Sound Radiated by Two and Three-Dimensional Supercritical Airfoils Operating in Low Mach Number Flows

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ABSTRACT

Measurements of the far-field sound radiated by two and three-dimensional supercritical airfoils operating in a low Mach number flow were performed in an anechoic open-jet facility. For the three-dimensional case, two aspect ratios (AR = span/chord) of 1.0 and 1.5 were considered. The far-field sound was measured using a 64 microphone phased array placed outside the flow region and the array output was beamformed to reveal the acoustic sources. The results show that the trailing-edge noise from the 2D airfoil is larger than the 3D cases up to a frequency of 5 kHz, while above 7 kHz, the 3D airfoils generate more noise. Further, for the 3D airfoils, trailing-edge is the dominant noise source at 4 kHz, whereas at 8 kHz the source is concentrated near the free-end of the trailing-edge. Qualitatively, the source behaviour is the same for both ARs, but the airfoil with lower AR generates less broadband noise.

1 INTRODUCTION

The far-field sound generated by a two-dimensional airfoil is a widely studied problem and the trailing-edge of such an airfoil is a well-characterized sound-source (Lee *et al.*, 2021). However, in most applications the airfoils are not two-dimensional, instead they are finite with a bounded and a free-end that generate complex flow structures not present in the two-dimensional counterpart, changing the character of the generated sound. Recent studies (Moreau *et al.*, 2014) have identified that the sound generation by the flow over a three-dimensional, wall-mounted airfoils is a strong function of the airfoil aspect ratio (AR = span/chord). These studies, however, were concerned with symmetric airfoils, and the effect of the camber was not considered. Here, we present a study on the noise generated by two and three-dimensional supercritical airfoils with a sharp camber. Although supercritical airfoils are typically used in transonic applications, the present study aims to characterise their aeroacoustic behaviour in low Mach number flows that is important from the standpoint of airframe noise during landing and take-off.

2 EXPERIMENTAL SETUP AND INSTRUMENTATION

The measurements were performed in the UNSW Anechoic Wind Tunnel (UAT). The UAT is an open-jet type facility where the test-section is surrounded by a 3 m x 4.7 m x 2.15 m anechoic chamber with a cutoff frequency of 350 Hz. The free-stream turbulence levels in the facility are minimal (< 0.4% at 30 m/s) and the test-section measures 0.455 m x 0.455 m x 1.7 m. More details of the facility can be found in Doolan *et al.* (2018).

The airfoils considered in the study was an ONERA OAT-15A supercritical airfoil with a chord-length (c) of 152 mm. The span of the three-dimensional airfoils was 152 mm and 228 mm that corresponds to AR = 1.0 and 1.5, respectively. Additionally, a full-span, two-dimensional airfoil (span = 455 mm) was also considered to evaluate the trailing-edge noise generated by the profile. The geometric angle of attack in the measurements was 0° and the measurements were performed at a free-stream velocity of 30 m/s which corresponds to a chord-based Reynolds number of approximately 312,500. The boundary layer on both surfaces of the airfoils were tripped at 10% chord location to supress any laminar instability noise. The far-field sound radiated by the airfoils was measured using a 64 microphone spiral phased array that was located towards the airfoil pressure-side, approximately 1.09 m from the airfoil chord-line with the array plane parallel to the free-stream.

The acoustic pressure sensed by the array microphones was recorded using a National Instrument® PXI data acquisition system for 32 seconds at a sampling rate of 2^{16} Hz. The resulting time-series pressure were Fourier transformed using a periodogram method with a record length of 2^{13} points, an overlap of 50% with a Hanning window applied to each record. The array cross-spectral matrix (CSM) thus obtained was beamformed in 1/3rd octave band using the conventional, frequency-domain delay and sum beamforming algorithm as described in Brooks and Humphreys (2006). The phase shift which occurs in the beamforming results due to the refraction of the acoustic waves through the open-jet shear layer was corrected using the method described in Padois *et al.* (2013). The beamformed source levels will be presented as sound pressure level (SPL) in dB/Hz.

