Roll cells in turbulent plane Couette flow with system rotation

Takahiro Tsukahara*†, Nils Tillmark* and P. Henrik Alfredsson*

To determine the flow in a rotating reference frame, as in the case of rotating fluid machinery or geophysical flows, the effect of system rotation must be clarified. It is known that system rotation gives rise to a Coriolis force, which may substantially affect the flow stability, transition between laminar and turbulent flow as well as the mean flow pattern. If there is a rotation-vector component that is parallel (anti-parallel) to the mean flow vorticity, the Coriolis effect may lead to stable (unstable) 'stratification' of the flow field. Previous theoretical[1] and experimental[2] studies on plane Couette flow (PCF) with spanwise system rotation indicate that when the destabilizing rotation is imposed, a tertiary flow in form of a 3D roll-cell state occurs via transition from a secondary flow with a 2D roll cell. These studies show that such a stable 3D roll-cell structure may exist within a limited low-Reynolds-number range up to $Re = 150$, where Re is based on half the relative wall speed U_w and the channel half-width h. In the present work, experiments on the rotating PCF are carried out for a rather wide Re range, and we have observed 3D roll cells even in turbulent flow.

Our PCF apparatus has been used in a number of reported experiments[1,3]. The flow is governed by Re and the rotation number $\Omega = 2\Omega_0 h^2/\nu$, with Ω_0 the angular velocity of the PCF apparatus itself, and ν the kinematic viscosity of water as the working fluid. Visualization of the pattern is accomplished by the addition of light-reflecting platelets. Figure 1 (a) shows rather homogeneous fine-scale turbulent structures, while the time-averaged (a long exposure time) flow field reveals the coexistence of 3D roll cells [see (b)] of a much larger scale. The observed spanwise wavelength of these structures resembles that in laminar flow, but the streamwise wavelength is about twice of that observed in the laminar case. For high rotation numbers ($\Omega > 25$ at $Re = 600$), the 3D roll cells are more distinct, whereas for $\Omega < 15$, the turbulent flow instead contains stable 2D roll cells.

*Linné Flow Centre, KTH Mechanics, Royal Inst. of Tech., SE-100 44 Stockholm, Sweden.
†Dept. of Mech. Eng., Tokyo Univ. of Science, 2641 Yamazaki, Noda, Chiba 278-8510, Japan.

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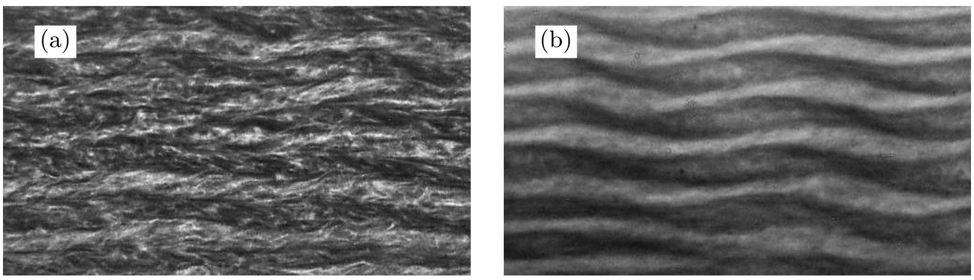

Figure 1: The 3D roll cell in turbulent background, for $Re = 600$ and $\Omega = 24.4$. The exposure time of the camera is set to 1/25 sec in (a), and 3.0 sec in (b). Each picture displays nearly simultaneous observations in an area of 24.8×14.3 cm^2, i.e. $52h \times 30h$.