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1 Numerical simulations

The present investigation focuses on alternately laminar and turbulent oblique patterns observed during the subcritical transition to turbulence in wall-bounded flows. It is shown in the example of plane Couette flow that cyclonic spanwise rotation can delay the formation of such patterns to arbitrary large values of the Reynolds number.

1.1 Transition to turbulence in non-rotating plane Couette flow

Plane Couette flow (pCf), the flow between two parallel walls moving in opposite directions, is the simplest canonical example of the effect of a wall-induced shear on a viscous fluid. The only nondimensional parameter ruling the flow is the Reynolds number, here defined as $Re = \frac{Uh}{\nu}$, where $\pm U$ is the velocity of the two walls, h is the half-gap between them, and ν is the kinematic viscosity of the fluid. We are interested in the way sustained turbulence appears in this system near the onset of transition, knowing that the laminar base flow is linearly stable for all Re. We present here direct numerical simulations in large periodic domains, using a pseudo-spectral code [4]. Two thresholds value for the Reynolds number characterise this subcritical transition: Re_g, below which all perturbations are found to eventually decay, and Re_t, above which turbulent motion, once triggered, contaminates the whole domain. In the interval $[Re_g, Re_t]$, the turbulent flow features robust coexisting laminar and turbulent domains separated by oblique fronts [2, 3, 4].

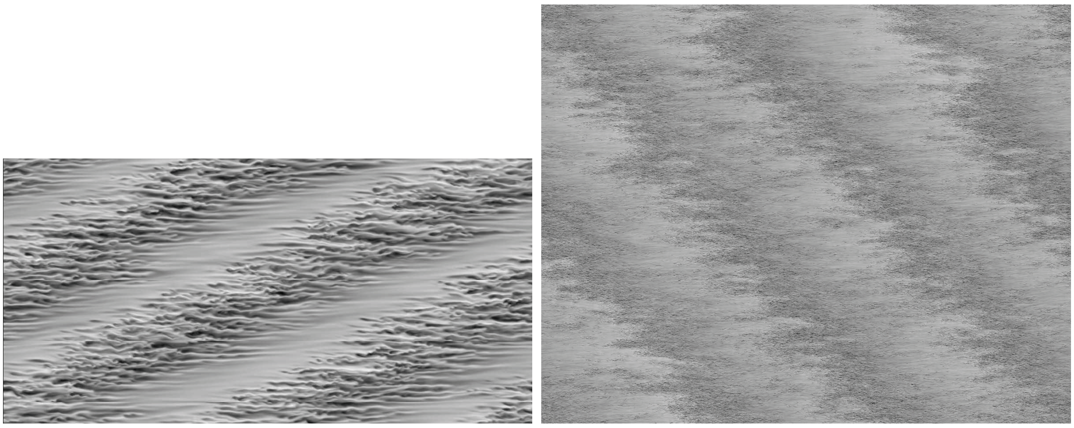

Figure 1: Streamwise velocity in the mid-plane between the plates. The mean flow direction is horizontal. Left: non-rotating pCf for Re=350. Right: rotating pCf for Re=6000 and Ro=-0.104. Domain sizes: $250h \times 125h$ (top) and $250h \times 200h$ (bottom).

1.2 Effects of a spanwise cyclonic rotation

Cyclonic rotation applied to pCf in the spanwise direction (i.e. where the rotation vector has the same direction as the mean flow vorticity) does not modify the laminar base flow. Furthermore it is known to stabilise the laminar state, thus potentially delaying transition to turbulence in pCf [1]. If F is a parameter measuring the amplitude of this cyclonic rotation (here the opposite of a Rossby number), experimental evidence suggests that the two previously defined thresholds Re_g and Re_t still exist yet directly increase with F. In particular, the flow just above Re_g is still characterised by the stable coexistence of alternatively laminar and turbulent domains. We show here numerical evidence of the laminar/turbulent patterns forming at arbitrary large values of Re in the presence of rotation (see Figure 1). Note that very similar conclusions can be drawn under other stabilizing external forces than rotation, such as a spanwise magnetic field or a stable density stratification.

2 Scale separation

Spectral analysis of the mean flow suggests the existence of two length scales for the patterned flow: a large-scale wavelength Λ_z (resp. Λ_x) corresponding to the oblique patterns and a small-scale wavelength λ_z (resp. λ_x) related to the presence of near-wall streaks, as in fully developed wall turbulence. It is shown that λ_z scales classically with wall units following the relation $\lambda_z \approx 100h^+$, while Λ_z scales directly in outer units of h. It follows that parameter space-tracking of the patterned regime at higher and higher rotation rates widens the associated scale separation. An analysis of the mean flow also reveals its complex three-dimensional structure. A tempting conclusion is that the small-scale (turbulent) fluctuations do not directly contribute to the mechanism for the formation of the patterns, apart throught their active role in sustaining the large-scale circulation.

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References

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