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Computational Aero-Acoustic application with OpenFOAM in a fault tolerant HPC framework

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Objectives

High-Performance Computing (HPC) frameworks are susceptible to failures, especially to unexpected hardware failures during computation runtimes. To prevent time expensive re-computations of long-term simulations, the BMBF-project *"FEToL–A Fault Tolerant Framework for peta-scale MPI-Solvers"* has been started in 2011 The principle idea of FEToL is to bundle several MPI-Worlds to process bundles (PB), which have the opportunity to restart the failed PB only. Within the FEToL-project the Chair of Mechanics and Robotics, University of Duisburg-Essen contributes in running OpenFOAM-applications within the new fault-tolerant framework. Computational Aero-acoustics (CAA) applications need high computation performance and are convenient applications for FEToL. Therefore OpenFOAM has to be customized for CAA-simulations. Air-intake noises of different technical systems are often very dominant, which was occasional a reason for implementing such a simulation case as shown in *Fig.3* in OpenFOAM.

Methods

- The computational domain of an air-intake pipe is discretized two and three dimensional domains as shown in *Fig.1+2*
- Simulation of incompressible, isothermal fluid flow of Air with OpenFOAM 2.1.1 concerning different boundary conditions
- Finite volume method is used to solve the continuity and momentum equations

$$\nabla \cdot \vec{u} = 0$$

$$\rho\left[\frac{\partial \vec{u}}{\partial t} + \nabla \cdot (\vec{u}\vec{u})\right] = -\nabla p + \eta \nabla \cdot (\nabla \vec{u}) + \rho \vec{g}$$

- Principal implementation of acoustic analogies in OpenFOAM 2.1.1 according to M. J. Lighthill by neglected viscous effects and compressibility

$$\frac{\partial^2 T_{ij}}{\partial x_i \partial xj} \approx \frac{\partial^2 \rho u_i u_j}{\partial x_i \partial x_j}$$

- Computation of acoustic sources of the fluid flow

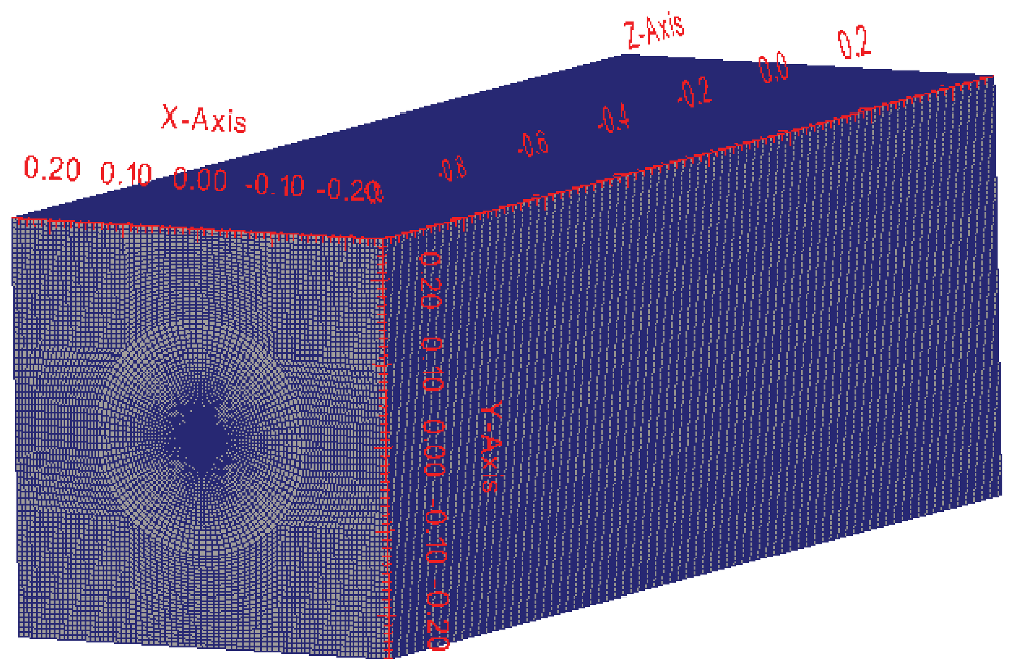

Fig.1: Three dimensional computation domain with approx. 3 million hexahedral control volumes generated with blockMesh in OpenFOAM® 2.1.1

