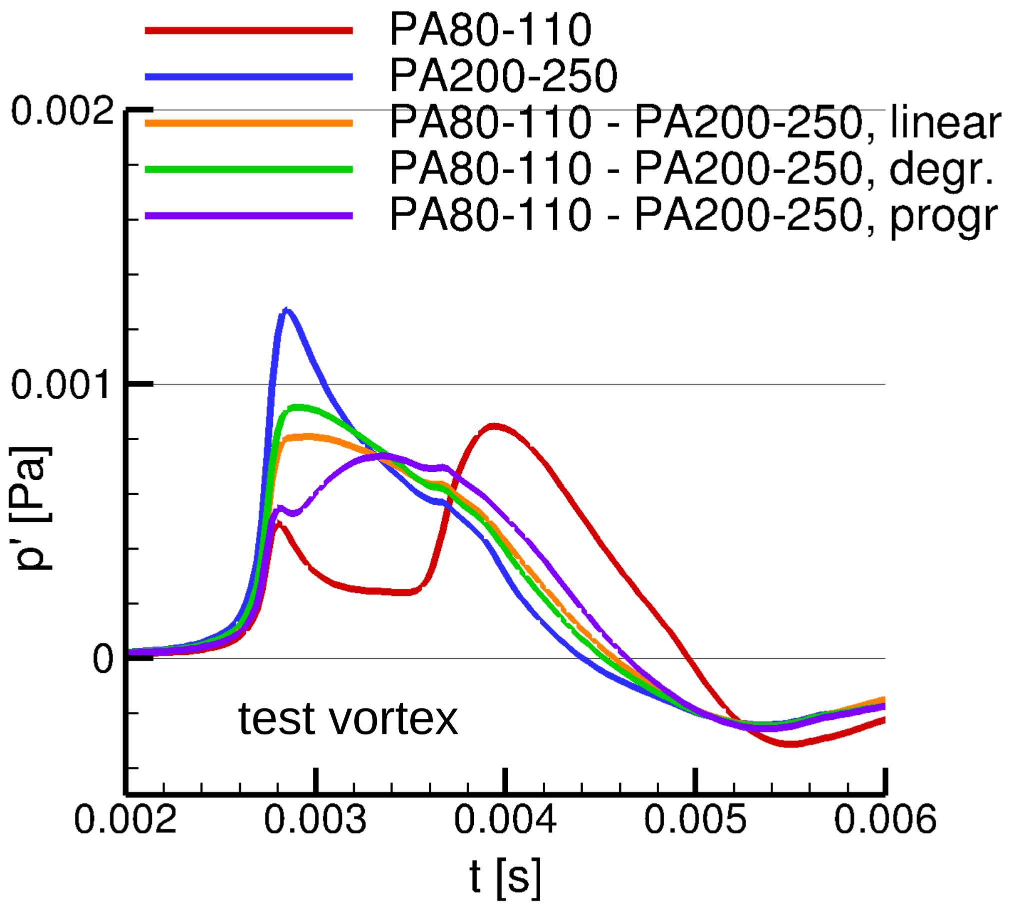


Simulation results
Tailored materials

- porous materials with locally varying permeability favorable for noise reduction

- different slopes feasible
  - linear
  - progressive quadratic
  - degressive quadratic





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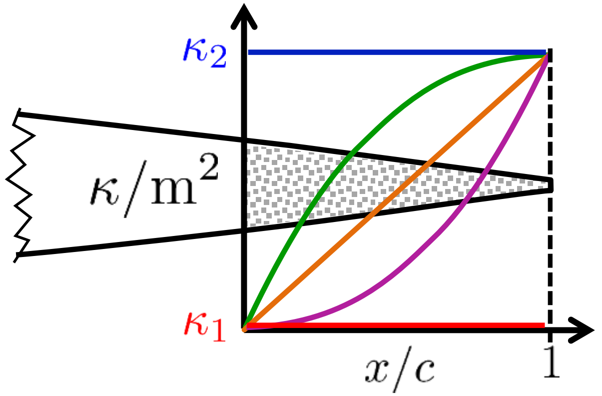

