Measurement of Wall Shear Stress on an Airfoil Surface by Using the Oil Film Interferometry

Y. Yoshioka and Y. Szuki

Abstract In this study, measurement of wall shear stress on an airfoil surface under the lifting condition by using oil film interferometry (OFI) is performed. Reynolds number of the airfoil flow is 8×10^4. Silicon oil and sodium lamp are used for Fizeau fringes formation. The 300–600 images with time interval snap shot in 1–2 s depends on velocity by digital camera are acquired for the calculation of thickness of oil film and moving velocity on surface of it. Also, airfoil surface is covered with PET film for more clearly Fizeau fringes. Time-averaged wall shear stress measured by OFI are compared to numerical simulation by the LES. Maximum difference in the distributions between by the OFI and by the LES has at $x/C = 0.58$, and it has $C_f = 0.00439$ by the OFI and $C_f = 0.00455$ by the LES.

Keywords Flow measurement · Wall shear stress · Boundary layer

1 Introduction

Measurement of wall shear stress with high accuracy is important for evaluating friction drag on vehicle or turbomachinery. Although oil film interferometry (OFI) is a direct method and it need not complicated apparatus, wall shear stress can be measured with high accuracy. OFI has developed by Tanner et al., Znoun et al., Dressler, Imai et al. and Ruedi. It is applied for studying on boundary layer flow developed on a channel or a flat plate. The authors aim for OFI applying for many objects with various shapes in wind tunnel test. In this study, it is performed that time-averaged wall shear stress acting on suction surface of an airfoil is measured by using the OFI technique and the results are compared to the large eddy simulation (LES) calculation [1].

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2 Experimental Details

2.1 OFI Technique and Oil Viscosity Calibration

A series of Fizeau interferometric fringes which has same principle to Newton's ring are observed by monochromatic light irradiation to oil film formed on surface of flat plate in uniform flow. Oil film thickness can be calculated from a pitch of the fringes and velocity on the oil film surface can be calculated from moving velocity of the fringes to downstream. Then, friction on surface of the flat plate can be estimated based on Newton's law of friction by using the oil viscosity calibrated because velocity gradient can be computed from the velocity and the pitch. Silicone oil is generally used for the OFI. Since the properties of the silicone oil change depending on the temperature, viscosity calibration is conducted. The calibration is performed with Ubbelohde viscometer in a water tank controlled in temperature. The temperature is changed from 15 to 40 °C assuming room temperature. K type thermocouple and data logger is used for water temperature. Three kinds of silicone oil which have 50, 100 and 300 CS are measured in the calibration.

2.2 Experimental Apparatus

The low noise wind tunnel facility with Goettingen type at Nihon University is used for this study. It has nozzle exit of 300 mm × 200 mm cross section, maximum wind speed of 28 m/s, non-uniformity and turbulence intensity of the main flow are 1.5% or less and 0.5% or less, respectively. Airfoil model which has NACA0012 section, chord length of 60 mm and span length of 120 mm is used. The airfoil is vertically installed in the test section of the wind tunnel at 100 mm downstream from the nozzle exit as shown in Fig. 1. It sets to wind speed of 20 m/s and angle of attack of 12° under the lifting condition. The angle of attack is geometric and is not effective for main flow. Effective angle for main flow is estimated about 9°. The Reynolds numbers of $Re = 8 \times 10^4$ is given based on the chord length C and the wind speed U. An end of the airfoil is fixed to the ground, but the other end is in the main flow and tip vortex is formed. Therefore, the measurement is performed at the middle span to avoid the influence of the tip vortex.

A sodium lamp is used as the light source and the angle between the light source and the airfoil surface is set to 23.4°. Also, the angle between the camera and airfoil surface is set to 18.3°. A thermal anemometer is used for measurement of main-stream flow velocity. In order to observe Fizeau fringes more clearly, a PET film with a thickness of 0.05 mm is put to the suction surface of the airfoil. 300–600 images are taken at intervals of 1–2 s per measurement by digital camera and image analysis is performed by using MATLAB from the images.