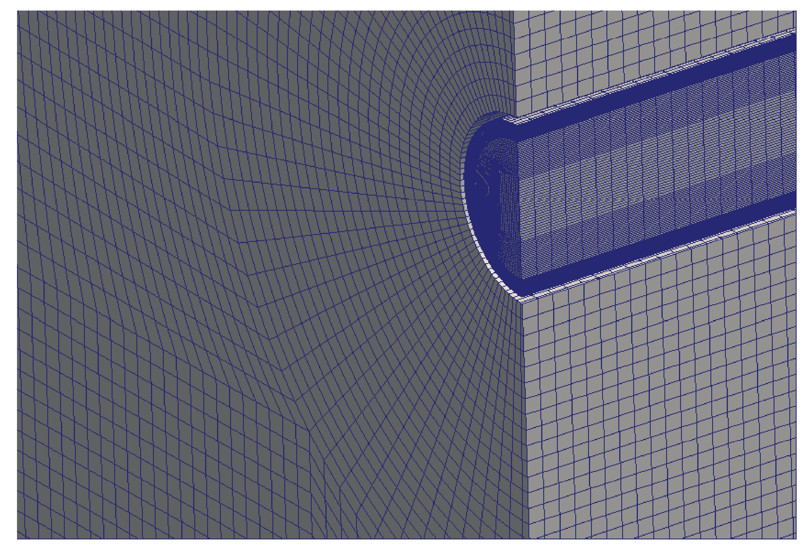

Fig.2: Detail of cut hexahedral mesh next to the defined outlet of the computation domain

