Measurement of Universal Velocity Profile in a Turbulent Channel Flow with a Fiber-Optic Profile Sensor

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Keywords: turbulence, boundary layer, shear flow, Laser Doppler technique, high spatial resolution, velocity profile

We report on the application of novel laser-Doppler velocity profile sensors to the turbulent boundary layer of a fully developed two-dimensional channel flow. The flow measurements were conducted in the near-wall region through a glass window attached flush to the wall.

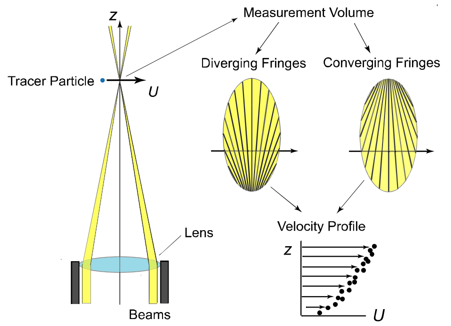

Figure 1 Principle of velocity profile sensor.

The laser-Doppler velocity-profile sensor is based on two fringe systems created in the measurement volume (Fig. 1). It enables spatially high resolved measurement of the velocity profile without traversing the sensor head. The spatial resolution of even up to submicrometer range can be achieved inside several hundreds micrometers length of the measurement volume. Two velocity-profile sensors based on different techniques were used in the present investigation. One of the sensors utilized two different wavelengths to distinguish the two fringe systems (WDM technique). The other one was based on the use of a single wavelength but two different carrier frequencies (FDM technique). For signal processing, software-based burst detection was developed to properly cut out the signals with a wide dynamic range of velocity occurrence in a turbulent boundary layer. Refined validation conditions as well as new data reduction scheme were developed for reducing the outlier data.

Table1 Sensor and flow conditions ($l_x \times l_y \times l_z$: measurement volume size, Δ_z: spatial resolution, $\Delta_{U/U}$: relative velocity measurement accuracy, T_{glass} : glass plate thickness, Re_τ: Reynolds number based on friction velocity and channel full-width, l_τ: viscous length)

sensor type	$l_x \times l_y \times l_z$ [μm]	Δ_z [μm]	$\Delta_{U/U}$ [%]	T_{glass} [mm]	Re_τ	l_τ [μm]
WDM	100x100x500	1.5	0.06	2	420	60
WDM	100x100x350	6	0.06	6	780	32
FDM	100x100x900	6	0.085	6	1100	23

Preliminary to the flow measurements, the effect of the glass plate used for the optical access was evaluated. The result shows the glass plate shifts the location of the measurement volume and hence the calibration curve. However, the slope of the calibration curve itself is not affected as long as the sensor is traversed perpendicular to the plate. The effect of chromatic aberration due to the plate was found to be minor although the glass plate without optical quality was found to smear the signal quality. These facts ensure the feasibility of the velocity-profile sensor to internal flows through glass window without any serious problem.

The flow measurements were carried out by the two velocity-profile sensors under three different conditions of Reynolds number and glass plate. The feature of the sensors and flow conditions are summarized in Table 1. The measured mean and fluctuating velocity profiles are scaled well with wall-variables (Fig. 2). They also show a good agreement with an available DNS data. The fluctuating velocity indicates that more samples should be taken for the reliable estimate of turbulent statistics. The universal constants for the logarithmic law-of-the-wall were not able to be determined from the present data, due to the relatively few samples taken in the limited duration of measurements.

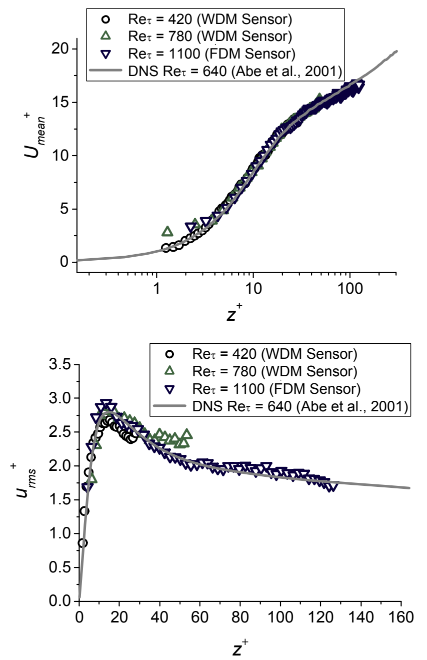

Figure 2 Mean (top) and fluctuating (bottom) velocity compared with DNS data at three Reynolds numbers.

As a conclusion, the feasibility of the sensor to the investigation of turbulent flows was clearly demonstrated. It was shown that the measurement through an optical window has no practical problem to apply the profile sensor to internal flows. Larger number of data samples would provide reliable turbulence statistics with high spatial resolution.