Broadband Noise Prediction of a Ducted Axial Fan by Means of a Discontinuous Galerkin Based CAA Solver

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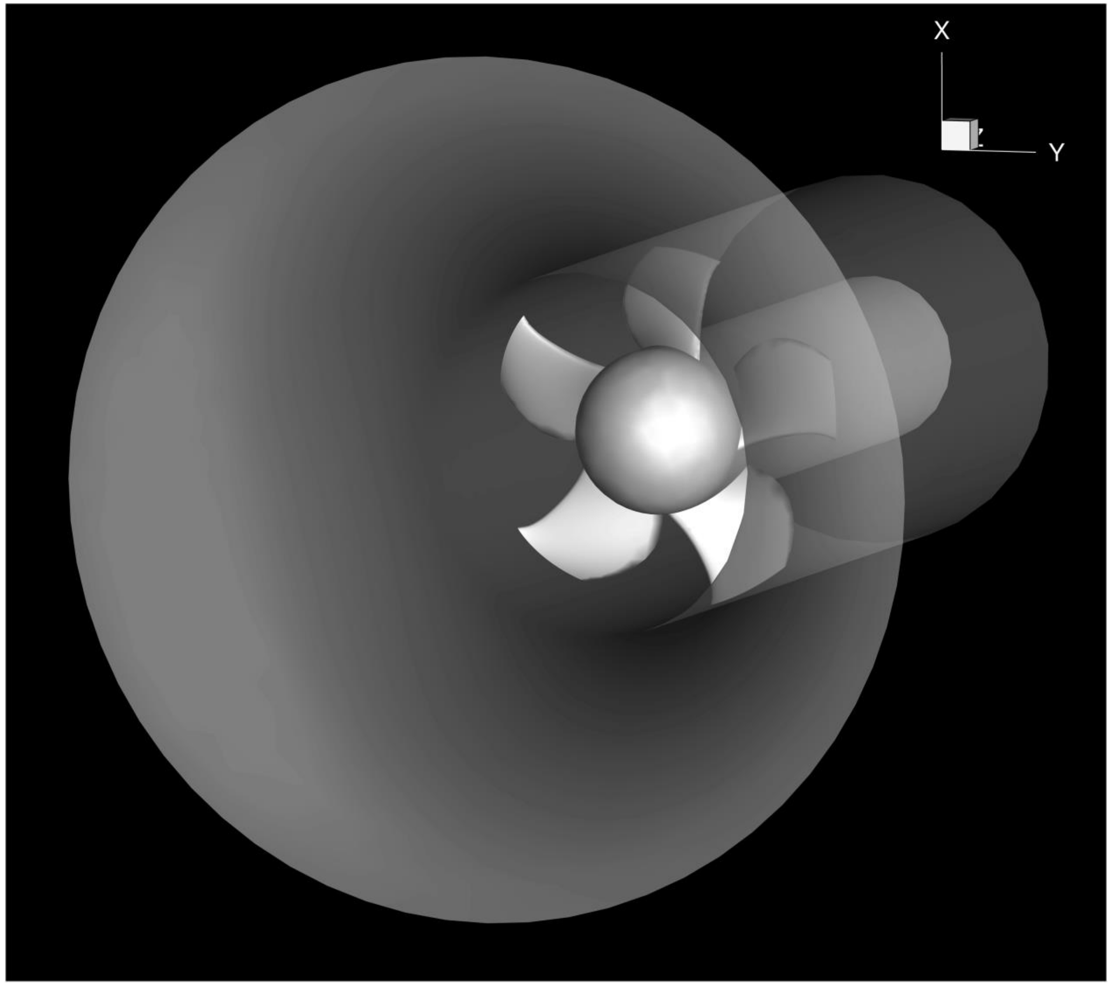
Motivation

- **Fan manufacturers** → rising demand for **noise optimization**
  - Investigation of **sound generation** in **complex 3D applications**
  - **CAA** method **used within** the **design process**
  - Easy setup, reasonable computation time

High efficiency

- **Unstructured meshing** beneficial
  - Spare cumbersome **“manual” grid generation**
  - Capability of **automation**

- **Hybrid approach** rather than full scale simulation
  - **Separation** of acoustic and flow simulation
  - **Locally** computed **acoustic sources**



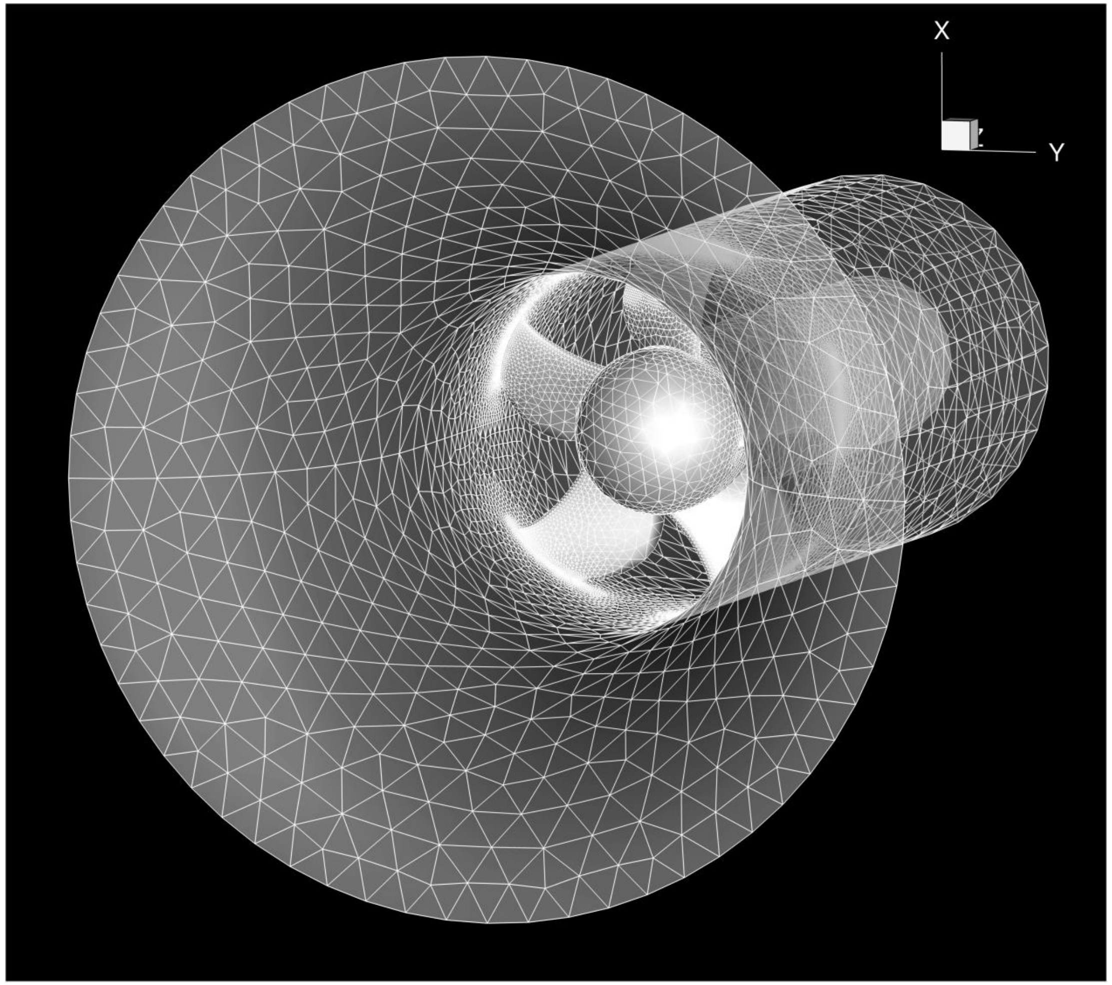
Method – DISCO++ coupled with FRPM

FRPM – Fast Random Particle Mesh (Method)
APE – Acoustic Perturbation Equations

- **CFD** computation (RANS / uRANS) as input
- **Unsteady acoustic sources** → **FRPM**
- **APE** for **sound propagation** → **DISCO++**