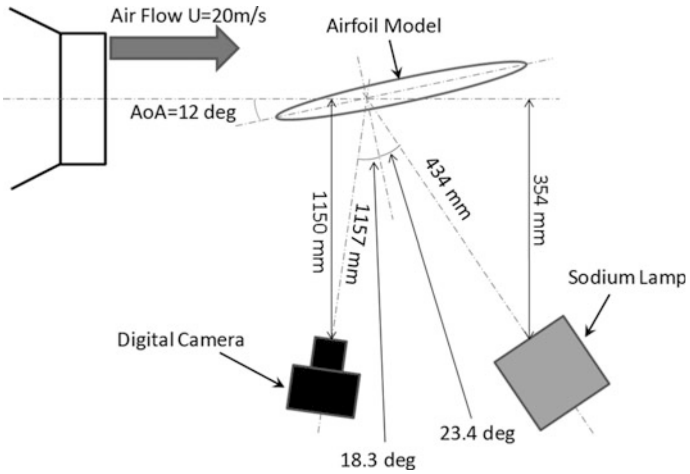

Fig. 1 General view of the test section

3 Results and Discussion

3.1 Oil Viscosity Calibration

The results of oil viscosity calibration for the temperature dependence are shown in Fig. 2. It is clear of temperature dependence characteristics of the three kinds of oils from Fig. 2.

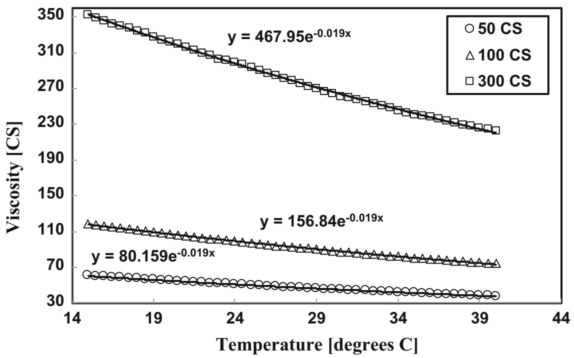

Fig. 2 Calibration carve of viscosity on temperature dependence

3.2 Measurement of Wall Shear Stress on the Airfoil Surface

Because Fizeau fringes cannot be observed under the condition of oil painted to the airfoil surface directly as shown in Fig. 3, the experiment is carried out under the PET film put on the airfoil surface. And Fizeau fringes generation can be observed clearly as shown in Fig. 4.

Also, because the model surface does not have monotonous color for wire cut electric spark, image processing that has difference between each images and background image and square brightness on images for improving of detection Fizeau fringes are performed. The pictures of without the differential image processing and with it are shown in Figs. 5 and 6. Fizeau fringes can be detected more clearly with the differential image processing than without it.

