COMSOL CONFERENCE
2016 MUNICH

Acoustic Scattering through a Circular Orifice in Low Mach-Number Flow

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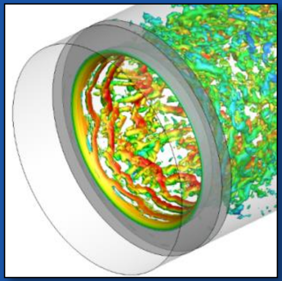
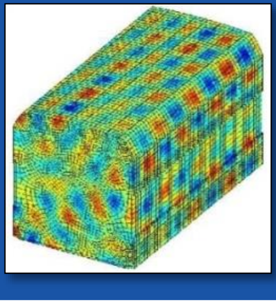
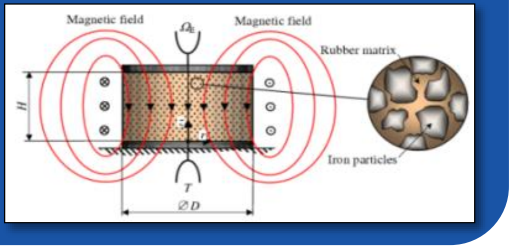
Research Areas



Aero-acoustics
Vibration isolators
Wave-based methods
Material acoustics





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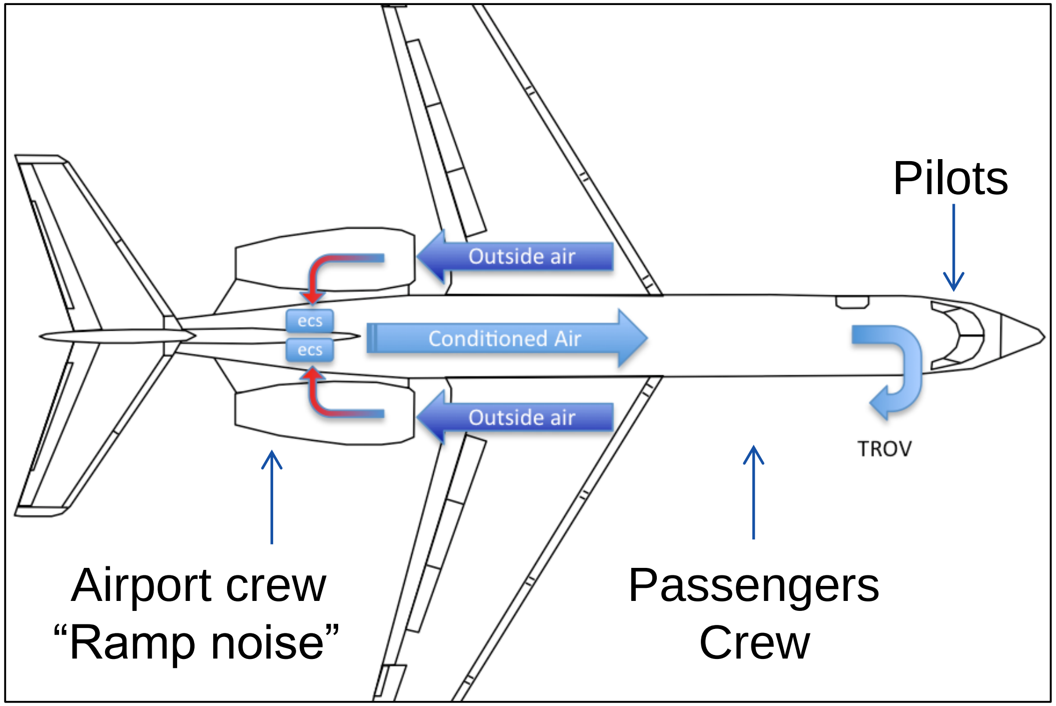
IdealVent Project

Integrated **De**sign of Optim**al** **Vent**ilation Systems for Low Cabin and Ramp Noise



Airport crew
“Ramp noise”