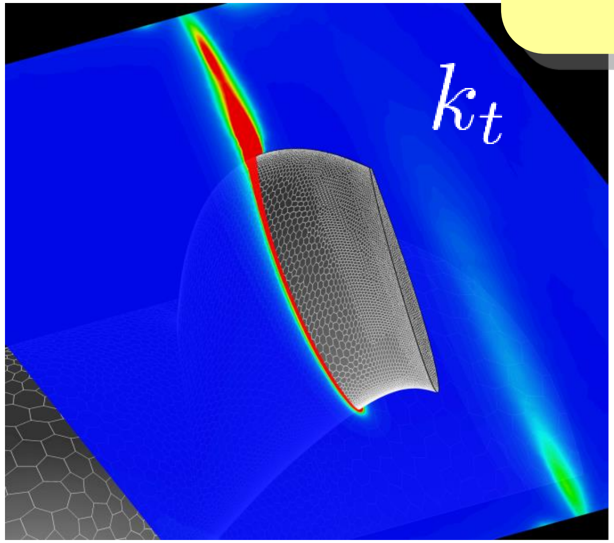
DISCO++

- **Discontinuous Galerkin (DG)** method **unstructured** grid of **tetrahedral** elements
  - Quantities → third-degree **polynomials**
  - **Coupling** through flux computation at **adjacent** elements
- High degree of **parallelization**
- Easily **extendable** through **modular code structure** (equation system, time integration method, etc.)



Fast Random Particle Mesh (Method)

ebmpapst



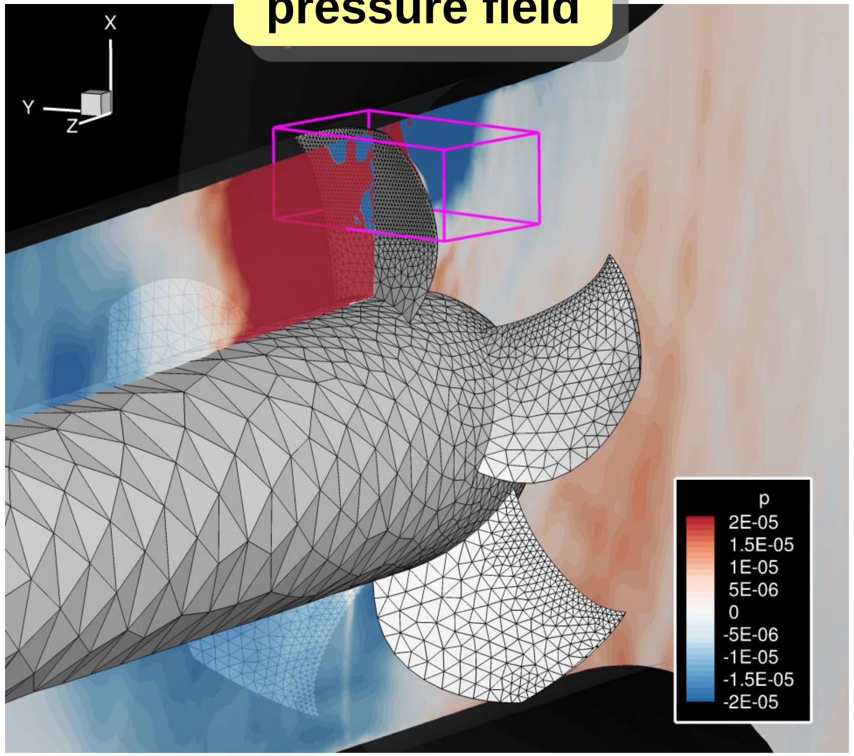
CFD
RANS

Mean flow

CAA
APE

p'

Instantaneous pressure field

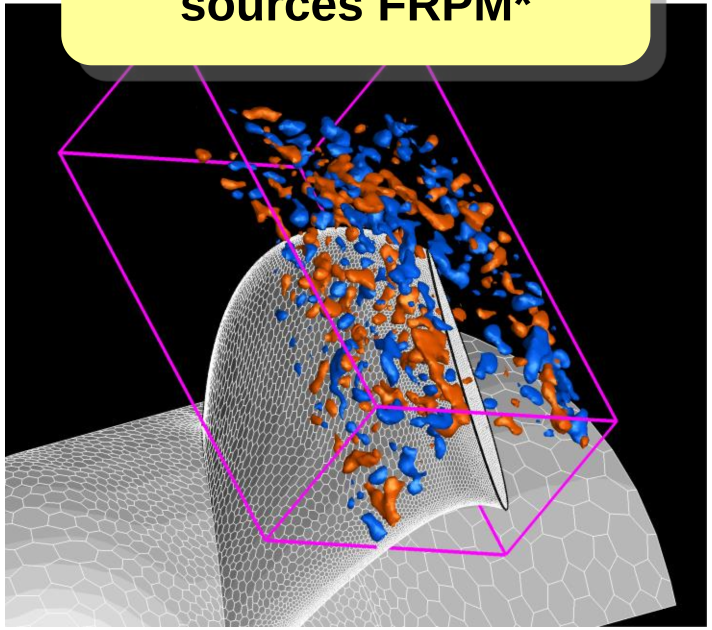


Source term
$\vec{L}'$

Turbulence statistics

k_t, ε

4D-stochastic sound sources FRPM*



Vortex sound source – Lamb vector

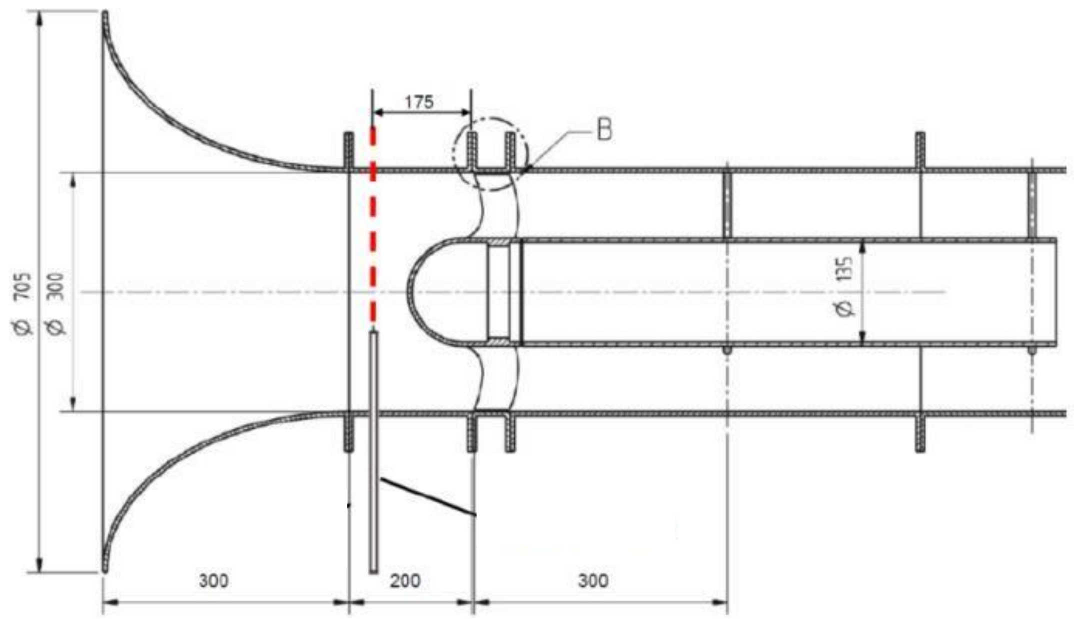
$$\vec{L}' = -\vec{\omega}_0 \times \vec{u}^t - \vec{\omega}^t \times \vec{u}_0$$

***Ewert, Comp. & Fluids (Vol. 37)**

Ducted axial fan – simulated test case
Purpose and setup

- **Benchmark case** developed at University of Siegen
  - Validation **base** for fluid dynamics and aeroacoustic simulations
- **Investigated setup**
  - Enclosing duct diameter D_a = 300 mm
  - **AMCA*** standard **nozzle** of length and diameter L = 300 mm, D_{max} = 700 mm
  - Axial rotor-only **fan „USI7“**
    - Diameter of rotor d_0 = 300 mm
    - Rotation speed n = 3000 rpm
  - **No further geometry** considered