Fig. 3 The fringes image without PET film

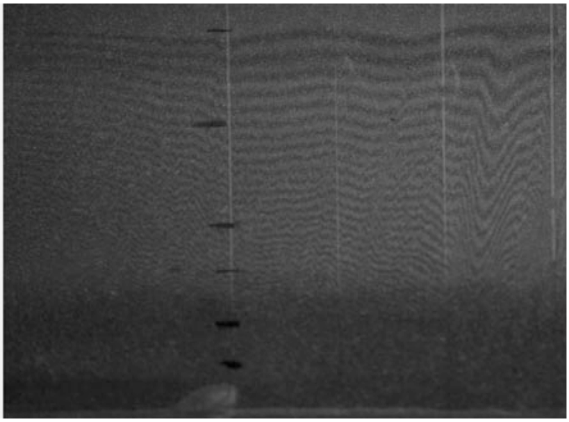

Fig. 4 The fringes image with PET film

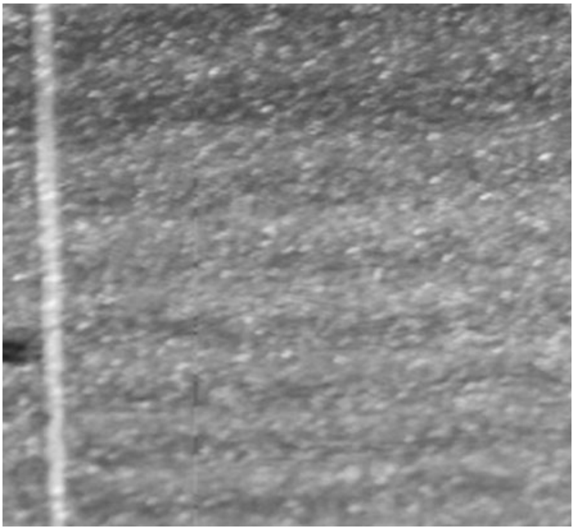

Fig. 5 An image without the processing

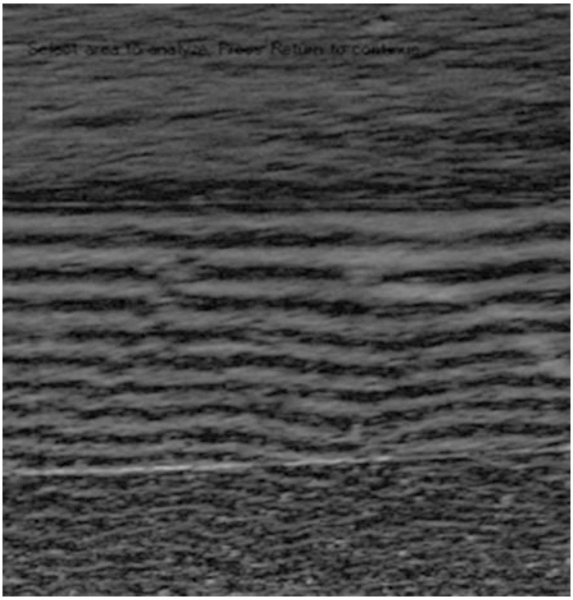

Fig. 6 An image with the image processing

Effect on local skin friction coefficient C_f by different kinematic viscosity is shown in Fig. 7. Local skin friction coefficient C_f has 0.0067 in case of 50 CS, 0.0062 in case of 100 CS and 0.0064 in case of 300 CS at $x/C = 0.33$ which is normalized position from leading edge of the airfoil by the chord length. C_f value in case of 50 CS is larger than in case of the other viscosity. It is considered that this is

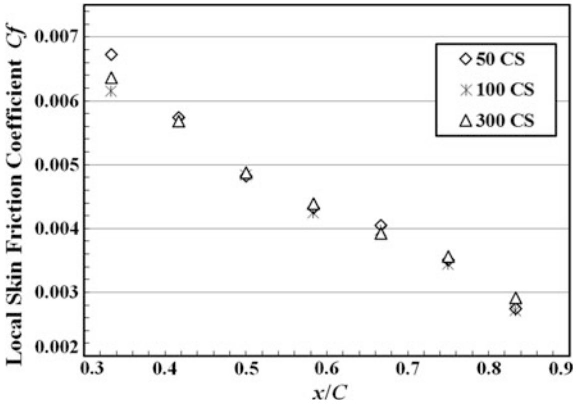

Fig. 7 Effect on local skin friction coefficient by different kinematic viscosity

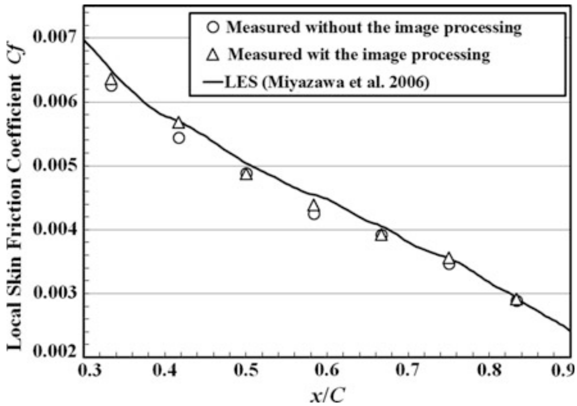

Fig. 8 Comparison between experimental and calculated local skin friction coefficient (Measured: 300 CS)

because of gravity and the oil of 50 CS is not suitable for the airfoil flow in this experimental condition. Experimental and calculated local skin friction coefficient C_f distributions are shown in Fig. 8. Experimental C_f value is measured with the 300 CS oil and calculated C_f value is computed with LES [1]. C_f value in case of 300 CS is used for comparison of the LES result because the OFI result in case of 300 CS is smaller difference between experimental and calculated C_f value than in case of 100 CS. It can be seen that C_f value and tendency that the local skin friction coefficient decreases from $x/C = 0.33$ to $x/C = 0.83$ toward the trailing edge between by the OFI and by the LES are in good agreement. C_f value is 0.00439 by the OFI but 0.00455 by the LES at $x/C = 0.58$, and the difference between in the OFI and in the LES is largest at the position.

4 Conclusions

Wall shear stress acting on the suction side of the airfoil at $x/C = 0.33$ to 0.83 is measured by oil film interferometry (OFI) in the airfoil flow with $\mathrm{Re} = 8 \times 10^4$. And the measured result is compared to calculated result with large eddy simulation by Miyazawa et al. As a result, the following findings are obtained. The visibility of Fizeau fringes generation can be improved by the PET film put on the airfoil surface. Distributions of local skin friction coefficient between by the OFI and by the LES are in good agreement, and they have same tendency that the local skin friction coefficient decreases toward to the trailing edge of the airfoil. Maximum difference in the distributions between by the OFI and by the LES has at $x/C = 0.58$, and it has $C_f = 0.00439$ by the OFI and $C_f = 0.00455$ by the LES.

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