Passengers
Crew

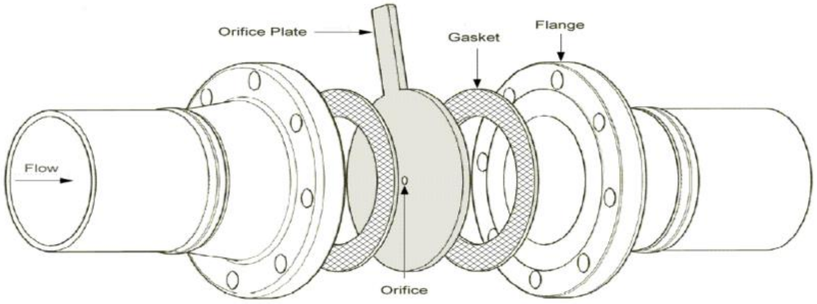
Consortium

1. VKI - von Karman Institute for Fluid Dynamics, Belgium
2. DLR - Forschungszentrum der BRD für Luft- und Raumfahrt, Germany
3. KTH - Kungliga Tekniska Högskolan, Sweden
4. KUL - Katholiehe Universiteit Leuven, Belgium
5. ECL - Ecole Centrale de Lyon, France
6. Siemens– (former LMS), Belgium
7. SNT - Odecon Sweden AB, Sweden
8. LTS - Liebherr Aerospace toulouse sas, France
9. NTS - New Technologies and services LLC, Russian Federation
10. EMB - Embraer S.A

Approach

A ventilation system contains (sophisticated) aero-acoustic sources (ducts, junctions, valves, nozzles, compressors, diaphragms)

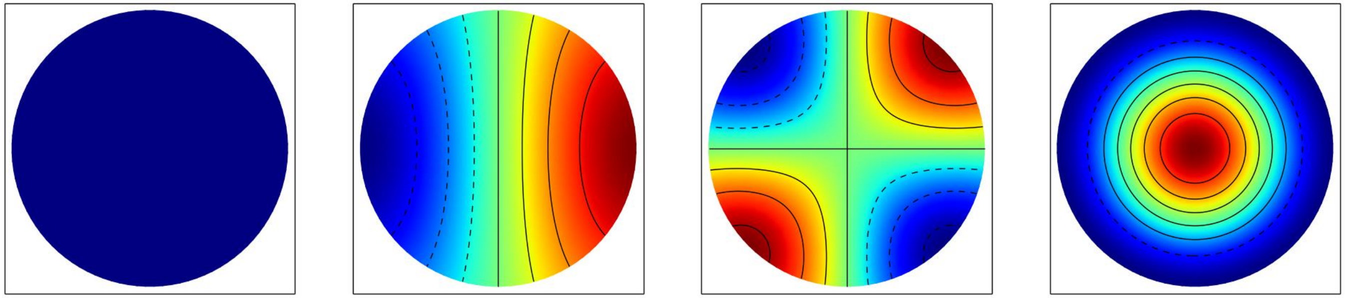
Idea: **Investigate the sources separately and combine them to a network of so called multi-ports**



