Wall-pressure Fluctuations of Separated and Reattaching Flow over Blunt Plate Subjected to Incident Vortex Street

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The separated and reattaching flow over a blunt plate, which has found its place in various engineering applications, has received widespread attention in fluid mechanics community. A literature survey shows that a majority of previous studies were made in the presence of the undisturbed free-stream flow. However, in the practical situation of engineering applications, the separated and reattaching flow would be usually under the considerable influence of complex behaviors of vortical structures buried in the upstream flow. Due to the intensified vortex-body interaction, this would introduce significant complexity into the features of the separated and reattaching flow, e.g., the shedding large-scale vortical structures, and the flapping separation bubble, which are closely related to fluid-induced structure vibration and acoustics (Ohya et al., 1992). The wall-pressure fluctuations which are certainly regarded as the excitation source of fluid-structure vibration and acoustics are also indicator of the unsteady events embedded in the flow field. Accordingly, a complete information of the wall-pressure fluctuations of the separated and reattachment flow subjected to incident vortical structures is highly desirable.

In the present study, experiments were performed in the low-speed open-circuit wind tunnel shown in Fig.1. Air was driven by a centrifugal blower and a 1.5 kW motor. The test section was 300 × 300 mm2 in the cross section and 2000 mm in length. A two-dimensional circular cylinder (D=24 mm) was placed spanning the width of the tunnel, generating a well-formed Karman vortex street; far downstream of the cylinder, a very long rectangular plate (L/D = 18) with blunt leading and trailing edges was immersed in the wake region. The total blockage ratio of the test section due to the rib and the false floor was 8.3%. The inlet free-stream velocity was fixed at U= 10 m s-1, resulting in a Reynolds number based on the cylinder width Re = 13,200. As shown in Fig.2, a total of 34 ICP-type 1/4″ microphones (G.R.A.S., 40PQ, Denmark), which have a wide dynamic range of 30~138 dB, were installed on the perforated plate to capture wall-pressure signatures of the convecting vortices buried in the shear layers (Liu et al., 2007). A total of 34 wall-pressure measurement stations beginning at x / D = 0.25 were arranged on the bottom wall at intervals of 0.5 D. To increase the spatial and frequency resolution of each microphone, a pinhole of diameter 1 mm and an installation cavity of diameter 7.0 mm were drilled concentrically on the bottom plate at each measurement station (Liu et al., 2005). In an effort to accurately estimate the spectral energy distribution, each microphone was calibrated against a piston phone (PCB 394A40, USA) and a half-inch reference microphone

(G.R.A.S.40AE, Denmark) in a calibrator, yielding specific frequency-magnitude and frequency-phase relationships for each microphone (Lee and Sung, 2002); typically, the sensitivity of the microphones was about 7.7 ~ 8.2 mV/Pa. In the frequency region of the present study, the magnitude error and phase delay of the microphones were within ±1 dB and ±3°, respectively. In the experiments, the time-series wall-pressure data were reconstructed in the frequency/phase domain (Liu et al., 2007). Simultaneous acquisition of the wall-pressure fluctuation signals at the sampling frequency of 5 kHz was performed using customized LabVIEW software and a data acquisition system (NI4472B/PXI-1042Q, NI Inc., USA). The cut-off frequency for measuring the wall-pressure fluctuations was fixed at 2.2 kHz. A total of 409,600 time series data were acquired for each microphone. A real-time PXI chassis (PXI-1042Q, NI Inc., USA), which was installed with six 24-bit dynamic signal acquisition cards (PXI-4472B, NI Inc., USA) and communicated with the personal computer through a fiber cable, was used to synchronize sampling of the fluctuating signals from the microphone array. This enabled reliable simultaneous acquisition of the wall-pressure fluctuations.

To reveal the influence of the incident Karman vortex street on the separated and reattaching flow over the blunt plate, experimental measurements of the wall-pressure fluctuations with and without presence of the circular cylinder were carried out for comparison. A comprehensive analysis of the difference was made in terms of wall-pressure fluctuation intensity, wall-pressure spectra, cross-correlation of wall-pressure, Proper orthogonal decomposition (POD) analysis of the wall-pressure field, and dipole sound source estimation based on Curle's integral formula.

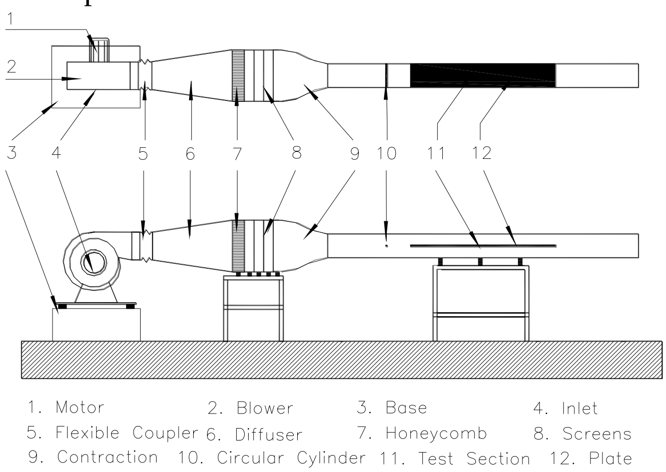

Fig.1 Schematic of the wind tunnel

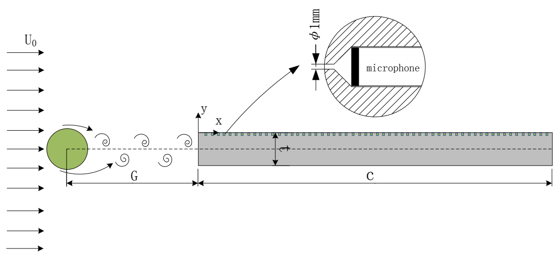

Fig.2 Schematic of the experimental model