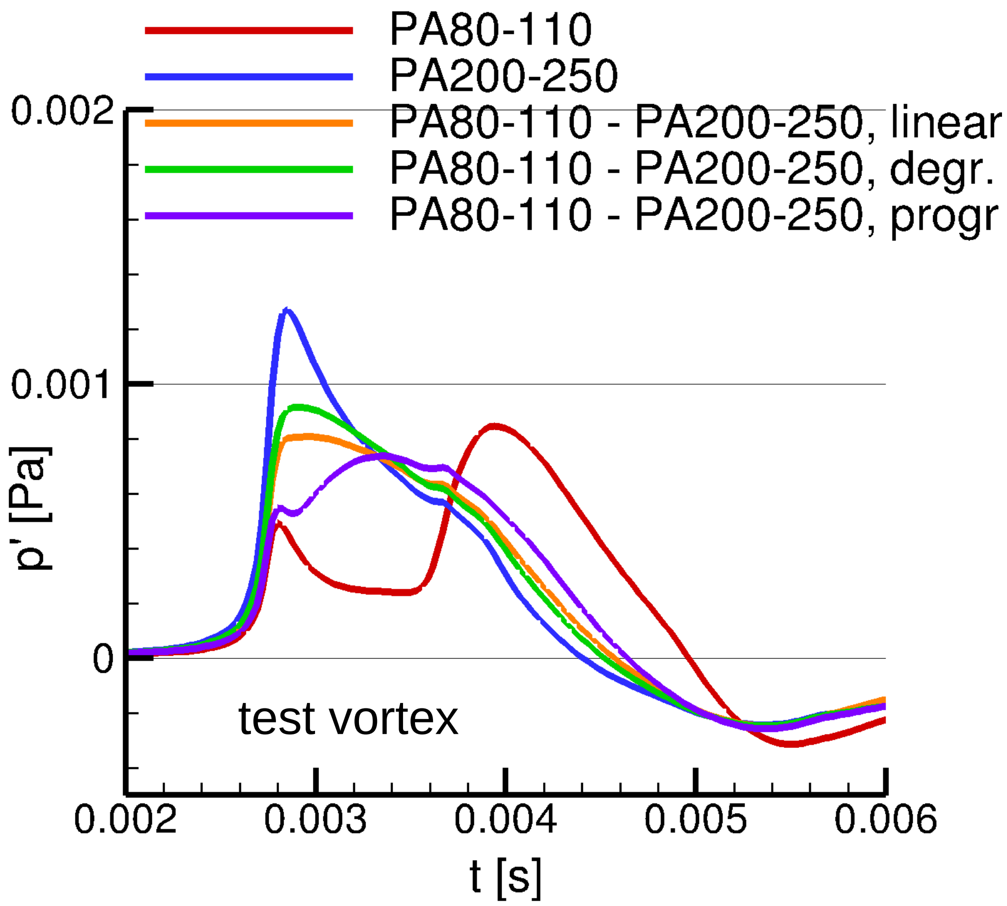

incompressible pressure fluctuations in fluid of porous material:

$$\Delta p' = -\nabla \cdot \nabla \cdot (\boldsymbol{v}\boldsymbol{v})' + \frac{\mathrm{Da}}{\mathrm{Re}} \frac{\phi}{\kappa^2} \boldsymbol{v}' \cdot \nabla \kappa,$$

$$\mathrm{Da} := \frac{\delta^2}{\overline{\kappa}}, \quad \mathrm{Re} := \frac{U_\infty \delta}{\nu} \qquad \overline{\kappa} = (\kappa_1 + \kappa_2)/2$$