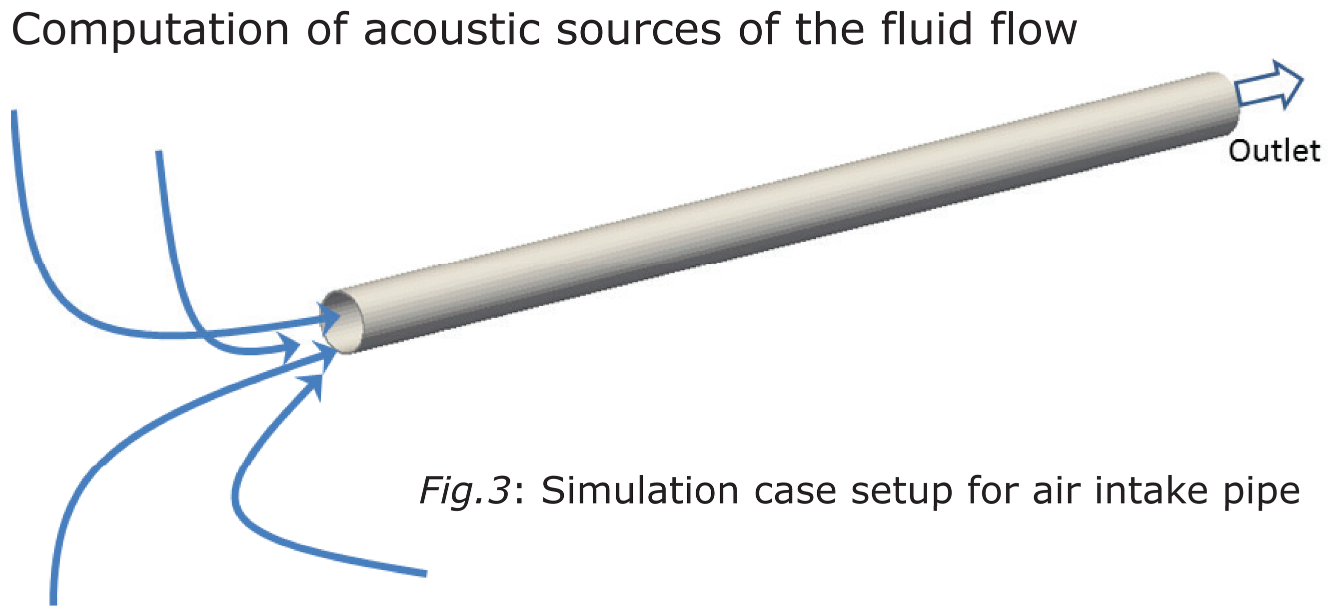

Fig.3: Simulation case setup for air intake pipe

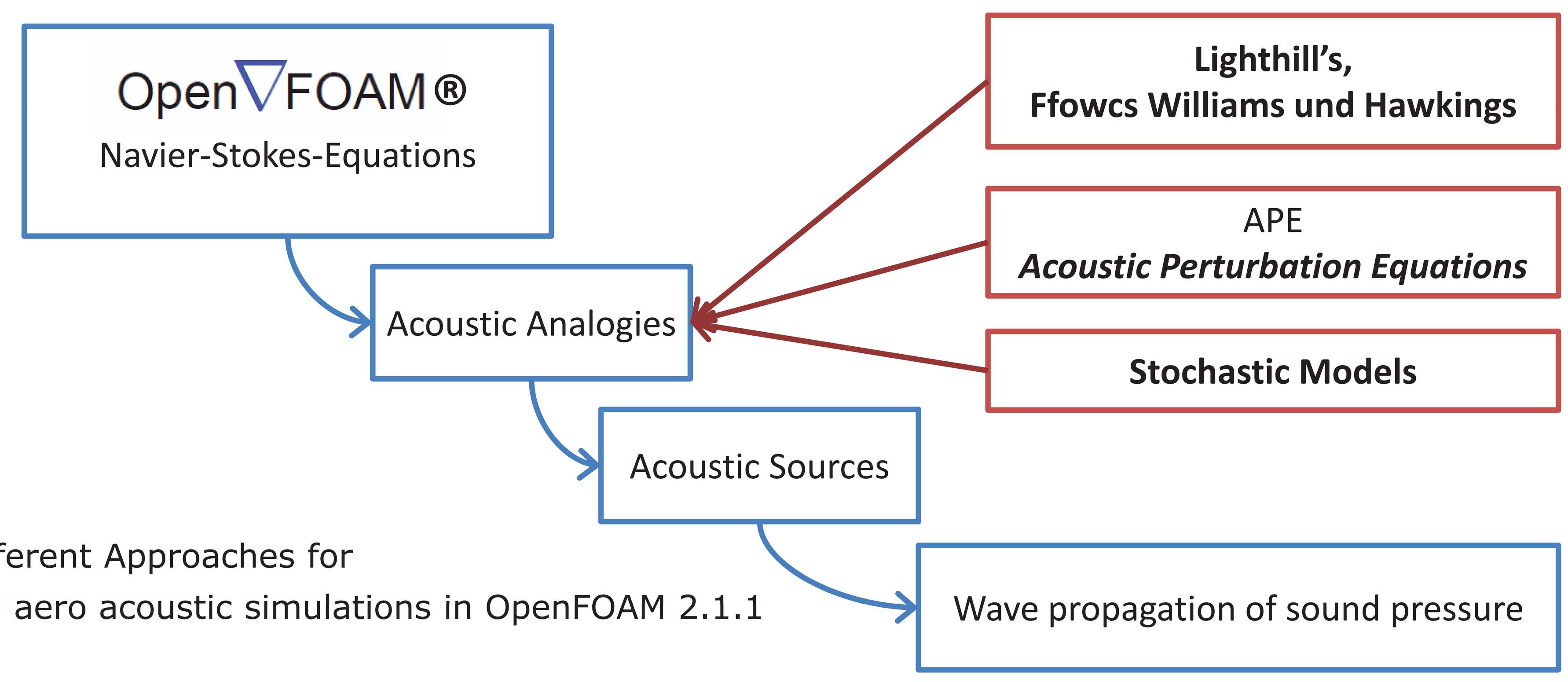

Fig.4: Different Approaches for numerical aero acoustic simulations in OpenFOAM 2.1.1

Results

- Following figures *Fig.5* and *Fig.6* present the visualized results of an incompressible, steady state and laminar computed 2D-OpenFOAM-simulation of the air intake pipe. The velocity at the outlet is set to 10 m/s. The expected eddies around the pipe walls next to the pipe opening are clearly visible in the pressure distribution in *Fig.6 left*. These eddies are mainly responsible for the acoustic sources as shown in *Fig.6 right*.

