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Short Paper

Near-Wall Velocity Measurement over an Airfoil by PIV

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1. Introduction

Measurement of velocity field and the understanding of flow phenomenon over an airfoil have been an important topic of interest in fluid mechanics. In the past, the velocity fields around various airfoils have been measured by particle image velocimetry (PIV) for studying the aerodynamic characteristics of airfoils (ex. Shih et al., 1995; Kompenhans et al., 2000; Tomimatsu and Fujisawa, 2002). However, there are fewer measurements, which fully resolve the near-wall velocity distribution over the airfoil. This is partly due to the relatively larger sizes of interrogation windows and partly due to the loss of near-wall treatment in the conventional cross-correlation algorithm, which assumes square interrogation and search windows. When the conventional cross-correlation algorithm is applied to the flow over the airfoil, the interrogation window contains the wall area near the airfoil, which results in an erroneous velocity vector by the presence of the wall itself and also by the smaller number of tracer particles in the reduced area of interrogation window. Although there are a few examples of PIV measurements (Kompenhans et al., 2000 and Shrestha et al., 2004), which consider the near-wall treatment in PIV for the analysis of flow over the complex geometries, the near-wall treatment technique for a generally curved surface has not been reported in literature.

The purpose of this paper is to evaluate the near-wall velocity field over a NACA0018 airfoil using a newly proposed near-wall treatment technique in PIV analysis.

2. Experimental Method

Experiments are carried out in a 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 and the wall of the test section is made transparent by acrylic-resin material for flow visualization purposes. The two-dimensional NACA0018 airfoil, which is made of acrylic-resin material, is placed at the center of the wind tunnel with full span in horizontal direction. The chord length of the airfoil is $C = 80$ mm and the center of the airfoil is located at $0.3C$ from the leading edge of the airfoil.

The PIV measurements are carried out using a standard PIV system, which is made of a pair of Nd:YAG lasers (532 nm, 30 mJ/pulse), high resolution CCD camera (1280 × 1024 pixels with 12 bits in gray level) and the pulse generator. The smoke is supplied from the smoke machine into the wind tunnel through the inlet of blower for flow visualization purposes. The laser-sheet illumination was provided from the outside of the wind tunnel to visualize the two-dimensional vertical plane of the flow field at the center of the test section. Details of experimental technique have been described by Tomimatsu and Fujisawa (2002).

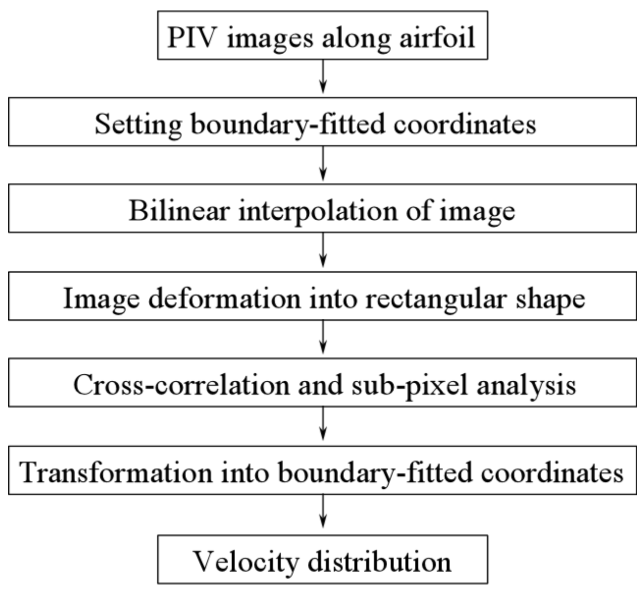

Fig. 1. Flow chart of near-wall treatment.

3. Image Deformation Technique for Near-Wall Treatment

Figure 1 shows the flow chart of image deformation technique for near-wall velocity measurement in the present study. The procedure of velocity measurement is as follows. The target area for near-wall velocity measurement is set on the PIV images along the airfoil surface. Note that the airfoil surface can be approximated by 3rd order polynomial expression. The gray level information on each pixel of the image in orthogonal arrangement is transformed into the boundary-fitted arrangement by bilinear interpolation technique. After the deformation of the fan-shaped image into rectangular shape, the conventional cross-correlation and sub-pixel analysis is carried out to extract the velocity field. The final velocity distributions are obtained by transforming the velocity vectors back into the original boundary-fitted coordinates. It should be mentioned that the error due to the image deformation by bilinear interpolation is smaller than the sub-pixel accuracy of the PIV analysis (Astarita and Gardone, 2005).