3 RESULTS AND DISCUSSION

Figure 1 (a) – (f) shows the beamformed sound-source maps at two different frequencies for the three airfoils. The outline of the airfoil and the endplates to which they were mounted is superimposed on these maps for spatial reference. The contour scale (in dB/Hz) of the source maps is shown to the right of each plot. The sound generated by each airfoil can be seen clearly in each of the source maps. The canonical trailing-edge noise from the 2D airfoil is dominant at 4 kHz, but it becomes weaker as the frequency increases to 8 kHz. For the three-dimensional airfoils, the trailing-edge is also the dominant sound-source at 4 kHz, but at 8 kHz the source is concentrated near the free-end of the trailing-edge. Qualitatively, the sound-source behaviour at these frequencies appears to be independent of the AR; however, there are quantitative differences, particularly at 8 kHz where the tip noise from the smaller AR is noticeably weaker than the taller airfoil.

In order to assess the quantitative effect of AR on the far-field sound, the beamformed source levels were integrated to obtain the acoustic spectra for each case. The integration volume over which the integration was carried out is shown as a dashed rectangle in Figure 1 (c). Since the beamforming output is a convolution between the actual source and the array point spread function (PSF), the integrated output was normalized on the array PSF of a point source placed at the center of the integration volume. Additionally, any sources with levels that were below 8 dB down from the maximum SPL in the maps were not included in the integration to minimise the contamination of the integrated levels by the array side-lobes. Figure 1 (g) shows the integrated source levels for the three airfoils as a function of frequency. The 2D airfoil generates more noise than the 3D airfoils up to 5 kHz, while at frequencies above 7 kHz the noise from the 3D cases is higher. The noise from the three geometries shows comparable levels between 6 – 7 kHz. The airfoil with smaller AR generates less noise up to a frequency of 5 kHz, while the sound levels for the two airfoils are comparable around 6 – 7 kHz. Then, at frequencies above 8 kHz, a rise in noise levels with increasing AR is observed again.

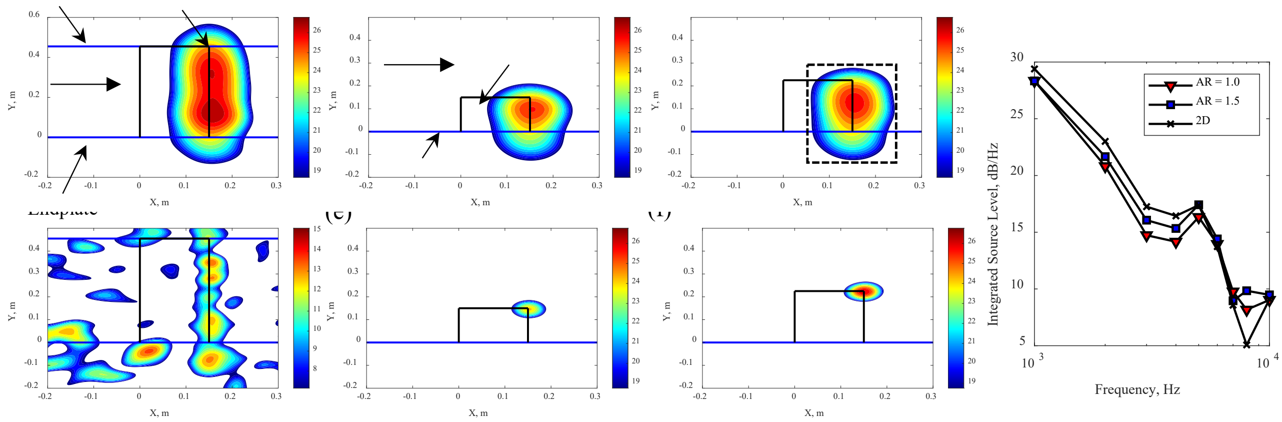

Figure 1: Beamformed sound-source maps for ONERA OAT-15A supercritical airfoil at U_∞ = 30 m/s for the 2D airfoil (a, d), AR = 1.0 (b, e) and AR = 1.5 (c, f) at f = 4 kHz (a, b, c) and 8 kHz (d, e, f). The source spectra obtained by integrating the beamforming output within the rectangular region depicted in (c) are shown in (g).

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