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Short Paper

Wind Tunnel Testing of Shear-Stress Measurement by Liquid-Crystal Coating

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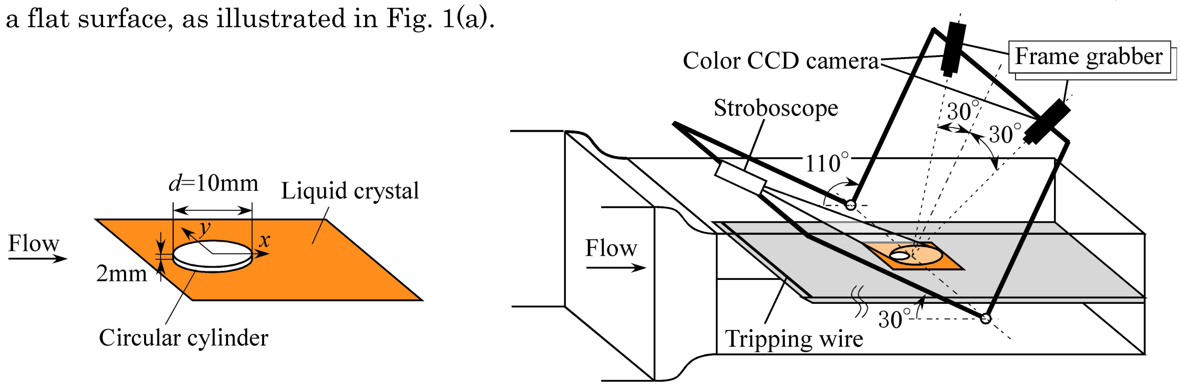
1. Introduction

Non-intrusive shear-stress measurement of a flow over a solid surface has been a topic of interests in the field of fluid engineering. A shear-stress measurement by liquid-crystal coating is one of such experimental techniques reported in literatures (ex. Reda et al., 1997). The essence of this method relies on the determination of shear-stress vector field from the color characteristics of liquid-crystal coating with respect to the changes of shear-stress magnitude and direction. The frequency response of the color change of the liquid crystals is higher than 1 kHz, thus it is applicable to the measurement of instantaneous shear-stress distributions. Very recently, a method of instantaneous shear-stress measurement of flow over a surface has been studied by Fujisawa et al. (2003) using a stereoscopic arrangement of the color CCD cameras placed side by side. The magnitude and direction of the shear stresses over a surface are determined from the stereo color images of liquid-crystal coating in combination with the calibrated relationships among the color of the liquid crystal, the shear-stress magnitude and the direction.

The purpose of this paper is to extend the experimental technique of shear-stress measurement by liquid-crystal coating to wind tunnel studies.

2. Experimental Method

Experiments are carried out in an acoustic wind tunnel, which is described by Tomimatsu and Fujisawa (2002). The cross-sectional area of the test section is 190 mm × 190 mm and 600 mm long. The test section is covered by transparent wall material made by acrylic resin. A flat plate of 190 mm wide and 600 mm long with sharp leading edge is placed along the center of the wind tunnel horizontally. A tripping wire of 1 mm in diameter is placed near the leading edge of the plate to generate a turbulent boundary-layer on the test section. A circular cylinder of 10 mm in diameter and 2 mm in height is placed on the center of the flat plate at 450 mm downstream from the leading edge of the plate. Thus, the shear stress measurements have been carried out around a circular cylinder on a flat surface, as illustrated in Fig. 1(a).



(a) Target flow field (b) Experimental test section

Fig. 1. Experimental apparatus.

A schematic description of test section and the experimental equipment for shear-stress measurement is shown in Fig. 1(b). The experimental equipment, consisting of two rotating arms with its axis set on the test surface, is placed over the test section of wind tunnel. Two color CCD cameras (768 × 492 pixels with 8 bit) are placed symmetrically against the free stream with the off-axis angles 30° and fixed on the arm downstream. The illumination is provided from the center of the arm upstream by using a stroboscope. The angles of observation and illumination are set to 110° and 30°, respectively, which are determined from the condition of highest color response of the liquid crystal.

The liquid-crystal coating used in the present experiment is a mixture of choresteric and chiral nematic liquid crystal. It was sprayed uniformly onto a polymer film (= 0.1 mm in thickness) after being mixed with the petroleum ether and pasted on the test surface. The calibration of the liquid-crystal coating is conducted by using the calibration equipment, which has been described by Fujisawa et al. (2003). This equipment consists of a straight channel having dimensions of 0.75 mm in height, 30 mm in width and 200 mm long. The liquid crystal is sprayed on the polymer film pasted on the bottom surface of the channel, and the surface images are taken from two color CCD cameras using the same experimental equipment as for the wind tunnel studies. Note that the observation and illumination angles are kept the same values as for the wind tunnel studies. The calibration of the liquid-crystal coating against the shear-stress magnitude and the direction is conducted by changing the flow rate of the channel flow and the channel angle around the vertical axis, respectively. The determination of the shear-stress magnitude and direction is made from the calibration curves obtained from the color image analysis of the liquid-crystal coatings. The details of the shear-stress analysis are described by Fujisawa et al. (2003).

3. Results and Discussions

Figure 2 shows typical examples of the instantaneous shear-stress coefficients $c_f'(= 0.5\tau / \rho U^2)$ over the test surface around a surface-mounted circular cylinder at two different instants of observation, where ρ : density of fluid and τ : shear stress. The experiments are conducted at free-stream velocity U = 30m/s, thus the Reynolds number is $\mathrm{Re}(= U\delta / \nu) = 2.2 \times 10^4$, where δ (= 10.8 mm) is a boundary-layer thickness and ν is kinematic viscosity of air. Note that the black region shows the shade of the illumination. These results indicate that a low-shear-stress region is generated in the near wake of the circular cylinder and the position changes with the instant of observation. The examination of the shear-stress distribution further downstream shows that the shear stresses are locally enhanced and the position moves unsteadily, which indicate the influence of the vortex shedding from the circular cylinder. These results demonstrate that the instantaneous measurement of shear-stress distribution by liquid-crystal coating provides important information in wind tunnel studies.

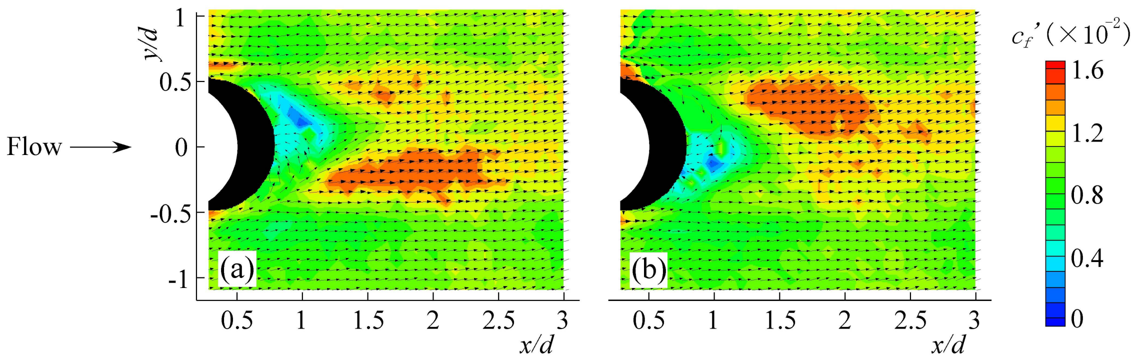


Fig. 2. Shear-stress distributions at two different instants ($\Delta t = 1/15$ s).

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