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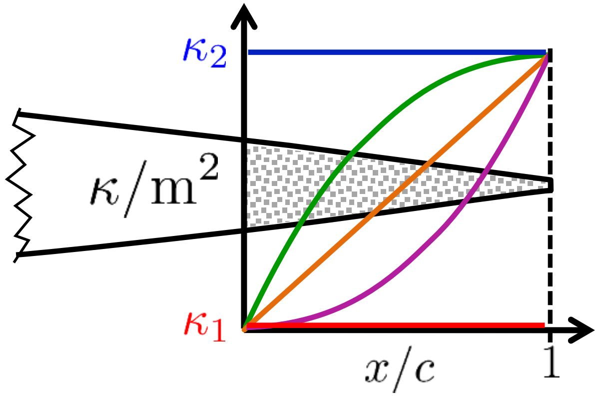

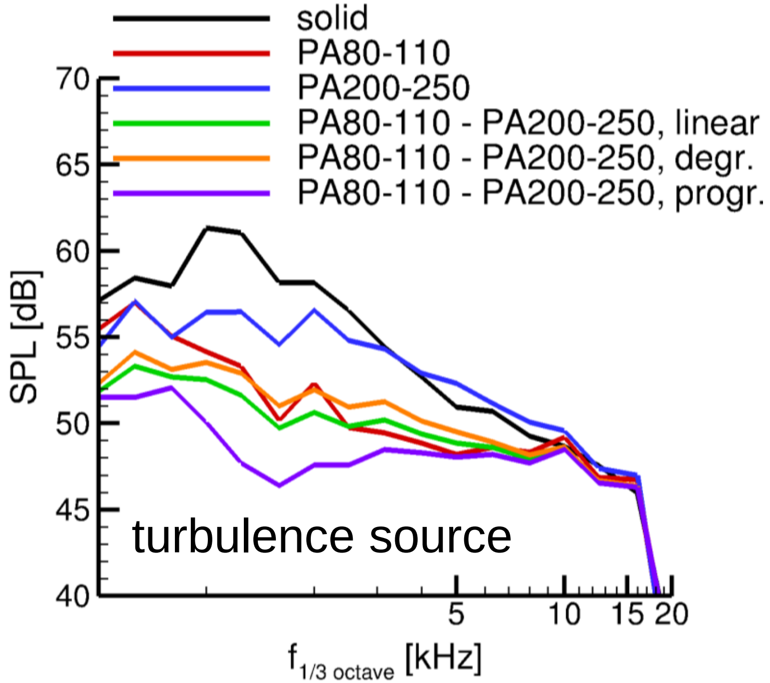