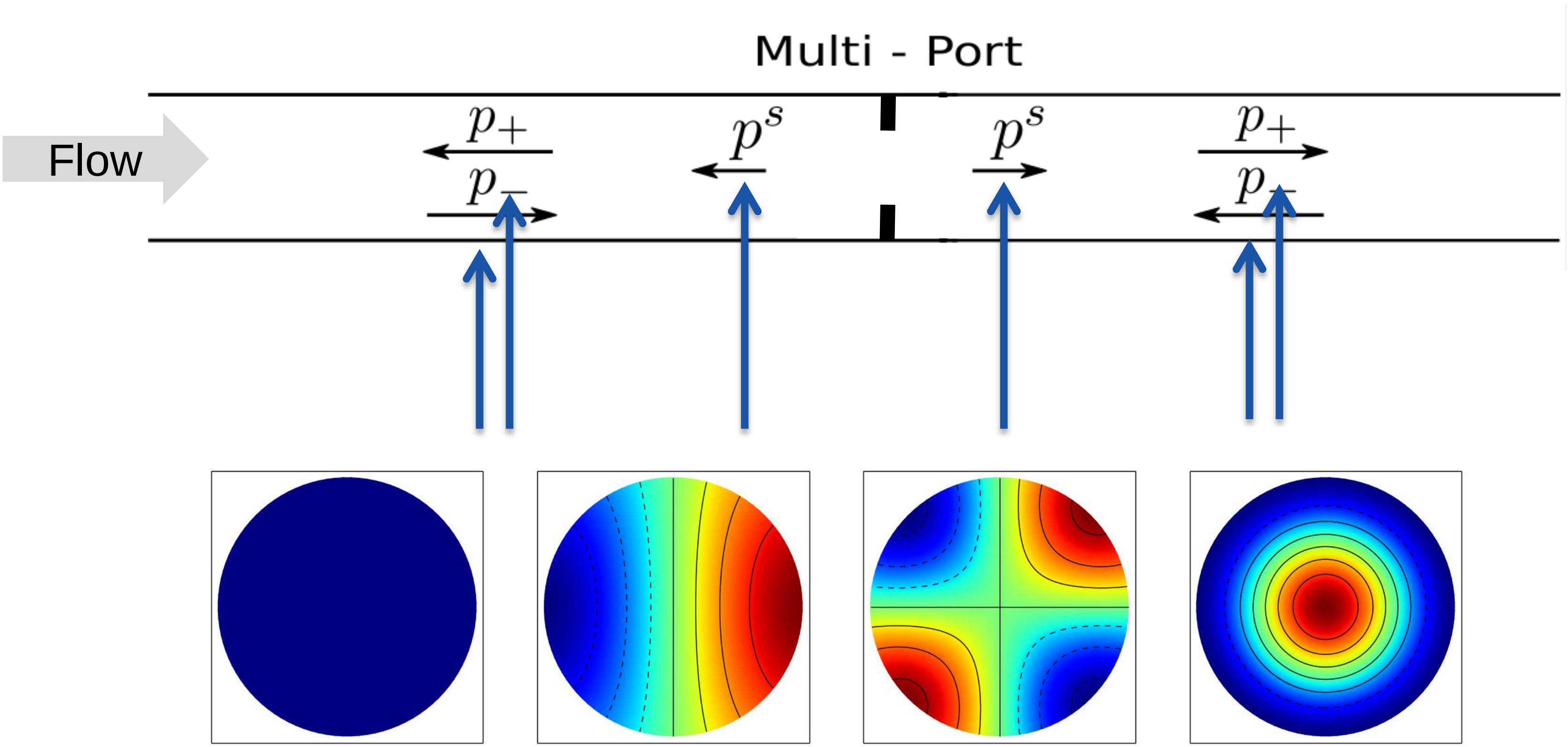
Multi-Port approach

The sound field inside the duct is a **superposition** of aeroacoustic **eigen-modes**

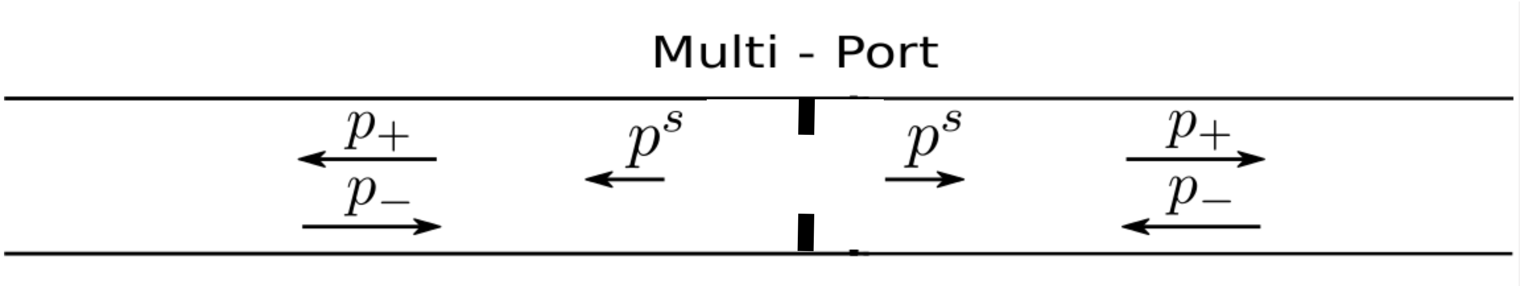
$$p(x,y,z) = \sum_{n=0}^{N} \hat{P}_n A_n(x,y,z)$$



Multi-Port approach



Multi-Port approach



We can find a linear system of equations

$$\mathbf{p}_+(f) = \mathbf{S}\mathbf{p}_-(f) + \mathbf{p}_+^s(f)$$

S	Scattering Matrix
$\mathbf{p}_+^s$	Source vector

See: **Lavrentjev, J. and Abom, M. (1996)**. *Characterization of Fluid Machines As Acoustic Multi-Port Sources*. Journal of Sound and Vibration, 197(1):1–16.

