Prediction of noise generated by wall-bounded flows at low Mach numbers

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1 Introduction

Aeroacoustics addresses the generation and propagation of sound by flow-related mechanisms. In this definition, aeroacoustics does not specifically involve the vibration of solid surfaces in the sound generation process, though both aero- and vibro-acoustic phenomena can naturally coexist, and even be coupled together. But in this lecture, we will exclude structural displacements, either as a sound generation mechanism or as a way for acoustic waves to transmit across a flexible panel.

Aeroacoustics theory provides a framework for the study and prediction of flow-acoustic conversion mechanisms. The emergence of aeroacoustics as a novel discipline traces back to the beginning of the fifties, with Lighthill's two seminal papers on sound generated aerodynamically. Little attention has nevertheless been given so far to aerodynamic noise in industry, compared to the important effort that has been dedicated to vibroacoustic issues. Several factors can be invoked to explain this apparent lack of interest. For a long time, flow-induced noise has been effectively masked by the structural noise... Aerodynamic noise has partly become a concern because of the progress accomplished in structure-borne noise reduction. A second factor stands in the complexity of the physics that needs be modelled, i.e. turbulent flow over complex geometries, at large Reynolds numbers. Details matter a lot in turbulent flows: apparently minor geometrical features can strongly affect unsteady flow features and the related sound producing mechanisms. The industrial use of Computational Fluid Dynamics was until recently mostly restricted to Reynolds-Averaged Navier-Stokes modelling, which discards any unsteady flow features. The calculation of a component aerodynamic performance, in terms of pressure loss for example, does not require expensive time-resolved numerical methods. Reynolds-Averaged Navier-Stokes (RANS) solvers may prove useful for broadband noise prediction, through a stochastic turbulence reconstruction process, but this approach is usually restricted to flow scales exhibiting a fair degree of isotropy and homogeneity. At the opposite, the modelling of the large scales, associated to the low-frequency part of the noise spectrum, requires a time-resolved description of the flow unsteadiness, *a fortiori* if a flow-acoustic feedback loop is present and causes whistling in duct systems for example. The two last arguments — sensitivity to geometrical details and expensive numerics — have so far hindered the inclusion of aerodynamic noise concerns in the design stage of industrial equipment. Fortunately, commercial CFD codes have made appreciable progress and propose now time-resolved Large Eddy Simulation or Detached Eddy Simulation to obtain transient flow information.

These simulation tools can nowadays be used to obtain within moderate computation times a reasonably accurate description of turbulent flows. In what is called the hybrid approach, the aeroacoustical analogy is implemented by coupling a CFD flow description with a wave propagation method. In absence of scattering objects in the propagation region, the aeroacoustical analogy applied to CFD results is sufficient to yield acoustical predictions. Three important variants of the aeroacoustical analogy are presented in Section 2. But when scattering entities are present, numerical acoustic techniques as the Finite Element Method (FEM) or the Boundary Element Method (BEM) are required. The Section 3 presents a brief overview of FEM and BEM methodologies, with some emphasis on the interpretation of CFD data as equivalent aeroacoustical sources. Combining CFD and BEM/FEM approaches permits tackling an important class of problems: broad-