4. Results and Discussions

Figure 2 shows the mean and fluctuating velocity distributions along a suction surface of NACA0018 airfoil in the present measurement. The angle of attack of the airfoil is set to 6° and the free-stream velocity U is 30 m/s, thus the Reynolds number is Re (= UC/ν) = 1.6 × 10^5. The experimental result shows that the flow over the suction surface separates at x_s/C = 0.25 and reattaches at x_s/C = 0.44, which are obtained from the gradient of the measured velocity distribution (x_s: distance from leading edge of airfoil along airfoil surface). Thus, a thin separating bubble is formed along the suction surface of the airfoil. The thickness of the bubble is estimated as 0.5 mm. Note that the flow on the pressure surface separates at x_s/C = 0.75 and approaches reattachment around the trailing edge. On the other hand, the velocity fluctuations are kept in a low level up to x_s/C = 0.4 and increases suddenly in the downstream. (Note that the white area in the map of velocity fluctuations denotes the region, where fewer tracer particles are observed.) Therefore, the laminar boundary layer in the upstream of the airfoil is promoted to turbulent one near the reattachment point and develops along the airfoil surface in the downstream. These results demonstrate the effectiveness of the present image deformation technique for near-wall velocity measurement along an airfoil.

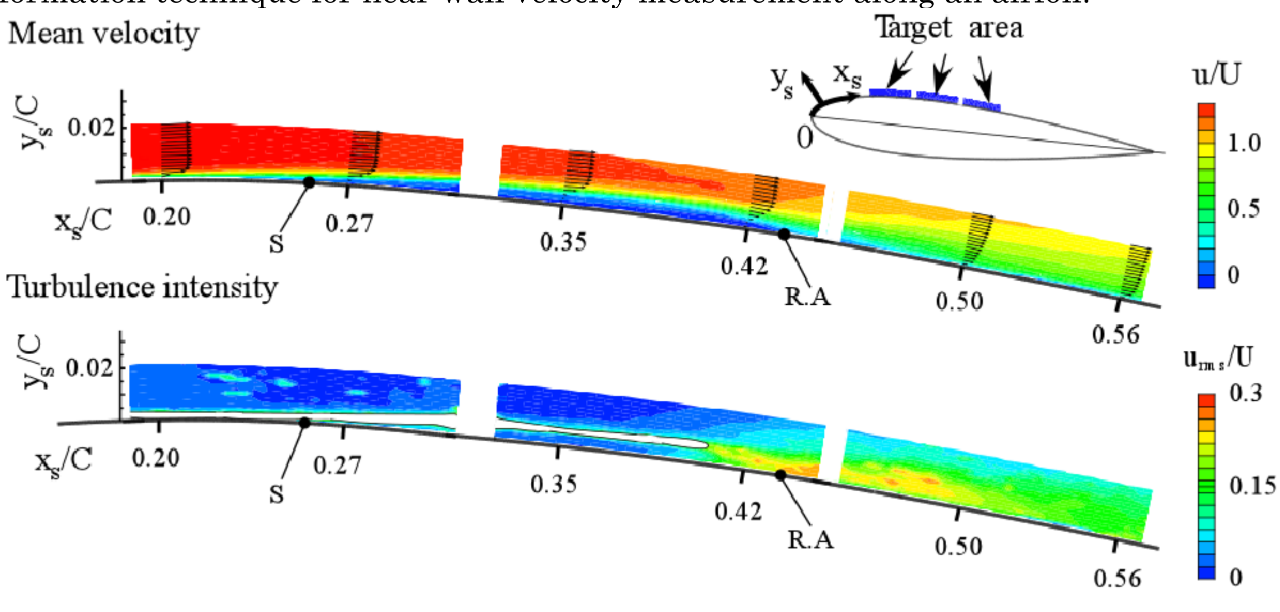

Fig. 2. Mean velocity and turbulence intensity distribution along NACA0018 airfoil at α= 6°.

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