Multi - Port Networks

Orifice-plate in a circular duct

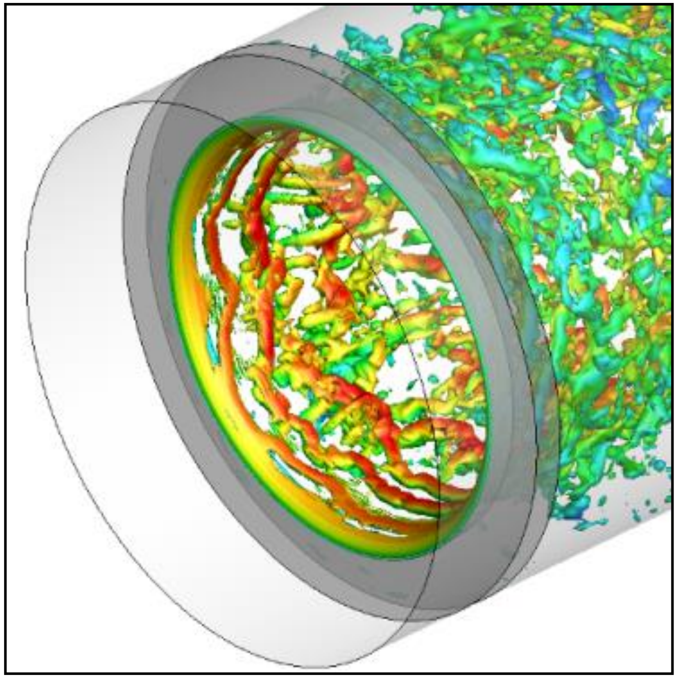
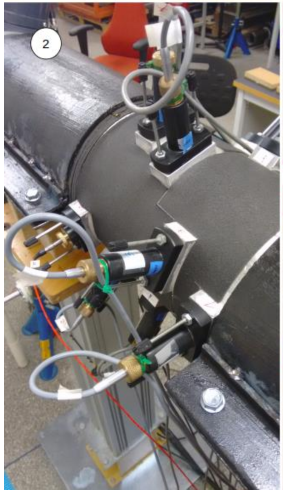
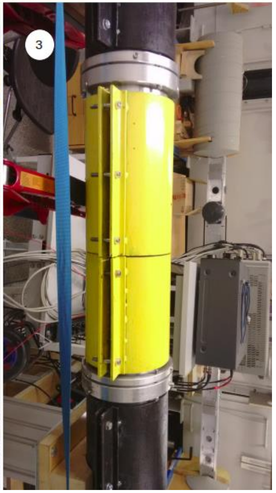


Figure from IDEES Computation by M. Shur et al., NTS

Measurements

Measurements for model-validation at the *Marcus Wallenberg Laboratory for Sound and Vibration Research at KTH*





- **24 microphones** and **16 loudspeakers** in an optimised setup
- Aluminum pipe-sections with **constraint layer damping**
- Multi-channel excitation with algorithms for **simultaneous, uncorrelated excitation**
- **Modal decomposition** with **advanced** wave-numbers to account for damping
- Two stage measurements for **accurate scattering** and **source** characterisation

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Sack, S., **Åbom**, M., & **Efraimsson**, G. (2016).

On Acoustic Multi-Port Characterisation Including Higher Order Modes.

Acta Acustica United with Acustica, *102*, 834–850.

Computations
Linearized-Navier-Stokes equation

We use the **Linearized Navier-Stokes-Equation** in the **frequency domain** on a **3D grid**

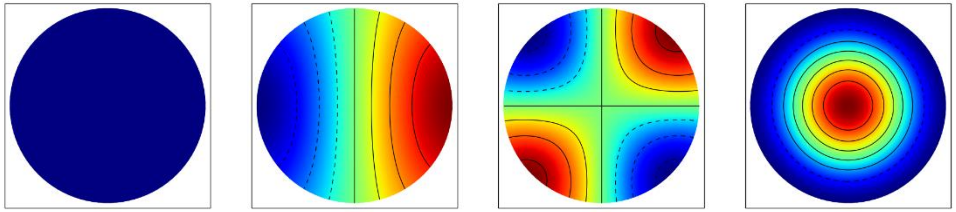
$$i\omega\rho + \nabla\cdot(\rho\mathbf{u}_0 + \rho_0\mathbf{u}) = M$$

