Visualizations of large-scale vortices in flow about a blunt-faced flat plate

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Abstract A new type of flow visualization method utilizing a smoke-wire, a high-speed camera with high framing rates and a laser light sheet was employed to delineate the unsteady processes of large-scale vortices in the separated shear layer about a blunt-faced flat plate at Re₉₅ = 560. The sequential images showed that the unsteady behavior of large-scale vortices in the separated shear layer varies as the shedding phases of large-scale vortices alter. Particularly, at a certain phase, a vortex-merging process between the two neighboring large-scale vortices took place.

List of symbols

- \( f \) frequency [1/s]
- \( h \) half thickness of the plate [m]
- \( \text{Re}_H \) Reynolds number (\( \text{Re}_H = U_o h / \nu \))
- \( U_o \) freestream mean velocity [m/s]

1 Introduction

When a uniform oncoming stream meets a flat plate of finite thickness, the flow separates at the leading-edge and reattaches on the surface of the plate at a downstream location. The reattachment process of this separated shear layer is known to be strongly influenced by rolling-up and growth of large-scale vortices, which shed from the separation bubble.

A literature survey reveals that the previous flow visualizations of the behavior of large-scale vortices over a blunt-faced flat plate are only limited to instantaneous snap shots (Cherry et al. 1984; Sasaki and Kiya 1991); descriptions of the unsteady behavior of large-scale vortices have rarely been carried out. Therefore, the present note employs a new type of flow visualization technique using a high-speed camera with high framing rates and a laser light sheet, and proposes to present sequential pictures of visualizations of the time-dependent process of rolling-up and shedding of large-scale vortices from the separation bubble. Based on the detailed sequential images, physical explanations are offered for the evolutionary flow processes of growth and merging of these vortices.

2 Experimental facilities and procedures

A special-purpose wind tunnel was fabricated (Hwang et al. 1998). The test section was 250 × 250 × 1200 mm in width, height, and length. The size of the flat plate used was 12.1 × 250 × 1000 mm in thickness, width, and length. The freestream turbulent intensity was measured to be less than 0.3%. The Reynolds number was set at \( \text{Re}_H = 560 \), which was low enough to enable effective flow visualizations.

Spectral peaks and microphone measurements were conducted to determine whether there occur any acoustic resonances. No spectral peaks were detected in the autospectrum of longitudinal velocity fluctuations. At the test speed \( U_o = 1.43 \) m/s, the fan blade-passing tones were detected at four different frequencies \((f_H/U_o = 0.44, 0.58, 0.81 \text{ and } 1.66)\). These frequencies do not match the large-scale vortex shedding frequency \((f_H/U_o = 0.08)\). The large-scale vortex shedding frequency is far apart from the acoustic resonant frequency \((f_H/U_o = 0.20)\) of the space surrounding the blunt-flat plate in the test section. In summary, it is highly unlikely that the acoustic modes excite any corresponding shear layer fluctuations.

The widely-used smoke-wire technique was employed. Smoke was generated by burning paraffin oil from a resistive wire (diameter 0.2 mm, electrical resistance 41.6 Ω/m). The wire was made to have a saw-tooth configuration to secure the formation of evenly-spaced fine smoke streaklines at the peaks of the wire. The smoke-wire was inserted on the centerline plane of the flat plate 60 mm upstream of the forward blunt face on the plate. A sensitivity study undertaken with the smoke-wire placed at eight different upstream locations (10, 20, 30, 40, 50, 60, 70 and 80 mm) illustrated that at \( \text{Re}_H = 560 \), the separated shear layer was little influenced by the locations of the smoke-wire.

The movement of the smoke was illuminated by a laser sheet which passed through the outlet of the test section. The laser is emitted from a 6-W Argon-ion laser, and it goes through reflecting mirrors, a collimator and a...
Fig. 1. Flow visualizations depicting the processes of rolling-up, growing-up and shedding of a large-scale; Re_H = 560; Δt = 0.002

Fig. 2. Flow visualizations depicting the process of a vortex-merging between two consecutive large-scale vortices; Re_H = 560; Δt = 0.002