Measurements of wall pressure wavenumber-frequency spectra: experimental challenges and recent advances

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The wall pressure fluctuations beneath turbulent boundary layers have been the topic of many studies in the past decades [3], motived by applications such as cabin noise reduction for aeroplanes or sonar performance. In addition to vibro-acoustic considerations, the wall pressure fluctuations are a source of airfoil self noise which has also attracted the attention of researchers. Despite this continued interest, the complexity of the physics involved still prevents a full understanding of the ins and outs of the matter.

There exists a rather well established set of models for pressure spectra in the case of a turbulent boundary layer with zero mean pressure gradient. However, when pressure gradients are involved theoretical understanding is limited and experimental databases are scarce. From an experimental point of view, the challenge lies in part in the choice of sensors, since they could create a spatial filtering that would alter the high frequency part of the pressure spectra.

The power spectra themselves are not sufficient in many cases, for which a description of both spatial and timewise evolutions of the pressure field is required. The cross-spectra, coherence length scales and the wavenumber-frequency spectra are thence needed. It is thus necessary to simultaneously measure the pressure at different locations, which calls for arrays of sensors. Such arrays have various constrains depending on the applications. For instance, small separations are needed for the correct description of hydrodynamic fluctuations, while the acoustic contributions require large separations. The installation of sensors is another aspect to consider: they can be flush-mounted or remote such as in Arguillat *et al.* [1], the latter allowing smaller separations and sensing area but raising questions about the calibration process. The arrays are then designed either to record one-dimensional data such as coherence and associated length scales along a direction of interest, or to perform two-dimensional analysis. In both cases, the signal processing to obtain the required spatial structure description raises the question of whether to use a uniform or an irregularly spaced array; the latter one is often preferred since, for a given number of sensors, it reduces the risk of aliasing when performing spatial Fourier transform, to compute the wavenumber-frequency spectra for instance.

Recently, two technologies have been used, both in terms of sensors and installation. First, a rotating one-dimensional array of remote microphones was used [1, 5] in a laboratory channel flow. Such technology offers a good dynamic range and enables a fine spatial resolution, its main draw-back being the intrusiveness of the array into the wall making it less applicable to measurements on vehicles, when the wall or fuselage cannot be altered. A second approach is to build an array of MEMS microphones [2], that is overall rather thin and can therefore be affixed onto a wall. This method, however, brings new inherent challenges, be it the complicated signal processing, the risk of sensors' saturation or even the manufacturing itself.

In the presentation, an overview of these various approaches will be offered. The pros and cons will be discussed and some illustrations will be given based on three recent experimental studies by some of the present authors.

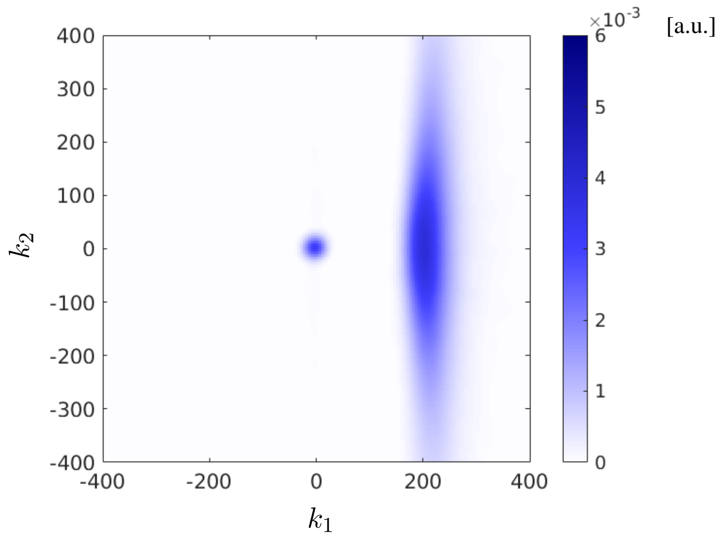

Figure 1: Wavenumber-frequency spectrum beneath a zero-pressure gradient boundary layer at $U_\infty = 50\,\mathrm{m.s}^{-1}$, obtained at $f = 1300\,\mathrm{Hz}$ with a rotating array of microphones.

The experimental techniques and limitations will be first illustrated by measurements conducted with a rotating array in a wind tunnel, with an attempt at obtaining two-dimensional wavenumber-frequency spectra and separating the acoustic and hydrodynamic contributions, see fig. 1. The array is made of 63 non-uniformly aligned remote microphones, and is rotated so as to achieve the desired azimuthal resolution. The use of MEMS microphones will then be discussed, with measurement conducted in a low-Mach number ducted ventilation control system. In this application, the propagating acoustic modes have been extracted and their representation in axial wavenumber-frequency spectra displays a good match with analytical prediction. Finally, measurements with cross-shaped arrays of MEMS microphones have also been carried out in the S2A aeroacoustic wind tunnel, on a full-scale business jet fore part mock-up. This experimental campaign is focused on the hydrodynamic contribution and the key parameters that can be extracted to serve as inputs for vibro-acoustic models.

References

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