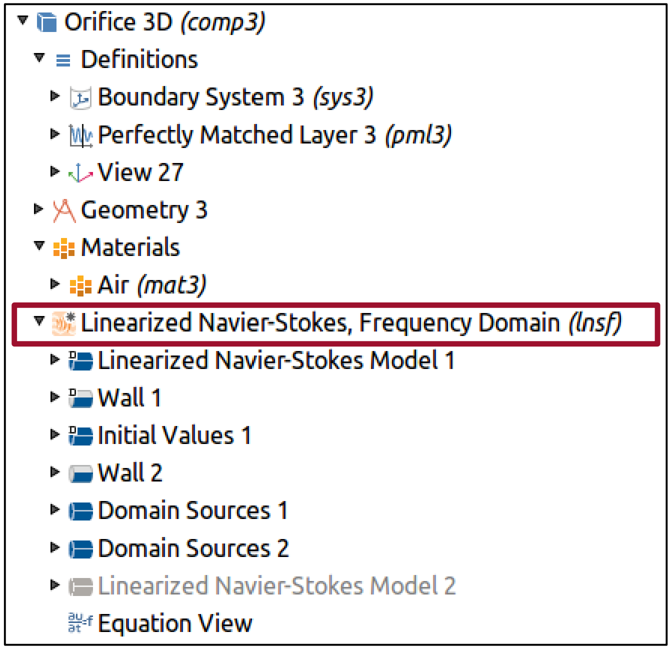
$$\rho_0\left(i\omega\mathbf{u} + (\mathbf{u}\cdot\nabla)\mathbf{u}_0 + (\mathbf{u}_0\cdot\nabla)\mathbf{u}\right) - \nabla\cdot\boldsymbol{\sigma} = \mathbf{F}$$

$$\rho_0 C_p\left(i\omega T + (\mathbf{u}\cdot\nabla)T_0 + (\mathbf{u}_0\cdot\nabla)T\right) + \rho C_p(\mathbf{u}_0\cdot\nabla)T_0$$
$$-\alpha_0 T_0\left(i\omega p + (\mathbf{u}\cdot\nabla)p_0 + (\mathbf{u}_0\cdot\nabla)p\right) - \alpha_0 T(\mathbf{u}_0\cdot\nabla)p_0 - \nabla\cdot(k\nabla T) = \Phi + Q$$

$$\boldsymbol{\sigma} = -p\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T) + \left(\mu_B - \frac{2}{3}\mu\right)(\nabla\cdot\mathbf{u})\mathbf{I}$$

$$\rho = \rho_0(\beta_T p - \alpha_0 T)$$

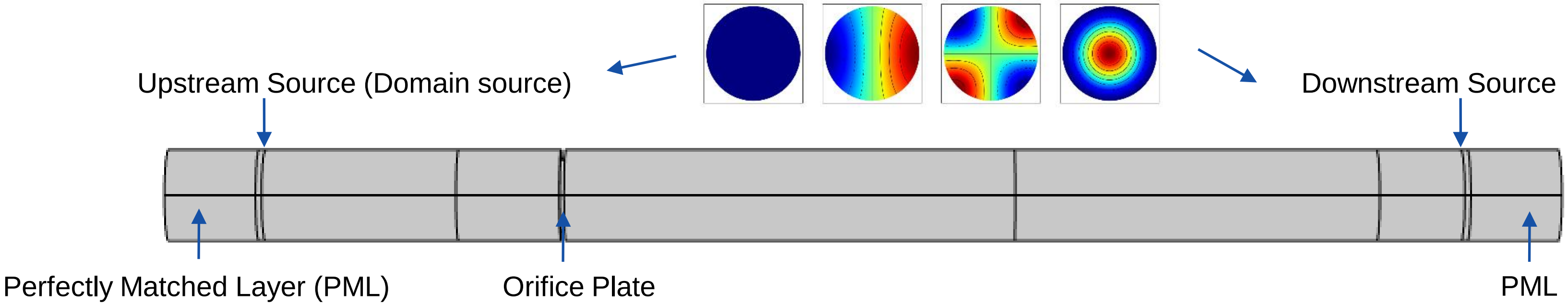




- Orifice 3D *(comp3)*
  - Definitions
    - Boundary System 3 *(sys3)*
    - Perfectly Matched Layer 3 *(pml3)*
    - View 27
  - Geometry 3
  - Materials
    - Air *(mat3)*
  - Linearized Navier-Stokes, Frequency Domain *(lnsf)*
    - Linearized Navier-Stokes Model 1
    - Wall 1
    - Initial Values 1
    - Wall 2
    - Domain Sources 1
    - Domain Sources 2
    - Linearized Navier-Stokes Model 2
    - Equation View

For Linearized-Navier-Stokes solver for acoustic plane wave modes see:
Kierkegaard et al. *(2012). Simulations of whistling and the whistling potentiality of an in-duct orifice with linear aeroacoustics.* Journal of Sound and Vibration.