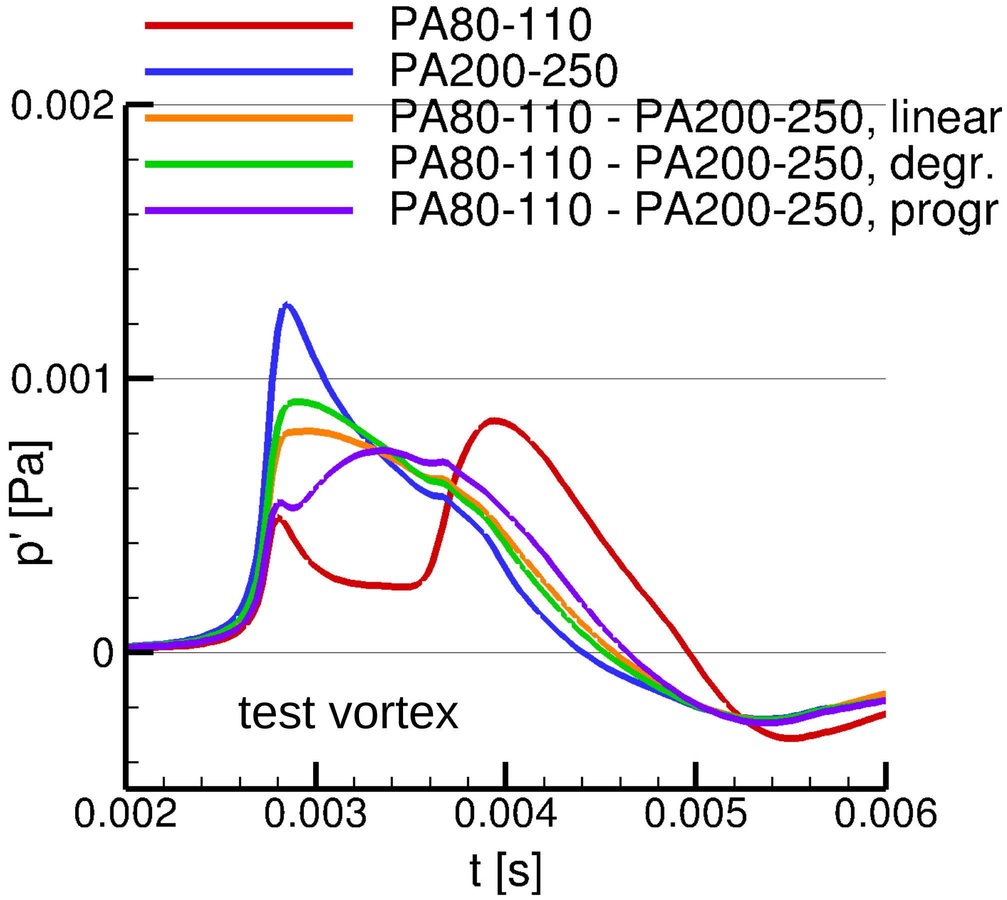

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