Aeroacoustics of flow over a forward-backward facing step

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ABSTRACT

An experimental study on aeroacoustics of low Mach number flow over a forward-backward facing step (FBS) with aspect ratio = 8 is presented. The height of the step being considered was 50% of the incoming boundary layer thickness($h/\delta \approx 0.5$) and the Reynolds number based on the step height Re_h ranged from 1.4×10^5 to 2.8×10^5. The acoustic measurement was conducted using a 64-microphone-phased array in the UNSW Anechoic Wind Tunnel (UAT). The beamforming results show that the noise source locates at the leading edge of the step. The sound spectra obtained from the center microphone of the array show that noise produced by the step is generally broadband without any distinct tonal noise. The data at different flow speeds collapse well using the scaling law proposed by Doolan and Moreau (2014).

1 INTRODUCTION

Surface discontinuities with step geometries such as forward-facing step (FFS), backward-facing step (BFS), and forward-backward facing step (FBS) are commonly found in engineering applications. These surface irregularities will modify the incoming flow and enhance the turbulence levels in the flow field, which are considered as one of the main sources of flow-induced noise. This study examines the aeroacoustic characteristics of low Mach number flow over a FBS.

Acoustic measurements were carried out in the UNSW Anechoic Wind Tunnel (UAT) using a 64-microphone phased array. Figure 1 (a) shows the experimental setup of the testing rig inside the UAT. A FBS with an aspect ratio $(l/h) = 8$ was mounted on an endplate, which was flush-mounted on the side of the wind tunnel contraction outlet. The freestream velocity U was set to be $20, 30$ and 40 m/s and the corresponding Reynolds number based on step height Re_h varied from 1.4×10^5 to 2.8×10^5. The boundary layer thickness on the endplate was 20 mm at $U = 40$ m/s and the step height was 10 mm $(h/\delta = 0.5)$.

The 64-microphone phased array was positioned 1.3 m away from the model and the center microphone was 150 mm downstream of the leading edge of the step, which results in an 83.4° observation angle θ (Fig. 1b). The array consisted of 64 1/4" GRAS 40PH phase-matched microphones arranged in spiral. The microphones are mounted on a 2 m × 2 m perforated steel grid.

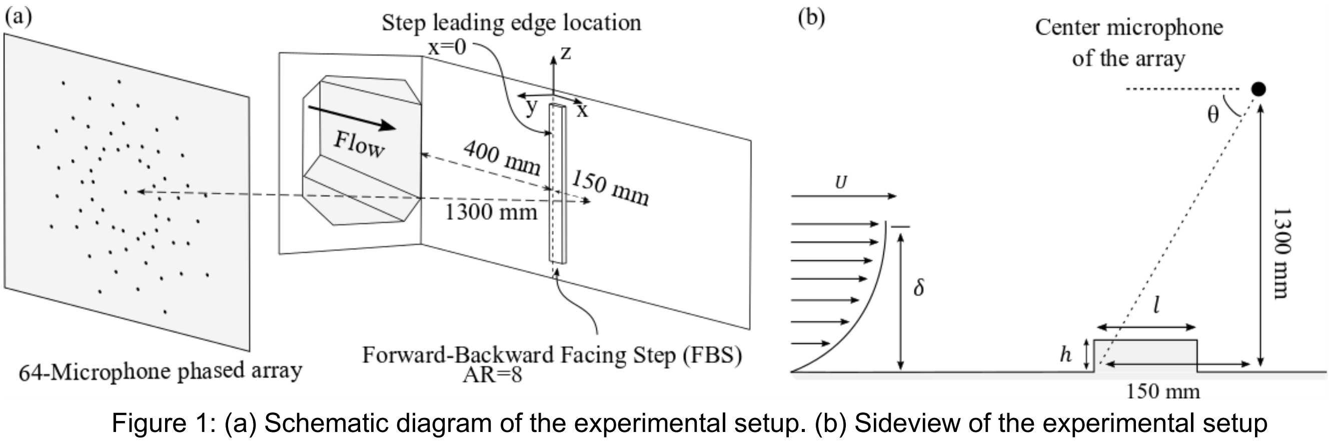

Figure 1: (a) Schematic diagram of the experimental setup. (b) Sideview of the experimental setup

2 RESULTS

The acoustic data were beamformed by using a conventional beamforming algorithm (Mueller, 2002). The background far-field noise (measured in the absence of the step) was removed from the diagonal of the step noise cross-spectra matrix (CSM) before beamforming. The beamforming was performed in 1/12th octave bands. Figure 2 shows the acoustic beamforming results at three different frequencies. In the figures, the flow is coming from the left ($U = 40$ m/s) and the green rectangle represents the location of the step. The results show that the noise produced by the FBS is mainly located at the step leading edge.