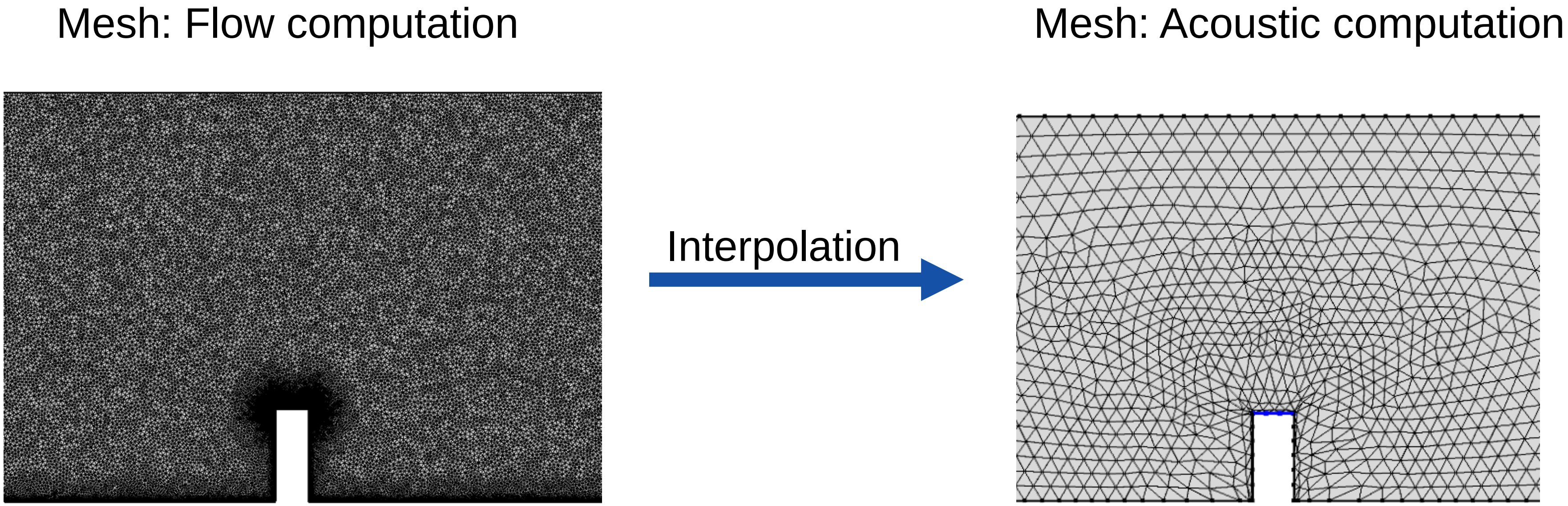
Computations
Linearized-Navier-Stokes equation



Computational Steps for scattering:

1. Background mean flow (pref. SST RANS), once
2. Acoustics, one computation for each mode and upstream and downstream side per frequency

Computations
Linearized-Navier-Stokes equation



<u>Problem:</u> The internal interpolation seems to be insufficient, as the gradients are not interpolated correctly on the langrage points inside the elements
<u>Solution:</u> “Dummy-study” for interpolation using weak formulation to minimize difference between flow and interpolated solution.

