THE CORRECTION OF LONGITUDINAL HEAT FLUX IN TURBULENCE MEASUREMENT

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ABSTRACT: In this paper the influence of temperature on velocity signal in hot-wire measurement of turbulence is analysed. It is pointed out that when the temperature influence is small, the temperature influence on measured intensity of velocity fluctuations is second order small and negligible. However, the temperature influence on measuring longitudinal heat flux is of first order quantity, and must be corrected, or large error will occur. The method to correct the temperature influence on measuring $\rho_{\theta u}$ and the procedure to decide experimentally temperature influence coefficient have been given.

KEY WORDS: heat flux, turbulence, hot-wire measurement

I. INTRODUCTION

In studying turbulence, especially in studying heat transfer, water vapour and contaminant diffusion in the atmosphere, combustion and so on, the cross-correlations between scalar variables and velocity ($\bar{\theta}u$, $\bar{\theta}v$, $c_u$ and $c_v$ etc.) are very important. The equipment for measuring these correlations is usually hot-wire system. By using suitable model and measurement circuit, hot-wire system could also be used to measure some scalar fluctuations, e.g. temperature and concentration. For example, using very low heating current (a few $\mu$A) and a fast-response a.c. temperature bridge [6,7], the temperature fluctuations can be measured. It is pointed out that the influence of velocity fluctuation is small. Because this influence on intensity measurement is second order small, it is unnecessary to correct it for temperature variance measurement.

When the overheat ratio was suitable (say $H = 1.8$) and temperature is passive scalar, the temperature influence on velocity was small too. So, in measuring $\bar{u}^2$, $\bar{v}^2$ and $\bar{\theta}^2$ the influences of velocity and temperature on each other can be neglected. However, in measuring $\rho_{\theta u}$, these influences have to be taken into consideration and some necessary correction should be made. In this paper this problem is discussed and the correction technique through some examples is introduced. The experiment was done at Cornell University and the apparatus were the same as those used by Warhaft in [7].

II. THE INTERACTION BETWEEN VELOCITY AND TEMPERATURE FLUCTUATIONS

Hot-wire is sensitive not only to velocity but to temperature as well. The temperature of air flow may influence the velocity measurement signal. Generally, the overheat ratio

$$H = R_w/R_a = T_w/T_a$$

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is kept constant (say $H = 1.8$) to eliminate its influence. However, when there are temperature fluctuations in turbulent flow, it is impossible to keep $T_w/T_a$ unchanged. Thus temperature influence may cause an additional signal on velocity signal and the measured velocity fluctuation may be written as

$$u_m = u + u_\theta = u + \alpha \theta$$

Here, $u$ is velocity fluctuation, $\theta$ is temperature fluctuation, and $\alpha$ is the influence coefficient of temperature on velocity measurement. The velocity variance is

$$\overline{u^2}_m = u^2 \left( 1 + \alpha^2 \frac{\theta^2}{u^2} + 2\alpha \rho_{uv} \sqrt{\frac{\theta^2}{u^2}} \right)$$

(1)

In common experiments ($H = 1.8$), $\alpha$ is much smaller than 1.0 (e.g., at $U = 7$ m/s, the unit of $\sqrt{\theta^2}$ is °C and unit of $\sqrt{u^2}$ is m/s, $\alpha$ is about 0.1). When temperature is a passive scalar the second and third terms on right side are second order small. Therefore, velocity variance may be measured directly without any correction. Considering the influence of velocity fluctuation on temperature measurement, we have

$$\overline{\theta^2}_m = \overline{\theta^2} \left( 1 + \beta^2 \frac{u^2}{\bar{\theta}^2} + 2\beta \rho_{uv} \sqrt{\frac{\theta^2}{u^2}} \right)$$

(2)

where $\beta$ is the influence coefficient. With very small heating current (a few $\mu$A) in temperature probe we have $\beta \ll 1.0$. Thus as in the case of velocity variance, the correction terms of temperature variance are negligible. Actually, we have made an experiment to estimate the value of $\beta$. In test flow we set the temperature fluctuation $\theta = 0$ (no heating), and measured velocity variance $\overline{u^2}|_{\theta = 0}$ and temperature variance $\overline{\theta^2}|_{\theta = 0}$. Obviously, $\overline{u^2}|_{\theta = 0} = \overline{u^2}$ and $\overline{\theta^2}|_{\theta = 0}$ is the influence of velocity fluctuation on temperature variance measurement. Our experiment shows that under usual conditions (e.g., $U = 7.0$ m/s, $\sqrt{u^2} = 0.1-0.5$ m/s and $\sqrt{\theta^2} \leq 0.5$°C) the results are

$$\frac{(u_m^2 - u^2)}{u^2} < 1\% \quad \text{and} \quad \frac{(\overline{\theta^2}_m - \overline{\theta^2})}{\overline{\theta^2}} < 0.5\%$$

In fact, it is found that $\overline{\theta^2}|_{\theta = 0}$ is caused mainly by electrical noise, so $\beta \approx 0$. Therefore, when the influence coefficient is small enough, the correction terms of variance measurement are of second order small quantities and are negligible.

But, for correlation $u\theta$, we have

$$\overline{(u\theta)_m} = \overline{u_m \theta_m}$$

$$= \overline{u\theta} \left( 1 + \alpha \frac{\theta^2}{u^2} + \beta \frac{u^2}{\theta^2} + \alpha \beta \right)$$

(3)