DIRECT AND IN-DIRECT MEASUREMENTS OF MOMENTUM STRUCTURE IN COLAPIPE

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As far as the mean properties of fully developed turbulent pipe flows are concerned, they are well described by the following simplified and normalized momentum equation:

$$\frac{\mathrm{d}U^+}{\mathrm{d}y^+} = \left[1 - \frac{y^+}{R^+}\right] - (-\overline{uv}^+), \tag{1}$$

where the normalization was carried out in so-called wall units, i.e. with the characteristic velocity $u_c = \sqrt{\tau_w/\rho}$, length $\ell_c = \nu/u_\tau$, and time $t_c = \nu/{u_\tau}^2$ scales. Here R^+ denotes the friction Reynolds number and is defined as $R^+ = u_\tau R/\nu$, with R being the pipe radius.

Examining the momentum transport in various wall layers and its contribution to turbulent kinetic energy is a key issue for better understanding of turbulence scale structures, e.g. the large-scale motions (LSMs) and the very large-scale motions (VLSMs) in pipe flows, see [5]. Considering eq. (1), it suggests that the data needed to analyze this type of momentum transport are to be of the form $\mathrm{d}U^+/\mathrm{d}y^+$ or $-\overline{uv}^+$. If one of these quantities is known from experiments, the other can be deduced using equation stated above. To measure or model $-\overline{uv}^+$ in the region where it is the much larger term in equation (1) was claimed not to be the right approach since a small error in $-\overline{uv}^+$ yields a large error in the deduced $U^+(y^+)$ distribution, see [7]. This might be attributed to the inadequate spatial and temporal resolutions of measuring techniques or inappropriate turbulence model used, in particular, in the region close to the wall where both of these terms exhibit strong gradients. Earlier attempts have been made either to model or to measure simultaneously the streamwise (u) and wall-normal (v) fluctuations to obtain $-\overline{uv}^+$. For instance, [2] concluded that the directly measured turbulence shear stress is on average 10% smaller than the theoretical distribution deduced from the momentum balance and the mean flow data in agreement with [1, 6]. It was also observed by [4] that the total shearing stress obtained from the direct fluctuation measurements was approximately 20% lower than that of the computed values from the mean velocity and the mean pressure–gradient measurements. The present study therefore reviews few aspects on both the low and the high turbulent momentum transport distributions in fully developed turbulent pipe flows, and discusses them in light of recent hot wire and laser Doppler velocimetry measurements performed in CoLaPipe facility [3] for a wide range of Reynolds number. In particular, difficulties in carrying out simultaneous measurements of both the streamwise and the wall-normal velocity fluctuations with adequate spatial and temporal resolutions will be addressed.

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