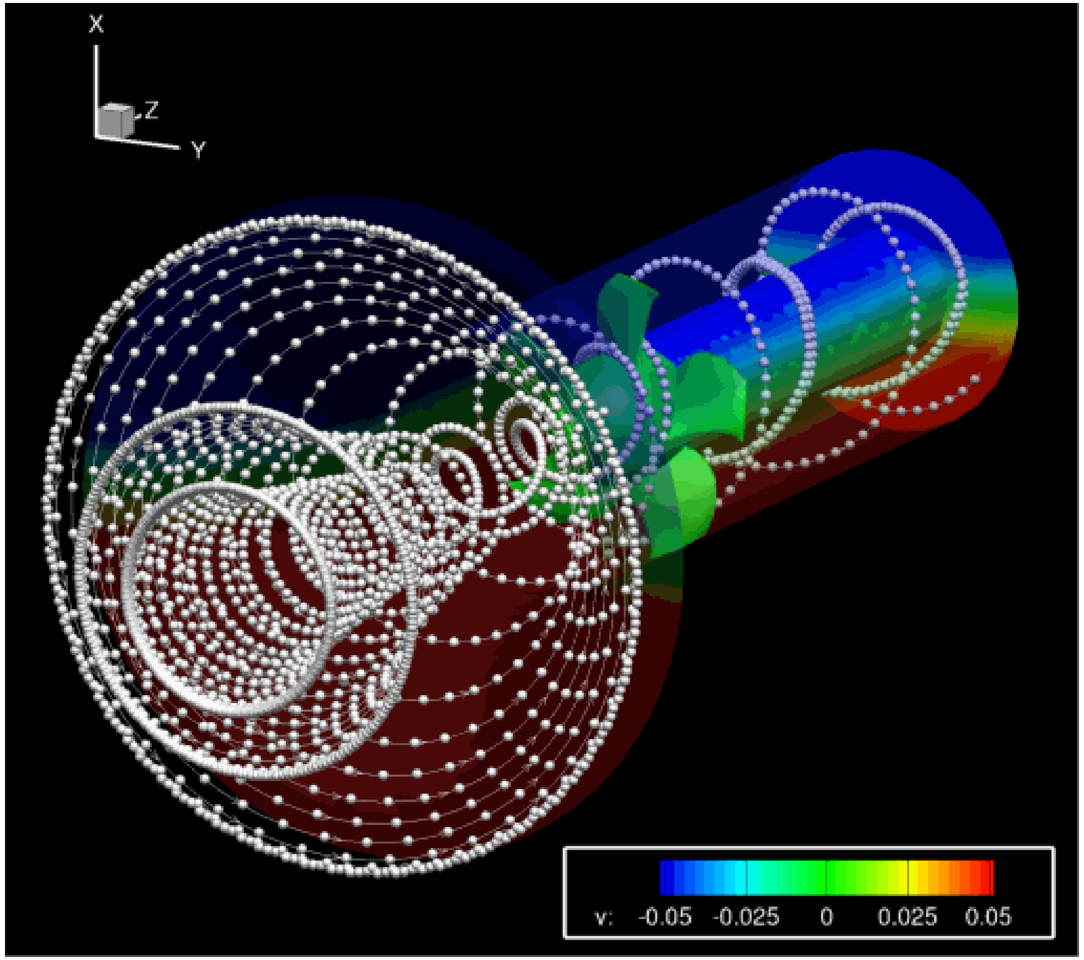
- Flow rate coefficient $\boldsymbol{\Phi}$ **= 0.195**
- Two variations of **blade tip clearance**
  - $\boldsymbol{s_{A1}}$ **= 0.1 %** and $\boldsymbol{s_{A2}}$ **= 1.0 %** of rotor diameter d_0



*Air Movement & Control Association

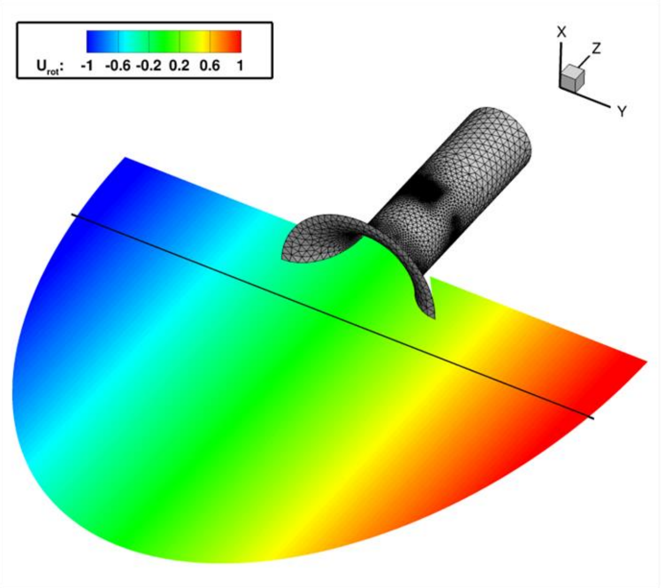
Ducted axial fan
Rotating frame of reference

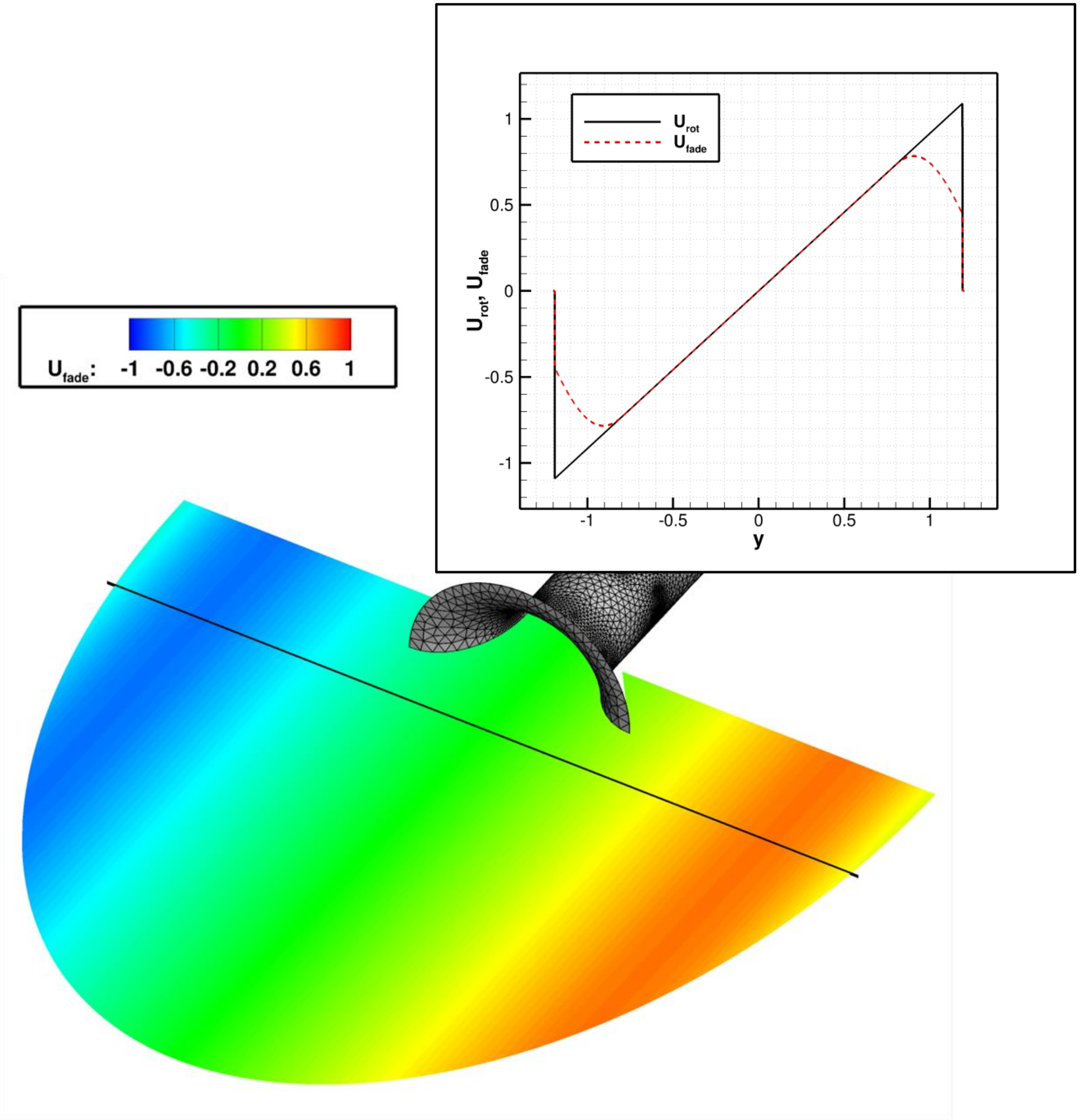
- Simulation performed in **rotating frame of reference** → effects of rotation captured
  - **Rotor** is **stationary**
  - **„World“ revolves** around rotational axis with **constant angular velocity *Ω*** → expressed through the **mean flow**
  - **No-slip** condition satisfied on **non-moving** boundaries → only **rotor**
  - Slip velocities on all remaining boundaries