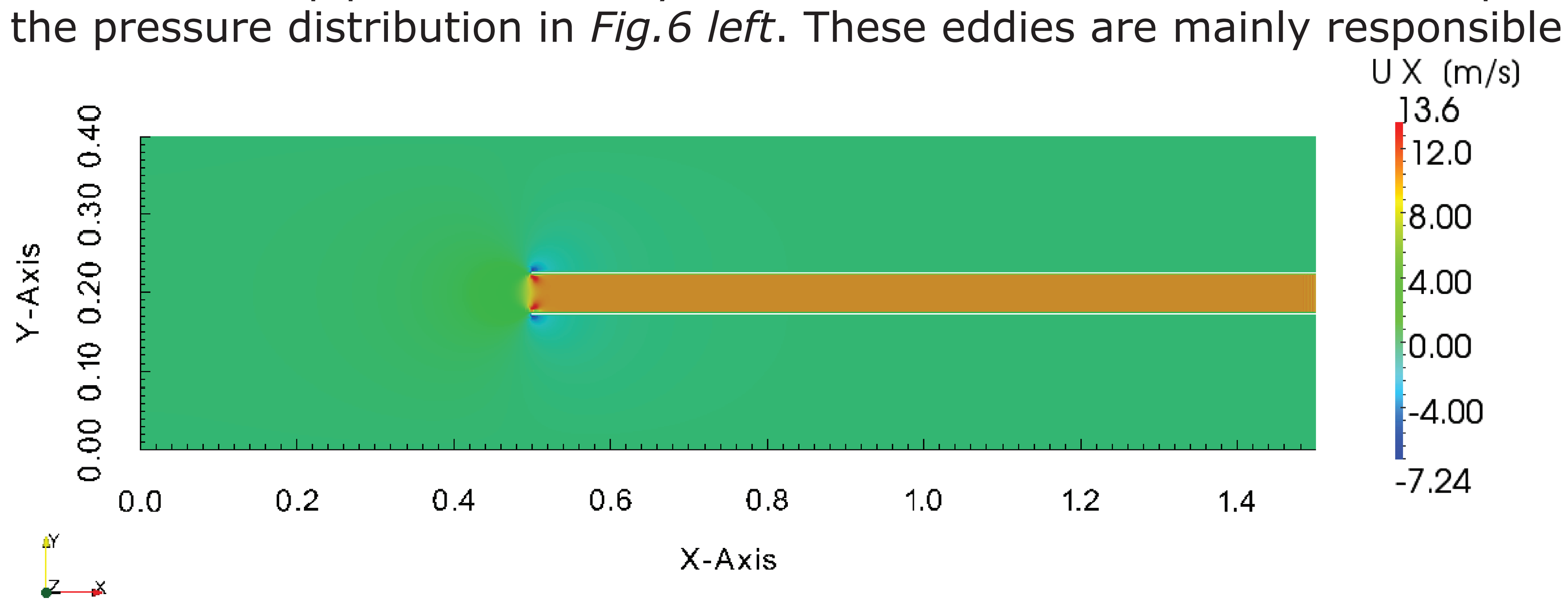

Fig.5: Velocity field of velocity component in x-direction of the incompressible, laminar and steady state 2D-OpenFOAM-case (velocity U_{out} = 10m/s)

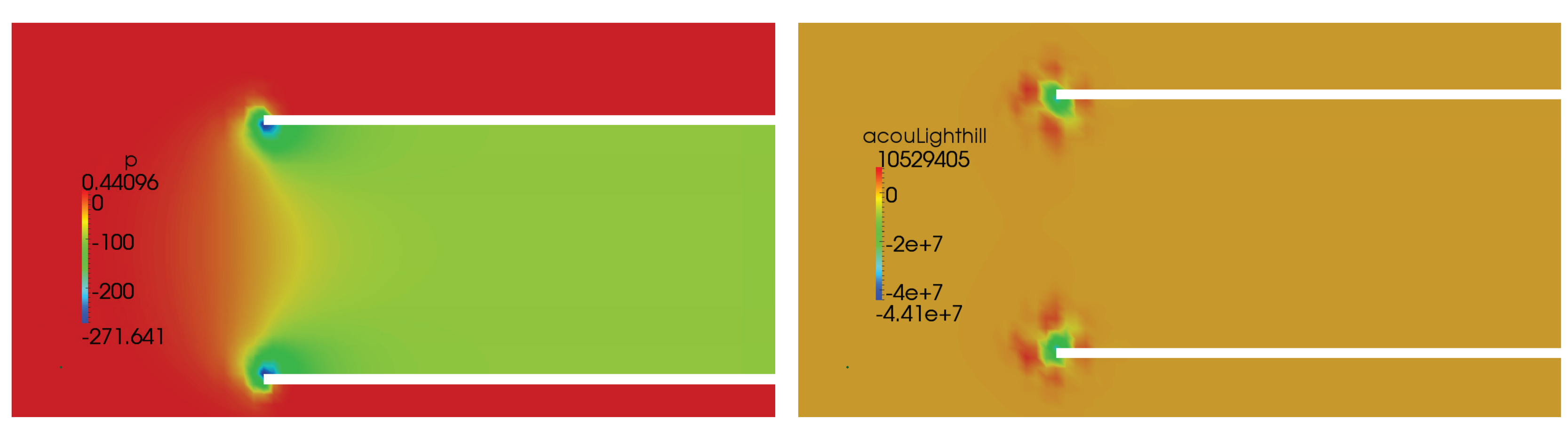

Fig.6: Computed pressure distribution and acoustic sources according to Lighthill at tube opening based on the incompressible, laminar steady state fluid simulation

Conclusion and Perspectives

- The results, especially of the acoustic source show the principle ability of OpenFOAM for CAA
- The acoustic sources in *Fig.6 right* according to Lighthill represent quadripole acoustic sources only and neglect the influence of walls or any reflections
- Implementation of different acoustic analogies as Ffowks-Williams and Hawikngs, APE or stochastic Models including corresponding boundary conditions
- Basic turbulent Simulation 2D / 3D with different turbulence models for RANS and LES
- Computation of wave propagation of sound pressure on same mesh
- Implementation of the customized OpenFOAM acoustic tool into FEToL-HPC framework

References

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