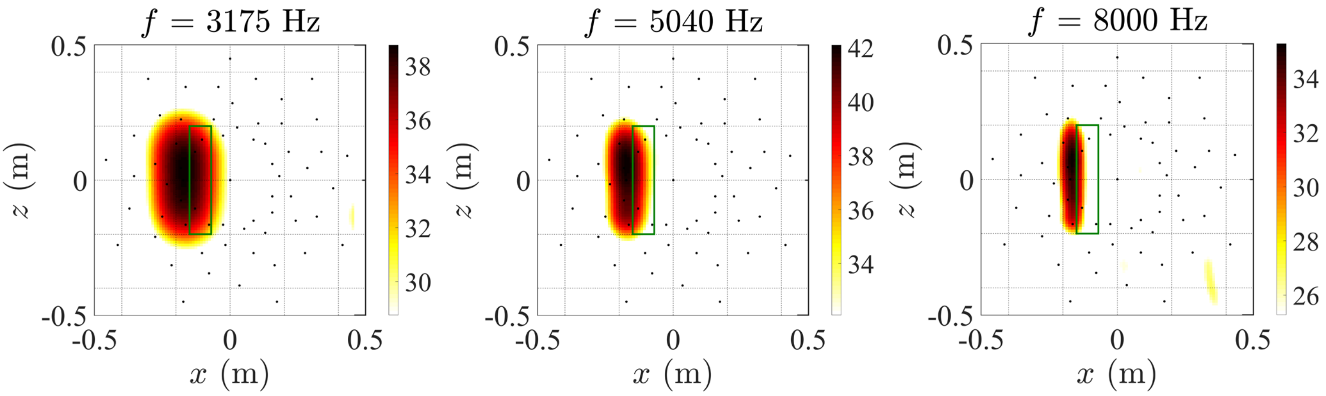

Figure 2: The acoustic beamforming maps for the FBS at $U = 40$ m/s. The green rectangles and black dots indicate the FBS location and the microphones, respectively, and the level is in dB. The results are presented at 3175 Hz, 5040 Hz, and 8000 Hz.

The 1/12-octave band sound pressure spectra measured at $U = 20, 30$, and 40 m/s are shown in Figure 3 (a). The results were obtained by the center microphone of the array with an observation angle of 83.4° from the leading edge. The noise produced by the step is mostly broadband without any distinct tonal noise. A downward trend can be observed in the high frequency region (> 8k Hz). The result shows a strong influence of the flow velocity. Doolan & Moreau (2014) proposed a scaling law considering the effects of Mach number and step geometries for the sound spectra of FBS at a fixed observation angle. The non-dimensional model was given as

$$St_L \; v.s. \; 10\log_{10}\left(\frac{\Phi r^2}{p_0^2 M^2 Ll}\right) \tag{1}$$

where Φ is the acoustic pressure spectra, M is Mach number, p_0 is the dynamic pressure ρU^2 (ρ is the air density), l is the step length, r is the distance from the step leading edge location to the microphone, and St_L is the Strouhal number based on the characteristic length L of the flow, which was selected to be the step height in this study. The scaled acoustics data are shown in Figure 3(b). A good collapse of the data can be seen at St_L below 1.5. Doolan & Moreau (2014) observed a good data collapse at St between 0.3 to 2 at a similar observation angle.

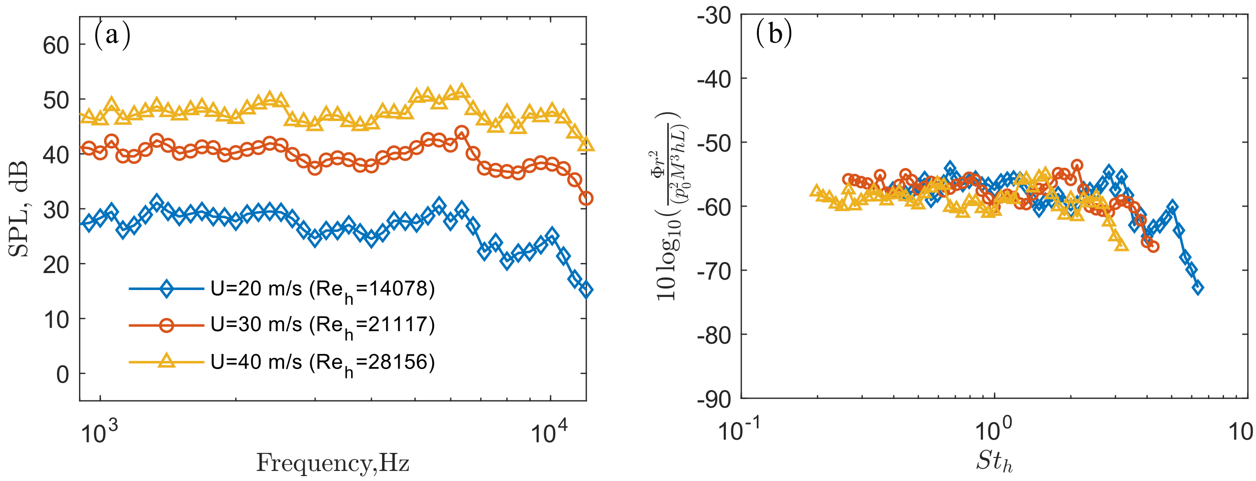

Figure 3: (a) 1/12th octave band sound spectra for FBS at an observation angle $\theta = 83.4°$,
(b) Scaled 1/12th octave band sound spectra using Eq. (1).

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