Ducted axial fan
Supersonic mean flow

- **Rotating mean flow** → linearly **increasing** azimuthal velocity $\boldsymbol{v_{\theta,rot}}$ **component**
- **Reduction** required, since implemented APE system **not stable** for ***Ma* > 1**

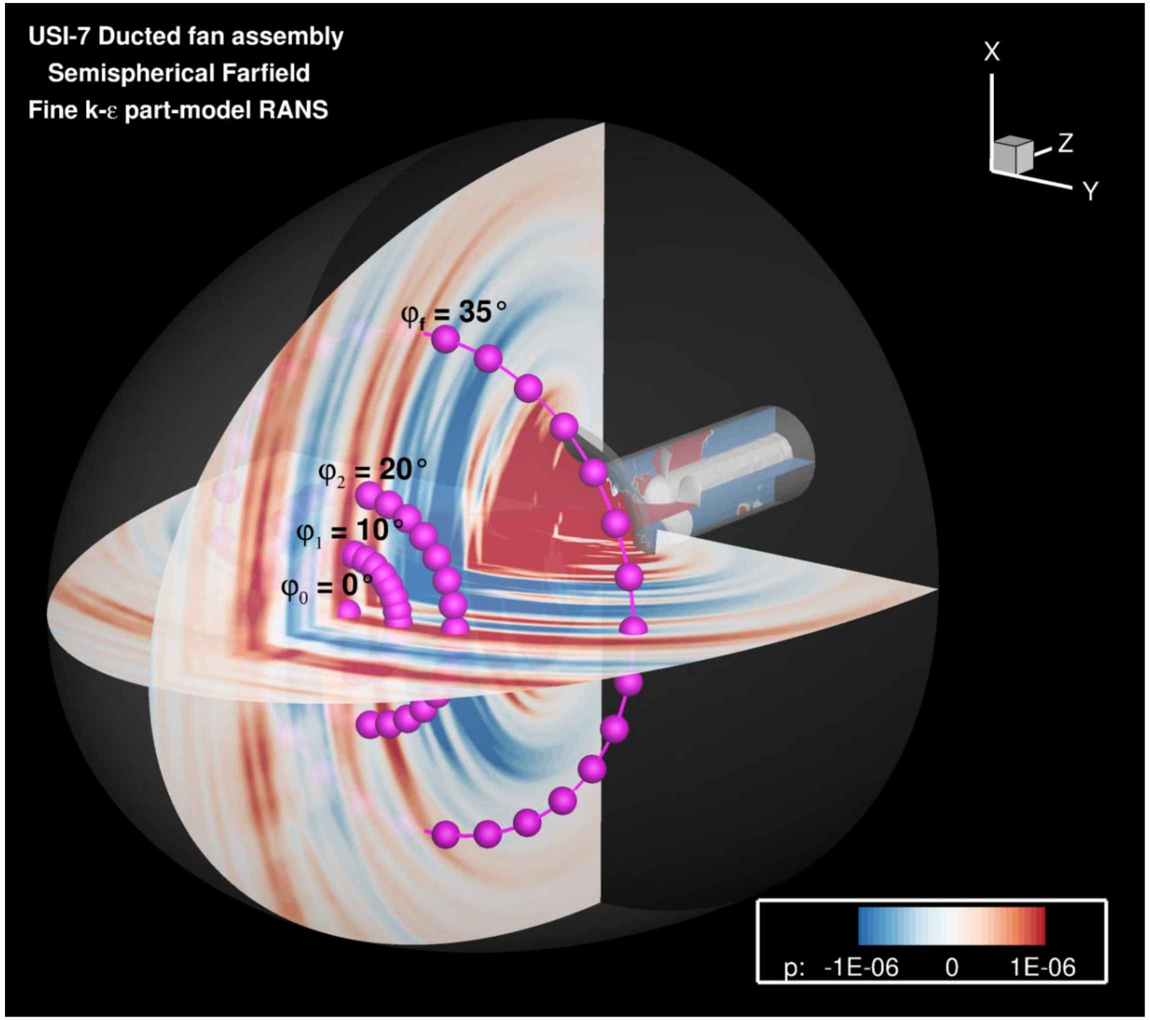




Faded mean flow velocity profile

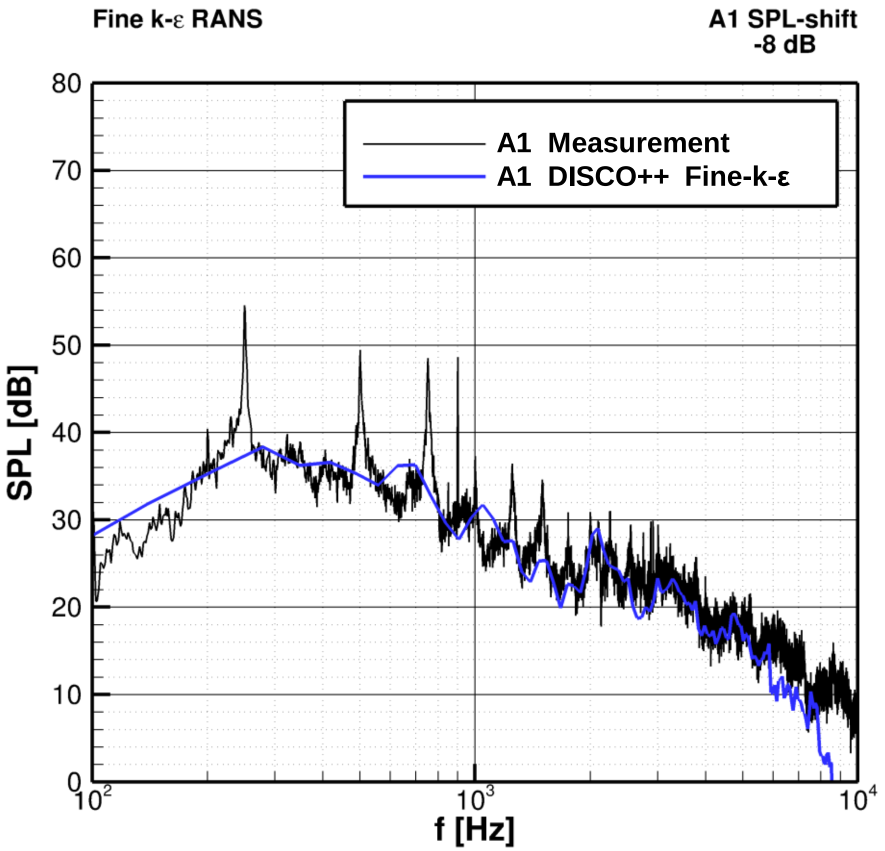
Results – Case A1 (s_{A1} = 0.3 mm) Fine k-ε RANS

- **Tip clearance not resolved** → blades cut through duct geometry
- **FRPM source** reconstruction **at one blade only** → **blades** stochastically **independent**
- CAA-grid containing **~1.3 million tetrahedra** → f_{max} **≈ 6 kHz** (5 ppw)
- Simulated approx. **4.9 revolutions of fan**
- **Virtual microphones** located on **circular paths** → counter-rotating evaluation