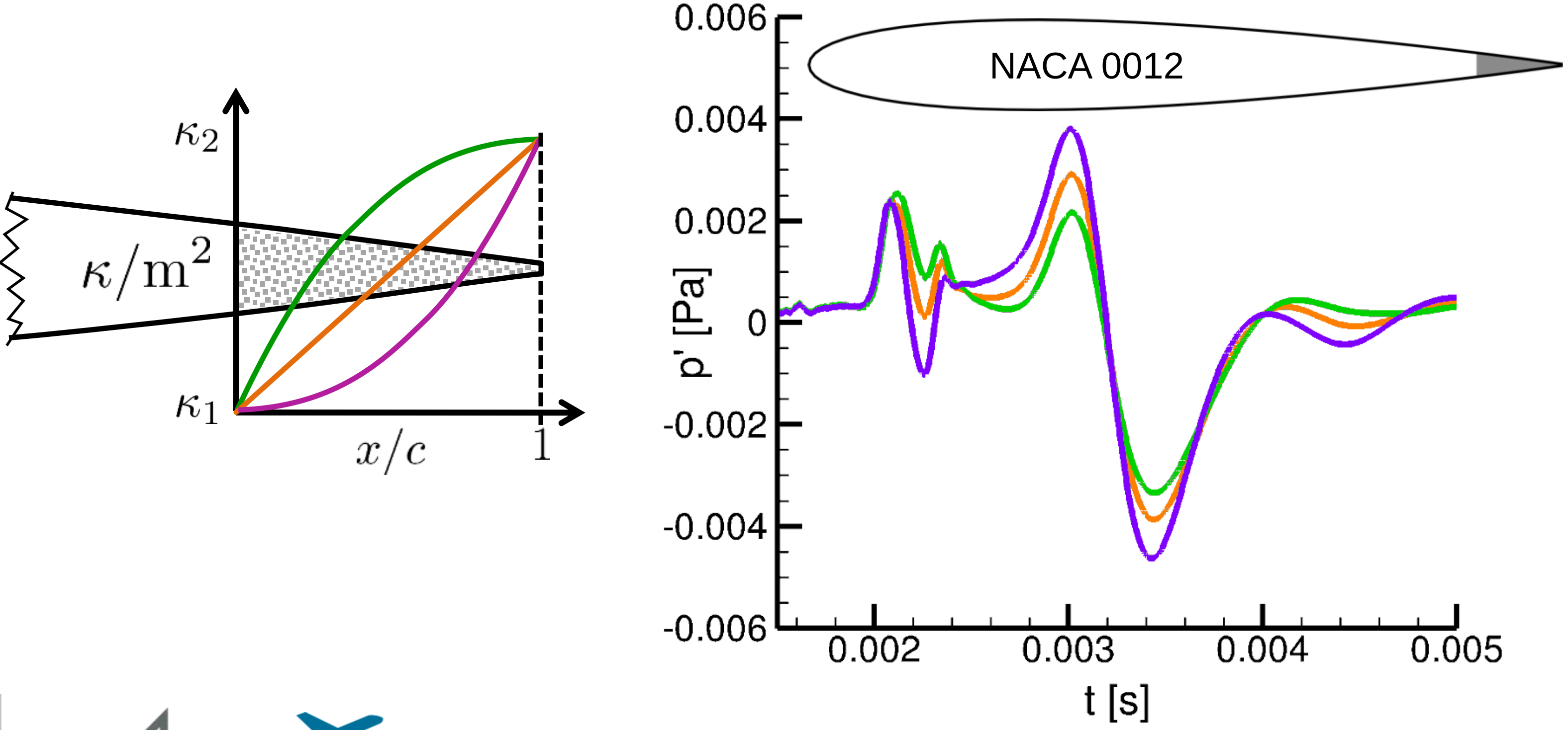
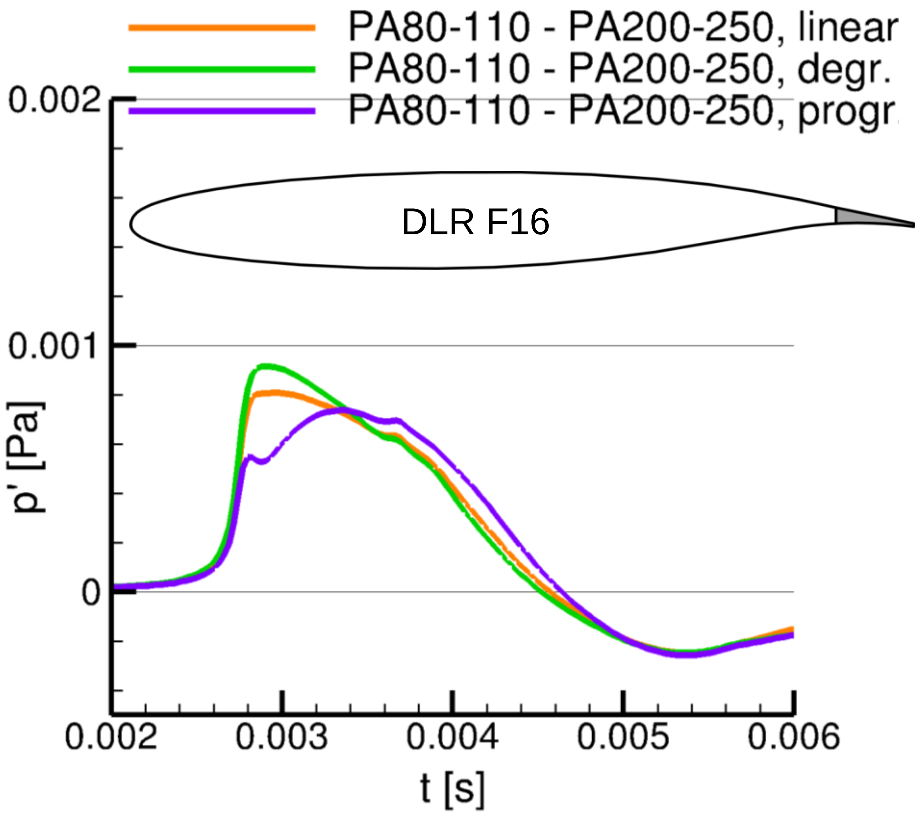
Simulation results
Tailored materials

