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A remote microphone technique for aeroacoustic measurements in large wind tunnels

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ABSTRACT

The present study was devoted to the development and application of a remote microphone technique for aeroacoustic measurements in large aerodynamic wind tunnels. In this technique, the microphone and its connecting line to the sensing port are fitted within an aerodynamically streamlined fairing. A model-based calibration method was applied to account for the phase lag and dissipation within the microphone connecting line. The proposed system permits to carry out acoustic measurements when the wind tunnel surface cannot be altered, since the fairing can be simply glued on the wall. The fairing is streamlined to minimize flow disturbances as well as the risk of separation which would otherwise contaminate the wind tunnel flow quality and acoustic measurements. It was furthermore hoped that the acceleration of the flow over the fairing surface might reduce the turbulence fluctuations and thereby increase the signal-to-noise ratio of the acoustic measurements. Those aerodynamic effects were investigated with a set of hot-wire measurements performed in the subsonic L2B small wind tunnel of von Karman Institute (VKI). The mean velocity and the turbulence intensity profile were analyzed in the presence of different inflow turbulence characteristics at 5, 10 and 15 m/s freestream velocity. The effect of incident turbulence on the acoustic measurement was investigated applying the calibration procedure and comparing the measurements with a wall-mounted reference microphone signal in similar flow conditions. The results indicate that the wished beneficial effects of the flow acceleration are not significant. As an application, this technique is used to measure the noise emitted from the contra-rotating fans of the large L1 subsonic wind tunnel of the von Karman Institute, where the microphone fairing is placed inside the diffuser and thus subjected to a thick turbulent boundary layer. The results indicate that in spite of the mitigated turbulence-reduction performance of the fairing, it provides a measurement solution that is suitable for large wind tunnels provided the signals are compensated using the measured dynamic calibration. While it should be stressed that the calibration procedure itself is not new, the originality of the present paper stands in the proposed fairing design, and in the aerodynamic/acoustic investigation of its effect on the flow.

1. Introduction

The reduction of flow-generated noise has become one of the demanding design criteria for numerous engineering applications. Consequently, a growth of interest has emerged in the field of experimental aeroacoustics, in order to better understand aerodynamic sound production mechanisms and to validate noise prediction methods.

Large aerodynamic wind tunnels have been and are currently being refurbished to permit measuring the noise emissions of wing components, landing gears, wind turbine blade sections, etc., at realistic Reynolds numbers Moreau et al. [10]. In this context the von Karman Institute for Fluid Dynamics (VKI) is investigating the possibility of using its largest subsonic wind tunnel L1 as a mean to study contra-rotating rotor (CRR) noise. In this instance, the CRR under consideration is the twin-rotor fan that provides the flow to the wind tunnel. In order to measure the tonal and broadband noise resulting from the viscous wake interactions, an array of wall-mounted microphones has been designed, to be located in the divergent section of the wind tunnel (Fig. 1).

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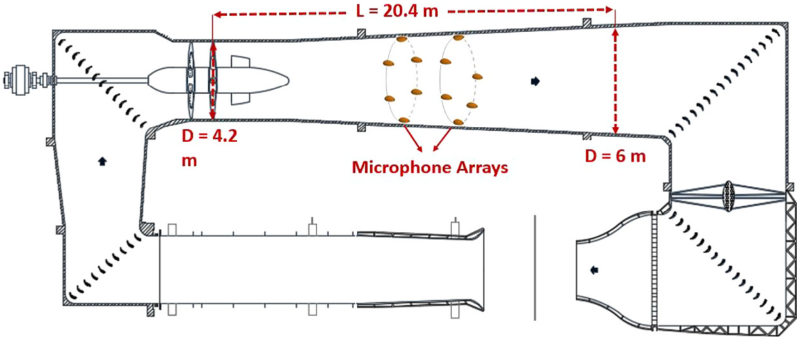

Fig. 1. L1 wind tunnel.