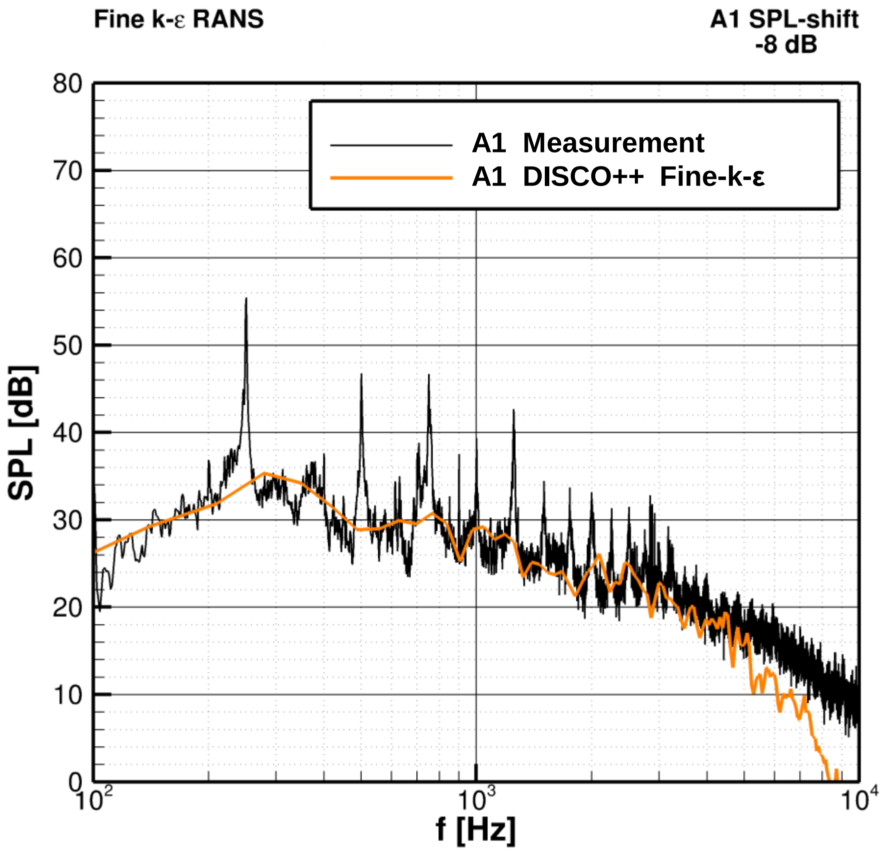


Sliced instantaneous pressure field with virtual microphone paths

Case A1 (s_{A1} = 0.3 mm) Fine k-ε RANS

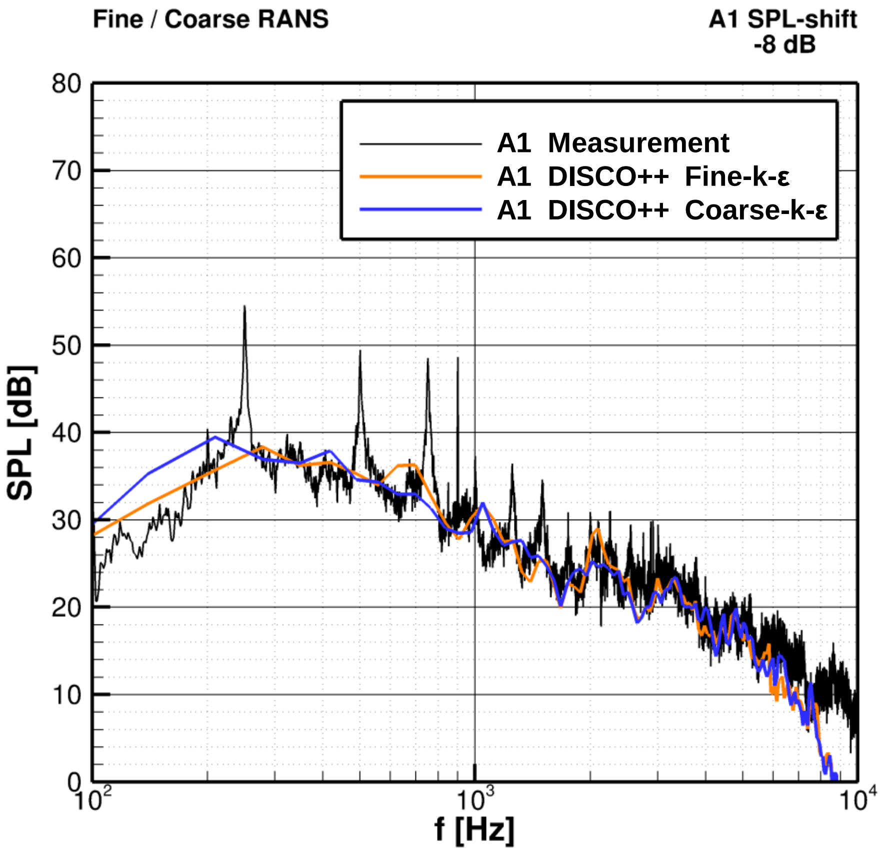


Axial mic.

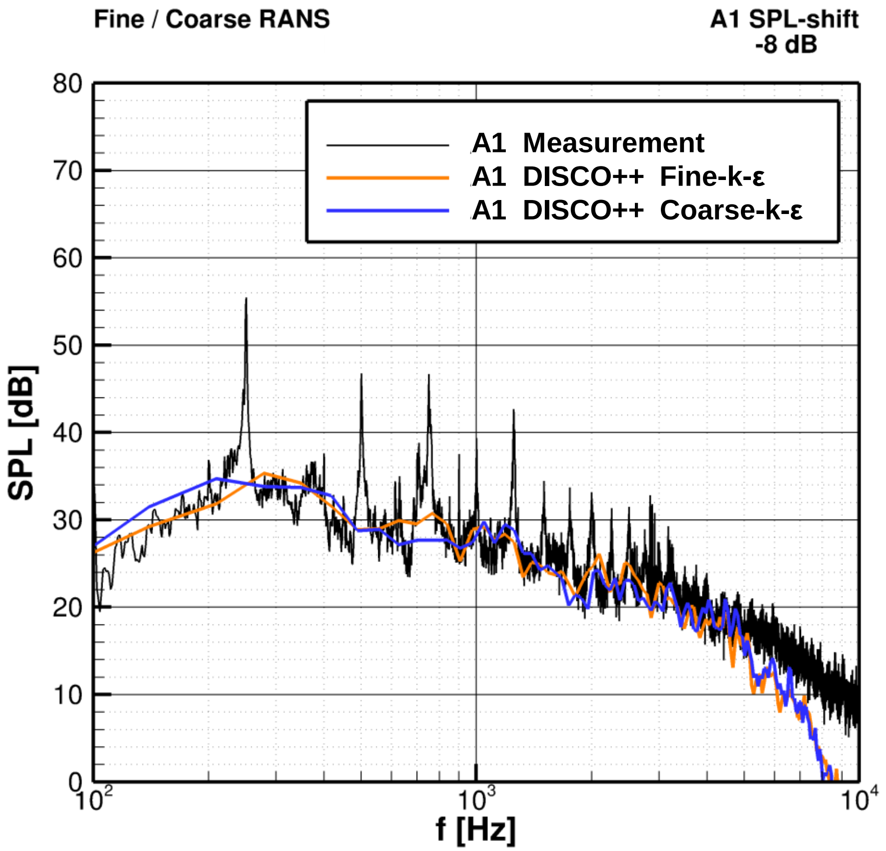


35° mic.

