Experimental investigation of airfoil-turbulence interaction noise

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ABSTRACT

Airfoil-turbulence-interaction noise, which is created whenever turbulent flow encounters an airfoil, is a major contributor of unwanted noise emitted by aircraft, turbomachinery and alike. The experimental study presented here is the precursor to a larger investigation of the impact of complex turbulence on noise generation at the airfoil's leading-edge and airfoil-wall junction. In the current study, the authors examine links between the experimentally acquired properties of isotropic turbulence and the sound radiation of the immersed airfoil. This is achieved by varying the in-flow turbulence intensity using two different turbulence grids. A NACA0012 airfoil was analysed at a range of geometric angles of attack up to 16 degrees and Reynolds numbers of $1 \cdot 10^5$ up to $3 \cdot 10^5$. Stereoscopic Particle Image Velocimetry (SPIV) was conducted beforehand to capture the turbulence characteristics of the free flow. Additionally, acoustic beamforming with a phased microphone array provides insight into the sound generation at the leading-edge. Pressure taps along the centre chord-line were used to measure the mean static pressure, thereby allowing for an open-jet deflection correction of the angle of attack.

1 INTRODUCTION

The underlying physical phenomenon of noise generated at the leading-edge of an airfoil immersed in isotropic homogeneous turbulence is very well understood. Its theoretical foundation has been established by the seminal work of Amiet as early as 1975 (Amiet, 1975) and has since been refined and adapted to account for various geometric parameters (Kim et al., 2015; Lysak et al., 2016). The mutual and, at the same time, limiting assumption for these models is the isotropy of the inflow turbulence. Experimental and numerical studies (Devenport et al., 2010; Gea-Aguilera et al., 2016) show that the anisotropy of the turbulent stream significantly altered the sound radiation of the airfoil compared to the isotropic scenario. In real-world environments, the turbulence that is encountered by airfoils is mostly anisotropic to varying degrees. For this reason, there is a need for the development of leading-edge noise radiation models which account for anisotropic turbulence.The present work shall provide insight into the authors' current progress towards the establishment of an experimental test rig at UNSW Sydney which is intended to experimentally scrutinise the effect of anisotropy, airfoil geometry and angle of attack on the generation of leading-edge noise. This first phase of the overall experimental project is to examine leading-edge noise generation in the presence of isotropic homogeneous turbulence. It serves as a benchmark to validate the experimental setup.

2 Methodology

For the investigation of noise generated by an airfoil in isotropic turbulence, three major measurement techniques are applied: Stereoscopic PIV, acoustic beamforming, and unsteady surface pressure measurements via remote microphones. Stereoscopic PIV provides spatially resolved information about time-averaged mean flow and turbulence characteristics of the incoming flow. Acoustic beamforming via a phased array of 64 microphones measures the radiated far-field noise and enables a targeted investigation of noise spectra from the area of interest, i.e. the leading-edge. An array of pressure taps located on the surface of the airfoil measures the unsteady surface pressure via remote microphones. The unsteady surface pressure is measured in parallel with the acoustic beamforming. This allows for a correlation of the spatially resolved unsteady surface pressure spectra with the localised acoustic beamforming spectra. Additionally, a subset of the pressure taps is utilised to measure the mean static pressure coefficients along the chord of the airfoil. This information is then used to correct for the actual angle of attack which deviates from the geometrical angle of attack due to the open jet wind tunnel influence.

All measurements are undertaken inside the open section of the open-jet anechoic wind tunnel at UNSW Sydney which exhibits particularly low background noise levels from 200 Hz onwards. Schematics and photographs of the experimental test rig and measurement instrumentation will be presented at the conference. The two-dimensional NACA0012 airfoil has a chord of 150 mm and the internal 61 hollow channels, which are connected to the remote microphones, have a diameter of 1 mm. Two differently sized turbulence grids generated isotropic homogeneous turbulence with turbulence intensities (TI) of 4.6 % (grid 1) and 4.2 % (grid 2). Mean free stream velocities of 10 m/s, 20 m/s, and 30 m/s are set for all cases.