Computations
Mean Flow

Problem with flow computation: No convergence for SST RANS, even in 2D

Tried different “tricks”:

K-Epsilon / K-omega start solution
Inconsistent stabilisation
Pseudo time stepping
Smooth corners

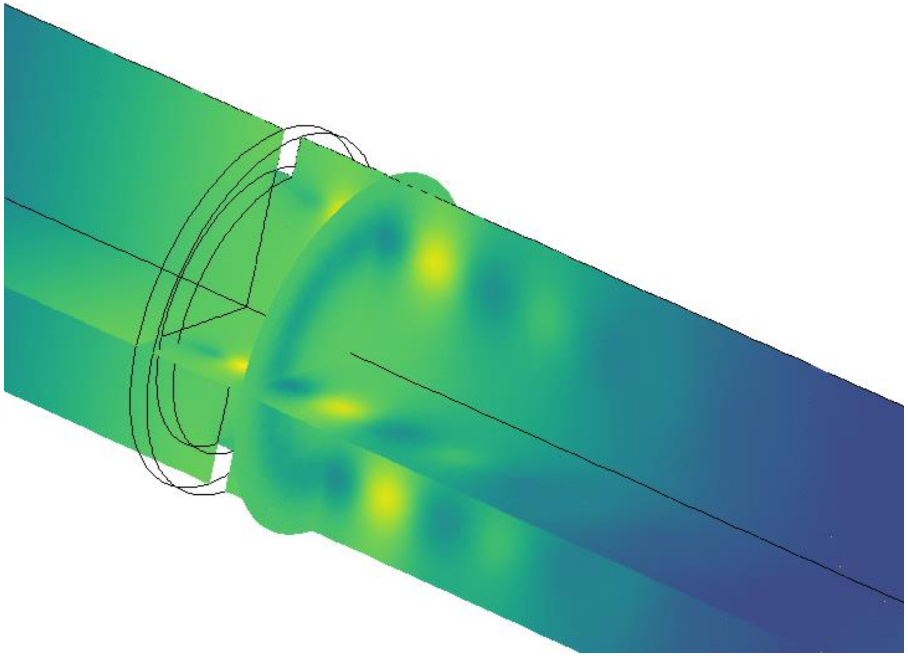
No solution. Approach: Compute flow in different software and import it into Comsol.
(this is not optimal, any ideas are more than appreciated)

Computations
Acoustics

In general, acoustic computations worked very well!

Density fluctuation

(0,0)-Mode



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Computations
Acoustics

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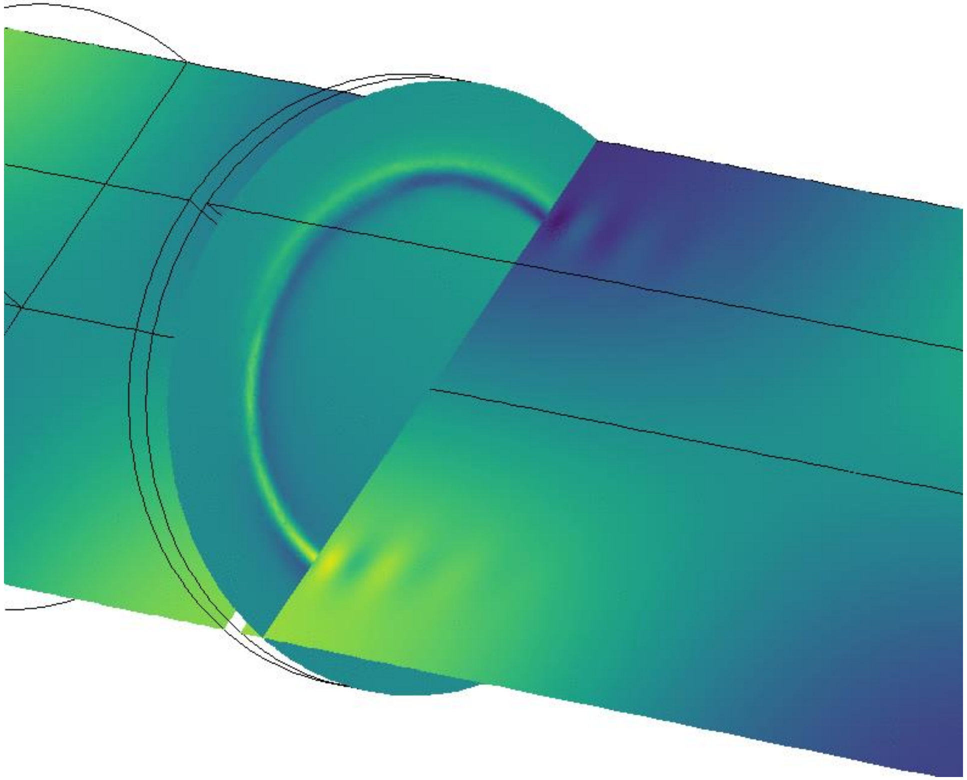
Density fluctuation