The following guidelines drove the design:

1. The number and spatial distribution of microphones should permit extracting the acoustic field in terms of its duct modal components, up to the second azimuthal mode.
2. The placement of the microphones should not require drilling into the thick (about 0.3 m) concrete walls of the divergent section. As a result, the microphones should be encapsulated within fairings, to be glued on the inner wall of the divergent section.
3. The microphones fairings should not introduce additional turbulence, for the sake of flow quality in the test section firstly, and secondly to avoid extraneous noise generation by the guide vanes at the downstream end of the divergent section.
4. If possible, the fairings should enhance the signal-to-noise ratio between the incident acoustic field and the hydrodynamic pressure fluctuations induced by the turbulent boundary layer (TBL) at the microphone locations.

While the first aspect above won't be treated in this paper – it is discussed in length in the literature, e.g. by Sack et al. [13], the other objectives and proposed solutions are detailed in what follows. While it should be stressed that the calibration procedure itself is not new, the originality of the present paper stands in the proposed fairing design, and in the aerodynamic/acoustic investigation of its effect on the flow.

The structure of the paper is the following: Section 2 describes the technical solution adopted to meet the above objectives, which implies a modelling of the acoustic response of the system (Section 3) and evaluating the influence of TBL pressure fluctuations on the measurement accuracy (Section 4). Conclusions are drawn in Section 5.

2. Microphone fairing

In order to minimize flow separation, which would otherwise alter the wind tunnel flow quality and contaminate the microphone signal, the fairing encapsulating the microphone was designed using a streamlined profile, shown in Fig. 2(a). It is a combination of two arcs in which the trailing edge radius, 0.2 m, is twice the leading edge radius. The fairing has 0.224 m length, maximum height of 0.047 m and maximum width of 0.12 m. This shape is not the result of an aerodynamic optimization, but follows empirical guidelines to mitigate the risk of flow separation with a size compatible with the curvature of the wind tunnel wall. The microphone is lying horizontal to minimize blockage, and its holding part was designed in a modular way, such that it can be disassembled from the fairing and fitted on a calibrator shown in Fig. 2(b). The aim is here to permit a calibration as close to *in situ* conditions as possible, accounting for the acoustic response of the channel and cavity that lead from the pressure port to the microphone membrane. The dimensioning of the line-cavity system was performed by means of a linear response model detailed in Section 3, together with its experimental validation.

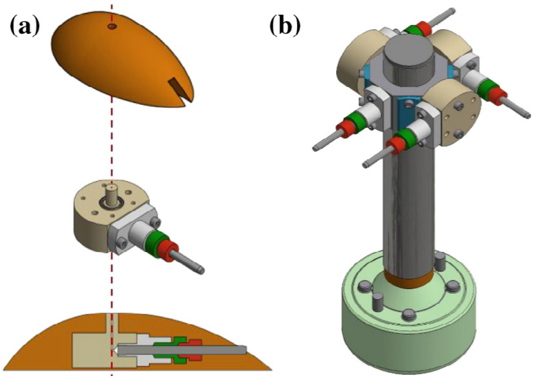

Fig. 2. CAD drawing of (a) the fairing, the holding part with the microphone and the assembly, (b) the calibrator with the holding parts and a reference microphone.

Another purpose of the design, justifying the position of the pressure tap on the fairing top, is to take advantage of the local acceleration that occurs from the leading edge of the fairing, in a view to reduce the turbulent fluctuations and improve the relative importance of the acoustic signal. Section 4 details the hot wire measurements that were conducted over the fairing in order to quantify the effect of the acceleration on the turbulence intensity, and to correlate this effect to the quality of the acoustic measurements.

3. Line-cavity response model

The microphone is connected to the pressure port via a L-shape line and cone shape cavity system as shown in Fig. 3(a). The length and diameter of the line, as well as the cavity volume, have an important effect on the amplitude and phase lag of the pressure fluctuations sensed by the microphone membrane. Since the frequency response of the line-cavity system can exhibit strong resonances that are detrimental to the measurement accuracy, several methods can be employed to damp out the resonance. A possibility is to use a small diameter flexible tube. However, this can introduce a signal distortion. Another method is to insert dampers to suppress the resonance in the system as described in Surry and Stathopoulos [15]. Eventually, the most promising solution was found to consist in correcting the signal based on the measured transfer function of the system. A correction of the amplitude is sufficient when single sensor measurements are to be processed, but in our case a phase calibration is also needed since the duct