3 Results

The analysis of the isotropic grid-turbulence yielded the confirmation that the generated turbulence is sufficiently isotropic by investigating metrics such as turbulent velocity fluctuation ratios, scalar invariants of the anisotropic stress tensor, homogeneity, and turbulence length scales. Furthermore, the utilisation of the internal channels to measure the mean static pressure coefficients on the airfoil's surface allowed a correction of the angle of attack.

The integration of narrow-band beamforming maps enabled the extraction of the frequency spectra of the sound that is radiated from a central leading-edge (LE) region. The left image in Figure (1) shows the noise sources on a beamforming map using conventional beamforming at a mean flow speed of 30 m/s. It confirms that the noise sources are concentrated around the leading-edge due to the LE-turbulence interaction as well as at the trailing edge. The integration region was restricted to the leading edge. The right graph illustrates the comparison of the integrated noise spectra of the leading-edge at three different cases: no (turbulence) grid, grid 2 (TI = 4.2 %) and grid 1 (TI = 4.6 %). Despite the lower turbulence intensity of grid 2, the radiated noise between 3 and 6 kHz is up to 4 dB louder. Grid 2 exhibits bar widths of 7 mm and thus smaller integral length scales compared to the 8 mm thick bars of grid 1. Thus, it is believed that more turbulent energy is contained in the smaller scales of grid 2 turbulence than in the grid 1 case. The turbulence characterisation also yielded smaller integral length scales for grid 2 than for grid 1. The higher energy content in the smaller scales in the grid 2 case would support the obversation of the increase in radiated noise at higher frequencies despite the lower overall turbulence intensity. Further analysis towards the validation of the measured spectra will be presented at the conference. In addition, the presentation will provide further results of the simultaneously measured unsteady surface pressure.

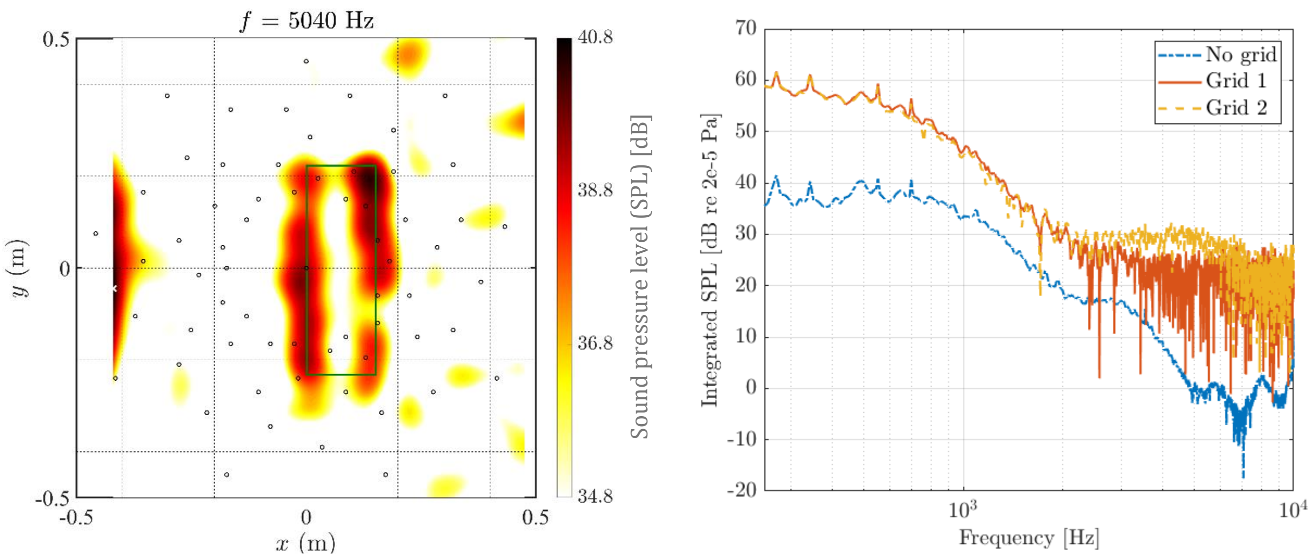

Figure 1: **(Left)** Beamforming map at the third-octave band of 5040 Hz with the green box indicating the wing location. Flow from left to right. **(Right)** Integrated SPL frequency spectra of different grid cases.

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