Case A1 (s_{A1} = 0.3 mm)
Coarse k-ε RANS



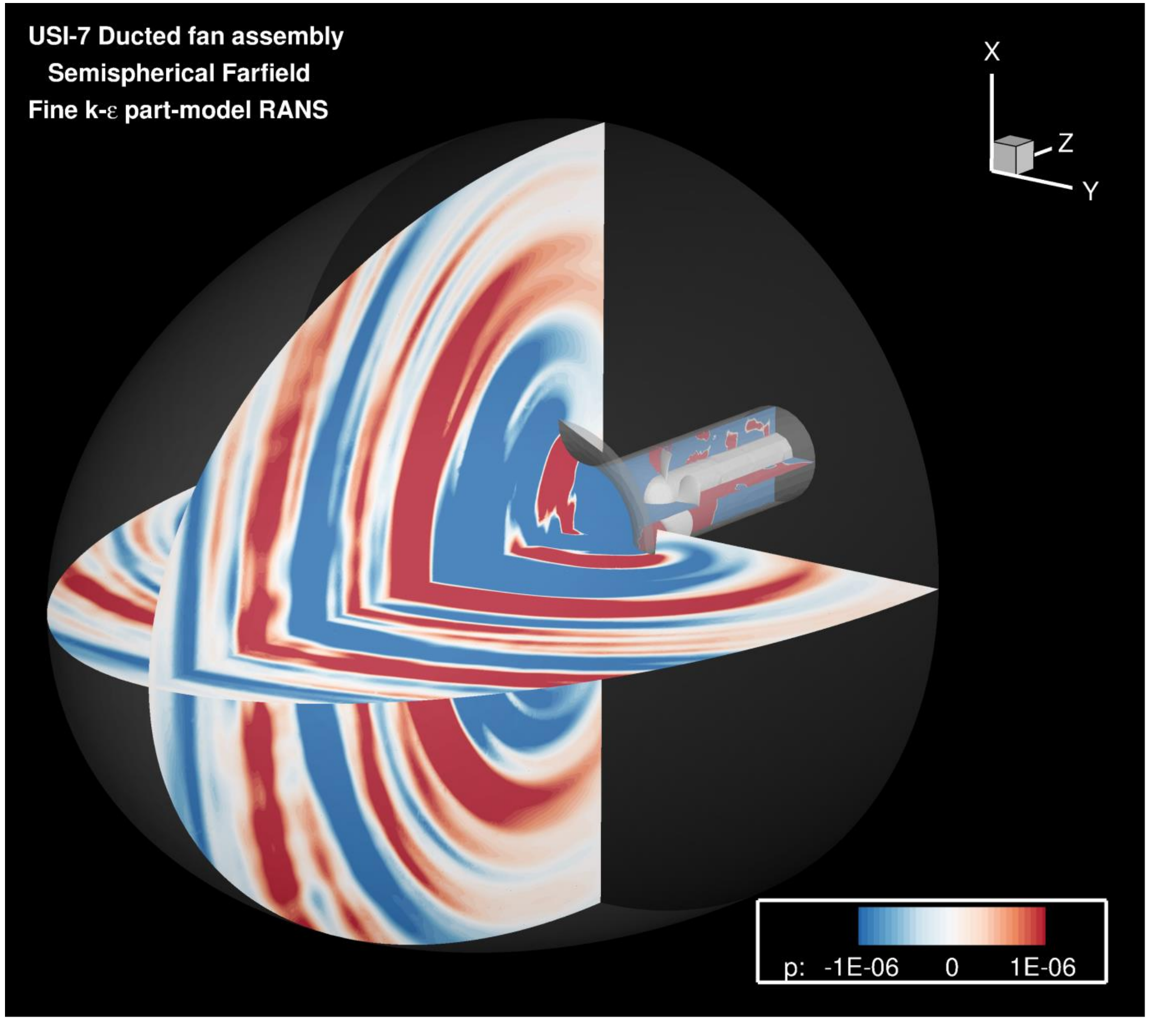
Axial mic.



35° mic.

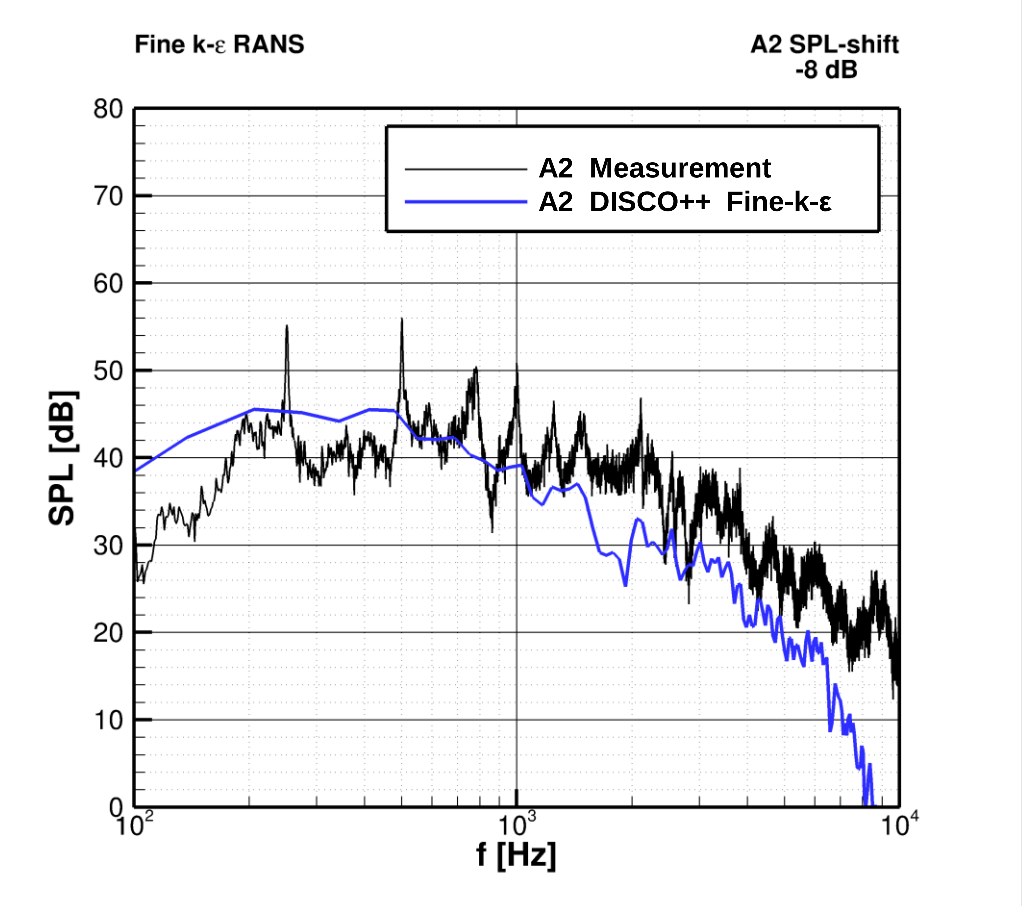
Results – Case A2 (s_{A2} = 3.0 mm) Fine k-ε RANS

- **Tip clearance resolved**
- **FRPM source** reconstruction **at one blade only → blades** stochastically **independent**
- CAA-grid containing **~1.4 million tetrahedra**
- Simulated approx. **4.9 revolutions of fan**
- **Virtual microphones** located on **circular paths →** counter-rotating evaluation

