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Flow over NACA0012 airfoil influenced by upstream circular cylinder wake

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INTRODUCTION

Boundary layer bypass transition induced by upstream wake was usually simplified as a flat-plate boundary layer transition induced by convecting wake shedding from steady circular cylinder upstream in the past years[1-6]. However, flow separation, common in engineering application, attracted little attention in the past when discussing wake/boundary-layer interaction.

Experiment Apparatus

The present experiment investigated the flow around a NACA0012 airfoil under the influence of cylinder wake at low Reynolds number, with the purpose of finding the effect of adverse-pressure-gradient to the boundary layer bypass transition. The experiment was conducted in a low-speed water tunnel, using Hydrogen bubble visualization techniques and particle image velocimetry. The model configuration and the coordinate definition were shown in Figure 1. The airfoil model had a chord length of c=120 mm and the span of 510mm, corresponding to aspect ratio of 4.25. In present experiment, the angle-of-attack of the airfoil was set to $\alpha = 0°$. A circular cylinder with a diameter of D=10mm was placed horizontally, spanning the whole width of the airfoil. The horizontal spacing of the cylinder was fixed at x_c= -40 mm (x_c/c=-0.333), and 7 different vertical heights (y_c/c=0, 0.042, 0.083, 0.125, 0.167, 0.25 & 0.333) have been investigated.

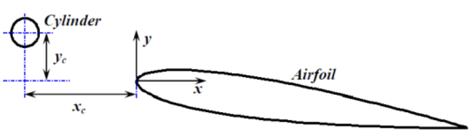
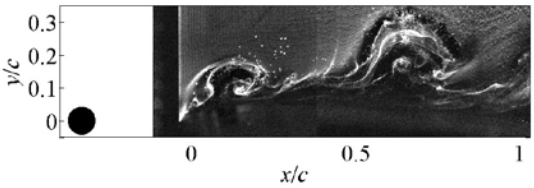


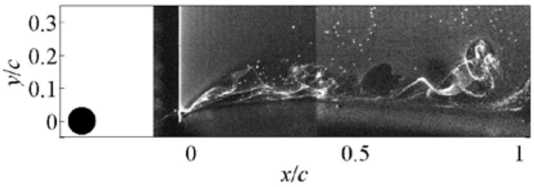
Figure 1 Model configuration and coordinate definition

RESULTS AND DISCUSSION

It is found that the cylinder wake could effectively change the flow structures on the suction surface of the airfoil, and the structures could be different for different vertical heights of the cylinder. As the cylinder is fixed just ahead of the airfoil (y_c/c=0), it is found that two flow patterns, depicted in Figure 2, were captured alternate at aperiodic time intervals, similar to that reported by Munekata et al[7]. As the vertical height rises to y_c/c=0.042~0.167, secondary vortices, in one-to-one relationship with the rollers in the cylinder wake, are observed in the near-wall region on the suction surface of the airfoil. (illustrated in Figure 3). When the vertical height becomes higher (y_c/c>0.2), there is not any secondary vortex found in the near-wall region on the suction surface of the airfoil, indicating that the cylinder wake is too weak to induce vortices.



(a) roller formed



(b) roller did not form

Figure 2 Instantaneous Hydrogen bubble visualization of flow structures (y_c/c=0)

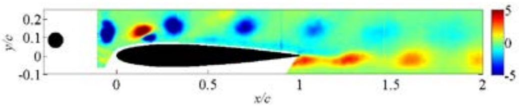


Figure 3 phase-averaged λ_{ci} field of flow structures (y_c/c=0.083)

Furthermore, dynamic mode decomposition[8,9] and frequency analysis are used to find out the receptivity of boundary layer to the upstream wake.

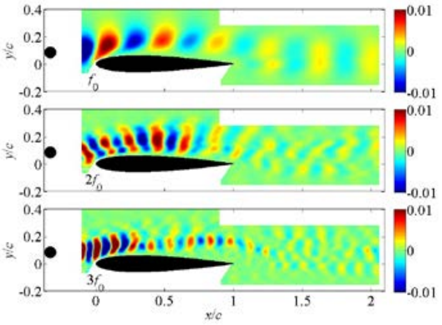


Figure 4 Spatial pattern of the dynamic mode at the frequency of f_0, $2f_0$ and $3f_0$. For simplicity, only the v component is shown. (y_c/c=0.083, f_0=1.05Hz)

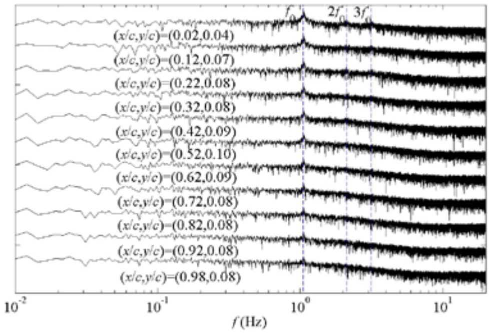


Figure 5 Power spectra of u component along the trajectory of the shedding vortices in the boundary layer on the suction surface of the airfoil. (y_c/c=0.083, f_0=1.05Hz)

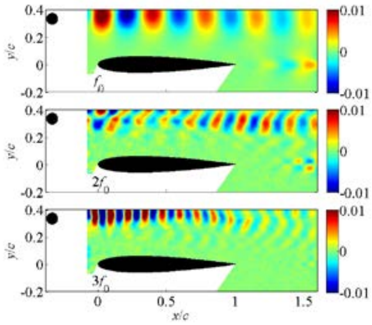


Figure 6 Spatial pattern of the dynamic mode at the frequency of f_0, $2f_0$ and $3f_0$. For simplicity, only the v component is shown. (y_c/c=0.333, f_0=1.192Hz)

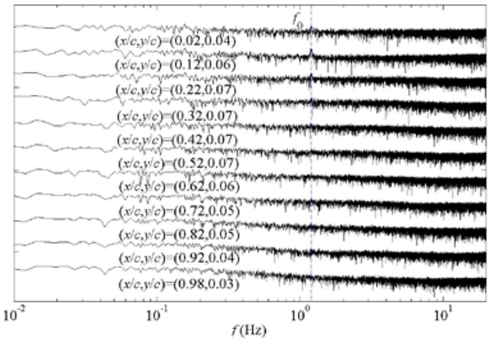


Figure 7 Power spectra of u component along the trajectory of the shedding vortices in the boundary layer on the suction surface of the airfoil. (y_c/c=0.333, f_0=1.192Hz)

It is found that for lower vertical heights (y_c/c=0.042~0.167), disturbances with fundamental and higher frequencies could enter into the boundary layer at the leading edge of the airfoil. The amplification of the disturbance with fundamental frequency leads to secondary vortices rolling-up, and disturbances with other frequencies decrease. As the vertical height increase to y_c/c>0.2, only spectral peak of fundamental frequency is observed at the leading edge of the airfoil, suggesting the external disturbance with such frequency enter into the boundary layer here. However, the spectral peak decreases fast when flow convecting downstream, which explain the reason of no secondary vortex observed.

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