

Computational Aeroacoustics for HVAC Systems Utilizing a Hybrid Approach

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ABSTRACT

We present a recently developed computational scheme for the numerical simulation of flow induced sound for rotating systems. Thereby, the flow is computed by scale resolving simulations using an arbitrary mesh interface scheme for connecting rotating and stationary domains. The acoustic field is modeled by a perturbation ansatz resulting in a convective wave equation based on the acoustic scalar potential and the substantial time derivative of the incompressible flow pressure as a source term. We use the Finite-Element (FE) method for solving the convective wave equation and apply a Nitsche type mortaring at the interface between rotating and stationary domains. The whole scheme is applied to the numerical computation of a side channel blower.

Key words: CFD, CAA, Arbitrary Mesh Interface, Multiphysics, Non-conforming Grids

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1. INTRODUCTION

The cabin noise of modern ground vehicles is highly affected by flow related noise sources. Especially in case of a stationary vehicle, fan-noise and noise generated from the outlet of the air-conditioning system may significantly reduce passenger's comfort. Thereby, fans generate a highly turbulent flow field and may significantly contribute to the overall noise in air conditioning units.

Numerical methods such as Computational Aero Acoustics (CAA) are very capable of locating the sources of sound generation and also to predict the propagation of sound. The simulation and visualization of the occurring phenomena can contribute to a better understanding of the generation mechanisms and help to minimize unwanted noise and to optimize entire components.

This contribution focuses on the Computational Fluid Dynamics (CFD) simulation of rotating parts in air conditioning units using the Arbitrary Mesh Interface (AMI). Since a precise resolution of the acoustic sources requires unsteady CFD simulations, we apply scale resolving simulations: Detached Eddy Simulation (DES) and Large

Eddy Simulation (LES). Thereby, we utilize for the flow computation the open source software OpenFoam and the commercial software StarCCM+. The acoustic field computation is based on a perturbation ansatz, resulting in a convective wave equation which can be solved efficiently by an advanced Finite-Element (FE) formulation implemented in the in-house research software CFS++ [1]. Thereby, a Nitsche-type mortaring is applied to couple the acoustic field between rotating and stationary parts [1]. By introducing on the interface between moving and quiescent grid an appropriate flux term in combination with a penalization term, the method retains symmetry, consistency and stability of the algebraic system of equations. Furthermore, to precisely approximate the acoustic far field condition, we apply our recently developed PML (Perfectly Matched Layer) technique [2].

Based on a side channel blower of an industrial HVAC system including the main components, all relevant details of the CFD computations, the evaluation of the acoustic source terms and finally the computation of the sound propagation by CFS++ will be discussed and the obtained computational results will be compared to measurements.

2. COMPUTATIONAL AEROACOUSTICS

The acoustic/viscous splitting technique for the prediction of flow induced sound was first introduced in [3], and afterwards many groups presented alternative and improved formulations for linear and non linear wave propagation [4, 5, 6, 7]. These formulations are all based on the idea, that the flow field quantities are split into compressible and incompressible parts.

We introduce a generic splitting of physical quantities to the Navier-Stokes equations. For this purpose we choose the following ansatz

$$p = \bar{p} + p^{\text{ic}} + p^{\text{c}} = \bar{p} + p^{\text{ic}} + p^{\text{a}} \quad (1)$$

$$\mathbf{v} = \bar{\mathbf{v}} + \mathbf{v}^{\text{ic}} + \mathbf{v}^{\text{c}} = \bar{\mathbf{v}} + \mathbf{v}^{\text{ic}} + \mathbf{v}^{\text{a}} \quad (2)$$

$$\rho = \bar{\rho} + \rho_1 + \rho^{\text{a}} \quad (3)$$

for the total pressure p , velocity $\mathbf{v}$ and density ρ . Thereby the field variables are split into mean $(\bar{p}, \bar{\mathbf{v}}, \bar{\rho})$ and fluctuating parts just like in the Linearized Euler Equations (LEE). In addition the fluctuating field variables are split into acoustic $(p^{\text{a}}, \mathbf{v}^{\text{a}}, \rho^{\text{a}})$ and flow components $(p^{\text{ic}}, \mathbf{v}^{\text{ic}})$. Finally, a density correction ρ_1 is build in according to (3). This choice is motivated by the following assumptions:

- The acoustic field is a fluctuating field.
- The acoustic field is irrotational, i.e. $\nabla \times \mathbf{v}^{\text{a}} = 0$, and therefore may be expressed by the acoustic scalar potential ψ^{a} via

$$\mathbf{v}^{\text{a}} = -\nabla \psi^{\text{a}}. \quad (4)$$

- The acoustic field requires compressible media and an incompressible pressure fluctuation is not equivalent to an acoustic pressure fluctuation.

By doing so, we arrive for the perturbed convective wave equation (PCWE) for the scalar acoustic potential [8]

$$\frac{1}{c^2} \frac{D^2 \psi^{\text{a}}}{Dt^2} - \Delta \psi^{\text{a}} = -\frac{1}{c^2} \frac{Dp^{\text{ic}}}{Dt};$$

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + (\bar{\mathbf{v}} - \mathbf{v}_r) \cdot \nabla. \quad (5)$$

Thereby, c denotes the speed of sound and $\mathbf{v}_r$ the mechanical velocity of rotating parts. This convective wave equation fully describes acoustic sources generated by incompressible flow structures and its wave propagation through flowing media. In addition, instead of the original unknowns p^{a} and $\mathbf{v}^{\text{a}}$ we have now just the scalar unknown ψ^{a} . Furthermore, it allows to perform computations on stationary and rotating domains and results in the acoustic scalar potential, from which the acoustic pressure p^{a} is computed via

$$p^{\text{a}} = \bar{\rho} \frac{D\psi^{\text{a}}}{Dt}. \quad (6)$$

3. APPLICATION

The setup of investigation consists of a side channel blower as used in today's automotive air conditioning units [9]. Figure 1 displays the geometry with the stationary and rotating domains.

The measurement setup with the position of the microphones is displayed in Fig. 2.

3.1. Computational Fluid Dynamics

3.1.1. OpenFoam

OpenFOAM is an Open Source library of C++ routines to solve the Navier-Stokes equations based on the finite volume method. Since version 2.1.0 the arbitrary mesh interface (AMI) was implemented based on the algorithm described in [10]. The AMI allows simulation across disconnected, but adjacent mesh domains, which are especially required for rotating geometries.

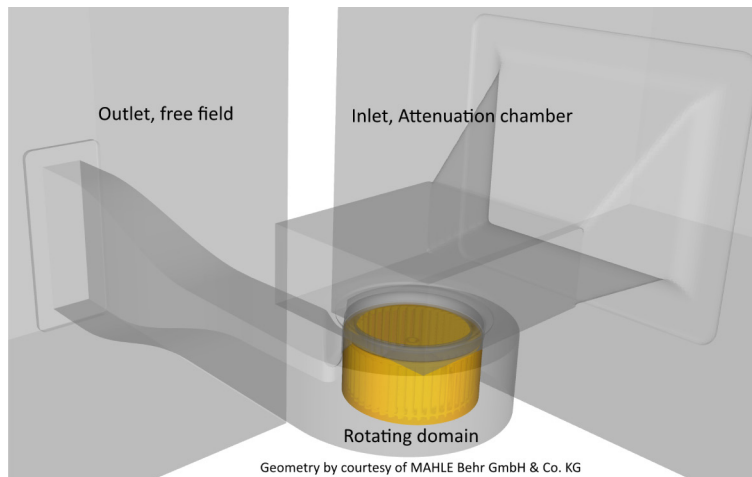


Figure 1. Geometry with rotating domain.