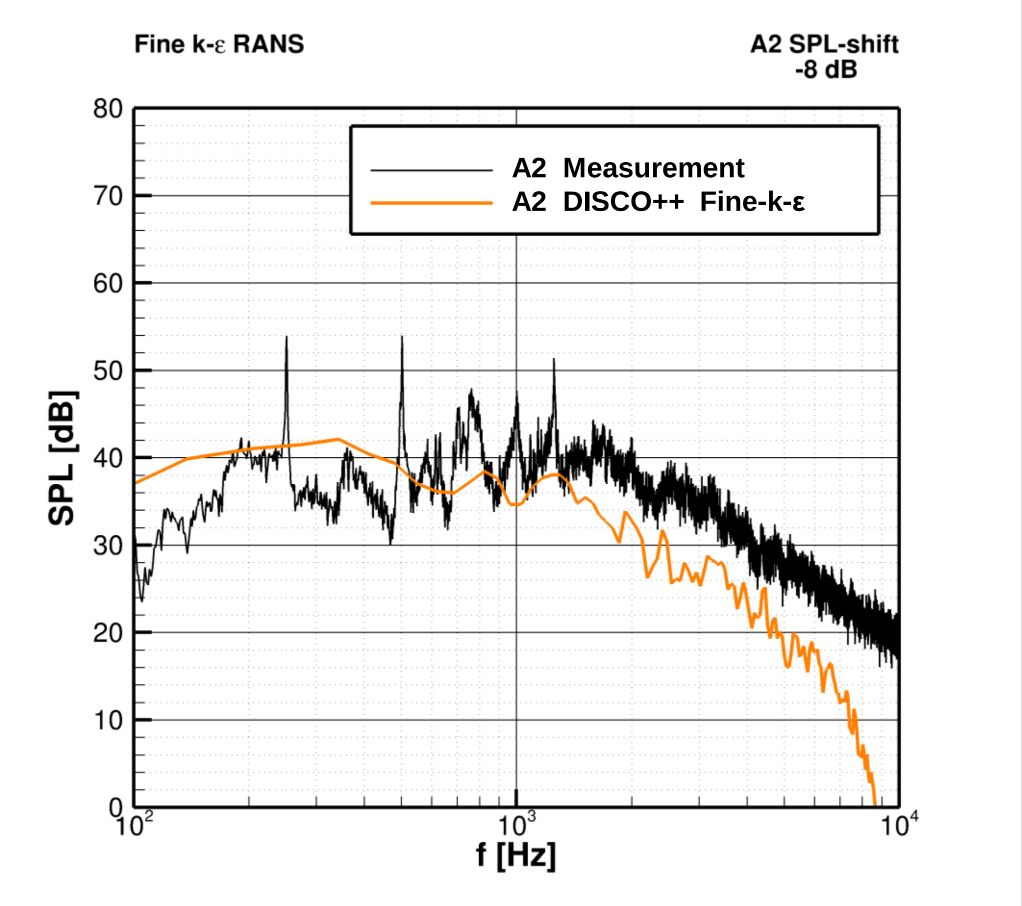


Sliced instantaneous pressure field with virtual microphone paths

Case A2 (s_{A2} = 3.0 mm)
Fine k-ε RANS

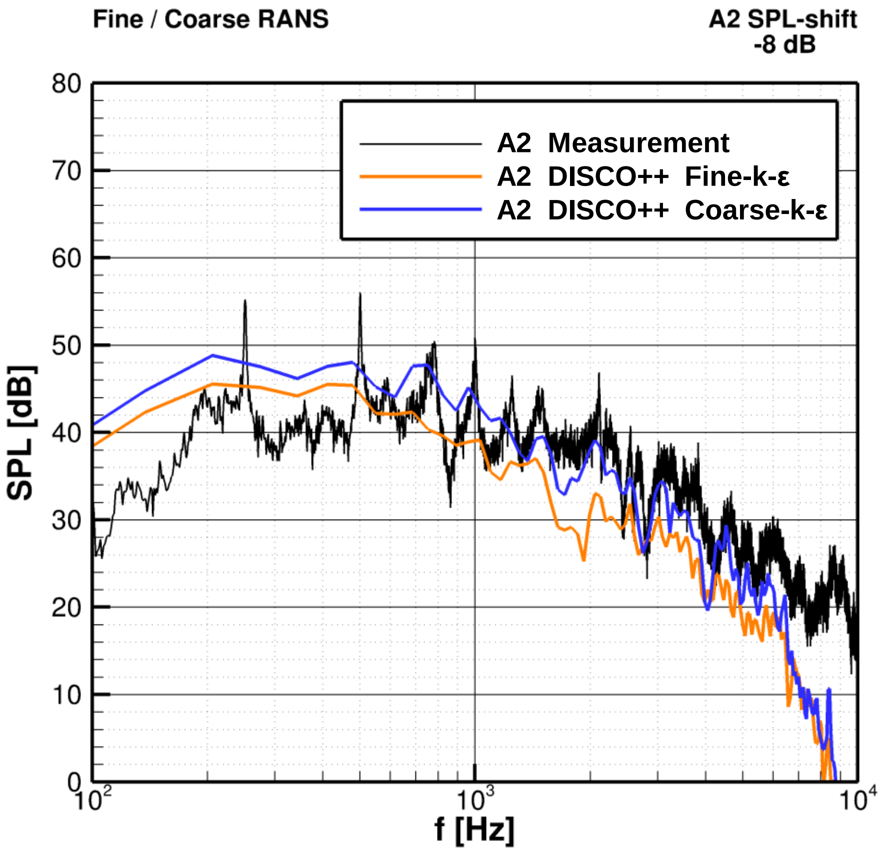


Axial mic.

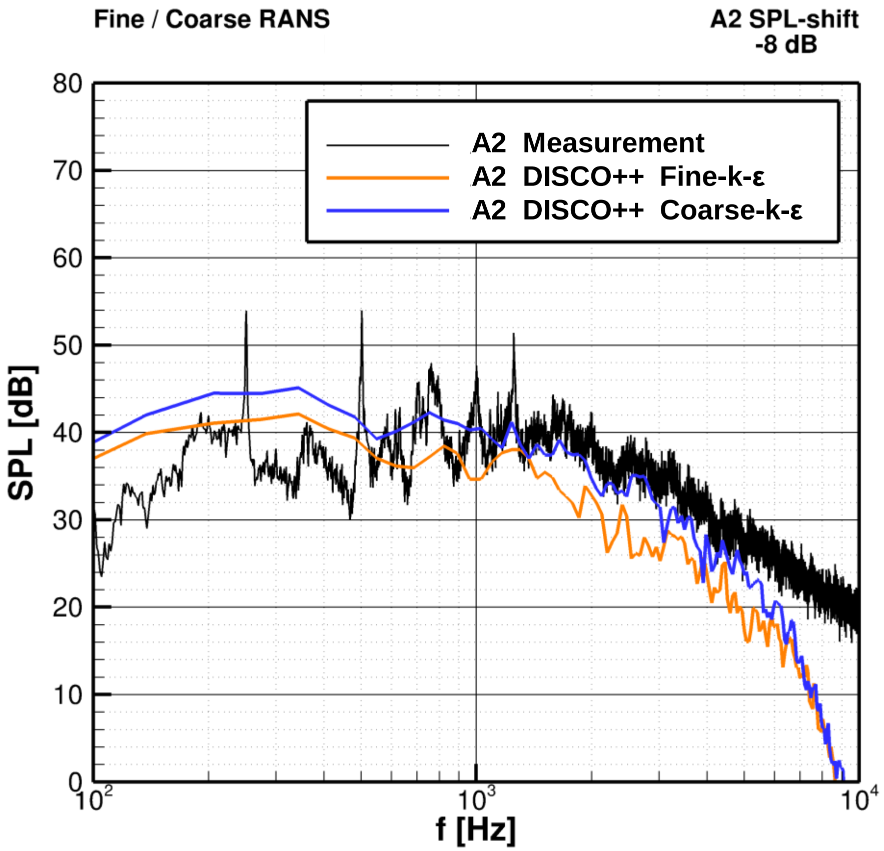


35° mic.