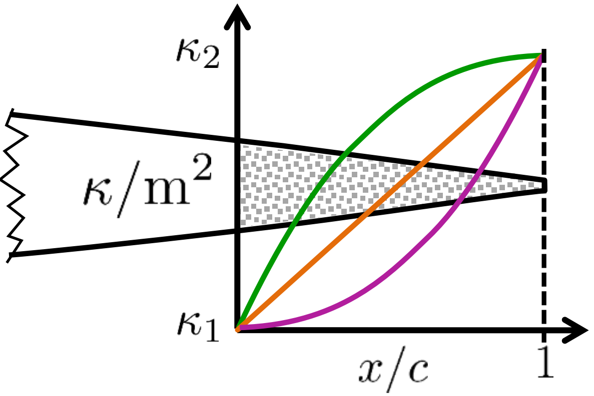
- Influence of material gradient depends on
    - airfoil shape

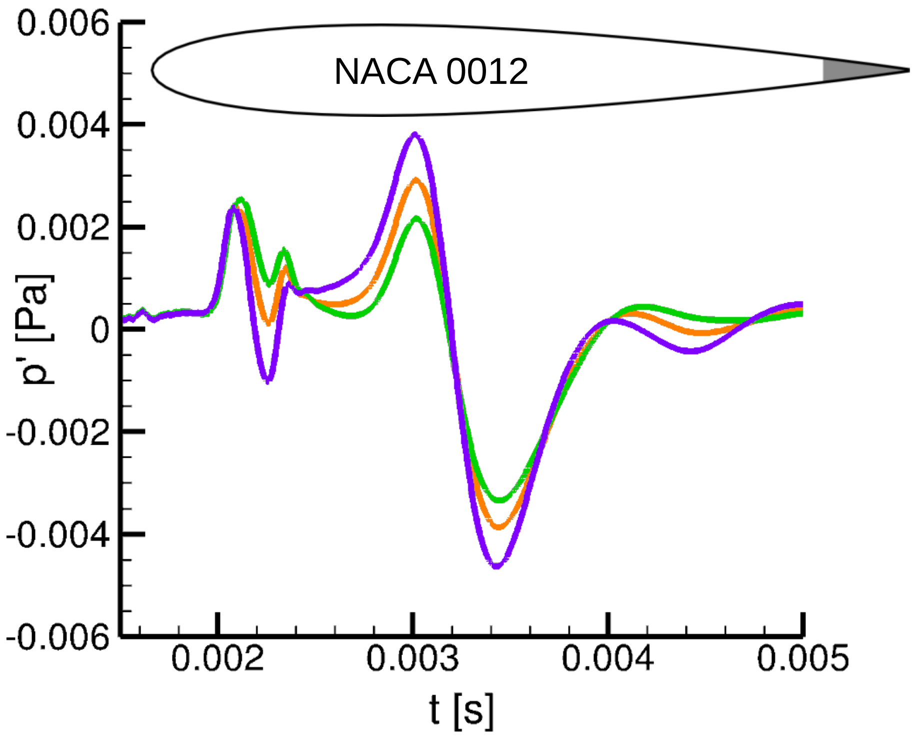


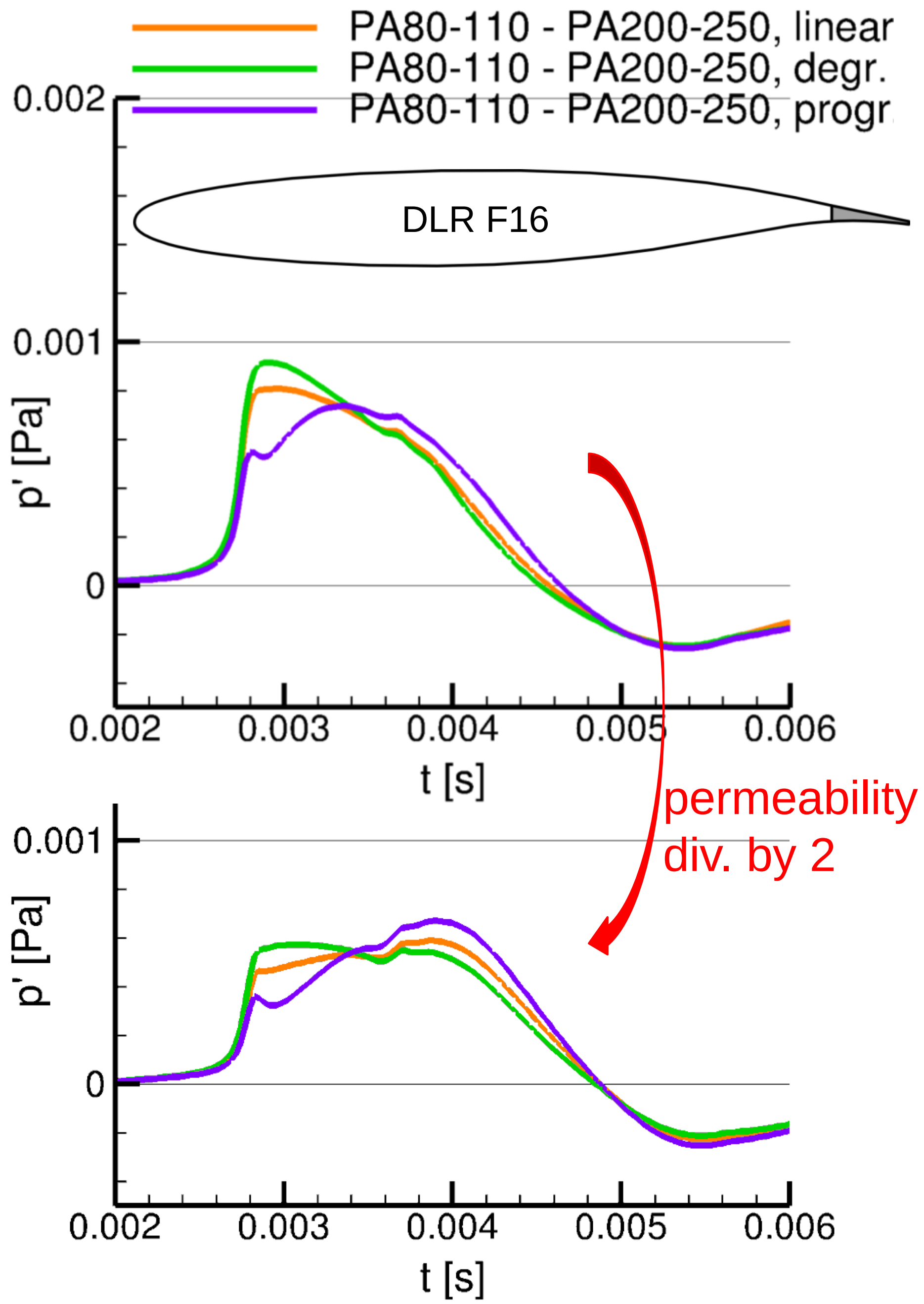


Simulation results
Tailored materials

- Influence of material gradient depends on
  - airfoil shape
  - Darcy number $\mathrm{Da} := \frac{\delta^2}{\overline{\kappa}}$ (or mean value $\overline{\kappa} = (\kappa_1 + \kappa_2)/2$)







Conclusions

- simulations and experiments show potential for airfoil bb. self-noise reduction by porous materials
- numerical results reveal that a locally varying permeability (graded material) is favorable
- the distribution of the gradation influences the noise reduction (complex dependence)
- porous materials alter the sound generation at edges by
  - reducing the conversion from vortical perturbations into sound
  - changing the boundary layer turbulence (intensity and distribution)

- primary open questions:
  - generalize turbulence models for i) flow simulation and ii) turbulence source to account for the high frequency noise increase (porous surface roughness effect, relating to e.g. average pore size)?
  - effect of changes in spanwise correlation length important ? (i.e. turn to 3D simulations)

Thank you