(1,0)-Mode



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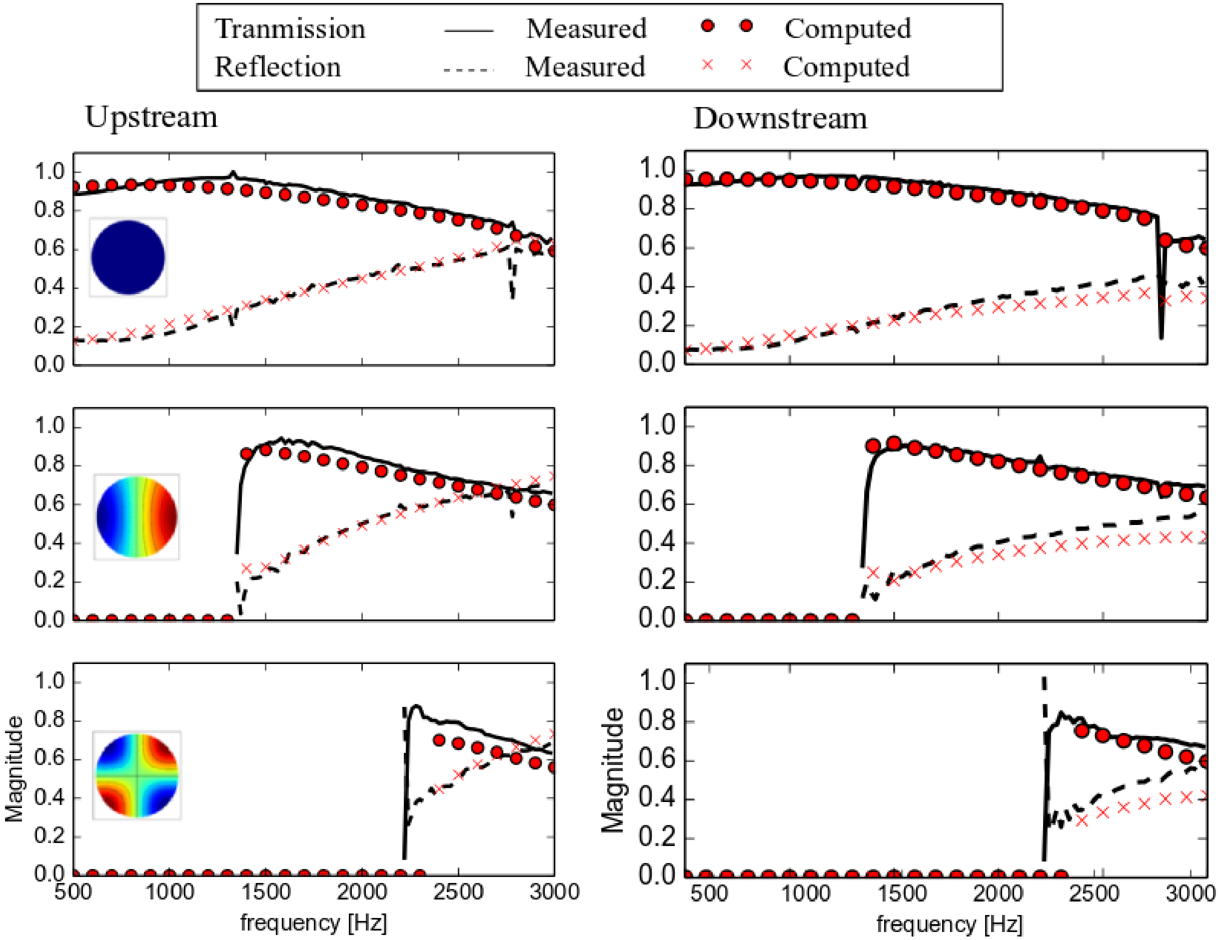
Computations
Acoustics



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Summery

- The linearized Navier-Stokes Interface can be used to compute the scattering of sound including effects of acoustic-flow interaction
- For circular orifice plates, the crucial point seems to be computing the mean flow, esp. the thin shear layers in the jet downstream the orifice
- If the mean-flow is computed and interpolated, very accurate results can be achieved with rather low computational costs

Full Multi-Port Characterization of a Circular Orifice Plate

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