Case A2 (s_{A2} = 3.0 mm)
Coarse k-ε RANS

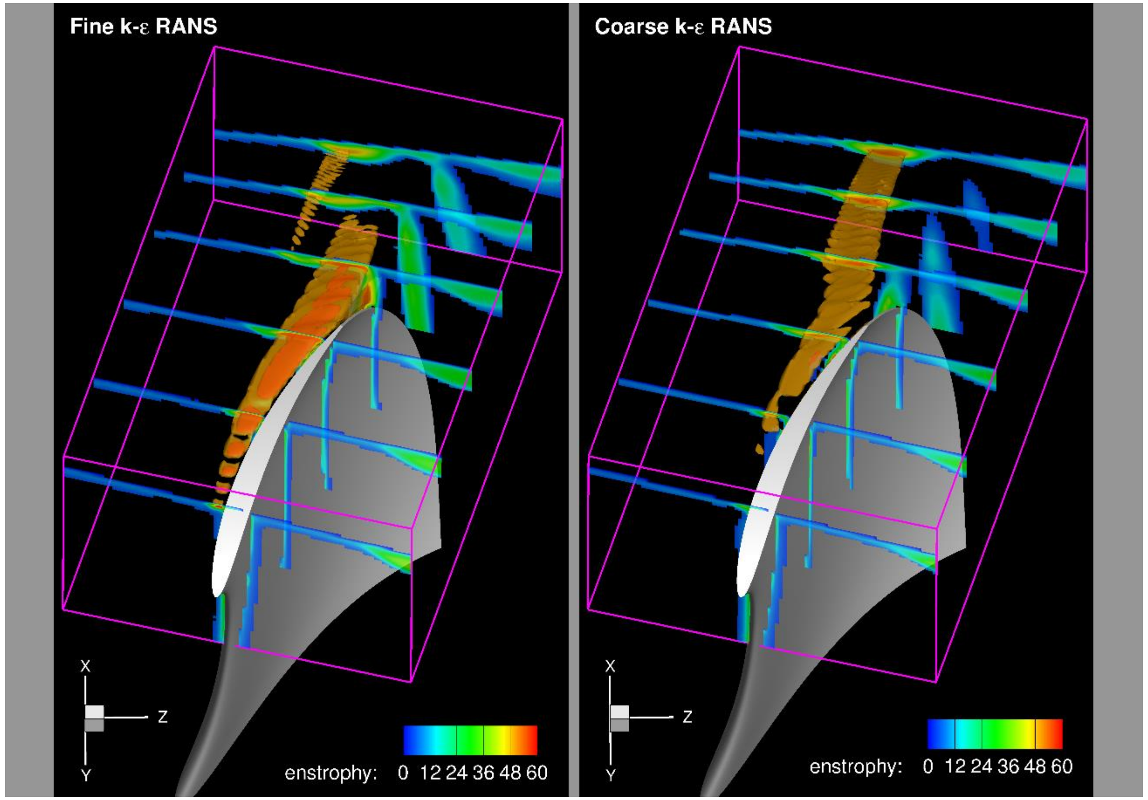


Axial mic.

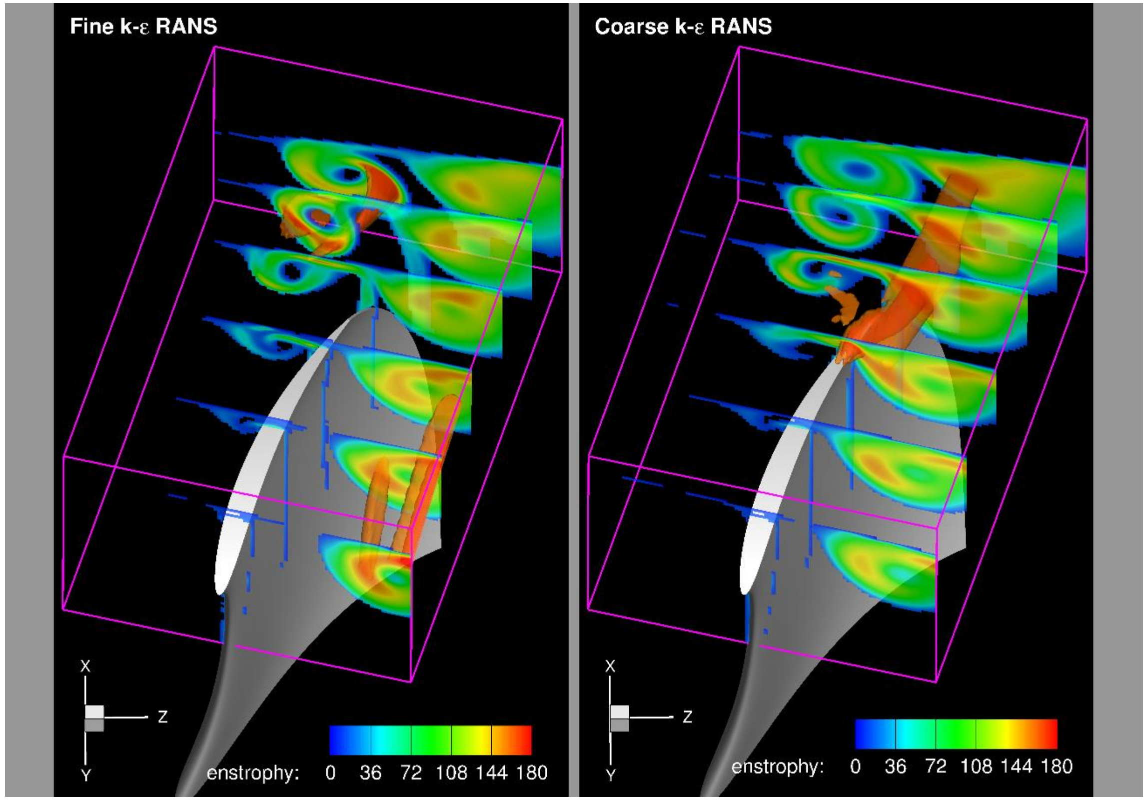


35° mic.

Investigation of FRPM – domain
Acoustic source variance



A1 – Case



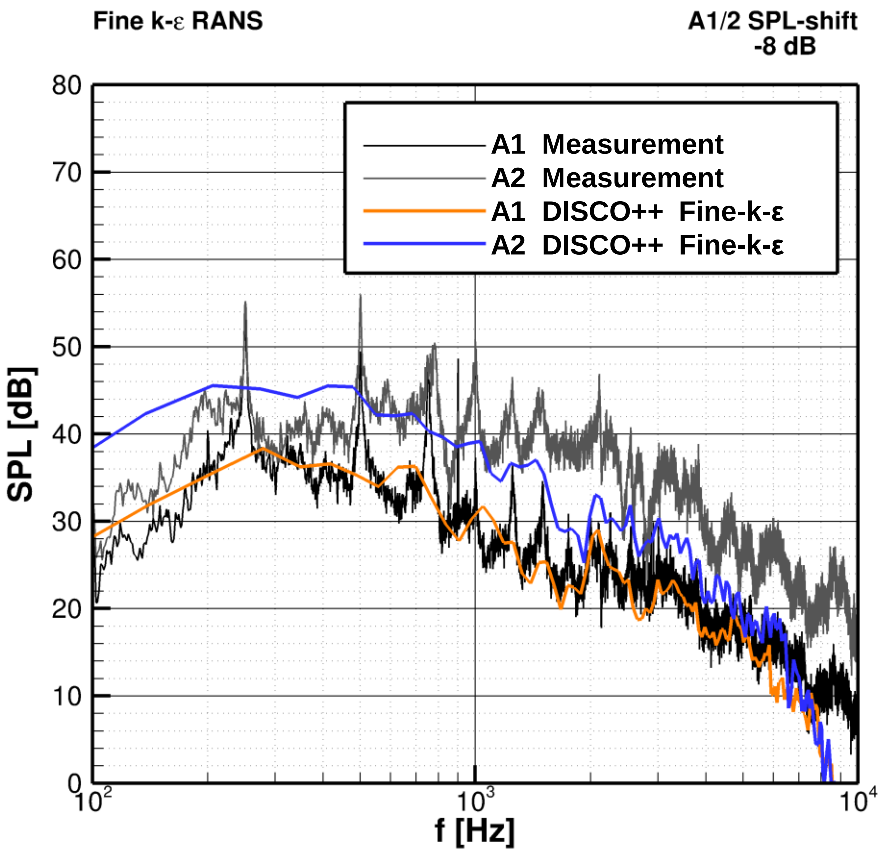
A2 – Case

Summary and outlook

- **DISCO++ / FRPM method** shows promising results for **fan noise** computation
  - Easy handling of **complex 3D geometry**
  - **Spectral shape → good agreement** with experimental data for A1 case
  - Insufficient prediction of **SPL deltas** for **tip gap variation**

- Investigation of **A2 case →** additional **noise generation mechanisms?**
  - **Unresolved** or **uncaptured** by the **source** model?
  - Simulation at **other flow rate coefficients** $\boldsymbol{\Phi}$

- **Outlook** – DISCO++ / FRPM method
  - Investigation / improvement of **efficiency**
  - **Absolute SPL** prediction
  - **Inhomogeneous inflow conditions** for axial fans



Axial mic.

Thank you!

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