Broadband noise source prediction for HVAC-ducts by RANS-Simulation due to vortex sound theory

Thorsten Grahs∗†‡

1move-csc UG, Schuntental 10, D-38108 Braunschweig, Germany
2Institut Computational Mathematics, Technical University Braunschweig, Pockelsstr. 14, D-38106 Braunschweig

March 15, 2011

aero acoustics, vortex sound theory, broadband noise source prediction, RANS simulation

In the last years, the importance of noise prediction became more and more relevant in the design of technical systems. This is due to the grow of computational power which brought Computational Aero Acoustics (CAA) into the scope of virtual development time frames. Nevertheless, the computation of aero acoustics is still very challenging regarding the different spatial and temporal scales which are involved. Thus, for proper CAA or Segregated Source-Propagation Methods (SSPM), e.g. Lighthill[1] and Ffowcs-Williams-Hawkings[?], one needs accurate flow solutions, e.g. transient computations with sophisticated turbulence simulation like Large Eddy Simulation (LES) and fine spatial and temporal resolution.

On the other hand, these simulation are too exaggerated for the most relevant objectives in the design process. These methods allows detailed prediction of sound spectra, directivity and propagation, but these complex details are very seldom necessary in an practical design process. Here, on focus manly on the comparison of different designs, i.e. a ranking of different designs in terms of noise.

In our work, we focus on isothermal low Mach number flows in HVAC-ducts. Here, we are only interested in broadband noise generation which is mainly driven by mean flow velocity fluctuations. This can be described in vortex dynamics [2, 3, 4]. We adapted this vortex noise theory and apply these ideas to internal flows.

Starting from Crocco’s Equation [2], for an incompressible flow the momentum equation can be cast into vorticity formulation,

$$\frac{\partial \omega}{\partial t} + \omega \times \mathbf{v} + \nabla B = -\nu \text{curl} \omega$$

with velocity $\mathbf{v}$, vorticity $\omega$ and total enthalpy $B$.

†Thorsten Grahs (grahs@move-csc.de)
Reformulation and the fact that we focus on low Mach number flows leads to the simplified equation for the production of sound,

\[
\left( \frac{1}{c_0^2} \frac{\partial^2}{\partial t^2} - \nabla^2 \right) B = \text{div}(\omega \times v)
\]

This is a convective wave equation with the right-hand side as the production term for sound generation. These sources are vorticity generated pressure waves. The advantage of this approach is the compactness of the vorticity field around the sources. Thus, noisy regions can be identified and processed more easily than, for example, in SSPM-methods.

We use these considerations to derive a qualitative measure for noise generation in steady state RANS simulations. This has the great benefit that we don’t have to conduct time-consuming and large data generating transient LES (Large Eddy Simulation) calculations to compare different designs in terms of their noise production. The resulting algorithm will be applied to internal flows, i.e., different designs of HVAC-ducts.

![HVAC-duct register with vortex noise source strength](image)

Figure 1: HVAC-duct register with vortex noise source strength

References