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Short Paper

Measurement of Pressure Field around a NACA0018 Airfoil from PIV Velocity Data

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1. Introduction

Measurement of mean pressure distribution on an airfoil is an important topic of interest in wind tunnel studies. Such measurements are usually conducted by detecting the local static pressure from the pressure holes located on the airfoil surface by the use of pressure transducer. Therefore, such classical technique requires the construction of elaborate experimental test rig and model for pressure tubing. Recently, the pressure field on a circular cylinder is evaluated from PIV velocity measurement in combination with the pressure Poisson equation (Fujisawa et al., 2005). This experimental technique is non-intrusive and allows the field measurement of static pressure over the circular cylinder, so that it is well suited to the pressure measurement in wind tunnel studies. Although this approach is applicable to the evaluation of instantaneous pressure and fluid forces acting on the bluff body, the time-averaged pressure measurement is practically important in usual wind tunnel studies (Van Oudheusden et al., 2007). However, such pressure measurement has not been carried out for the flow over the complex geometry, such as airfoils.

The purpose of this short paper is to demonstrate the experimental technique for measuring the pressure distributions on arbitrary geometry, such as NACA0018 airfoil, using the time-averaged PIV velocity data combined with the turbulent pressure Poisson equation.

2. Evaluation of Pressure Field

When the time-averaged velocity field over a NACA0018 airfoil is measured by particle image velocimetry (PIV), the mean pressure field around the airfoil is evaluated from the turbulent pressure Poisson equation, which is written as follows:

$$\nabla^2 \overline{p} = -\rho \nabla \cdot \left\{ \overline{V} \cdot \nabla \overline{V} \right\} + \nabla \cdot \partial / \partial x_j \left(\overline{u'_i u'_j} \right) \tag{1}$$

where p is the mean static pressure, U_i is the mean velocity and ρ is the density of fluid. Note that the second term on the right hand side of Eq. (1) is the turbulence term, which appears in turbulent flows (Gurka et al., 1999). In solving the turbulent pressure Poisson equation, the Neumann type boundary conditions are applied on the inner and outer boundaries, which are given by the following equation.

$$\nabla \overline{p} = -\rho \left(\overline{V} \cdot \nabla \overline{V} \right) + \mu \nabla^2 \overline{V} \tag{2}$$

In solving these equations numerically, Eqs. (1) and (2) are transformed into general coordinates and they are solved by SOR scheme to obtain the time-averaged static pressure field around the airfoil. Note that the numerical grids are given by O type in the present study and the grid spacing is controlled to be fine near the airfoil and outer boundary, which is set at 5 times of the chord length C of the airfoil from the airfoil center. The number of grids is 600 x 300 in circumferential and radial direction, respectively. In solving these equations, all velocities on the right hand side of Eq. (1) are evaluated from the experimental velocity data measured by PIV.

3. Experiment

The velocity field around a NACA0018 airfoil is measured using a standard PIV system, which consists of Nd:YAG laser (532 nm, 30 mJ/pulse), CCD camera with frame straddling function (1280 x 1024 pixels with 12 bits in gray level) and the pulse controller. The experiment is carried out in an open-jet wind tunnel, which has a cross sectional area of 190 mm x 190 mm in the test section. The flow visualization is conducted by smoke injected from the inlet of the blower using the smoke machine. The planar PIV measurement of the flow field is carried out in the central section of the airfoil, which has a chord length C = 80 mm. Details of the experimental setup are described by Tomimatsu and Fujisawa (2002).

In order to obtain the time-averaged velocity field around the NACA0018 airfoil, 300 instantaneous velocity fields were evaluated from visualized images using the direct cross-correlation analysis with sub-pixel interpolation technique. The image area is set to 50 mm x 50 mm in the far region, while it is 15 mm x15 mm near the wall. It should be mentioned that the near-wall velocity field was measured with high spatial resolution with a use of image deformation technique (Oguma and Fujisawa, 2007), which minimizes the appearance of erroneous velocity vectors near the airfoil surface. The interrogation window size is 41 x 41 pixels in the far region and 101 x 21 pixels near the wall. Then, the contour map of mean velocity and turbulence intensities around the airfoil are obtained from the PIV analysis.

4. Results and Discussion

Figures 1(a) and (b) show the mean pressure fields around a NACA0018 airfoil at an attack angle of 6 degree, which are evaluated from the present PIV measurement and pressure analysis. The free-stream velocity is set to U= 30 m/s, which corresponds to the Reynolds number Re (= UC/ν) = 1.6 x 10^5, where ν is the kinematic viscosity of fluid. Note that the pressure coefficient C_p is defined by $2(p-p_r)/\rho U^2$, where p is the static pressure, p_r is the reference pressure far from the airfoil. The contour map of mean pressure field around the airfoil (Fig. 1(a)) indicates that the stagnation pressure appears near the lower side of the leading edge of the airfoil, while the low pressure region prevails over the suction side of the airfoil and the pressure increases gradually along the airfoil surface downstream. In order to confirm the validity of the mean pressure coefficient C_{pw} on the airfoil surface, the present measurement is compared with that of the direct pressure measurement by Nakano et al. (2007), which is shown in Fig. 1(b). Although the wall-pressure coefficient near the leading edge of the airfoil is evaluated slightly lower than that of the direct measurement, both wall-pressure coefficients are generally in close agreement with each other in most of the region over the airfoil. The result without turbulence term is also shown in Fig. 1(b), which shows higher wall-pressure coefficient in most of the airfoil region. This result indicates that the turbulence term plays an important role for evaluating the pressure field over the airfoil. These results indicate that the present approach is very effective for measuring the pressure field over the airfoil.

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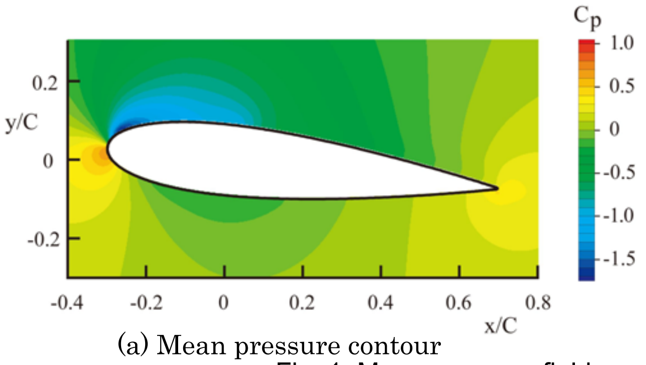
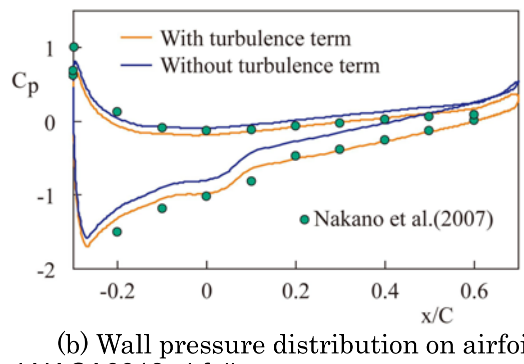


(a) Mean pressure contour



(b) Wall pressure distribution on airfoil

Fig. 1. Mean pressure field around NACA0018 airfoil.

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